The Byzantine Cisterns of Constantinople

K. A. Ward*, M. Crapper**, K. Altuğ***, J. Crow****

* School of Engineering, University of Edinburgh, The King's Buildings, Thomas Bayes Road, Edinburgh, EH9 3FG, UK.
(E-mail: *Kate.Ward@ed.ac.uk*)
** Department of Mechanical and Construction Engineering, Northumbria University, Ellison Place, Newcastle-upon-Tyne, NE1 8ST, UK.
(E-mail: *Martin.Crapper@northumbria.ac.uk*)
*** Inspector archaeologist of the Historical Peninsula, İstanbul Metropolitan Municipality, Directorate for the Inspection of Conservation Implementations (İBB KUDEB), Turkey.
(E-mail:*kerimaltug@hotmail.com*)
**** School of History, Classics and Archaeology, University of Edinburgh, Old Medical School, Teviot Place, Edinburgh, EH8 9AG, UK.
(E-mail: *Jim.Crow@ed.ac.uk*)

Abstract
The most unusual aspect of Byzantine Constantinople's water system was the large number of cisterns throughout the city. This research integrates the two most recent in-depth studies of the cisterns to determine that there have been at least 211 cisterns attributed to the Byzantine city. The distribution of the cisterns indicates that the size and number of cisterns constructed reduced over time, with more and larger cisterns developed prior to the seventh century. Cisterns are concentrated in the older area of the City and sparser on the periphery, but with later ones more common in the peripheral areas, suggesting that water provision was extended over time, and although the majority of cisterns are small, most storage volume is concentrated in the three largest open-air cisterns. The extended, detailed list produced will allow more in-depth investigations to proceed. Analysis of the distribution of cisterns across the City creates a framework for understanding the development and functioning of Byzantine Constantinople's complex water supply system.

Keywords
Constantinople; Water supply; Cisterns

INTRODUCTION

Cisterns have been used by many ancient civilisations to store water (Mays, 2014), but those in Constantinople are unparalleled in scale and number. The distribution of cisterns in Constantinople indicates the approach to water supply in Constantinople differed significantly from that of Rome. Understanding the reasons behind this alteration in strategy is one of the long term goals of our research programme "Engineering the Byzantine water supply: procurement, construction and operation". The present study investigates the cisterns, which are key evidence of the different approach used in Constantinople. These cisterns embody the change in strategy – from abundance to careful storage and management – that allowed the city to flourish as the new Rome.

Constantinople was constructed as the new capital of the Roman Empire in the early fourth century on the site of Byzantium. Located on a peninsula at the edge of Thrace, the City, as illustrated in **Error! Reference source not found.**, was bounded by the Sea of Marmara to the south, the Golden Horn to the north and the Bosphorus to the east. Although the City was surrounded by water, there were no substantial nearby sources of fresh water. Initially, the city relied on the 47 km long Hadrianic aqueduct, which was constructed in the 2nd century A.D. to

bring water to the town of Byzantium. However, this aqueduct alone was not sufficient for the growing city and work started in the mid-4th century A.D. on constructing a monumental aqueduct bringing water from springs in the Thracian hinterland (Çeçen, 1996; Crow *et al.*, 2008; Snyder, 2011, 2013). This new aqueduct, the Valens aqueduct, was added to by a second phase of construction in the early to mid-5th century A.D. which brought the length of the system to at least 426 km and perhaps as much as 564 km (Ruggeri *et. al.* 2016). Around the same time (the mid-5th century A.D.) the focus of water infrastructure investment switched from water collection structures outside the city to major cisterns within the city walls.

Figure 1. Byzantine Constantinople with main features marked, Hills of the City numbered one to seven, and the locations of 211 Byzantine era cisterns.

In modern times, the number of cisterns found and recorded has grown considerably. Gilles (Byrd 2008) described nine cisterns, some still in use, during his time in the city in the 1540s. The first attempt to systematically catalogue the cisterns was by Forchheimer & Strzygowski (1893). It listed, within the City, three open-air reservoirs and 40 closed cisterns, and reported descriptions of 27 sites that were unable to be confirmed. Müller-Wiener (1977) records about 75 cisterns in his study of the topography of Byzantine and Ottoman Constantinople. The most recent works are Bardill's bibliographical concordance within Crow *et al.* (2008) which lists

161 entries (including two in Sycae (Galata), north of the Golden Horn) and the cistern catalogue by Altuğ (2013) which has 158 entries. Despite these publications, even recent works, such as Mays (2014), state the number of known cisterns in the City at around 70.

