39th IAHR WORLD CONGRESS GRANADA, SPAIN 2022 From Snow to Sea 19-24 June 2022

Proceedings of the 39th IAHR World Congress
19–24 June 2022, Granada, Spain
doi://10.3850/IAHR-39WC2521716X20221573

Water Management in Roman Times. A State of Question on Hispanic Aqueducts

Elena H. Sánchez López

Fundación AguaGranada, Granada, España.
Fundacionaguagranada@fundacionaguagranada.es

Abstract

The Roman aqueducts were important engineering projects that had already aroused the interest of their contemporaries. The most recent data show more than 70 known aqueducts on the Iberian Peninsula. In some cases we only have knowledge of their existence thanks to historical references that allude to their construction or reparation, but there are usually archaeological remains linked to different elements of the pipelines. Also, although most of the cities that built aqueducts only had one of them, there are also examples of cities in Hispania that benefited from the water carried by several of these water channels. The objective of this paper is to present a brief analysis of the question of the studies on Roman hydraulics in the Iberian Peninsula, with special emphasis on the state of knowledge of the Roman aqueducts of Hispania.

Keywords: Water management; Roman archaeology; Roman aqueducts; Hispania; Iberian Peninsula.

1. INTRODUCTION

The relationship between Romans and water has been reflected prolifically in literature, both legal and technical, in a large number of inscriptions publicizing the construction of hydraulic infrastructures but also in numerous archeological remains. Some of which still represent fundamental milestones in our current landscapes. This is specially the case of aqueducts. Huge engineering projects that, although they were not the only way in which the Romans were supplied with water, because of their complexity and sometimes monumentality, they had already aroused the interest of their contemporaries. It is enough to remember the proclamation of Frontino (Aquaed. XVI): “compare the numerous and necessary masses of stonework of the many aqueducts to the evidently idle pyramids or the useless but famous building projects of the Greeks”. A fascination that was maintained over the centuries, and which arose again in the second half of the twentieth century, a moment in which research in to this subject began to flourish as evidenced by the emergence, at the international level, of a prolific literature on the subject.

In the case of Hispania the first aqueduct to find a monographic study of this type was the one published by Fernández Casado (1949) about the aqueduct that supplied the city of Almuñecar. In 1972, as a result of decades of work dedicated to the study, and sometimes restoration (in the case of Segovia) of Roman aqueducts, he would publish the book “Acueductos Romanos” en Spain, as a true starting point of the studies on the Roman water channels in the Iberian Peninsula. Also in the 70s, the works of several researchers, presented in a symposium on Roman archeology to celebrate and commemorate the bimillenary of Segovia would see the light and be published in 1977 (AAVV,1977)[1]. Almost contemporary were the papers published by Jiménez (1973 y 1976) about the aqueducts of Baelo Claudia and Mérida, by Étienne y Alarcão (1974) about Conimbriga, by Mezquiriz Irujo (1979) about Alcanadre, or by Canto (1978) about the aqueduct of Italica. As well as Ramírez Gallardo´s book (1975) about the aqueduct of Segovia, the first monograph devoted entirely to the study of a Spanish Roman aqueduct. Research would continue over the following decades, marking a fundamental milestone in the methodological study at the Hispanic level with the works of Ventura Villanueva (1993 y 1996) about Córdoba[2].

To this day, the number of known Roman aqueducts linked to urban supply exceeds 70 (Sánchez and Martínez, 2016 and 2022) (figure 1), leaving aside those with a clearly rural purpose and those that have not been able to be related to any specific urban entity up to the moment.

[1] About the aqueducts of Segovia (hand in hand of M. Almagro and L. Caballero, and A. Blanco Freijeiro), Mérida (published by J.M. Álvarez Martínez), Los Bañales (by de A. Beltrán Martínez), Barcelona (by M. Mayer and I. Rodá), Tarragona (by F. Sáenz Ridruejo) and Ceuta (by Posac Mon), as well as a first reflection on water management in roman Hispania (work of J.M. Blázquez Martínez).

[2] For an exhaustive analysis of the historigraphy of Hispanic aqueducts, consult Sánchez y Martínez (2016) and Castro (2016).

Figure 1. Updated map with the location of the Roman aqueducts of the Iberian Peninsula

2. EVOLUTION OF METHODOLOGIES APPLIED TO DE STUDY OF ROMAN AQUEDUCTS

Early research on Hispanic aqueducts focused mainly on the analysis of the most monumental sections of the channels, the *arcuationes* or the constructions of arches. Soon, however, studies began to be generalized that took into account the total route of the aqueducts, from its collection point (*caput aquae*) to the terminal depot in the city (*castellum aquae*), in line with the roman conception of aqueducts, in other words, the channeling as a whole.

Over the decades these analyses have benefited from methodological advances experienced by the archeological discipline. Thus, prospecting on foot was completed in addition to archival documentation along with the analysis of aerial photographs that allowed the visualization of hard-to-reach areas, the documentation of non-visible structures, or those that had disappeared at the time of the study. Since the use of paper cartography on site, the work methodology has incorporated various instruments, first from GPS, then total stations and differential GPS; currently certain mobile apps (such as Geo Tracker-GPS Track o QFIELD) have allowed an increasingly accurate and fast positioning of the archeological remains.

