

The Organization of Building Work and Construction of Siphons in Roman Aqueducts in Hispania

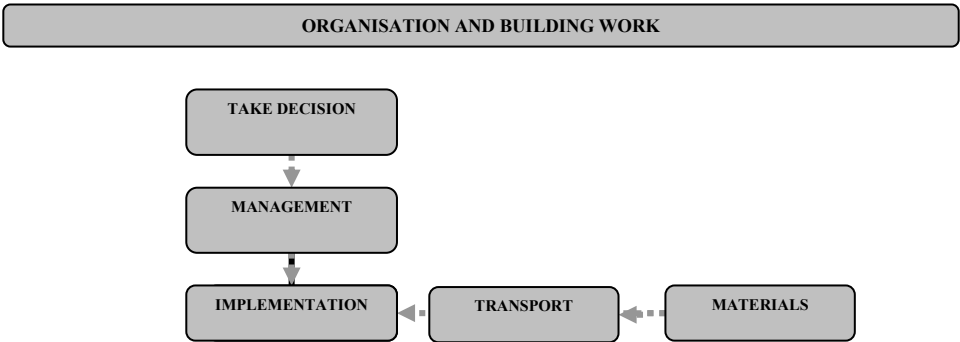
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The large-scale use of siphons in aqueducts used for supplying water to towns was an invention that first appeared in the Ancient Greek world and was brought to Spain by Roman engineers. In *Hispania*, a significant part of city water supply systems used the siphon device to cross depressions in the terrain. Given that there are still no specific studies of the aqueducts in Spain that use siphons, we will briefly refer to the main cities that used these devices. We will describe the main siphons of which there is documented or archaeological evidence, by studying the materials and techniques that were used in their construction and their most relevant design features.

THE ORGANISATION OF WATERWORKS

Siphons were one of the most complex engineering solutions used by Roman engineers in their designs for aqueducts. The Romans used aqueducts extensively for supplying good quality water to towns and cities. In the case of both underground water and above-ground streams, it was necessary to ensure that the water was of sufficient quality or *bonitas* for human consumption, and that the volume or *conceptus* available was sufficient to meet supply needs even in times of shortage. It was therefore a decision of great social, political and economic importance, which had to be taken quickly after receiving advice from the experts.

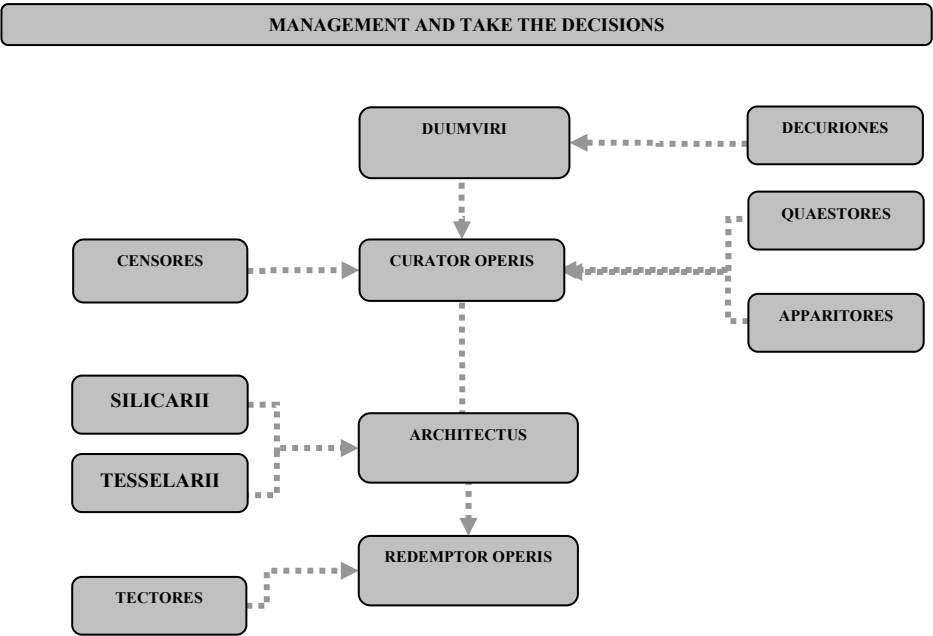
Table 1. Organisation of building waterworks.



In Rome, the political decision to commence building works on this scale was the responsibility of the *censor*, while in the colonies it fell to the *duumvir* or Mayor who would award the work by organizing a public invitation to *redemptores* or contractors to tender for the work. The contractors

had to present *praedes* or guarantors whose properties would be liable in the event of any breach of the provisions of the contracts for the works.

Table 2. Organisation of management of building waterworks.



The proposals for building works made by the *duumviri* were authorised by the *ordo decurionum*, local Senators, who were members of the legislative assembly of the towns or colonies. These Senators also approved the *munitio* or provision of obligatory, unpaid labour to reduce the cost of the works.

