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21

The Role of Water in Production Processes in Antiquity

Panel 3.19

Elena H. Sánchez López (Ed.)

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Volume 21: The Role of Water
in Production Processes in Antiquity

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PREFACE

On behalf of the 'Associazione Internazionale di Archaeologica Classica (AIAC)' the 19th International Congress for Classical Archaeology took place in Cologne and Bonn from 22 to 26 May 2018. It was jointly organized by the two Archaeological Institutes of the Universities of Cologne and Bonn, and the primary theme of the congress was 'Archaeology and Economy in the Ancient World'. In fact, economic aspects permeate all areas of public and private life in ancient societies, whether in urban development, religion, art, housing, or in death.

Research on ancient economies has long played a significant role in ancient history. Increasingly in the last decades, awareness has grown in archaeology that the material culture of ancient societies offers excellent opportunities for studying the structure, performance, and dynamics of ancient economic systems and economic processes. Therefore, the main objective of this congress was to understand economy as a central element of classical societies and to analyze its interaction with ecological, political, social, religious, and cultural factors. The theme of the congress was addressed to all disciplines that deal with the Greco-Roman civilization and their neighbouring cultures from the Aegean Bronze Age to the end of Late Antiquity.

The participation of more than 1.200 scholars from more than 40 countries demonstrates the great response to the topic of the congress. Altogether, more than 900 papers in 128 panels were presented, as were more than 110 posters. The publication of the congress is in two stages: larger panels are initially presented as independent volumes, such as this publication. Finally, at the end of the editing process, all contributions will be published in a joint conference volume.

We would like to take this opportunity to thank all participants and helpers of the congress who made it such a great success. Its realization would not have been possible without the generous support of many institutions, whom we would like to thank once again: the Universities of Bonn and Cologne, the Archaeological Society of Cologne, the Archaeology Foundation of Cologne, the Gerda Henkel Foundation, the Fritz Thyssen Foundation, the Sal. Oppenheim Foundation, the German Research Foundation (DFG), the German Academic Exchange Service (DAAD), the Romano-Germanic Museum Cologne and the LVR-LandesMuseum Bonn. Finally, our thanks go to all colleagues and panel organizers who were involved in the editing and printing process.

Bonn/Cologne, in August 2019

Martin Bentz & Michael Heinzelmann

The Role of Water in Production Processes in Antiquity

Elena H. Sánchez López

Water has been highlighted as a valuable natural resource and an essential element for life. Archaeological, historical and anthropological studies have analysed the water supply systems in different periods and regions. In this sense, the statement of the first paragraph in the Agenda about Water as one of the societal challenges for H2020 must be remembered: "(Water) has a wide range of applications in our daily life and it is a driver for economic prosperity. Water can be used for energy production and it is necessary for the development of industrial and agricultural activities" (Water JPI 2014).

According to this assertion, it is a fact that water is fundamental for the economic prosperity of any society, as it is vital in the development of many economic activities, both now and in the past. Nevertheless, studies about the past usually do not take into account water, further than analysing in some cases, the water supply systems. The uses given to this water, is rarely referred. Since most of the research topics have their roots in our daily lives and problems, this lack of interest can be related to the fact that, at least in the western world, water has not been a problem for the last decades. But in the past, in so arid areas as the south of Spain, the north of Africa or the Near East, it may have been a determinant issue.

In this line the objective of the Project *Agua y actividades econonómicas. Gestión y usos del agua en contextos productivos en el Occidente Mediterráneo durante la Antigüedad (AQUAECO)*, funded by the University of Granada (Spain), is to analyse the use of water in productive activities from Late Iron Age to Late Antiquity

Most production processes in the past required water. Sometimes it was one of the elements directly used in the making process, in other cases it was used for the cleaning of raw material or facilities, or it could be used as a source of power (in the case of watermills for example). Modern research has focused on the ancient hydraulic systems and their different parts, and on the water supply to the settlements and the water distribution within them, especially for Roman times. But how this water was used has rarely been analysed. Furthermore, while we have an understanding of the marketing of the main productions in antiquity thanks to archaeology and classical literature, very little research has been done about production processes themselves, and more specifically about which was the rule of water. In this sense, it is time to take into account another aspect on the water studies, its use in economic contexts.

In this sense Panel 3.19 within the 19th International Congress of Classical Archaeology, held in Cologne/Bonn (Germany) in May 2018, was entitled *The Role of Water in Production Processes in Antiquity*. Four papers were presented covering

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the use of water in pottery, glass and metal production, construction and agriculture in Roman times and Late Antiquity.

The paper by Dr. Elena Sánchez (University of Granada) and Dr. Juan Jesús Padilla (University Complutense) combines ethnographical and archaeological data for reviewing the pottery production process analysing the role of water in each of the steps. Experiments carried on in collaboration with nowadays traditional potters allow a first quantification of the water needs of potteries and the conclusion that water was most probably the determining factor in the location of these workshops.

The contribution by Dr. Javier Martínez (University of Cambridge) analyses the role of water in construction activities, highlighting it was essential for the production of mortar, lime, bricks or plaster, and concluding that the study of the building activities must take into account not only the supply of ashlar, lime, *marmorae*, but also the water supply to the construction site, since for instance, mortars are made on site.

The work by Dr. Beth Munro (University College London) reflects on the usual presence of water related structures in late antique metal and glass recycling workshops. Since those were occupying pre-existing spaces, there is the possibility that their location in or near fountains, latrines, baths, or dining rooms with water features, was related to the common presence of recycling material in there. But there is also the chance that the location of those workshops was related with the actual presence of water, essential for their work.

The paper by Davide Gangale Risoleo (PhD student at the University of Pisa) analyses the water management in Roman villas, introducing a new approach that differs from the traditional ones focussing on decorative and symbolic uses (linked to the owner's prestige). In this case he reflects on possible productive uses of this water by trying to identify their archaeological and textual evidences.

Not Only Clay. The Role of Water throughout the Pottery Making Process

Elena H. Sánchez López – Juan Jesús Padilla Fernández

Studies about pottery workshops in antiquity generally focus on two elements: one of the activities in the production processes, the firing of the wares, thoroughly studying the kilns, and the results of the production processes, the pottery itself. Only in very few cases other structures or activities within a pottery workshop and the pottery production process are really taken into account. In this sense, three elements are essential in the pottery production process: apart from the clay, vegetable combustible and water were also essential. It is true that in many cases, those two other raw materials and their uses are difficult to identify in the archaeological record, especially in the case of the water supply or water management. The fact is that in many cases the presence of water channels, vats or cisterns, is noted while the structures remain un-described; as a result of a lack of interest toward them. In spite of which, the importance of water in the pottery making is very often highlighted by archaeologist analysing those pottery workshops[1] and even by ancient texts. *P. Oxy.* L 3595-3597, three leases dated from the mid third century AD, refer to the renting of potter's workshops in Oxyrhynchus (Egypt). In every case, the owner of the facilities had to provide all the elements needed: earth, firing material and, of course, water.[2]

In this paper we will use ethnological analyses to complete the information given by the archaeological record about the pottery making process, to determine the role of water throughout the different stages.

The first step is the preparation of the clay, which starts with the curing, in which after the collection of the clay, it is left in the open air in order to eliminate organic impurities. Next step is the rehydration of the clay in large basins of still water in order to favour sedimentation, by the action of gravity, of the stones and other impurities that would negatively affect the rest of the processes. The identification of those settling vats in the archaeological record is slowly increasing, even if some data are still missing, and sometimes it is difficult to know for example the total volume of this kind of structures. Most of the remains belong to quadrangular vats (fig. 1), but some circular examples have been identified, it is the case for instance of the ones in La Bourderie[3] (Rezé, Loire-Atlantique, France). They were made of different kind of materials: stones, case of the potter's workshop at rue Chapeau Rouge at Lyon-Vaise[4] (France); tiles, like the settling vats at Cartuja[5](Granada, Spain); or bricks, case of the potteries of the Hospital de las Cinco Llagas[6] (Sevilla, Spain).

The sedimentation was made possible by the addition of water to the cured clay. But which are the evidences for the presence of water in the workshops? The most common structures related to the water supply of these facilities are wells, like

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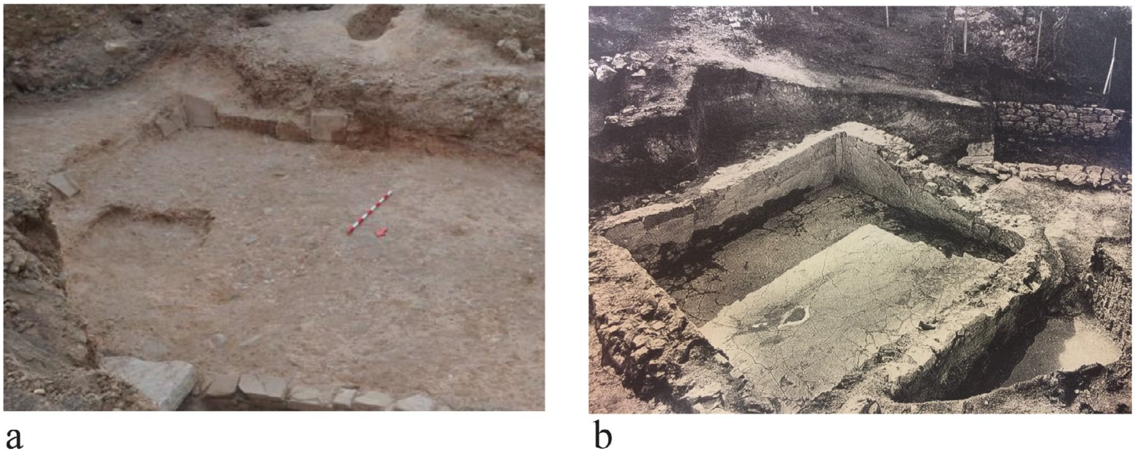

Fig. 1: Settling vats at Cartuja (a) and Phari (b).

the ones in the potteries of Venta del Carmen[7] (Los Barrios, Cádiz, Spain) or La Bouderie[8]. A bit less common are cisterns, like the ones in the potteries of Via dei Sepolcri and Via Nocera in Pompeii[9] or the three chambered one in Puente Melchor[10] (Puerto Real, Cádiz, Spain) (fig. 2). In other cases, the water could be taken from a nearby aqueduct, what seems to be the case in La Maja and the aqueduct of Sierra de la Hez, which supplied the city of *Calagurris*[11]. It has even been suggested that in some cases water could have been directly diverted from a nearby river or stream. It must be noted that many potter's workshops were near rivers, since those were essential also in the transport and marketing of the vessels. But in other cases they are close to small streams that could not have been useful in the transport, but could have been able to provide the water needed. This could be the case in the potteries of Casas de Luján[12] (Saelices, Cuenca), Villares de Andújar[13] (Spain) or La Graufesenque[14] (Millau, France).