As the number of cisterns known within the city has grown it has become clearer that the cisterns are central to Constantinople's water supply strategy. In fact the number of cisterns within the city is higher than even the most recent studies concluded. At first glance, the studies of Crow *et al.* (2008) and Altuğ (2013), despite using different methods for compiling their lists, appear to agree that there are around 160 Byzantine era cisterns within the city. The bibliographical concordance in Crow *et al.* (2008, 143-155, Maps 12-15) lists cisterns collected from previous studies going back to the sixteenth century, whereas the catalogue of Altuğ (2013) comprises cisterns that either still exist or have firm records and can be mapped precisely. When these two works are compared, it is clear that not all cisterns feature on both lists, some being unique to one or the other. The combination of the two sources has revealed that there is evidence of at least 211 Byzantine era cisterns in Istanbul. Of the 211 entries, 97 were present on both lists, 61 were exclusive to Altuğ's catalogue and 53 were exclusive to the concordance of Crow *et al.* (2008).

Our understanding of the water supply system is still at an early stage, but with this expanded dataset we are able to begin exploring the role of the cistern within the city, provide a foundation for future investigations and raise some of the questions that can be asked about the water supply system as a whole.

DEVELOPMENT OF CISTERN TECHNOLOGY

Cisterns are an old technology with examples dating to the Neolithic Age. Typically these cisterns were small in scale and collected rainwater in a domestic setting (Angelakis & Spyridakis 2010; Mays *et al.* 2007). This type of cistern was also used through the Roman era, often built into the structure of a house with the roof acting as a catchment. In the Roman era larger cisterns start to be constructed, often associated with high demand users where the constant flow from the aqueduct would be insufficient to meet short term supply needs, such as the Piscina Mirabilis (12,600 m^3), constructed to serve the naval port at Misenum (De Feo *et al*. 2010). In Roman North Africa, the concept of storage and management of water on a non-domestic scale appears to be reflected in the larger cisterns, for example in Carthage the La Malga, Dar Saniat and Bordj Djedid cisterns, all associated with aqueduct or groundwater sources (Wilson 1998). These cisterns can bridge a short-term imbalance between demand and what the aqueduct can supply and prevent waste of this important resource.

However, it is in Constantinople that we appear to see the store and manage approach deployed across an entire city. The cisterns in Constantinople exist at scales far beyond the domestic rainwater-harvesting cisterns of Greece and in numbers far beyond those of North Africa. In Constantinople we believe that the cisterns formed a unique storage and distribution system that would have required significant operation and management to be successful.

CISTERNS IN CONSTANTINOPLE

Our longer list of cisterns, along with the collated data on dimensions and construction period enable us to reflect on what can now be surmised about the water supply in Constantinople.

Rainwater harvesting

Although the source of water for the cisterns of Constantinople is unverified, it is highly likely that the cisterns were fed by the two aqueducts rather than by rainwater harvesting (Crow *et al*. 2008, 140-141). The majority of cisterns in the city are far larger than those typically associated with rainwater harvesting; only 14 cisterns are known to have a volume less than 100 m^3 (see the section below on the distribution of volume of cisterns). The collection areas required for the larger cisterns would be colossal, but the topography of the city, with steeply sloping spurs, and the location of cisterns, generally high up the slope, reduce the available collection area. The tendency for cisterns to be found in clusters also reduces the available collection catchment per cistern. Rainwater is likely to have been the primary source of water for the smallest cisterns in the city which we can assume are domestic cisterns not to be associated with the wider network. Rain may also have provided a secondary source of water for some larger cisterns where roofs and courtyards surfaces could be conveniently channelled.

A full calculation of rainwater harvesting potential is outwith the scope of this paper but with annual rainfall of between 630 and 730 mm estimated for the Antique period (these estimates are from a preliminary unpublished Macrophysical Climate Model study) and an estimated population of 360,000 (Jacoby 1961), the entire historic peninsula at approximately 13.4 million m^2 would only be able to provide 64 litres/person/day. As soon as we start to make this calculation more realistic (by reducing the area available for collection, assuming some losses of rainfall and taking into consideration seasonal variation) the water available per capita becomes unfeasibly small. The enormous investment represented by the cisterns was not to enable the city to just struggle along but in order to let it flourish. To do that, the cisterns must have been fed by the aqueducts.