Once the works had been approved, the *censores* then had to establish the conditions or clauses of the public contracts or *lex locationis operarum*. The money for paying the contractors of the works was provided by the *quaestores*, and the *curator* or *locator operis* was responsible for supervising the work and ensuring that the clauses and conditions of the contract were fulfilled. The general control of the works and the execution thereof was managed by the *statio aquarum*, the central administration for the water supply system (González Tascón and Velázquez 2005).

The technical decisions as to the design or *directura* of the aqueduct, the materials to be used and the best technical solutions for each type of terrain were taken by the *architecti*, water-system architects or engineers who drew the sketches for the project, carried out the measurements and estimated the cost of the work. They were therefore the senior technical authority in any works

carried out on behalf of the administration. The architects were surrounded by a number of technical specialists who would carry out the preliminary work. The *aquilegi* or *inventores* for example were experts in locating or discovering underground water sources. Once they had confirmed that good quality water was available, a team of *libratores*, *agrimensores*, *gromaticus* or topographers carried out careful levelling operations known as *libramentum*, so as to make sure that the force of gravity would move the water down to its final deposits. In this case any small miscalculation could ruin what were highly expensive public works.

By using the *libella* and the *chorabates*, the *agrimensor* was able to make accurate measurements of the drop and the gradient, *declivitatibus mensura*, of the different stages of the aqueduct. This enabled him to establish what building work, levelling work or tunnels would be required to ensure the successful transportation of the water. It was at this point that it became necessary in some stages of the aqueduct to calculate whether it would be more economical to negotiate the differences in the level of the terrain by using *arcuationes* or series of arches, or whether on the contrary it would be preferable to build inverted siphons using the most suitable materials for the job.

BUILDING MATERIALS AND THEIR SUPPLY DURING THE WORKS

Stone, ceramics and lead were the materials used for building siphons in Hispania. Each of these building materials was supplied during the works by suppliers and workmen who were specialists in the particular product. The men who worked in the extraction of these materials were divided up into *metallarii* and *illychiniarii*. These workmen extracted blocks of stone from the quarries using iron tools and wedges of wood which were wetted to make them swell up, putting pressure on the stones which broke up into smaller blocks. This work was so hard it was always given to slaves. Skilled men known as *lapidarii* and *quadrataarii* then sculpted the blocks mined from the quarry into ashlar, voussoirs and other pieces. Senior to them were the *marmorarii*, who were in charge of sculpting pedestals or cornices and of carving inscriptions.

Perforated stone was used quite frequently throughout the Iberian Peninsula. Perhaps the most important example of this type of aqueduct was the pipeline that formed part of the siphons that supplied water to *Gades*, which at 65 kms long was the longest of its kind in Roman Spain.

The most difficult job when using stone pipes was to drill a large circular hole through which the water would pass precisely and accurately. Little is known about the way the drills were made, except for what Vitruvius says in the last of his books *De architectura* on the importance of scale when moving from a small scale-model to a large prototype.

Vitruvius informs us that small orifices could be made using a bow drill. However in order to make holes in hollow blocks of stone over half a ft diameter as occurred in the pipes for *Gades*, a very different procedure was required. We do not know what this procedure entailed, but we can at least

hazard a plausible guess, as explained and developed in the *Veintiún libros de los Ingenios y las Máquinas*, compiled in Aragon in the sixteenth century. The manual system for perforating blocks of stone began by making a small hole with a pick. When it was impossible to go any deeper, the pick was exchanged for a long iron bar of a particular size and shape, which was used for striking and rotating until perforation had been completed.



Figure 1. Pipeline of Gades aqueduct. Part of stone siphon.

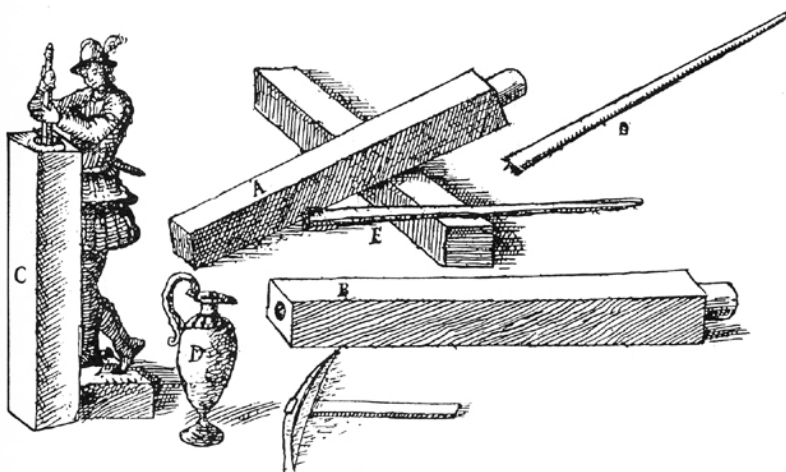


Figure 2. Manufacture system of roman stone pipe. (Fundación Juanelo Turriano, 1996).

In *Gades* these pipes were manufactured using a fossiliferous limestone called *ostionera* stone which was relatively soft and therefore easy to perforate. Each stage has an inner diameter of about 32 cms and the stone is squared off on the outside. The joints were made with a special paste which was extremely hard.