The distribution of water within the potter's workshops is more difficult to analyse. Different kinds of channels, made of bricks, blocks, *caementicium*, or even pottery pipes[15] (fig. 3) or pipes reusing amphorae,[16] have been published from several of these facilities, but in most cases the provenance or destination of those channels or pipes is unknown since there is no information about their gradient.

Back to the clay preparation process, the fluid clay, free of impurities thanks to sedimentation, is stocked in vats in order to lose part of its water by evaporation. Once the clay reaches the adequate texture, it has to be kneaded (sometimes treaded), before been stored. During the storing time the clay may lose part of its water, and need to be rehydrated before the modelling. Then the process of modelling the clay to build the pottery vases also needs water, since the potter's hands and all the tools used need to be soaked. Water was also used for the decoration of the ceramic wares, in case for instance of the preparation of the slip (engobe), made with clay diluted in water, or the glaze.[17]

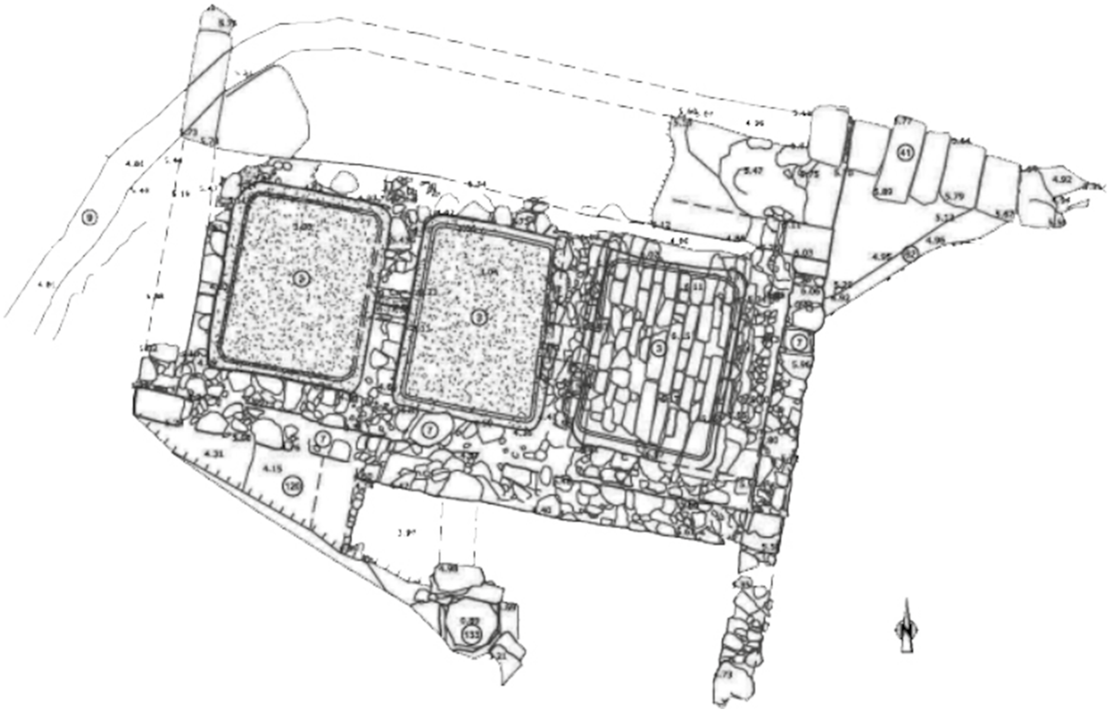

Fig. 2: Cistern at Puente Merchor’s workshop.

The final steps in pottery production would be drying the wares in a place away from direct sunlight and airy, and the firing in the kilns.

Summarising, the addition of water is essential in the preparation of the clay (primarily in the sedimentation process), and then its presence is also required for the rehydration of the clay before the modelling, during the modelling itself and even for the decoration of the wares (fig. 4). Accordingly several researchers have stated that a lot of water was used in those workshops.[18] Recent studies about ancient economies defend the idea that their quantification, in a similar way to what is done in modern economy studies, is not only possible but also necessary.[19] In this line, the assertion that an important amount of water was needed for the production of pottery is too general. The combination of archaeological and ethnological data could help to create a more accurate picture, which would help in the assessment of the real role of water in pottery production processes.

For this reason, ethnoarchaeological experiments were carried out in collaboration with Antonio and Bartolomé Padilla Herrera, potters still using traditional methods to produce pottery in Bailén (Spain). According to these experiments, the decanted liquid clay obtained after the decantation processes already explained, was composed by water (40%) and clay ready to be modelled (60%). Analysing the loss of volume during drying and firing processes, we concluded that 30% of the modelling clay was still water. That means that 60% of the decanted liquid clay was

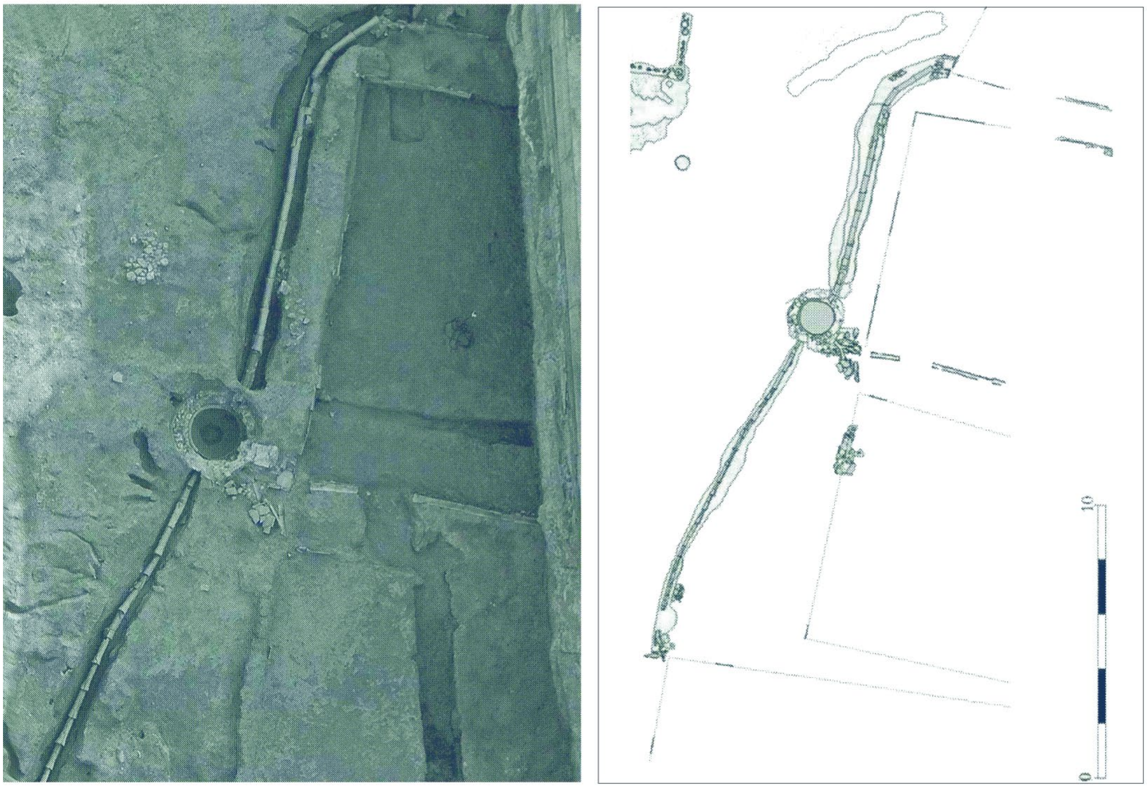

Fig. 3: Pottery pipe at Illa Fradera.

actually water. Being aware that these numbers refer to traditional pottery making process in this Andalusian workshop, we think they can apply in a very general way also to ancient pottery. This means that 42 kg of modelling clay were used to build a Dressel 20 amphora that once fired weighted around 30 kg; 12 litres of water were lost during drying and firing processes added to almost 30 litres already lost during the dehydration. The liquid lost in the decantation together with what was used during the modelling and decoration of the wares must be added to these figures. That means that the fabrication of the 191 Dressel 20 amphorae and the 28 supporting bowls that could be fired in kiln 3 of Las Delicias, according to the recently published reconstruction,[20] would have consumed at least 8.250 litres of water.

In view of those references we can conclude that in antiquity water was a very critical resource for the production of pottery. It was needed in huge quantities and despite clay or firewood, its transport and storage would have needed some planification and the construction of infrastructures. That is to say, even if potter's workshops had to be placed nearby clay quarries and woods, it is very possible that the determining factor for their location was the presence of water (wells, rivers, aqueducts) or the possibility of storing it (cisterns).

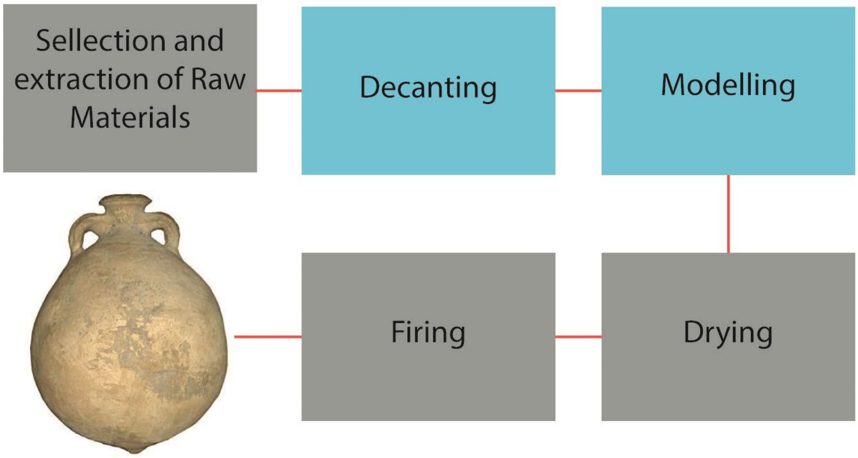

Fig. 4: Diagram of the pottery manufacturing process. The steps in which water was essential have been highlighted in blue.

Notes

[1] Peacock 1982; Echallier – Montagu 1985; Jubier-Galinier et al. 2004; Cuomo di Caprio 2007; Díaz Rodríguez 2008 and 2013.

[2] Cockle 1981; Mayerson 2000.

[3] Pirault et al. 2001, 152.

[4] Desbat 2002, 202.

[5] Moreno – Orfila 2017, 196–199.

[6] Díaz Rodríguez 2013, 51.

[7] Bernal – Sánchez 1998.

[8] Pirault et al. 2001, 150.

[9] Cavassa et al. 2014; Peña – McCallum 2009.

[10] Chacón Mohedano 2013.

[11] González Blanco et al. 1989, 51; González - Amante 1992, 47–48; Sáenz – Sáenz 2013, 475.

[12] Almeida et al. 2013, 368.

[13] Ruiz Montes 2011, 259.

[14] Vernhet 1986, 96.