Cistern distribution – location and volume

Figure 2 illustrates the overall distribution across the City, with a clear concentration of cisterns along the ridge that comprises Hills One to Six. This concentration follows the likely route of the two aqueducts within the City, with the earlier Hadrianic aqueduct running half way up the northern slope from Hills Six to Two, and the later Valens aqueduct further to the south, running close to the crest and across the Bozdoğan Kemeri, again from Hills Six to Two. Given that the cisterns tend to follow the route of the aqueduct, we can suggest that the cluster of cisterns around Hill One indicates that at least one of the aqueducts extended this far. Many of the new cisterns from Altuğ's catalogue are located on the south side of the City, where few cisterns were previously known. These finds confirm the notion that cisterns were present throughout most parts of the City.

Figure 2. The City's 211 cisterns categorised by volume. Extra Large >100,000 m³; Large 5,000 – 99,999 m³; Medium 1,000 – 4,999 m³; Small 100 – 999 m³; Tiny <100 m³. Numbers indicate the Hills of the City.

From Figure 2 it is apparent that there is a greater concentration of cisterns around Hills One and Two, the oldest area of the City, where the population was likely to be the highest. We know that some households had piped water supplies, based on law codes governing the size of supply pipe permitted (Codex Theodosianus 15.2.3 in Crow *et al.* 2008). Public fountains are also mentioned in the law codes and it is around fountains that people are reported to gather in times of water shortage (Procopius, *Secret History* 26.23 in Crow *et al.* 2008). So people are unlikely to live far from a cistern and there are cisterns distributed across the City, which would maximise the ease of access to water by the population. The furthest distance of any point in the City from a cistern is 1,300 m, on Hill Seven, in the zone between the Constantinian and Theodosian Walls. If considering the more populated area within the Constantinian Walls, the maximum distance to a cistern drops to just 500 m. Again, this is on the periphery, where the population density was likely to have been lower.

There is volume data for just under half of the 211 cisterns, although in some cases the depth had to be estimated from photographs. From the known data it is possible to state that the

cisterns range in size from under 2 m³ to over 370,000 m³. It should be noted that these volumes represent the upper bound of possible storage, as there is no clear evidence that cisterns were used up to the maximum possible capacity and the depth of a cistern might have been influenced by factors other than the need for storage. The distribution of cisterns across the range is illustrated in Figure 3, where five size categories have been used. The volume of unknown cisterns should not be dismissed as trivial, with at least two cisterns thought to be very large, the cistern on top of Hill Two of which only a 90 m long section of wall remains and the Modestus cistern, tentatively identified by Forchheimer and Strzygowski (1893, 52) as a 154 m long and 90 m wide structure housing the later Saraçhane market near the Bozdoğan Kemeri.

The largest cisterns are three open-air cisterns that provide over three-quarters of the known storage volume within the city and may have a function feeding the rest of the system when inflows are low or have other purposes associated with agriculture or industry.