Ceramic pipes or *tubuli*, which were cheap and easy to manufacture, were often used in *Hispania*. They were more fragile than stone pipes and required more frequent joints as the pieces were relatively short. Ceramic products such as bricks (*cocti lateres*), roof tiles or *tegulae* and pipes or *tubuli* were produced in the *figlina* or *officina* which were run and owned by the *figuli* who in turn employed workers known as *laterarii* that worked in the factory making the ceramic pieces.

Ceramic pipes were used for example in the final stage of the aqueduct of *Sexi*, today Almuñécar, in the province of Granada. This stage involved a very large drop in height which was negotiated using a siphon. In this case the ceramic pipes had an outer diameter of 20 cms and an inner diameter of 16 cms. Each section of pipe was about 34 cms long.

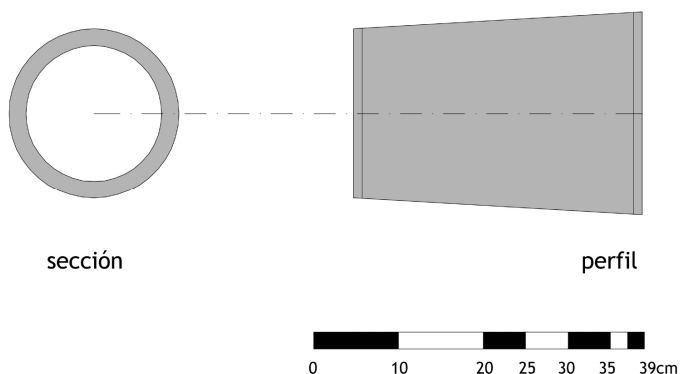


Figure 3. Section and profile of ceramic pipe of Almuñécar aqueduct

Hispania had a large number of silver mines which exported the precious metal through the port of *Carthago Nova*. A by-product of this work of less value was lead, which was available in enormous amounts. The *plumbarii* were responsible for making sheets of lead from which later they would make the pipes or *fistulae*. These workmen were also responsible for welding work with lead and tin, for repairs and for installing stopcocks and taps.

Thanks to the plentiful supplies of this material in Roman Spain, it was widely used for making pipes. However not many large diameter lead pipes survive today, as they were normally reused for construction purposes in later eras. Perhaps the best example is in the sources for the Roman reservoirs of Proserpina and Cornalvo which supplied water to *Augusta Emerita*, the modern-day town of Mérida, in the province of Extremadura.

Lead pipes, *fistulae* of about 10 cms in diameter have also been found in the siphon that supplied water to the city of *Segobriga* next to Saelices, province of Cuenca, a very important mining area which supplied most of the *lapis specularis* that was used in the construction of windows and hot baths in Rome.

Although today they no longer exist, we know thanks to the discovery of a manuscript from 1804 that we published recently, that the main supply network for the city of *Caesaraugusta*, today known as Zaragoza, used thick lead pipes or *plumbum nigrum* which we will now go on to describe briefly. From the drawing in the manuscript we can see that the pipes had an inner diameter of 38 cms and were about 1 cm thick. The five sections of pipe, *fistulae*, found in the River Ebro were 25, 19, 15, 15 and 15 Castilian Palms, *palmos castellanos*, long. The author of the manuscript, Juan Antonio Fernández, states that in fact all the *fistulae* had a standard length of 15 palms, as the section measuring 25 palms was made up of a complete pipe of 15 palms, an 8 palms fragment and a subsequent joint or repair measuring two palms. The same applies to the second section which measures 19 palms, which was made up of a complete tube of 15 palms and a fragment measuring 4 palms. 4 palms make a rod, *vara*, and imagining that the author was taking the Castilian rod as a reference 0.8359 m, the pipes would have been 3.13 m long, just over 10 Roman ft, in line with the minimum length recommended by Vitruvio in his famous treatise.

On the basis of these dimensions, we can surmise that the pipes were made from sheets of lead measuring 313 x 116 x 1 cms, which were rolled around a cylinder and then welded, which meant that they had an almost circular cross-section, according to Type I, subgroup D of the Vassy classification.

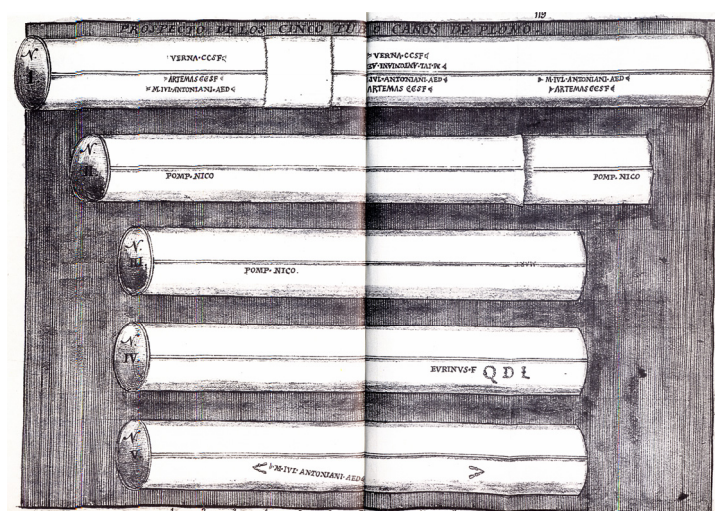


Figure 4. Engraving of the tubes of lead found in river Ebro next to the Puente de Piedra bridge in 1804, according to J. A. Fernández. (Cehopu 1994, p. 136).