[15] A *tubuli* pipe was identified for example at Illa Fradera (Badalona, Spain); Padrós et al. 2013, 450.

[16] A recycled amphorae water channel was excavated for instance at the potter's workshop of Venta del Carmen; Bernal – Sánchez 1998.

[17] Coll Conesa 2000, 196.

[18] For instance Díaz Rodríguez 2008, 95.

[19] Bowman – Wilson 2009; Callataÿ 2014.

[20] Carrato et al. 2018, 313.

Image Credits

Fig. 1: (a) Moreno – Orfila 2017; (b) Blondé et al. 1992. – Fig. 2: Chacón Mohedano 2013. – Fig. 3: Padrós et al. 2013. – Fig. 4: by the authors.

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Water in Ancient Construction

Javier Martínez Jiménez

The importance of water in the Roman world needs no underlining: from aqueducts and sewers, to powering flour mills, mining and, above all, bathing. The importance of water in Roman industries and secondary productions (pottery, textiles, fish sauces, etc.) has also usually been acknowledged in recent research, but without enough detail regarding the sourcing, use, storage, and distribution of water in these facilities. In this context, construction as an industry is no different. Water was necessary at many stages on construction sites, and in the larger projects, the logistics of sourcing, storing and disposing of water must have been quite complex. Furthermore, most of the studies done on the economics of construction[1] have focused on the amounts, sourcing, and expense of all other elements: lime, bricks, tiles, stone, manpower, metal, timber, etc. Perhaps because water is freely sourced and it has no apparent impact on the budget it is felt that water had no economic impact on construction projects. However, stone, lime and timber can be easily stored and, even if heavy, easily transported; water poses, from this perspective, different challenges, especially in those cases when water was needed on site.

In this paper I will address three elements of construction that require water: mortars, plasters, and pisé. From ancient mixing proportion (largely from Vitruvius and Pliny, together with modern reconstructions, and technical recommendations), it may be possible to obtain some volumetric ratios between the final (archaeological) structure and the original amount of water input, which could serve as a stepping platform from which to infer the order of magnitude of water necessary on Roman construction sites.

Pisé

Mud was the earliest material used in construction. Mud structures have been identified in a pre-ceramic site at the Wadi Faynan in Jordan,[2] and it remained in use both structurally and as a binder into the Roman period and beyond. From Pliny we know that structural rammed earth was characteristically used *in Africa Hispaniaque* already in the time of Hannibal, something also evident archaeologically.[3] Mud was also used in the form of pre-fabricated blocks: either uncooked (mudbrick) or baked (bricks, terracottas) forms.

Rammed earth or pisé[4] is the technique by which earth is trampled into a coffering, usually on top of stone or rubble foundations. It is simple and cheap, while offering good insulating properties and, despite what it may seem, is durable. Pisé walls, as calculated from granulometric analyses, are made of clay (15–25%, as more would result in cracks during the drying process), sand to increase the volume

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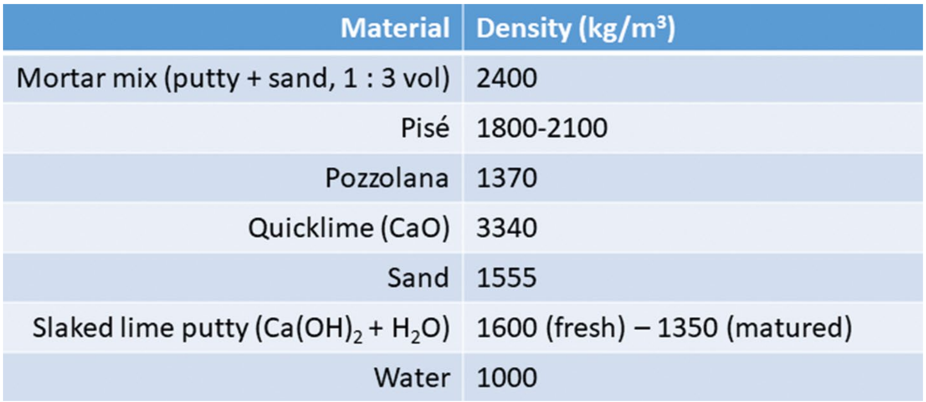


Material	Density (kg/m^3)
Mortar mix (putty + sand, 1 : 3 vol)	2400
Pisé	1800-2100
Pozzolana	1370
Quicklime (CaO)	3340
Sand	1555
Slaked lime putty ($Ca(OH)_2 + H_2O$)	1600 (fresh) – 1350 (matured)
Water	1000

Fig. 1: Reference table with the densities of the materials discussed in the text.

(40–50%), gravels (0–15%), and silts (20–35%). Lime and straw were sometimes added to improve the physical characteristics of the earth: straw gave further cohesion by diminishing retraction (and cracking) during curing while lime (which partly reacted with the humidity of the clay), improved the hardness.[5]

The way pisé was prepared was by mixing the clay with the aggregates and adding enough water to ensure that the mix absorbed 8–10% of its weight in water – a very stiff mix. Considering that the clays and the aggregates, even if they had been left to cure and dry for several months[6], already had some humidity in them, the amount of water that was necessary to add to the mix appears to have been minimal. Considering the density of pisé, for every cubic meter of earth only between 144 and 210 l of water would have been needed, meaning that an approximate maximum of 15–20% of the final volume of pisé was originally added as water.

Mortars

Lime mortars are a material widely used in construction because of their cementitious properties. This means, that they chemically transform when mixed with water into a paste, as they cure (dry) to become new rigid solids (losing moisture to the air, and carbonising CO_2 from the atmosphere) that bind coarser aggregates together (fig. 2).[7]

Lime mortars are made by mixing quicklime (obtained from burning limestone) with water (a process known as slaking), which results in a slaked lime putty. Slaking requires large quantities of water, which is normally done theoretically in a proportion of 1 : 4, 1 : 3[8] or, more experimentally, 1 : 2.1[9], lime to water, per weight. Considering the densities of both quicklime and of water, these rise up to a 1 : 7 and even 1 : 13 in volume (fig. 3).

This lime putty (which might have been between 60–80% water in volume) could have either been used fresh, or left to cure over a period of time, during which the

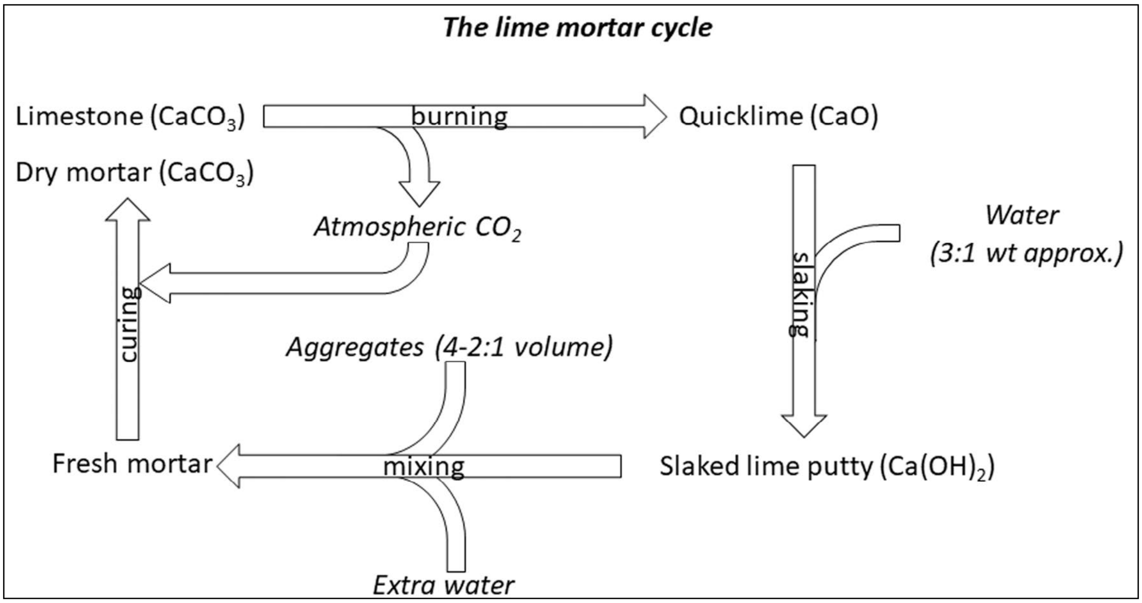
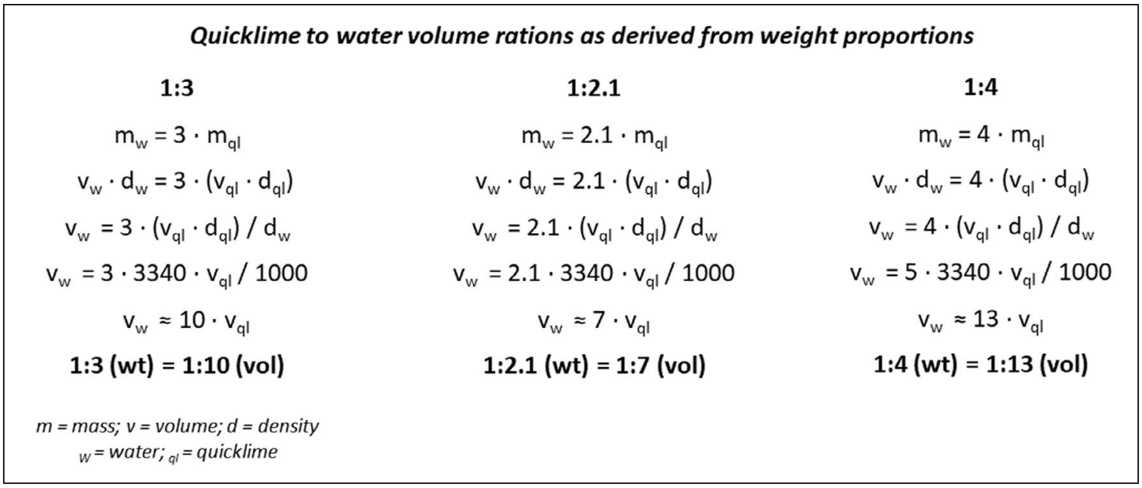


Fig. 2: The chemical cycle of lime mortar.