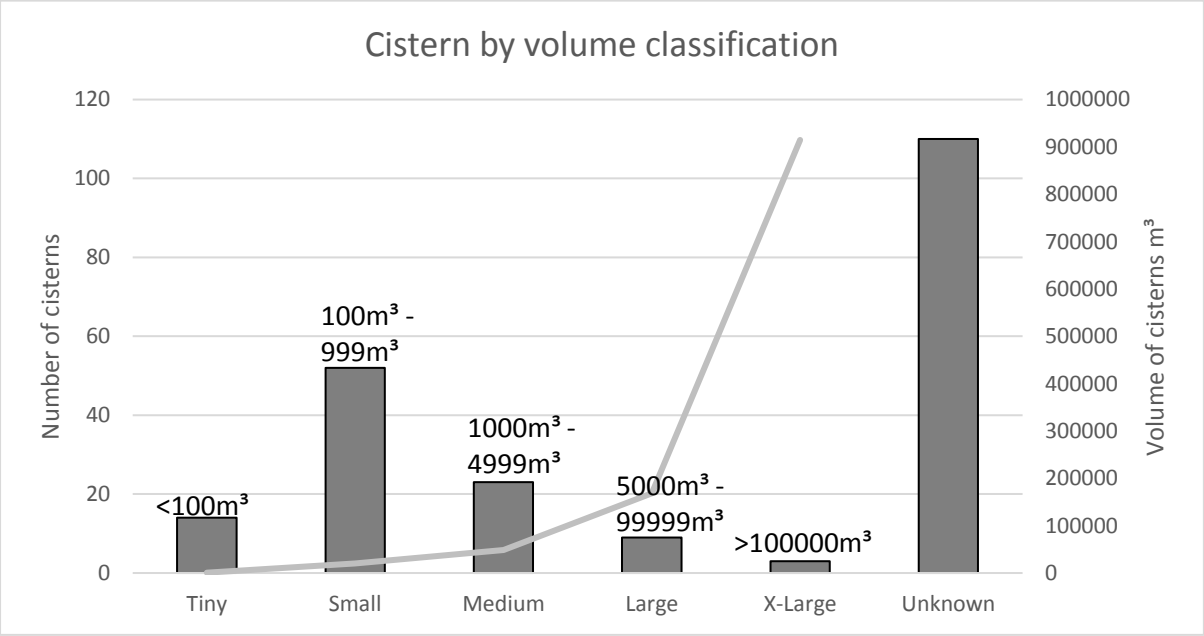

Figure 3. Number of cisterns in each volume classification

Distribution of cisterns over time

Most cisterns are difficult to date with any precision, some, like the Yerebatan Sarayı (Basilica) cistern, can be dated with some certainty from historical sources, although often these have different interpretations. Others may be dated from specific forms of construction, and others through the reuse of dateable architectural members which provides a *terminus post quem* for the works. Altuğ's catalogue includes volume and an estimate of the date of construction, which allows us to examine the water supply and its development more closely, although it should be noted that this is a preliminary attempt which will be supplemented by further analysis of those listed in Bardill's concordance (Crow *et al.* 2008). The attribution of cisterns by period is shown in Table 1 below and the distribution is illustrated in Figure 4.

Table 1. Distribution of cisterns by period

Early (4th – 7th century)	33.8%
Mid (8th – 12th century)	21.9%

Late (13th – 15th century)	6.2%
Unknown era	38.1%

In the early period, defined by Altuğ as the fourth to seventh century, the distribution is well-defined. The extremely large open-air reservoirs are located on the periphery of the City in the intramural area (*i.e.* between the Constantinian and Theodosian Walls) where population density was likely to be very low and space plentiful (Jacoby 1961). All the large covered cisterns are clustered in the oldest area of the City, on Hills One and Two. The size of the cisterns reflects the density of the population, which would imply a high demand for water. But the same density would preclude open cisterns, since space is at a premium. Covered cisterns can be built on, though the initial construction is disruptive. The medium cisterns are also mostly concentrated around Hills One and Two, with a few other cisterns further out, around Hills Three, Four and Five. The small cisterns are evenly spread between Hills One, Two and Three and are the only early-period cisterns on the northern slopes of Hills Two and Three.