From the 1990s, in parallel with the incorporation of geolocation instruments, geographic information systems have also began to be applied to the study of aqueducts, while its application in other facets of landscape archaeology was also beginning. The first published example of the use of GIS for the study of the layout of an aqueduct in the Iberian Peninsula was Cádiz (Roldán et al., 1997). But this new tool has allowed not only to generate more accurate maps of the recognizable paths of the aqueducts, but also to make proposals for the layout of lost segments from calculations linked to contour lines, or to make the connection between sections that were initially linked to different aqueducts, like what happened, for example, in Barcelona (Orengo et al., 2013). The most recent addition to these studies on the layout of the aqueducts has been thanks to LiDAR technology (Light Detection And Ranging), an optical remote sensing technique that uses light from a laser emitter to obtain a dense sample of the Earth´s surface producing accurate measurements in three dimensions (x, y, z). Maps with this information, available for the Spanish territory in the *Centro Nacional de Información Geográfica*, have been used for example to make new proposals for the layout of the aqueducts of Mérida (Feijoo y Gaspar 2019).

Finally, archaeological excavations cannot be ignored, either within a systematic research program or as a result of an emergency excavation, thus they have allowed the exhumation and analysis of sections of aqueducts.

However, beyond the studies and methodologies aimed at the reconstruction of the routes, the research on Roman aqueducts has raised other lines of analysis. From those pioneering flow calculations done by Bailhache

(1983) for the Gallo-Roman aqueducts and those applied over the decades to a multitude of Hispanic channels (Sánchez y Martínez 2016), to calculations based on 3D modeling of complex structures such as drop shafts (Borau et al., 2020).

Furthermore, adding to the traditional involvement of architects and engineers in studies of aqueducts[3], other specialist have in recent decades, joined and turned the study of aqueducts into a real multidisciplinary work thanks to the incorporation of chemistry (for example in relation to sinter analysis to which we will refer later), hydrogeology (as an example the work of Martín Montañés et al. (2020) in Ronda) or biology (as evidenced by the work of Luna Fernández (2020) about biodiversity in the aqueduct of Huelva).

3. HISPANIC AQUEDUCTS. SOME TECHNICAL CHARACTERISTIES

In general, Hispania’s aqueducts are not among the longest from the Roman world, and their paths are very far from the more than 400km aqueduct of Constantinople, the 150km of the Apamea or 105km of the aqueduct of Serino. According to the data published today, the longest aqueduct on the Iberian Peninsula is that of Cádiz, at 75km; while the majority the routes are less than 25km (Sánchez and Martínez, 2016).

As it generally happens with Roman aqueducts, in the cases of Hispania, the conduction could free flow or pressurized. The conduction of water in free flow was done by what historiography identifies as *specus*, a channel, usually built in masonry or *opus caementicium*, coated on the inside with a layer of some hydrophobic material - commonly with *opus signinum*, although there are also examples in which clay was used, for example in Valencia (Martínez Jiménez, 2011), or plaster in Caraca (Gamo Pazos et al., 2017) -, and with a domed (vaulted or gabled roof) of *caementicium* or latericio work masonry. In the peninsula only one case of wooden channel has been proposed, in the aqueduct of Los Bañales (Viartola Laborda, 2011). In the case of pressure pipes, generally reserved for specific sections, they used pipes that could have been made of lead (Segobriga o Andelos), ceramic (Almuñécar or Ronda) or stone (Cádiz o Sasamón).

But fundamental to the design of the aqueducts, was the attention paid to the slopes, to prevent excessive water speed which would contribute to the deterioration of the conduction or a too slight slope causing stagnation of the liquid. To help design and execute the right path, more or less complex solutions were used from a technical point of view. Among the simplest, was the prolonging of the routes, following contour lines, or the construction of *substructiones*, walls that allowed a certain elevation of the channel. But there were more complex solutions, such as *arcuationes* or reverse siphons, to handle unevenness, or pressure break systems, to drastically reduce the water speed.

About these resources, historiography initially paid fundamental attention to the *arcuationes* or arcade sections, especially in the cases of the most monumental examples (Segovia, Mérida, Tarragona, Almuñécar). More recent studies have been carried out on siphons, systems that involved the use of pressure conduction to save a trough in which either because of its depth or its length, the construction of an *arcuatio* would have been ruled out (probably because of economic reasons). Although initial research (already refuted by Hodge, 1983) proposed a reduced use of these elements by Roman engineers due to their technical complexity and increased need for long-term maintenance, the reality is that documentation of their use is becoming more common, also on the Iberian Peninsula. Siphons have been documented in Segobriga, Andelos, Segisamo, Cádiz (3 siphons), Almuñécar (one double siphon), Ronda and Braga, and have also been proposed for Zaragoza, Toledo, Uxama, Ocurri and Recopolis (Sánchez y Martínez, 2022). However, in the face of Hodge´s assertation (1983, 191) that the fundamental characteristic of Hispania's siphons is the use of a single pipe, of terracotta, inserted in an accessible gallery. Reality is much more complex today, as shown for example by the more and more numerous cases of siphons with pipes of perforated ashlars (Sasamón – Moreno Gallo, 2004; Cádiz – Pérez Marrero, 2011; or Braga – Morais and Lagóstena, 2019), a possibility not mentioned by Vitruvius.