Quicklime to water volume rations as derived from weight proportions

1:3	**1:2.1**	**1:4**
$m_w = 3 \cdot m_{ql}$	$m_w = 2.1 \cdot m_{ql}$	$m_w = 4 \cdot m_{ql}$
$v_w \cdot d_w = 3 \cdot (v_{ql} \cdot d_{ql})$	$v_w \cdot d_w = 2.1 \cdot (v_{ql} \cdot d_{ql})$	$v_w \cdot d_w = 4 \cdot (v_{ql} \cdot d_{ql})$
$v_w = 3 \cdot (v_{ql} \cdot d_{ql}) / d_w$	$v_w = 2.1 \cdot (v_{ql} \cdot d_{ql}) / d_w$	$v_w = 4 \cdot (v_{ql} \cdot d_{ql}) / d_w$
$v_w = 3 \cdot 3340 \cdot v_{ql} / 1000$	$v_w = 2.1 \cdot 3340 \cdot v_{ql} / 1000$	$v_w = 5 \cdot 3340 \cdot v_{ql} / 1000$
$v_w \approx 10 \cdot v_{ql}$	$v_w \approx 7 \cdot v_{ql}$	$v_w \approx 13 \cdot v_{ql}$
1:3 (wt) = 1:10 (vol)	**1:2.1 (wt) = 1:7 (vol)**	**1:4 (wt) = 1:13 (vol)**

m = mass; v = volume; d = density
$_w$ = water; $_{ql}$ = quicklime

Fig. 3: Conversion of the slaking proportions from weight to volume ratios, as calculated using the formula V = m · d.

density would decrease as the lime expands. Cured appears to have been preferred in Roman times (sometimes after years of curing: Pliny *NH* XXXVI.55). The putty is then mixed with dry aggregates (most commonly sand) in a volume proportion, which varies from 1 : 2 to 1 : 4 [10], to increase the volume and prevent the mix from shrinking when curing.[11] However, traditional masons appear to have applied this 1 : 3 rule to the amount of quicklime, and not of slaked lime putty[12] – perhaps

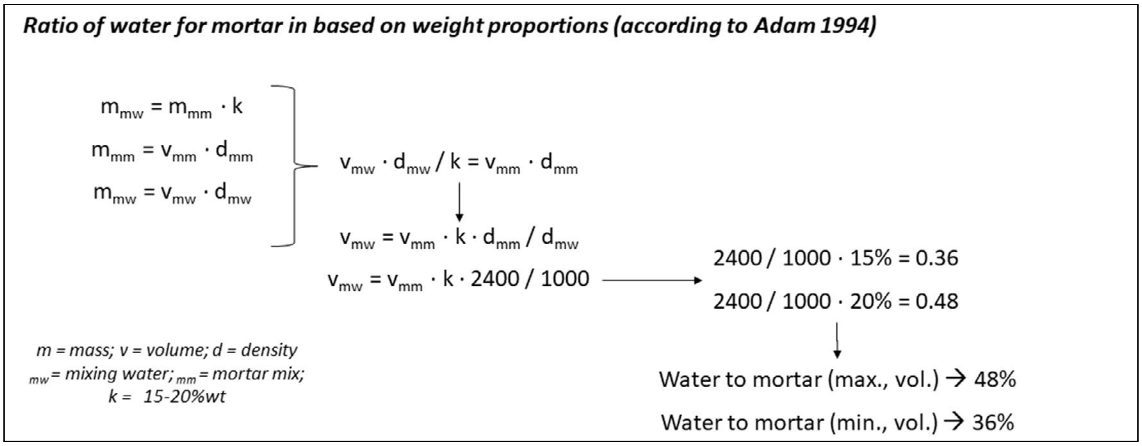


Fig. 4: Calculations for the ratio (percentage) in volume between fresh mortar and the water necessary to mix it, given an ideal mix of putty to sand (1 : 3 vol), where the putty was slaked in a 1 : 3 (wt) mix.

as a way of cost-management from the beginning of the project, and linked to on-site slaking with a 'volcano'. This may account as to why some analyses on Roman concretes show that this 1 : 3 ratio appears to not have been followed.[13] Aggregates absorb water and humidity from the putty during the mixing.[14] In order to correct the rheology, and to counter this water absorbed by the aggregates (ranging between 0.6–8%wt for sand, 10–20%wt for bricks and 10–30%wt for sands), more water is then added to the mix. This amount of corrective water depends too much on the individual circumstances of each mortar mix,[15] and from experimental trials,[16] it appears to be between 15–20% of the final weight of the putty mixed with the aggregates. With the densities of putty and sand, this means that the volume ratio is close to 36–48% of the mortar mix (fig. 4), although this is based on an average density for the mortar mix, and it will vary greatly according to the putty to aggregate ratio and the varying densities of the aggregates themselves.

In some cases (especially in Italy, with the use of local volcanic sands), the dry aggregates added to the lime putty were not chemically inert. Volcanic materials and crushed pottery have pozzolanic properties, which means that they react with the slaked lime, stopping it from carbonising back to limestone, forming a new silicon-based compound. As a result, these mortars cure under water, and are waterproof on land. This was developed during the first century BC in Italy and then spread through the empire.[17] The mixing proportions of putty to aggregate appear to have been the same as with normal lime mortars.

This mortar (whether with pozzolanic materials or not) on its own cannot be used for construction; it has to be a binder. This can be done in a masonry structure (rubble, stone, bricks) or, in "Roman concrete", with coarser aggregate (the *caementa*), which could be used structurally in walls, vaults and domes. These elements also absorb moisture from

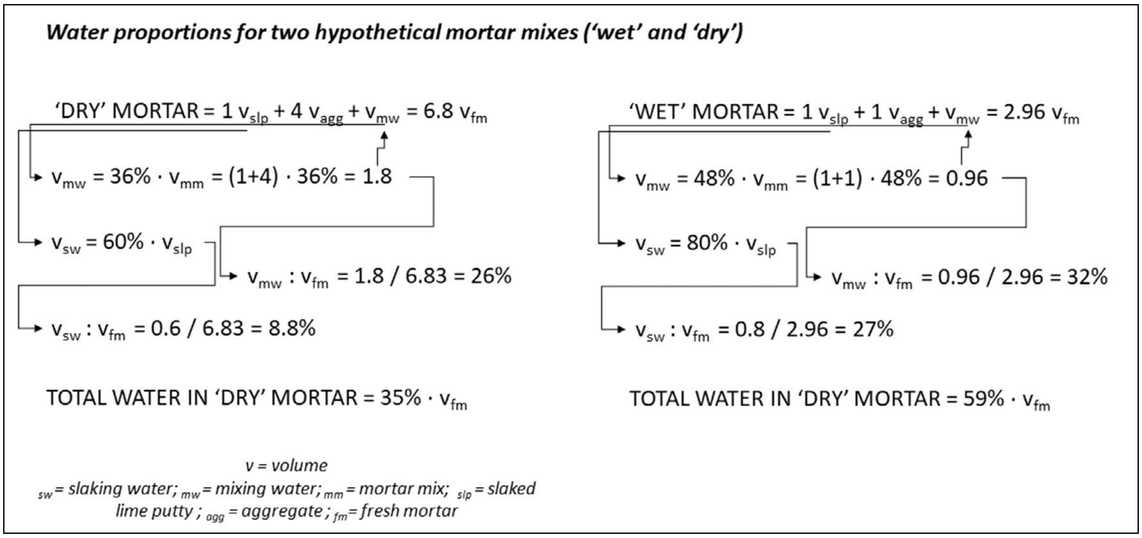


Fig. 5: Overall water consumption necessary (slaking and mixing) for a given volume of fresh mortar.

the freshly mixed mortar. In order to prevent the mortar from drying to quickly (which would cause cracks), it is necessary to soak the *caementa* (especially bricks) and other porous elements in contact with the mortar (like timbers). Furthermore, and depending on the weather, water may need to be splashed over the surfaces. The amount of water needed for this varies according to the absorption properties of each material and the weather conditions, making it impossible to calculate.

For the mix and the slaking, however, it is possible to present these over simplified calculations, based on two different mixes, a 'wet' and a 'dry' mortar. A more detailed study will give more accurate results. But put together, it appears that a standard ideal lime mortar, might have had a 35–60% input as water (fig. 5), plus any excess mortar, variations in the mix proportions, the water added to saturate the *caementa* or to keep the mortar from drying too quickly. The actual range may be closer to 50–75%.[19]

Plaster

Plaster is, like mortar, a substance that can be hydrated into putty, which quickly dries to a solid.[20] Plaster was usually applied on walls to protect it, but was also a way of decorating them, both inside and outside. Because of their exposed nature, plasterworks need to be renovated periodically. Plasters and stuccoes could, furthermore, be painted over or moulded into different shapes, and were applied on timber, stone or bricks.

Most plasters are based on lime and gypsum, the latter having two main advantages: it does not require high-temperature furnaces to become active, and it cures quickly after being mixed with water. Rather than going through a whole calcium cycle, when gypsum ($CaSO_4{\cdot}2H_2O$) is fired it loses part of its internal water ($2\ CaSO_4{\cdot}H_2O$), which is then reabsorbed from the hydrated putty forming gypsum again. This is a much quicker process, as already described by Pliny[21] and Vitruvius[22], which is why lime and gypsum were mixed.

Plastering is in itself a complex process, which involves various layers (normally three) of different mixes before the final one is applied; and if to be painted on, this will have to be done on a fourth one. Modern and medieval plasterworks from Iberia were formed as follows:[23] The undercoat was a first (sometimes also a second), rough surface to even and flatten the wall, some 10–15mm in thickness. This was done with a stiff lime mortar, with a 1 : 1 or 1 : 2 lime putty-to-sand volume ratio. The preparation coat was similarly used to create an even surface on which to work the final layer. This gypsum-lime-sand plaster (volume mix of 1 : 2 : 1), was applied in two coats: one rough and the second smoothed, and up to 10mm thick. After this layer cures, it is dampened again before applying the finishing coat, which is much finer, with hardly any sand and either a gypsum-lime mix or only gypsum putty.

All of these mixes had to be hydrated while mixing, probably quite often to prevent the gypsum plaster from drying too quickly. While the lime putty would have been brought on site already hydrated, the gypsum mix would have had to be watered in situ.

Thinking about Water Logistics

Considering the amounts of water proposed in this quick overview, it is now possible to think about the dynamics and logistics of water supply in Roman construction sites. For example, in pisé construction, the amount of water necessary does not seem to have been very big. Furthermore, because each course of coffering needs to be fully dry before the next one can be trampled, and average coffers were no more than three or four planks high, pisé constructions would have only required water at the sporadic moments of mixing the clay.

In mortar construction, however, water is much more abundant in proportion and in frequency, which would require a steady supply at different stages, especially slaking and mixing. Slaking could be done on site, which has the advantage of giving easy access and facilitating the transportation of the lime (which is lighter than the putty). On site it would be possible to slake the lime in pits or vats and allow it to cure for some weeks (certainly not for long years), although not all construction sites would have had enough space to accommodate this (or could secure enough water to do it). Plus, slaking is a very exothermic reaction, and thus dangerous. An alternative to this would be off-site slaking, which would also allow it to cure for as long as necessary and then transport the putty to wherever it was necessary. Adding a middleman such as a putty provider could have added costs to the budget. One of the houses of Pompeii, under repairs at the time of the eruption, had a stack of lime putty, suggestion that this solution appears ideal for small works, when it is only necessary to mix the lime and the aggregate in situ. However, on large construction sites, or at periods of large-scale construction, it might have been necessary to slake the lime on site, together with the mixing. An example of such 'volcano' mixing is depicted in a mosaic in the Bardo museum.[24] At this point, logistics could become more complicated if water was necessary in large quantities – especially over the summer. If the baths of Caracalla serve as an example, there we know that the aqueduct and the cisterns appear to have been the first things to be built.[25]

We should keep in mind that, thanks to the Roman concrete revolution, it was not only walls and vaults built with mortar. The tiles of the roof were bound with it, the floors (either *opus signinum* o mosaic) required mortar; so did the foundations, plastering and whitewashing. Lime and aggregates might have been essential in the budgeting – ultimately dictating the viability of the project,[26] but water was necessary at every stage of the process. Imperial baths and palaces, aqueducts, city walls, amphitheatres, etc. – these are structures in the range of thousands of cubic metres of structural concrete, roofs, decorations, etc.