MACHINES AND INSTRUMENTS USED IN CONSTRUCTION WORK

Work on the aqueduct began, as we said earlier, with a careful levelling of the terrain which enabled the engineers to gauge the feasibility of the job and assess which construction and structural methods would be most suitable. They had specific tools for this purpose, the *libela* and the *chorabates*.

The *libela* is one of the simplest levelling tools. It is made of three pieces of wood in an A-shape. Two of the pieces are the same size and function as supporting legs while the third acts as a graduated horizontal crossbar. With a plumb-line it was possible to read the difference between the respective heights of the two legs which were supported on the ground. Thanks to its simplicity, this tool continued to be used in construction for many centuries afterwards, as demonstrated by its appearance in an anonymous work published in the sixteenth century, the *Veintiún libros de los Ingenios y las Máquinas* (Fundación Juanelo Turriano 1996).

In the levelling work for the big aqueducts, the *chorabates*, which contained a water-based level, was a more important and more useful tool. We only know of its existence because it was described by Vitruvius in his famous treatise (Castañeda 1761). It was a wooden instrument about 20 ft long, almost 6 m, which must therefore have been heavy and cumbersome to transport, but which offered in return a high degree of precision in levelling operations.

It had a *canalis* or small groove carved into its top edge, which was filled with water, *regula*, so allowing it to be levelled easily and accurately. It also had plumb-lines which enabled it to be placed in a horizontal position. Once it had been correctly positioned and a check had been made to ensure that it was horizontal, the *librator* could then look through the sights situated at each end which defined a horizontal line. He then ordered the men who operated the graduated rod or ruler to stand in line with his line of sight, instructing them to raise or lower the mobile cursor until it was situated exactly in his line of sight. As they had no telescopic sights to help them with the reading, the man who used the *chorabates* could not read the graduated rod. The men who held the rod had to move the cursor on the rod up and down until it was in the right position and it was they then that took the reading. The drop in the terrain was thus the reading made on the rod minus the height of the *chorabates*.

Once the drop had been measured, it was then possible to decide what type of waterworks should be built so as to minimise costs and take advantage of existing natural features.

The construction of a hydraulic system of such huge proportions as an aqueduct meant that the channel for transporting the water had to maintain the minimum gradient so as to allow the water to flow in an open channel. For this reason, when the terrain on which the *specus* or channel was built went downhill, it was necessary to build a brick or stone wall structure or *substructio* which for

heights of more than 1 m approximately were carried out using the system of *arcuationes* or series of arches, as this was the most economical solution in these circumstances. These structures were built using a number of different systems ranging from the *opus quadratum* to the *opus incertum* and were carried out by workers such as *machinarii* and *maciones*, builders who specialised in stone or brickwork and who were assisted by labourers that prepared the lime mortar they used as a binder.

The use of large, heavy blocks of stone or ashlar meant that specific machinery was required that was capable of lifting heavy weights and transporting them to their position in the structure. The *machinatores* or *mechanici* were engineers who were responsible for the design and construction of all kinds of machinery from cranes to devices for removing water. The projects were then executed by the *tignarii* or carpenters with the aid of the *ferrarii*, blacksmiths who forged the metal pieces required for the machines.

According to Vitruvius, the machines, in particular those designed for traction purposes known as *tractoriae machinae*, were different from the *organa* in that they required several people to move them. However, Vitruvius applies the term *machina* to any type of mechanical device used as a crane or to lift weights. These had essentially two parts: the structure that was made of wood and the device for multiplying the force. The wooden structure was that of a cabin, i.e. an upside-down-V-shaped jib made up of two sturdy logs and held in position by braces anchored to the ground. This position allowed the jib to be moved up or down, but it could not rotate around a vertical axis.

The device for multiplying the force was either:

- An *orbiculus*, a single pulley that did not multiply the force at all and a *sucula* or crank which is what actually multiplied the force.
- *Trochlea*, multiple pulleys or hoists. This device produced a multiplication of the force which varied according to the number of pulleys in the hoist. As with the single pulley, these devices often finished with a crank. Multiple pulleys received their names according to the number of pulleys they had.
- *Pentaspaston*: made up of five pulleys grouped in three at the top and two at the bottom. In this way it was possible to lift a weight P by applying a force of $P/5$ to the rope.
- *Polyspaston*: According to Vitruvius, this device consisted of a large elevated log held in place with four ropes or *retinaculum*, to which two clamps or *chelonium* were fastened. These in turn were tied to a group of pulleys or *summa trochlea*, made up of three pulleys or *orbiculus* that were placed parallel to each other. Several ropes or *funis ductarii* that tied up the machine started from there and then passed several times through the bottom

pulleys and the top pulleys successively until they came to the last pulley known as the *artemon* which was used instead of a winch. Three rows of men pulled on these ropes to raise the loads.