On occasions, as a result of a very high difference in height between the *caput aquae* and the *castellum*, the slope of a canal was excessive, so it was necessary to radically reduce the speed of the water. For this purpose the so called drop shafts were used. Although the study of these elements is not new (Chanson 1995), and already in the decade of the 1990s, 40 structures from the aqueduct Valdepuentes in Córdoba were analyzed (Ventura Villanueva, 1993 and 1996). In recent years the study is also being completed of other aqueducts, such as those of Baelo Claudia (Borau, 2017; Borau et al., 2020). These are wells of variable depth in whose upper part the aqueduct channel empties and which have an outlet channel in their lower part. The fall and collision against the bottom of the well causes the loss of the accumulated kinetic energy, braking is further enhanced by the fact that the exit channel is generally much higher with respect to the bottom of the well.

The layouts of the Hispania's aqueducts show a wide variety of technical solutions to guarantee the arrival of water at the cities; a range that is fully in line with what has been documented for other provinces of the empire. In addition, to the resources briefly analyzed for being the ones that have had the greatest novelties in recent years, these aqueducts were also using tunnels or sections dugout at great depths below the level of

[3] Carlos Fernández Casado, Aurelio Gallardo e Ignacio González Tascón were civil engineers

passage, wells which gave access to the channels to ensure their maintenance, or elements intended for the cleaning of the water by decantation, the *piscinae limariae*.

4. CONCLUSIONS: NEW QUESTIONS IN THE STUDY ABOUT AQUEDUCTS

Beyond the changes in the methodologies discussed in the previous section, the study of aqueducts has been raising questions in recent years that go beyond the reconstruction of the paths they followed. An issue that nevertheless remains fundamental to the understanding of the operation of these engineering projects and the technical know-how of the engineers and builders who designed and built them.

So, thus among the lines of work recently opened on the Iberian peninsula, there is, for example, one that seeks not only to determine the date and contexts of the construction of the aqueducts, but also to date and understanding the contexts in which their abandonment took place. Showing how although for a time, sometimes centuries, maintenance and repair work was carried out to ensure the operation of the aqueducts, it seems that from the 5th century it was no longer technically possible to make major repairs to the channels, partly because of the lack of demand for generations and partly due to the breakdown in the transmission of knowledge, as the unsuccessful attempt to rebuild in the 6th century, a pillar in the aqueduct of Los Milagros in Mérida would indicate (Martínez Jiménez, 2019). Therefore, the construction of the aqueduct of Recópolis, linked to the founding of the city in 578, should probably be related to the presence of Byzantine engineers, and not to the work of local builders (Martínez Jiménez, 2015).

But determining the years or centuries in which an aqueduct was in use would benefit from the application of new study methodologies that begin to be applied to the analysis of channels outside the Iberian Peninsula. One such example is the dating of the calcareous concretions attached to the walls, as proposed by the team of S.Wenz from analysis of Thorium/Uranium (Th/U) (Wenz et al., 2016). In addition, sinter analysis can also be used to carry out paleoclimatic reconstructions (Passcher et al., 2020).

Another investigation tendency from recent years is that which advocates for a comprehensive study on water management in the city. Taking into account, not only the supply systems (among which in addition to the aqueducts, we must consider the wells to extract water from the subsoil, cisterns to store rainwater, or natural upwellings in the interior of cities), but also their urban management and distribution and their uses. Although traditionally the distribution of water transported by aqueducts has been linked only to the sources scattered throughout the streets, the thermal baths and the private houses of some of the privileged, archaeology has been showing a wider distribution (Sánchez 2018, 2020 y 2022; Padilla and Sánchez 2022). It is that water was fundamental in the city also in artisanal, recreational, religious or funerary spaces, although the relationship of these with water and aqueducts is a topic not yet generally addressed by research.

Similarly, the survival of the Roman hydraulic tradition in later stages has not yet been adequately analyzed, traditionally disassociating medieval Hispanic hydraulics from it (for example Barceló, 1996). And this despite the fact that it has been demonstrated the recovery, for example, in the Umayyad era, of some of the aqueducts of Roman Cordoba (Ventura 1993 and 1996), or the survival up to the twentieth century of the operation of aqueducts such as the one in Almuñécar, which was integrated by the local community of irrigators into one of the irrigation ditches of their system.

5. ACKNOWLEDGEMENTS

This research is the result of the I+D+I AQUAROLE project. Water for production. Water management in urban and peri-urban productive contexts in Roman times (PID2019.106686GA.I00) funded by MCIN/AEI/10.13039/501100011033.

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