How water was supplied to such large construction project still needs further research. Most certainly water from wells, rivers or cisterns (and fountains urban contexts) was obtained, but it would make a difference in term of man-hours if water was sourced or stored on site, and if stored, how it was supplied (water wheels? Pipelines? Bucket chains?). Construction in rural contexts (especially aqueducts, which required large amounts of mortar in difficult locations) would have required completely different dynamics and logistics, perhaps with a number of mixing stations and then the mixed mortar was carried to its final place – as can be seen on Trajan's column with fortification efforts.[27]

Lime, sand, timber, stone, bricks, manpower; all of these elements would be tallied in the final budget, but considering the amounts of water involved, more thought needs to be put into the logistics of water supply.

Notes

[1] e.g. DeLaine 1997.

[2] Mithen et al. 2011.

[3] Plin. nat. 35, 48; Uribe Agudo 2006.

[4] Pisé is understudied for the Ancient world. Wright 2005, 90 already pointed out that, "[a]t the present time[,] understanding of this construction is based on ancient reference fitted to modern practice".

[5] Fuentes García 2010, 3.42–3.70.

[6] Fuentes García 2010, 3.70.

[7] Adam 1994, 74 f.; Wright 2005, 46–84.
[8] Goldsworthy – Min 2009; Harper 1934; Lancaster 2005, 53; Wright 2005, 146.
[9] Brune 2010, 336.
[10] Lancaster 2005, 545; Siddall 2010, 166.
[11] At a proportion of 1:5 wt (=1:17 vol), the mix becomes limewash; Adam 1994, 73.
[12] Lynch 2007.
[13] Jackson et al. 2009, 2484.
[14] Oleson et al. 2004, 219.
[15] Brune 2010, 18. 330; but, as a general rule Adam 1994, 74.
[16] Brune 2010, 338.
[17] Mogetta 2013.
[18] Here we are leaving mortars with crushed pottery (opus signinum) aside, as pottery was never used on its own, but mixed with sand, and other aggregates, making the calculations more complicated.
[19] These are in relation to the mortar itself, not necessarily the concrete, which even if forming a monolithic solid, the mortar itself was mixed with coarse aggregate. For opus caementicium, etc., it will be necessary to calculate what proportion of it was caementa and how much mortar.
[20] Wright 2005, 159 f.
[21] Plin. nat. 36, 49.
[22] Vitr. 7, 3, 3.
[23] Malta da Silveira et al. 2007.
[24] Adam 1994, 76 fig. 164.
[25] DeLaine 1997.
[26] Oleson 2010.
[27] Goldsworthy – Min 2009, 237.

Image Credits

Fig. 1–5 by the author.

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Water Use in Metal and Glass Recycling Workshops in Late Antiquity

Beth Munro

Water availability for glass and metal workshops in antiquity was essential, but how water was used in these workshops is rarely discussed. By the late and post-Roman periods, glass and metal working begins to appear in the former rooms of domestic or public buildings, and the predominant function of such workshops appears to be recycling older Roman objects and materials.[1]

One of the curious things about these late antique recycling workshops was their frequent location in or immediately adjacent to bath complexes and major water features. For example, the Crypta Balbi workshops of the 5th–9th century were located in the former late Roman latrines, and a metal workshop at Grumentum was adjacent to a fountain.[2] Chavarria Arnau documents that just under half (10 out of 22) of the villas in her catalogue with "productive changes" were found in the bath complexes.[3]

The use of water in metal and glass recycling workshops included, broadly, pre-washing materials to remove superficial finishes or dirt, quenching, the use of a damp cloth to aid in forming blown glass vessels, the control of kiln temperatures, and the washing of hands and tools. There were two types of water features preserved in these recycling workshops: tanks and drains/channels.

Four villa sites in Italy – Monte Gelato, Aiano-Torraccia di Chiusi, Santa Cristina in Caio and Faragola – provide some of our best evidence for mixed metal and glass recycling in the post-Roman phase. But the evidence at these sites for water use in the workshops is highly variable and appears to have responded to sites specifically – where there was close access to a spring or stream, perhaps there was no need to build new water channels. However, some general observations can be noted.

Firstly, in the rural environment, the water systems used in the villas always seem to have been out of use by the time any recycling operations commence. This is evident from the dating of backfilling of drains and cisterns. However, because water was still essential in these recycling operations, we observe two main responses to this: the first was to cut new tanks and water channels through former floors, under floors that had already been removed, and through walls. This is the case of Monte Gelato and Aiano-Torraccia di Chiusi, but also at other sites, like El Ruedo and San Felice. Sometimes these drains were rather sophisticated – at Monte Gelato drain E23 was a double channel drain, with a bottom channel covered by a tile sealed with mortar, and an upper channel open to the workshop.[4]

The other solution at villas is not evident archaeologically – where there were no obvious water channels or plaster lined tanks. In these cases, one must assume that they were using buckets or pits to hold water, presumably collected from nearby streams, springs, rainwater, or wells.

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The choice of water solution does not necessarily correspond to the technological process used – for example, there was blacksmithing at Faragola, but no purpose built tank, while at Monte Gelato, a tank sat in the corner of the blacksmithing workshop. At Cesson-Sévigné, there was a glass blowing operation in the former baths of the villa, but no new water supply system put into place, while at Aiano-Torraccia di Chiusi water could have been used to pre-wash glass *tesserae* and finished moulded objects.[5] Thus it was not the material or kiln technology (heating of crucibles or forging) alone that dictated an established water provision. In general, I would argue that the investment in water provision that left an archaeological trace indicates the recycling of materials to make finished objects – tools, agricultural clamps, beads – not "raw" materials. It is also critical to note, however, that at Monte Gelato and San Felice there were also lime kilns used to make lime for mortar and concrete for on-site reconstructions. A significant amount of water was needed to make lime concrete, and thus these channels may have been primarily present to facilitate the slacking of the lime, and incidental to the metal- and glass-working.[6]

Finally, to return to the question of the relationship between these workshops and bath complexes. This relationship must be understood to be materially related, not water related. They were recycling the materials from the baths not its water supply.

Notes

[1] In cities, recycling workshops appeared in the former latrines of Crypta Balbi in Rome (Ricci 2001, 336–350) and the baths at Sabratha in North Africa (Leone 2007, 216 f.). I have documented the phenomenon in Roman villas at sites across the Mediterranean regions (Munro 2012; Munro 2010), but this also occurred in Germanic provinces (see Van Ossel 1992) and Britain (for example at the Brading on the Isle of Wight).

[2] Bison et al. 2016, 79.

[3] Chavarria Arnau 2007, 126. See also Catalogue in this volume.

[4] Potter – King 1997, 59 f.

[5] Deltenre – Orlandi 2016; Cavalieri 2012.

[6] On lime concrete and water provision, see Martínez Jiménez, this volume.

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Water for the Villas:
Water Distribution for Production Processes

Davide Gangale Risoleo

Abstract

Contemporary archaeological debate frequently discusses the presence of water in Roman villas, mainly focusing on the difference between decorative and functional aims. Past research has focused on the decorative and functional value of water in a residential building, trying to study on one hand water as a luxury element, highlighted with pools and fountains or on the other hand as an enhancing economic tool. However, the point is: how can we architecturally and structurally decline the functionality of water in a villa? Furthermore, is it possible to identify technological differences in water supply in relation to the productive process? Sometimes, water supply was secured by connecting it to a central system, like a city aqueduct, supplying the villas along its way in the suburban area. However, this was not the only possible solution. In fact, there are also villa securing their own water supply through private aqueducts, built, by public concession, for the exclusive use of a villa or a group of such. These particular cases seem to conceal a meaning that goes beyond the display of wealth and glamour. A new construction of an aqueduct was a huge expense, higher than connecting to an existing public network. Therefore, could we interpret this effort as the need of particular productive processes? Finally, is the huge expense for the construction of a private aqueduct justified by the gains that it would have generated in a certain agricultural or handicraft production?

> Haec utilitas haec amoenitas deficitur aqua salienti,
> sed puteos ac potius fontes habet; sunt enim in summo.
> Plin., Ep., 2, 17, 25

Introduction

This contribution will analyse an infrastructure in which some villas were included up in Roman times: aqueducts.[1] We will try to define the dimensions of the phenomenon and its possible connections with production cycles. In fact, these water supplies seem to show a direct connection with the production aspects of a villa rather than with decorative ones. Initially we will try to delineate the legal and historical background of the phenomenon, proposing a comparison with the literary sources and the archaeological remarks. Finally, we will try to pull the strings of the speech, trying to propose some preliminary interpretations.[2]

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Water and Private Property

Roman water servitudes start from these elements: the distinction between conduction and derivation; the flow of water to be perennis.[3] A water servitude gave the right to run water to its own property, passing through intermediate lands, but did not allow to derive the water to the same lands. Only perennis water was subject to law, rainwater was excluded.[4] A landowner could not ignore these aspects and was faced with two possibilities: the connection to a running water system or the collection of rainwater. The second solution would be the most common, achievable without any authorisation. Finally, we must remember that a water servitude starts from the caput aquae.[5] Private selling of water servitudes from perennial sources was impossible[6], but we can exclude small sources of water as streams or ponds.[7]

Otherwise, groups of more people could join, acquiring together the ius aquae ducendae. This seems to be most advantageous than a single concession, because it does not cease immediately on its expiry, but remained in place until at least one of the members remained alive[8], allowing circumventing the limit of the hereditary transmission of a concession.[9]

An example of group concession seems to be the Aqua Crabra.[10] The owners of the villas located near the municipium of Tusculum, in fact, including Cicero, obtained the exclusive right to use this water supply system, which they accessed through the