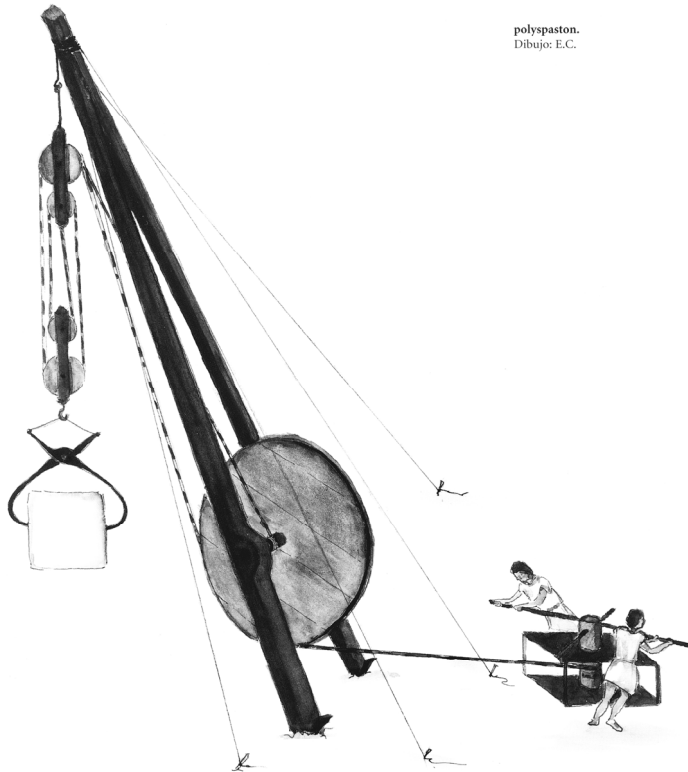


Figure 5. Polypaston (González Tascón, Velázquez 2005).

- *Trispaston*: A crane made up of a total of three pulleys, two at the top and one at the bottom. On these types of cranes, iron pliers or *ferreus forfex* were installed below the bottom pulley with teeth that embedded themselves in the slots that had been made in the stones to enable them to be lifted. In all these cases, the rope later passed through a roller that changed its direction but did not multiply the force and finished at an *ergata* or vertical axis winch that produced the multiplication of the force.
- System that used the *maius tympanum* or treadmill as the multiplying device. This was very large and had internal crossbars on which the workers would tread to make the drum go round. It was therefore made up of a single-pulley multiplication system and a treadmill.

DESIGN FEATURES

We shall now refer to a few specific features of siphons for which reliable information is available.

Sexi

Sexi is the modern-day town of Almuñécar, in the province of Granada. It is an ancient coastal settlement of Punic-Phoenician origin, which in the Roman era became famous for its salted fish production.

The main purpose of its aqueduct was to supply water to the large salted fish works in the town. The fact that it was used predominantly for industrial purposes is shown by the simple techniques that were used in its construction, *opus incertum*. However, despite its rough appearance and its relatively short length, 7 kms, this work of engineering used a great variety of building solutions, and is one of the few aqueducts in Hispania that changes over from one river to another, moving from the River Verde to the River Seco by means of a tunnel (Molina Fajardo 2000).



Figure 6. *Venter* of the siphon of the Almuñécar aqueduct.

The water is collected using a subterranean gallery over 0.5 kms long, and continues along a channel or *specus* with a rectangular cross-section, 50 cms wide, 75 cms high, with a vaulted roof, that sometimes runs underground and in other places runs high above the ground, supported on brick walls, *substructiones* or raised arches, *arcuationes* that in some cases even have saddle arches in the spandrels of the piles. The final stretch was negotiated using a siphon of about 1 100 m in length that crosses over a normally dry river bed, with a drop of approximately 40 m. The siphon

was made with ceramic pipes with an inner diameter of 16 cms and it supplied the city with an approximate flow volume of 2 134 cubic m/day.

Taking the lowest part of the valley as zero elevation, the siphon starts off at an elevation of 38 m from a box where the channel system becomes a pressurised pipeline. We have discovered the place where this box was located, although over the years it has changed completely. From here it drops down to the *venter*, that was recently excavated, with the crown being located at an elevation of 6 m, producing a maximum pressure in the pipe at this point of 32 m. c. a. It then rises again to the highest part of Sexi, without being able to reach a sufficient height to achieve the correct speed of water at the outlet from the siphon. It was therefore necessary to raise the inlet box above the ground, by building a high hollow tower or *columnaria* where the pipe drained out. Its impressive size was noted in medieval days by the Muslim chronicler al-Himyari (Lévi 1948, p. 225).

The height described by al-Himyari, 50 m, is undoubtedly an exaggeration, for two reasons: firstly, because with that height the water could not have been brought in a siphon, and secondly because the proper technology did not exist to allow the column to withstand such a huge load of water. The calculations must therefore have been made with different gradients, so leaving a wide range of possibilities open. Nowadays this water tower, suitably redecorated, has been converted into the bell tower of the Encarnación church in Almuñécar.