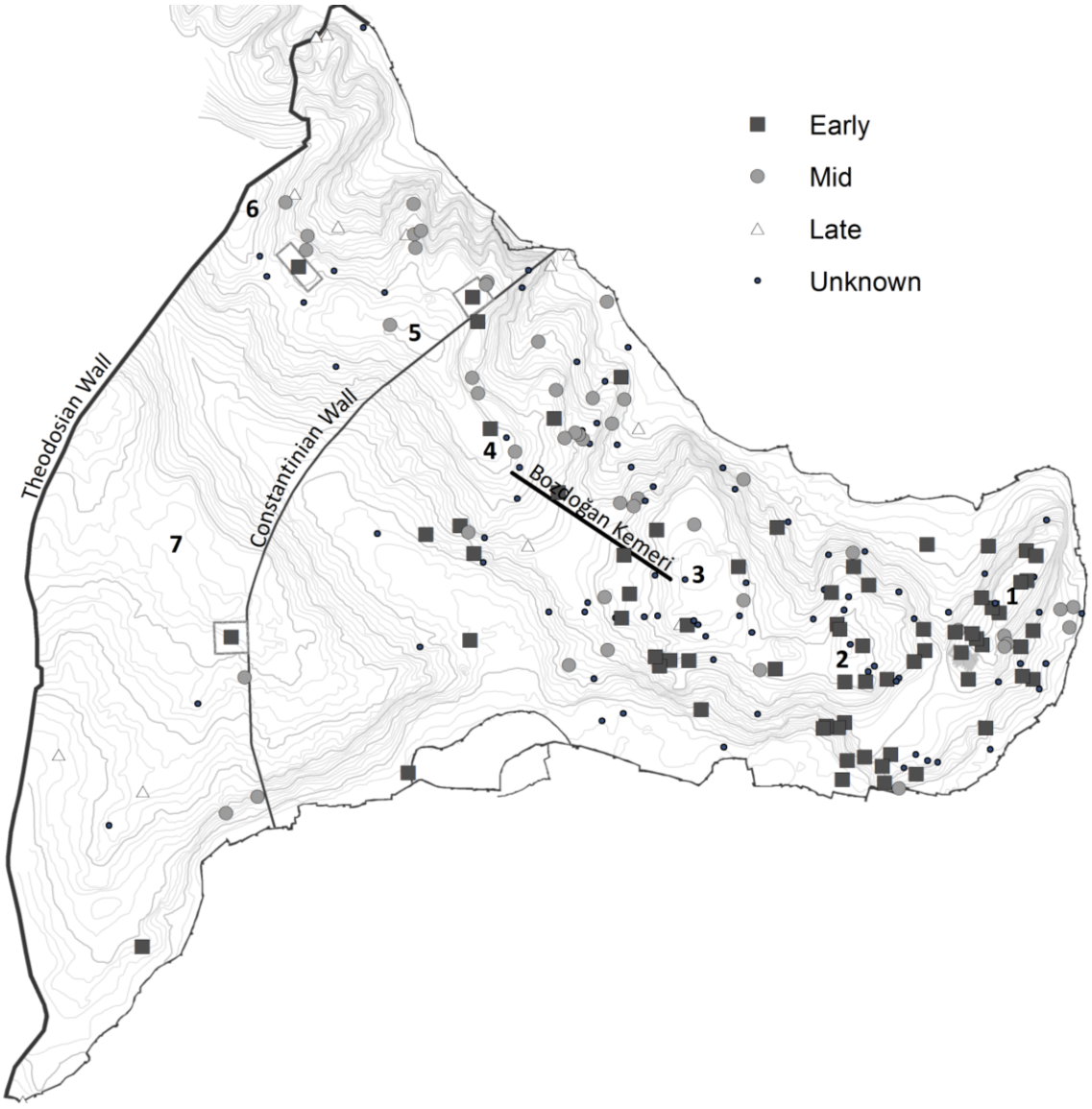

Figure 4. Cistern distribution by era: Early era (4th – 7th century) – square; Mid era (8th – 12th century) – circle; Late era (13th – 15th century) – triangle; Unknown era – dot. Numbers indicate the Hills of the City. Dating of cisterns comes from Altuğ (2013).

In the mid-period, covering the eighth to twelfth century, cisterns appear throughout the city but there is a concentration of cisterns constructed on the periphery of the City, especially on the northern slopes of Hills Four and Five. Previously there were few cisterns here, perhaps indicating that population density was higher here during this period. There is another cluster of mid-period cisterns around Hill One although their purpose is far from clear in an area already densely populated with cisterns.

The late-period cisterns also tend to be peripheral with over half located in the intramural region and the rest on the slopes of Hills Three, Four and Five.

The cisterns where the era is unknown are spread evenly across the City, with most inside the Constantinian Walls. Almost 40% of the cisterns are not attributed to a particular era, either because Altuğ was unable to determine the period or because the chronology of the cistern has not yet been systematically assessed.

There is no information available regarding if or when particular cisterns stopped being used. The fact that most of the middle and late period cisterns supply areas relatively poorly served by early-period cisterns suggests that many of the early cisterns continued to function into the middle and possibly the late period, although the question of why new cisterns continued to be built when the population is believed to have peaked during the early period remains to be answered.

CONCLUSIONS

We have established that there are three times as many cisterns as some currently report, and a third more than even the most in-depth previous research. The large number of cisterns in Constantinople are evidence that the water supply was significantly different from the typical Roman approach, being an extension of the managed storage used in Roman North Africa, also evident in Syria and Roman Mesopotamia (see Crow 2012, 41).

Studies of Constantinople's water supply can provide historians and archaeologists much insight about both everyday life in the city and the ability to use and manage technology for the benefit of citizens. The records on cistern construction period are currently basic and dimension data are only partial and unlikely to be improved much in the future. However, we are able to make some key inferences:

- The location of many cisterns on the high ground near the top of the ridge and the clustering of cisterns together substantially reduces the available collection catchment and effectively eliminates the possibility that the cisterns relied on rainwater harvesting for their primary water source.
- The distribution of cisterns in terms of location and volume suggests a complex network of storage and distribution that would have required active management to operate successfully.
- The distribution of cisterns through time illustrates a city that altered and adapted its water supply system throughout the 1000 years that it served the population of Byzantine Constantinople.