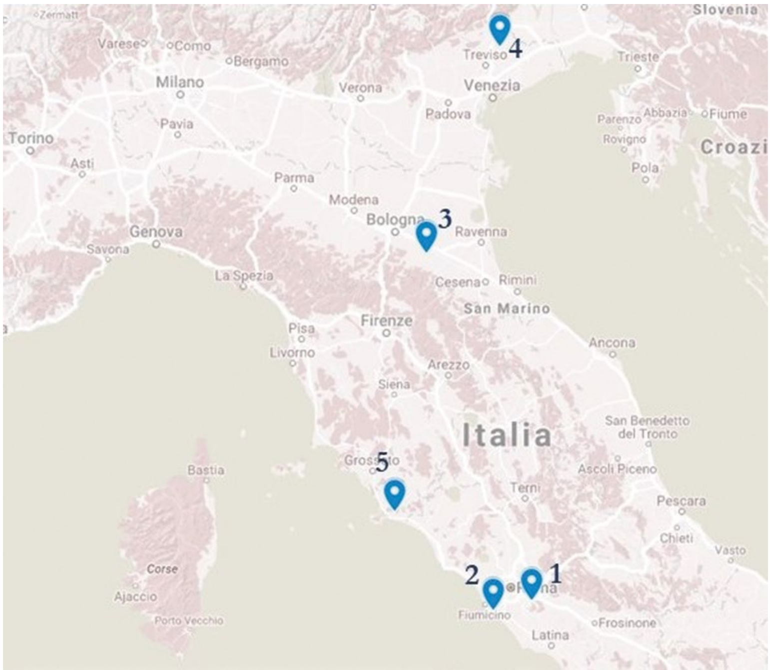

Fig. 1: Examples of water group concession: 1. Aqua Crabra, Tuscolo, 2. Ager Laurentinus, 3. the so called ‘Morine’ aqueduct, 4. San Polo di Piave (Treviso), 5. Gold valley, Cosa.

payment of a vectigal.[11] Other similar contexts are (fig. 1): the aqueduct recognised in the Ager Laurentinus[12], the so-called "Morine" aqueduct near Forlì[13], the water supply system recognised in San Polo di Piave (Treviso)[14] and the one along the Gold valley nearby Cosa.[15]

Frontinus depicts a new privatisation tendency of water management in its time, which, on the contrary, was originally exclusive public property. It is also interesting to note the reflection that the author proposes in this regard:

> ex quo manifestum est quanto potior cura maioribus communium utilitatium quam privatarum voluptatium fuerit, cum etiam ea aqua quam privati ducebant ad usum publicum pertineret.[16]

These private concessions in Rome, starting from the Augustan age, were guaranteed directly by the emperor in the form of beneficium, rigidly respected for the amount of water that was arranged.[17] All works related to the water supply were carried out under the control of a water curator, in order to ensure full compliance with the concessions. Because of that the person who guaranteed a derivation, could engage the public supply system only through intermediate tanks that were placed along the aqueduct path, no direct connection was allowed to the conduit.[18]

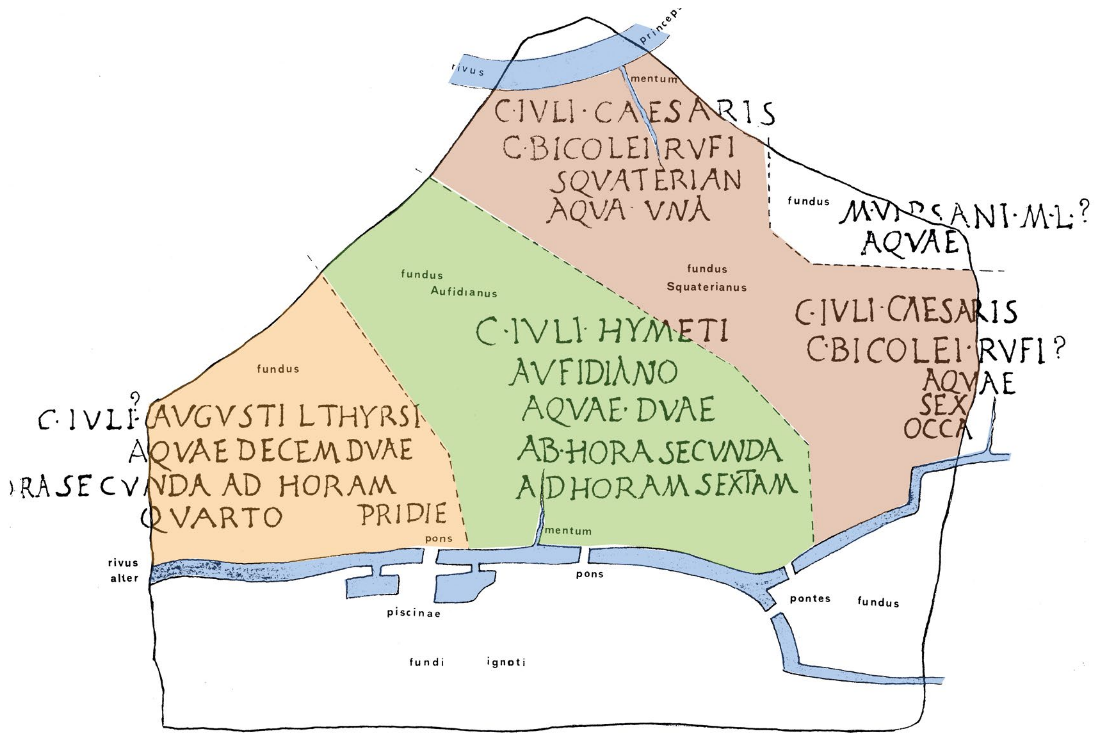

Fig. 2: The so called plan of the 'Priorato' or of the 'Aventine'.

The distribution of water to individuals is well clarified by some documents: the so-called "Plan of the Priorato or of the Aventine"[19] (fig. 2), the "Tivoli Plan"[20], the tabula of Lamasba[21] and the famous Lex rivi Hiberiensis.[22] From the first plan we learn that the water distribution involved a turnover of the dealers, who then received the water alternately and with a different frequency, sometimes connected to the granted amount of water.[23] The same context is confirmed in the others. It is clear that private water concessions limited the amount of water along with its frequency, but individuals had also another opportunity to overcome these limitations: undertaking the construction of their own aqueduct.[24]

The most famous case of a private aqueduct is the Pont d'Ael bridge/aqueduct[25] in Valle d'Aosta. It was built in 3 BC by Caius Avillius Caimus to guarantee the water supply of the quarries installed in the area. It is probably the only known case of this kind in the Roman world:

> Imp(eratore) Caesare Augusto XII co(n)s(ule) desig(nato) / C(aius) Avillius C(aii) f(ilius) Caimus Patavinus / Privatum[26]

The Aqua Vegetiana and the Aqua Corneliana

Talking about villas, the constructive practice of a private aqueduct is well described in the context of the so-called Aqua Vegetiana near Viterbo.[27] It is known because an epigraphic text reports its realisation, but there is no information about the villa. Lanciani proposed a graphic reconstruction of what was to be the path of the procurement work (fig. 3).[28]

> [Mummius Niger Val]erius Vegetus cons[ul(aris) / aquam suam Vegetianam, ex f]onte qui nascitur in fundo A[ntoniano Maiore / P(ublii) Tulli Varronis cum eo loco, in] quo is fons est emancipatu[s, du]xit per m[ilia passum ((quinque milia nongentos quinquaginta)) / in villam suam Calvisianam, quae est ad] [A]quas Passerianas suas, compar[a/tis] et ema[ncipatis sibi locis / itineribusque eius aquae a possessoribus sui cuiu/sque fundi, per quae aqua s[upra scripta, ducta est, / per latitudinem structuris pedes decem, fistulis per l]atitudinem pedes sex, per fundos Antonia[num Maiorem / et Antonian(um) Minor(em), P(ublii) Tullii Varronis et Ba]ebianum et Philianum Avilei Commo[di et Petronianum / Publii Tulii Varronis, et Volsonianum Here]nni Polibi et Fundanianum Caetenni Pr[oculi / et Cuttolonianum Cornelii Latini et Serranum I]nferiorem Quentinni Verecundi et C[apitonianum / Pistrani Celsi et crepidinem sinestrior]em viae publicae Ferentienses (!) et Scirp[ianum / Pistraniae Lepidae et per viam Cassiam in villam] Calvisianam suam, item per vias lim[itisque / publicos ex permissu] s(enatus) c(onsulto)[29]

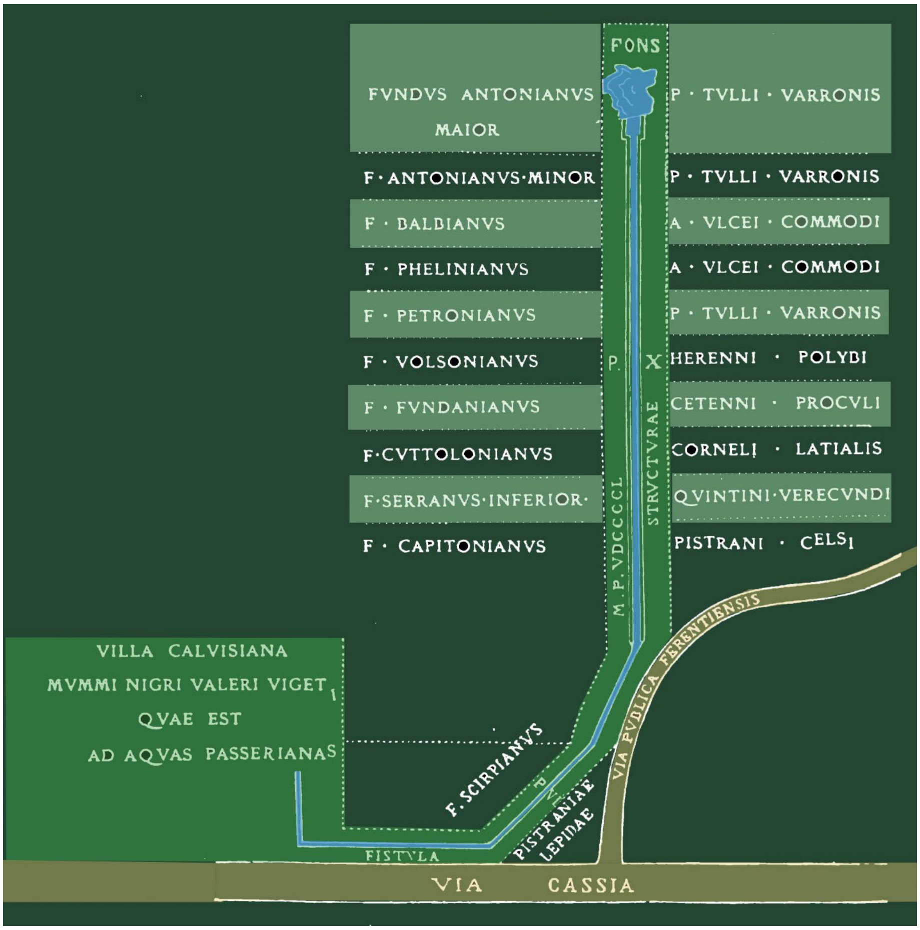

Fig. 3: Aqua Vegetiana, the graphic reconstruction of what was to be the path of the procurement work proposed by Lanciani.