Gades

The modern-day city of Cadiz was probably originally founded by the Phoenicians and later occupied by the Carthaginians around 501 BC. At the end of the Second Punic War, the city surrendered without a fight to Rome and soon enjoyed a new heyday under the government of Balbo the Younger, who promoted various public works, amongst them the great water supply system. The city's wealth was associated with sea trade, fishing and the production of salted fish. Nowadays Cadiz is on a peninsula, but in Roman times Gades was an island, with the aqueduct having to pass over a bridge to reach the water tanks in the city.

In spite of being the longest water supply system in Hispania, around 70 kms long, there is still no complete detailed study available. However there is some quite reliable documentation on its route, since in the eighteenth century, when Cadiz became the main city for trade with America, Count Alejandro O'Reylli, the governor of Cadiz from 1780 ordered that an attempt should be made to put it back into service. The works were never even started, however the whole run was studied and two interesting reports survive today, one that was printed, the work of the Roman engineer Scipione Perossini (Perossini 1784), who investigated the route throughout the year 1784 and another handwritten text by Vicente de Rueda (Rueda 1783).

The Roman engineers took the water from the natural springs in Tempul, and transported it to the tanks in *Gades*. This was done mostly underground, sometimes in an open channel, and at other

points using a siphon. When the siphon solution was used, it was done using stone pipes, which, because they were not easy to reuse, still appear nowadays along many stretches of the route of the aqueduct.

We are currently in the process of studying this monumental work that was built to provide water for human consumption, so here we shall only refer to the siphon, one of two in the group, that we have studied in detail. This siphon is located in a valley known as the Arquillos, because at the bottom of the valley alongside the river Salado, there are some arches that form part of the *venter* of the siphon.

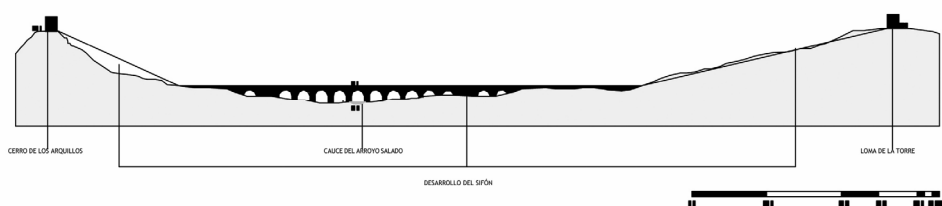


Figure 7. Scale profile of the Arquillos siphon in Cádiz aqueduct.

This siphon is 2 948 m long, 3 527 rods, according to the manuscript from Vicente de Rueda (Rueda 1783). The siphon of the Arquillos allowed the drop between the Loma de la Torre at an elevation of 132 m and the Cerro de los Arquillos Altos at an elevation of 129 m to be overcome, with a loss of load of 1 metre per 1 000. Taking the bottom of the valley as reference zero for the elevation, the head of the siphon, located on the Loma de la Torre, close to the estate called Isletes de San Luis, is at an elevation of 100 m, and its end is located on the Monte de la Silla, at an elevation of 97 m. The drop, of around 100 m, made it impossible to contemplate a solution using an aqueduct with arcades or *arcuaciones*. The preferred solution was thus the construction of a *venter* for a siphon that rose up about 25 m above the elevation of 0 metres of the Salado stream, and had a maximum pipe pressure of 75 cubic m.

Considering that the siphon was made up of a single stone pipe with an average diameter of 32 cms on the outside and 21 cms on the inside and assuming an average water speed of 1.23 m/second, as proposed by J. Bonnin (Bonin 1984, p. 162) for siphons, we obtain a flow volume of around 8 544 cubic metres/day for the city of Cadiz.

Segobriga

Segobriga is close to the modern-day town of Saelices, province of Cuenca. The ending *briga* denotes ancient Celtic inhabitants, but its importance goes back to the Roman era, when it was the largest town in a mining region specialising in the extraction of *lapis specularis*, a transparent

gypsum mentioned by Plinius the Elder (book 36,160). Large blocks of *lapis specularis* were sent from here to *Cartago Nova*, to be shipped to Rome, where they were used in enclosure walling for dwellings and public buildings.

We are quite familiar with the route of this aqueduct, which measured about 8 kms and most of which was underground, because some quite complete studies have been carried out (Almagro Bach 1976, pp. 875-901). The aqueduct collected the water using subterranean galleries dug to the north of Saelices. It was transferred to the Cerro del Griego and deposited in the so-called Pozo del Mar, from where the lead siphon, then a very abundant material thanks to the trade in *lapis specularis* (Bernárdez Gómez, Guisado di Monti 2002, p. 273-98) pipe began. This pipe had a diameter of 10 cms and was sometimes supported on a bed of *opus signinum* and in other places in a trough dug into the rock itself.