Our exploration of the full set of cisterns data also allows us to pose a number of questions which will be central to developing a full understanding of the water supply system in Constantinople:

- Why did Constantinople make such extensive use of cisterns compared with other cities in the Roman world?
- Given the number of decisions that would need to be made to divert water into the cisterns and store it there, how was this complex network managed and operated?
- How might the enormous volumes of water in the three 'extra-large' cisterns have been used?

The research programme "Engineering the Byzantine water supply: procurement, construction and operation" will use an engineering perspective to answer questions of interest to archaeologists. The conclusions drawn in this paper and the up-to-date catalogue of 211 Byzantine era cisterns will now feed into further work on the development of theoretical water networks and create further lines of enquiry into the archaeological and historical sources. Networks which connect cisterns, aqueducts and the population are now being developed to enable a more in-depth investigation into how the cisterns affected life in the Byzantine City of Constantinople.

ACKNOWLEDGEMENT

The authors express their gratitude to the EPSRC and the Leverhulme Trust for financial support for this work under grant agreement RPG-2013-410.

REFERENCES

Altuğ K., 2013 *İstanbul'da Bizans Dönemi Sarnıçlarının Mimari Özellikleri ve Kentin Tarihsel Topografyasındaki Dağılımı (Architectural Features of Byzantine Cisterns and Historical Topography of Istanbul)*. PhD thesis, İstanbul Teknik Üniversitesi, Istanbul, Turkey.

Angelakis A.N. & Spyridakis D.S., 2010 A brief history of water supply and wastewater management in ancient Greece. *Water Science and Technology: Water Supply,* 10 (4), 618-628.

Byrd K., 2008 *Pierre Gilles' Constantinople: A modern English translation.* Italica Press, New York.

Çeçen K., 1996 *The Longest Roman Water Supply Line.* TSKB, Istanbul.

Crow J., 2012 Ruling the Waters: Managing the Water Supply of Constantinople, AD 330-1204. *Water History,* 4, 34-55.

Crow J., Bardill J. and Bayliss R., 2008 *The Water Supply of Byzantine Constantinople*. Society for the Promotion of Roman Studies, London.

De Feo G., De Gisi S., Malvano C., De Biase O., 2010 The greatest water reservoirs in the Ancient Roman World and the "Piscina Mirabilis" in Misenum. *Water Science and Technology: Water Supply,* 10 (3), 350-358.

Forchheimer P., and Strzygowski J., 1893 *Die Byzantinischen Wasserbehälter von Konstantinopel (The Byzantine Cisterns of Constantinople).* Byzantinische Denkmäler 2, Vienna.

Jacoby D., 1961 La population de Constantinople à l'époque Byzantine: un problème de démographie urbaine (The population of Constantinople in the Byzantine age: a problem of urban demography). *Byzantion,* 1961, 81-109

Mays L., 2014 Use of cisterns during antiquity in the Mediterranean region for water resources sustainability. *Water Science and Technology: Water Supply,* 14 (1), 38-47.

Mays L., Koutsoyiannis D., Angelakis A.N., 2007 A brief history of urban water supply in antiquity. *Water Science and Technology: Water Supply,* 7 (1), 1-12.

Müller-Wiener W., 1977 *Bildlexikon zur Topographie Istanbuls (Illustrated encyclopaedia of the topography of Istanbul),* Wasmuth, Tübingen.

Ruggeri F., Crapper M., Snyder J.R., and Crow J., 2016 A GIS-based assessment of the Byzantine water supply system of Constantinople. In *4th IWA International Symposium on Water and Wastewater Technologies in*

Ancient Civilisations, Coimbra, Portugal.

Snyder J. R., 2011 Manipulating the Environment: the impact of the construction of the Water Supply of Constantinople. In: *Man and his Environment in the Byzantine Empire, proceedings of the Byzantinische Archaologie Mainz Interdisciplinary Conference*, Mainz, Germany.

Snyder J. R., 2013 *Construction requirements of the Water Supply of Constantinople and Anastasian Wall*. PhD Thesis, School of History, Classics and Archaeology, The University of Edinburgh, Edinburgh, UK.

Wilson A.I., 1998 'Water supply in ancient Carthage' in J.T. Peña, J.J. Rossiter, A.I. Wilson, C.Wells *et al.*, *Carthage papers, the early colony's economy, water supply, a public bath, and the mobilization of state olive oil*, JRA Supplement Series 28, Portsmouth RI, 65-102.