The text, dated to the mid-second century AD, allows us to understand the process of building a private aqueduct, placing particular emphasis on some important elements: the acquisition of the properties of the source, water and the strip of land on which the aqueduct would have to pass.[30] These three steps testify the complexity of the work and above all the dimensions of the economic investment, without neglecting the costs of labour for the realisation. The text gives us the route of the aqueduct towards villa Calvisiana but does not give us elements about the reasons that led the decision of the construction of such an expensive infrastructure. After all, the text does not celebrate the work, but presents itself as a land map, probably required by the local senate to document the entire route of the aqueduct in detail.

A similar context is the one located in S. Maria in Stelle, not far from Verona.[31] There is an aqueduct underneath the local church, where from the 4th century AD onwards, it shared the space with an oratorium for private devotion, probably belonging to the same gens Pomponia who had built the water supply and from which it seems we can trace the present inscription:

> P(ublius) Pomponius Corne/lianus et Iulia Magia cum / Iuliano et Magiano filiis a solo / fecerunt[32]

It is currently in a reuse context, inside the conduit, but it was probably once placed outside to remember the intervention of the important local family. The inscription does not mention terms that have anything to do with water, but the wording a solo leads one to believe that it wanted to indicate the integral construction of the work: from the source. At the same, in this context it would be superfluous specifying a water term, after all the monument itself helped to clarify it. In all likelihood the work served to guarantee the water supply of the family properties located in the area. The inscription is placed in the first half of the 3rd century AD.

Quintili Aqueduct

Another case of private aqueduct is the one at the Villa dei Quintili in Rome. This case should be interpreted as the acquisition of the right to the water servitude but not of the caput aquae by a private individual, since it is not an aqueduct specially built for the villa, but an urban one that led the waters towards Rome. It is also possible to recognise the acquisition of the caput aquae property, not coinciding with the source itself, but with the beginning of the private derivation. The aqueduct owes its name to the stamps that were found on the fistulae[33] connected to it and it is dated around the middle of the second century AD.[34] Lanciani believed that the waters of the Aqua Iulia derived from the villas, instead others propose that the aqueduct collected the waters from the Anio Novus.[35]

The water supply was organised around various tanks and served to irrigate the gardens of the villa and for thermal baths. The monumentality of the structure has induced to give it a representative value, typical of the monumental villas of the 2nd century, a phase probably connected to the figure of Commodus who became the owner. Before Commodus the owners of the villa were the brothers Sextus Quintilius Condianus and Sextus Quintilius Valerius Massimus, consuls in 151 AD, and it is to them that the aqueduct of the villa must be traced back.[36] The water interest of the two brothers should not have been new since they had obtained water servitudes in the area of Tusculum, as evidenced by a mark on a fistula aquaria found in Mondragone.[37] The aqueduct[38] (fig. 4) is partly built on round arches and partly in a blind cable conduit near the villa. To the Quintili phase also the exedra of the entrance, the median cistern (P) and a large cistern (G) fed by the first part of the aqueduct belong.[39] The structure does not reveal the reasons to the Quintili's choice to have a private aqueduct and a material

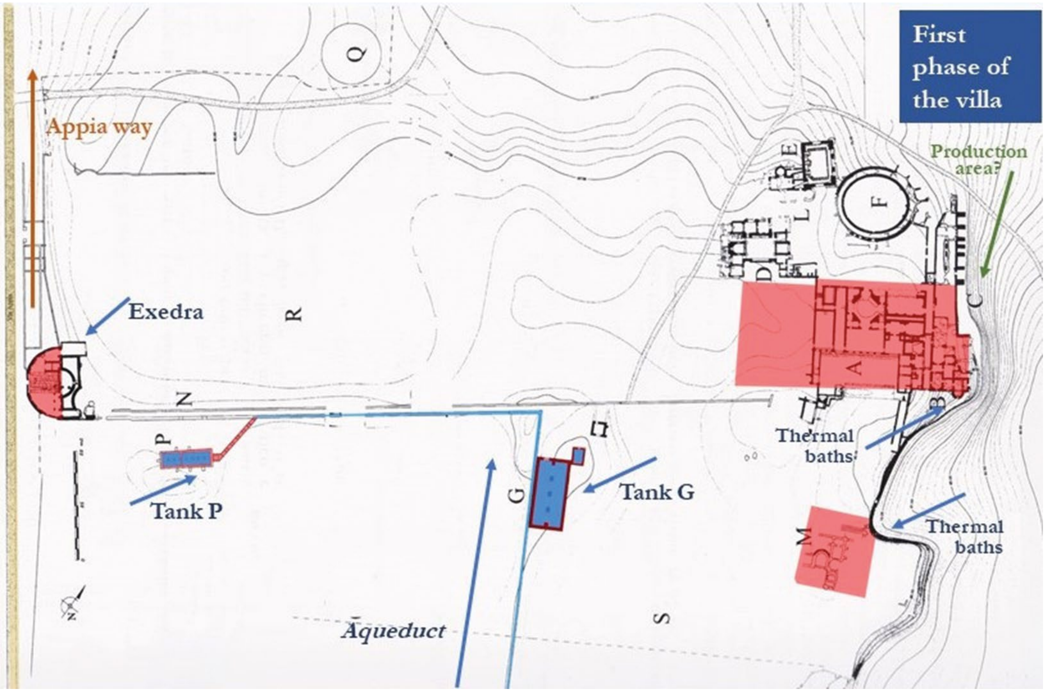

Fig. 4: The Quintili aqueduct and the first phase of the villa.

justification of such a large investment. The presence of two thermal baths, arranged by tanks for water collection, appears to be a weak justification.[40] At the same time it is plausible to assume that in the villa there were areas for agricultural work[41], partially discovered, perhaps dismantled during the "monumentalisation" phase of the villa started with Commodus. Finally, is also plausible, namely that the Quintili may have undertaken such an initiative perhaps as members of a consortium.[42] All the contexts shown lead our reflection to a further question: why did a private individual decide to undertake this investment?

Water as an Investment

The topic of water as investment has recently been the subject of a reflection by Christer Bruun.[43] Starting from the case of Valerius Vegetus, the author highlights some aspects of the work created by the senator. The aqueduct was about 9 km long and was used to convey the waters of a source that was supposed to be rich and did it through eleven different properties. The work was subject to a senatus consultum that authorised the passage along the Via Cassia. All these elements help to understand the extension of the investment, but trying to give it a more concrete dimension, the author proposes to reconstruct its economic value, drawing comparative ideas from the construction of the Aqua Claudia and the Anio Novus in Rome[44] together to the aqueduct built by Cicero's brother for his properties.[45] Comparing these two cases with the aqueduct made by Valeriis Vegetus, we obtain a hypothetical estimate of the entire work, which oscillates between 88.880 and 985.000 sesterces.[46] However, these costs do not take into account the expenses incurred for the acquisition of the land, even if Bruun hypothesises that such payment could also take place in kind, giving part of the water that was being carried to the landowners. Valerius Vegetus' investment it's not justified by the increase in the yields of its land, because even though cultivating them to vineyards[47] he would hardly be able to return the initial investment. Ultimately, the author hypothesises that "Valerius Vegetus was planning to sell the water transported by this aqueduct".[48]

The water supply contributed to the growth of agricultural production, but it is also true that in addition to the construction of an aqueduct, landowners faced other water collection solutions. Tanks inside villas are frequent and of considerable size. Moreover, the opportunity to derive waters that were not subject to public control such as torrents, ponds, not to mention rainwater, should not be underestimated. The construction of the aqueduct should therefore be understood as a choice based on obvious economic reasons that had to be very clear to the landowner and certainly went beyond ostentation.

Archaeology of Water Inside Villas

Water inside a villa was poised between two fundamental aspects: decorative and functional, but always placed inside a single circle that did not allow its waste and guaranteed its constant reuse.

Zaccaria Mari[49] proposes a periodisation of the use of water in the villas, starting from the literary sources and comparing them with the archaeological contexts of the Ager Tiburtinus[50] and Sabinus. From this analysis it follows that in the so-called "Catonian Villa"[51] there was usually a rectangular tank, located near the atrium of the house, from which water was collected for domestic use. A larger one was placed at a higher level, at the edge of the perimeter of the villa for production activities. The size of the second tank is proportional to the extension and productivity of the bottom in which it was placed. This approach continues in the so-called "Varronian villa", with two important innovations: the use of opus signinum for the coating of tanks and the construction of large piscinae for collecting rainwater probably used for watering the animals.[52] In summary, the reconstruction proposed by this scholar emphasises the role of water as an aid to productivity, where collateral uses are considered subordinates. Water was mainly used to irrigate fields and to water animals.

Another similar periodisation is also proposed by De Franceschini for the villas of the Roman countryside (fig. 5).[53] From her point of view the first element of

Fig. 5: Villas with a private aqueduct in Rome's suburbium: 1. Villa of Cinecittà; 2. Villa of the Sette Bassi; 3. Quintili villa; 4. Villa of the Vignacce; 5. Centroni villa; 6. Tor de Schiavi, 'dei Gordiani'; 7. Centocelle area.

evolution consists in the passage from cuniculi to tanks; then from underground tanks to above ground ones. Next to tanks she inserts the impluvia and the private aqueducts. Finally she indicates the villas that were provided with a private water supply[54] and connects the presence of it in all villas with one thing: luxury.[55] At the end of the analysis of the water-villa relationship, the author identifies in the introduction of tanks above ground the technical leap that allowed starting from the Augustan age the construction of the first decorative waterworks, but at the same time she underlines that water surplus spent for voluptuous uses was a circumscribed phenomenon.[56]

Conclusion

To conclude our paper we can underline that the archaeological remains can be divided into two categories: villas with a specific water supply system and water supply systems isolated in their context. It follows the presence of two distinct realities: private individuals connected to a water supply system and individuals who build their own one. Most cases are attributable to the first type and only two can be defined as specific private facilities. In these cases a figure emerges, or a family, in the organisation of the