In this case, the siphon ended in a *castellum aquae* located in the highest part of the city from which the covering stone was removed with the *opus caementicium* left bare. The most significant part of this siphon is the group of secondary *castella* built to avoid excess pressure in the pipes, since the city is on a steep slope, 75 m above the bed of the river Cigüela, and to ensure the water was distributed fairly, as otherwise those who lived in the bottom part would receive for the same *quinaria* a much larger amount of water than they had contracted.

Caesaraugusta

The Roman city of Caesaraugusta, the modern-day Zaragoza, was founded by the Romans around 24-14 BC. The walled city of 60 hectares is much larger than that of *Emerita Augusta*, 49 hectares and it was built next door to the Iberian town of *Salduie*. It became extremely important because of its strategic position on the roads (Beltrán Lloris 1983), although it was necessary to build a monumental stone bridge for this purpose, which, as we shall see later, was also the *venter* for the siphon that supplied water to the city. *Caesaraugusta* was a land communications node, an obligatory crossroads between *Emerita Augusta*, Mérida and the port city of *Tarraco*, Tarragona, as well as the starting point for many other Roman roads, like the ones that headed off towards *Osca* and *Pompaelo*.

A dispute about the construction of a channel between *Salduie* and the Basque town of *Alaun*, was judged by the Celtiberian city of Contrebia in 87 BC in favour of *Salduie*; the sentence, written in Latin, then the lingua franca for the administration, was cast in bronze and today represents the oldest document relating to water works in Spain.

Until 1979 no aqueduct was known to have supplied the city, as stated in the article by J Arce (1979, p. 22). Years later, in 1994, we located and published a hitherto unpublished manuscript describing a large aqueduct in *Caesaraugusta*, written by an academic called Juan Antonio Fernández (1752-1814), shortly after several large diameter lead pipes had been found in August

1804 that formed part of the final siphon for the Roman aqueduct (González Tascón, Vázquez de la Cueva, Ramírez Sádaba 1994).

Therefore, in this case we only know for certain the place where the lead siphon crossed the river Ebro. The discovery and subsequent description of the five thick lead pipes, mentioned earlier, next to the Puente de Piedra bridge, shows the location of the *venter* for the Roman lead siphon.

On the basis of the epigraphy of the letters found on the pipes, we estimate that it was built in the first few decades of the first century AD., perhaps in the era of Augustus or Tiberius, with subsequent repairs taking place in the second century AD, as revealed by signs of successive repairs on some of the pipes.

It is highly probable that the water came from the river Gállego, and that its route started up at the Rabal dam, close to the town of Zuera, some 28 kms away, upstream from Zaragoza, at an elevation of 250 m. Its route followed that of the modern-day Rabal irrigation channel, which is probably Roman, as is its dam, until it reached the left bank of the River Ebro. Once the channel reached this point, it managed to cross the river through the construction of a siphon whose *venter*, at an elevation of 203 m corresponds to the modern-day and highly modified Puente de Piedra bridge before later draining out into the *castellum aquae* in the city. These would have been in the highest part of the city, at an elevation of around 207 m, perhaps in the Puerta Cinegia.



Figure 8. Topographic map of. D. Casañal. 1880. Note in red the passage of the roman siphon.

The use of a siphon for crossing this large river turned out to be a cheap solution, as it could also be used as a bridge. The use of lead in this case was justified by the lack of good quality stone in the area.

We believe that the hypothesis that the Rabal irrigation channel was medieval or later, and therefore used for irrigation, does not stand up to scrutiny, as the elevation that carries the water is excessive for channels built exclusively for irrigation purposes. However, this elevation is necessary for the siphon system, since the left bank of the river, where the irrigation channel from Rabal arrives, is much lower than the right bank, where *Caesaraugusta* stands. This argument is reinforced by the fact that the Rabal irrigation channel, which along most of its route runs parallel to the river Gállego, some 3 kms from Zaragoza, takes an abrupt turn or swing of 90 degrees to the West, heading towards Juslibol. This abrupt change in direction was documented in medieval times as when the water reached the river it caused periodic floods in a nearby convent. By this time the aqueduct for the city was already redundant and its waters had been diverted to drive a water mill. Considering that the siphon had a large single pipe, 36.8 cms, the flow volume supplied to the city must have been around 11318 cubic m/day.

Toletum

The city of Toledo became part of Roman territory in the year 192 BC during a campaign to take control of the Southern Plateau, located in the so-called area of *Carpetania*, which meant that the Roman troops not only effectively controlled the territory, but also dominated the natural borders such as the fords over the river Tagus. Toledo, centre of a large and rich territory in the valley of the river Tagus and, at the same time, with certain influence within the region, was strengthened as the main urban centre for the indigenous carpetano inhabitants and backed up by military settlements as from the second century BC. From the Republican period onwards the city prospered with the development of a large city and in the imperial era it had some large public works.

The existence of the aqueduct that supplied water to the city of Toledo has been common knowledge for a long time (Navagero 1563). However, the way the Roman aqueduct crossed the river Tagus into the city remained, until recently, an enigma. The aqueduct, with a route 40 kms long, took its water from the Alcantarilla dam. It followed a route without any great changes in level that was built mostly in a free channel covered with a tunnel vault, and reached the vicinity of the city, at a place where the river Tagus forms a great drop over 100 m deep.

Many hypotheses have been put forward as to how the aqueduct crossed the river. The only possible solution would seem to be a siphon (Aranda, Carrobbles, 1997, pp. 323-30) which started out from the Cerro Cortado at an elevation of 550 m and then dropped down the Eastern bank of the river in a double elbow on the ground plan and elevation, so as to minimise the steep slope of over 50%, until it reached the riverbed at an elevation of 450 m. There, a 40 m high bridge acts as a *venter* for the

siphon, giving rise to a maximum pressure in the pipe of 60 cubic m. From this elevation the pipe or pipes rise up to an elevation of 548 m, the highest point in the city.

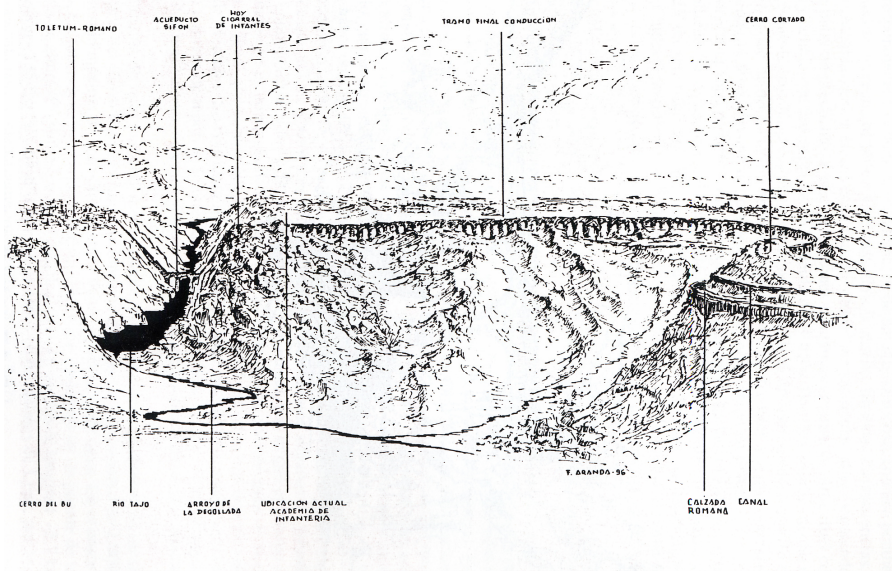


Figure 9. Possible development of the Toledo aqueduct. (Aranda, Carrobbles, 1997, p. 330).

The lead siphon, that was 2 000 m. in length, had a cross-section of 25 cms, and it remains to be ascertained whether there were one or several pipes in parallel in the supply system.

REFERENCES

Almagro Basch, M, 1976. "El acueducto romano de Segóbriga. Saelices (Cuenca)", *Revista de Archivos, Bibliotecas y Museos*, LXXIX, pp. 875-901, 35 láminas.

Aranda Gutiérrez, F, Carrobbles Santos, JL, Sánchez, I, 1997. *El sistema hidráulico romano de abastecimiento a Toledo*, Toledo, pp. 323-30.

Arce, J, 1979. *Caesaraugusta, ciudad romana*, Zaragoza, p. 22.

Beltrán Lloris, M, 1983. *Los orígenes de Zaragoza y la época de Augusto. Estado actual de los conocimientos*, Zaragoza.

Bernárdez Gómez, MJ and Guisado di Monti, JC, 2002. "Las explotaciones mineras de "lapis specularis" en Hispania". *Artifex. Ingeniería romana en España*, Madrid: Fundación Juanelo Turriano, pp. 273-98.

Bonin, J, 1984. *L'eau dans l'antiquité. L'hydraulique avant notre ère*. Paris, p. 162.

Catañeda, 1761. *Compendio de los Diez Libros de Arquitectura de Vitruvio*,

Fundación Juanelo Turriano, 1996; *Los Veintiún libros de los Ingenios y las Máquinas de Juanelo Turriano, Tomo I, libro V*, pp. 170-73, Madrid.

González Tascón, I, Vázquez de la Cueva, A, Ramírez Sádaba, 1994. *El acueducto romano de Caesaraugusta según el manuscrito de Juan Antonio Fernández (1752-1814)*. Madrid: CEHOPU.

González Tascón, I and Velásquez, I, 2005. *Ingeniería romana en Hispania*, Madrid.

Lévi, E, (ed.), 1948. Translation, *al-Himyari, La peninsule Ibérique au Moyen Age d'après le kitab at-Raud al Mitar d'al-Himyari*, Leiden: Provençal, p. 225.

Molina Fajardo, F, 2000. *Almuñécar romana*. Granada.

Navagero, A, 1563. *Il Viaggio fatto in Spagna et in Francia*, 1563.

Perossini, S, 1784. *Relación del estado del antiguo acueducto de Tempul*. Cádiz.

Rueda, V, 1783. *Manuscrito de notas puestas por el Teniente Coronel e Ingeniero ordinario D. Vicente Rueda al papel discursivo del Arquitecto romano D. Scipion Perosini*.