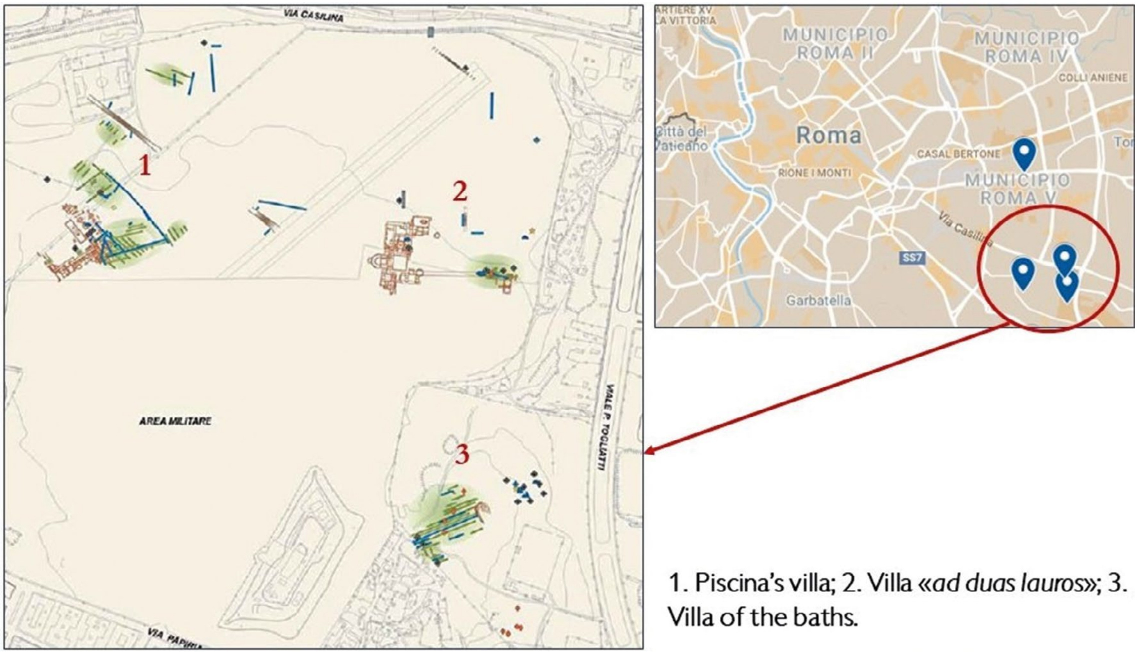

Fig. 6: The area of 'Centocelle': 1. Piscina's villa; 2. Villa 'ad duas lauros'; 3. Villa of the baths.

work that leaves therefore to intend the centrality also in the use. However, we do not have any traces attributable to the place where the water was conducted and about the primary origin that pushed private individuals towards this enterprise. The demand for a large amount of water leads us to believe that it could be necessary for the irrigation of crops in an extensive way, however this choice should be linked to economic reasons in order to justify the investment. Past studies have already shown that the presence of too large tanks could prove the presence of a water supply system, because they would not be fed only by rainwater.[57] This means that there could be more water supply systems than we think and identify. The known archaeological remains do not allow to recognise specific links between aqueducts-villas-type of production, even if, in a very preliminary way, it would seem appropriate to highlight the widespread presence of torcularia[58] for the production of oil or wine.

A good example could be the context of Centocelle[59] (fig. 6), in Rome, where three villas had a connection to the aqueduct, used both to power the thermal baths and irrigate the vineyards.

Another interesting case is the context of Masseria Ciccotti[60] (fig. 7), where starting from the second half of the 2nd century AD a villa was provided with a segment of a private aqueduct that in addition to feeding the thermal baths, served to ensure the functioning of a fullonica. In both cases the correlation between water and the aim to create an economic surplus remains clear.

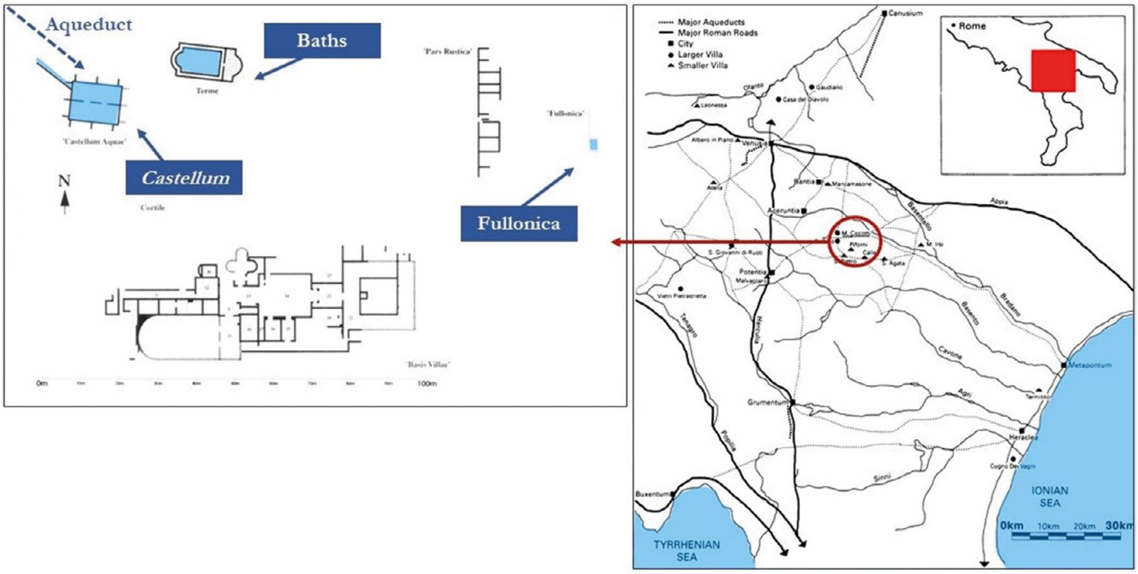

Fig. 7: The plan of the villa 'of Masseria Ciccotti'.

Attempting to outline a chronology, the 2nd century AD seems to be the period of greatest flowering of the phenomenon that probably had its beginning in the Augustan age, in the same way as attested for urban water supplies. Finally, although small, the contexts collected bear witness to a general diffusion that is not limited to Rome and central Italy, but also shows diffusion towards the Po Valley.

Notes

[1] De Franceschini 2005, 311 f.; Marzano 2007, 165–171.

[2] For more information about this subject see: Thomas-Wilson 1994; De Franceschini 2005, 311 f.; Marzano 2007, 165-171; Bannon 2009; Bruun 2015; Sánchez 2015; Longfellow 2018.

[3] Capogrossi Colognesi 1966, 1–13.

[4] Capogrossi Colognesi 1966, 5. See also Bruun 2015, 145–149.

[5] Capogrossi Colognesi 1966, 13.

[6] See Bruun 2015, 147–149.

[7] Capogrossi Colognesi 1966, 27–33; but see also Bruun 2015, 132–136.

[8] Frontin. aqu. 10, 5. See also Bruun 2015, 142–145.

[9] Frontin. aqu. 107; 108.

[10] Cic. leg. agr. 3, 2, 9.

[11] Marzano 2007, 167.

[12] Lauro 1998.

[13] Riera 1994.

[14] Mingotto 2000.

[15] Calastri 2007.

[16] Frontin. aqu. 94.

[17] Frontin. aqu. 103, 2 f.; 105. See also Del Chicca 2004, 90 f., 425–427, 425–431.

[18] Frontin. aqu. 106.

[19] CIL VI, 1261. See also Rodriguez Almeida 2002, 23–26.

[20] CIL XIV, 3676.

[21] CIL VIII, 18587 = ILS 5793. See also Bruun 2015, 142 f.; Maganzani 2012, 195–213.

[22] Bruun 2015, 145; Maganzani 2012, 171–185.

[23] About a similar organization in north Africa see also Plin. nat. 18, 188 f.

[24] See Bruun 2015, 138–140; Capogrossi Colognesi 1966, 52. Also interesting to read the opinion of Cicero about the aqueduct made by his brother Quintus: sumptum nusquam Melius posse poni (Cic. ad Q. fr. 3, 1, 3).

[25] Döring 2005.

[26] CIL V, 6899.

[27] CIL XI, 3003 = ILS 5771 = AE 2002, 471. See also Capogrossi Colognesi 1966, 91–94; Rovidotti 2002; Bianco 2007, 119, 195; Bannon 2009, 73–75; Maganzani 2012, 159–164; Bruun 2015, 136.

[28] Lanciani 1880, 379.

[29] CIL XI, 3003 = ILS 5771 = AE 2002, 471. See also Rovidotti 2002, 194.

[30] See Capogrossi Colognesi 1966, 93; also Bruun 2015, 136.

[31] Gangale Risoleo 2018.

[32] CIL V, 3318.

[33] CIL XV, 7518: II Quintiliorum Condiani et Maximi.

[34] Lanciani 1880, 183.

[35] Meogrossi 1985, 95 f.

[36] See Paris et al. 2015.

[37] Lanciani 1880, 184. 260 no. 350.

[38] Meogrossi 1985, 95–99.

[39] Paris et al. 2015, 204.

[40] De Franceschini 2005, 222–236.

[41] This hypothesis could be confirm thanks to the discover made in area c41, where they found some tanks lined with opus signinum and probably linked with oil and wine production; De Franceschini 2005, 223. 236.

[42] Lanciani 1880, 184.

[43] Bruun 2015.

[44] See also Plin. nat. 36, 122.

[45] See also Cic. ad Q. fr. 3, 1, 3.

[46] The variation in costs depends on the presence of arches.

[47] The most profitable: see Cato agr. 17.

[48] Bruun 2015, 141.

[49] Mari 2005, 9, 17 f.

[50] Marzano 2007, 168. See also Cappa – Felici 1998 and Mari 2013.

[51] See also De Franceschini 2005, 329–331.

[52] Varr. rust. I.11.2; Col. I, 3; Vitr. VIII, 6. 14.

[53] De Franceschini 2005, 305–313.

[54] Villa "of Cinecittà", villa "of Sette Bassi", villa "of the Quintili", villa "of the Vignacce", villa "of the Centroni", villa "Tor de'Schiavi, of Gordiani"; De Franceschini 2005, 144–156. 163–166. 199–202. 209–214. 222–236. About water inside Rome's suburbium: Dell'Era 2000, Bruun 2003, Vitanen-Korhonen 2014. An hypotetical private aqueduct was recently discovered along the Ardeatina way, see Fiocchi Nicolai – Vella 2017, 309–324.

[55] De Franceschini 2005, 312.

[56] De Franceschini 2005, 312 f.

[57] Thomas – Wilson 1994, 141.

[58] See villa "Tor de' Schiavi, of the Gordiani"; De Franceschini 2005, 144–156. Villa of "Pian della Civita"; Marzano 2007, 271. Villa "of the Selvicciola"; Marzano 2007, 387. Villa "of the Cecina"; Donati 2012.

[59] Santangeli Valenzani – Volpe 2012.

[60] Flohr 2013, 27; Gualtieri 1999, 133–139. 147–151.

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Fig. 1: by the author. – Fig. 2: Rodriguez-Almeida 2002, fig. 9. – Fig. 3: Lanciani 1880, 379. – Fig. 4: De Franceschini 2005, 81.1. – Fig. 5: by the author. – Fig. 6: Santangeli Valenzani – Volpe 2012, 65, fig. 4. – Fig. 7: Gualtieri 1999, 133, fig. 87.

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Session 3 | Production

Water is required in many production processes, both now and in the past. But water studies have traditionally focused on the analysis of water supply structures, in particular on aqueducts and monumental fountains, leaving aside most of the uses given to this precious liquid after bringing it into the urban settlements. Apart from the baths – already included in water studies decades ago – Classical Archaeologist have only recently begun to take into consideration other uses of water. Nevertheless, the uses related directly to productive activities have never been properly addressed.

Agriculture, pottery or glass production, building materials and construction techniques, are very common issues in recent research, however, the study of the different processes related to each of those activities has aroused much less interest and the role of water within these processes has been totally neglected. This volume includes four papers that are a first attempt to study water in production processes in the Roman period and in Late Antiquity.

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