

Northumbria Research Link

Citation: Ward, Kate, Crapper, Martin, Altuğ, Kerim and Crow, Jim (2017) The Byzantine Cisterns of Constantinople. *Water Science and Technology : Water Supply*, 17 (6). pp. 1499-1506. ISSN 1606-9749

Published by: IWA Publishing

URL: <http://dx.doi.org/10.2166/ws.2017.053> <<http://dx.doi.org/10.2166/ws.2017.053>>

This version was downloaded from Northumbria Research Link:
<http://nrl.northumbria.ac.uk/id/eprint/30139/>

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: <http://nrl.northumbria.ac.uk/policies.html>

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)



**Northumbria
University**
NEWCASTLE



UniversityLibrary

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, Istanbul 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

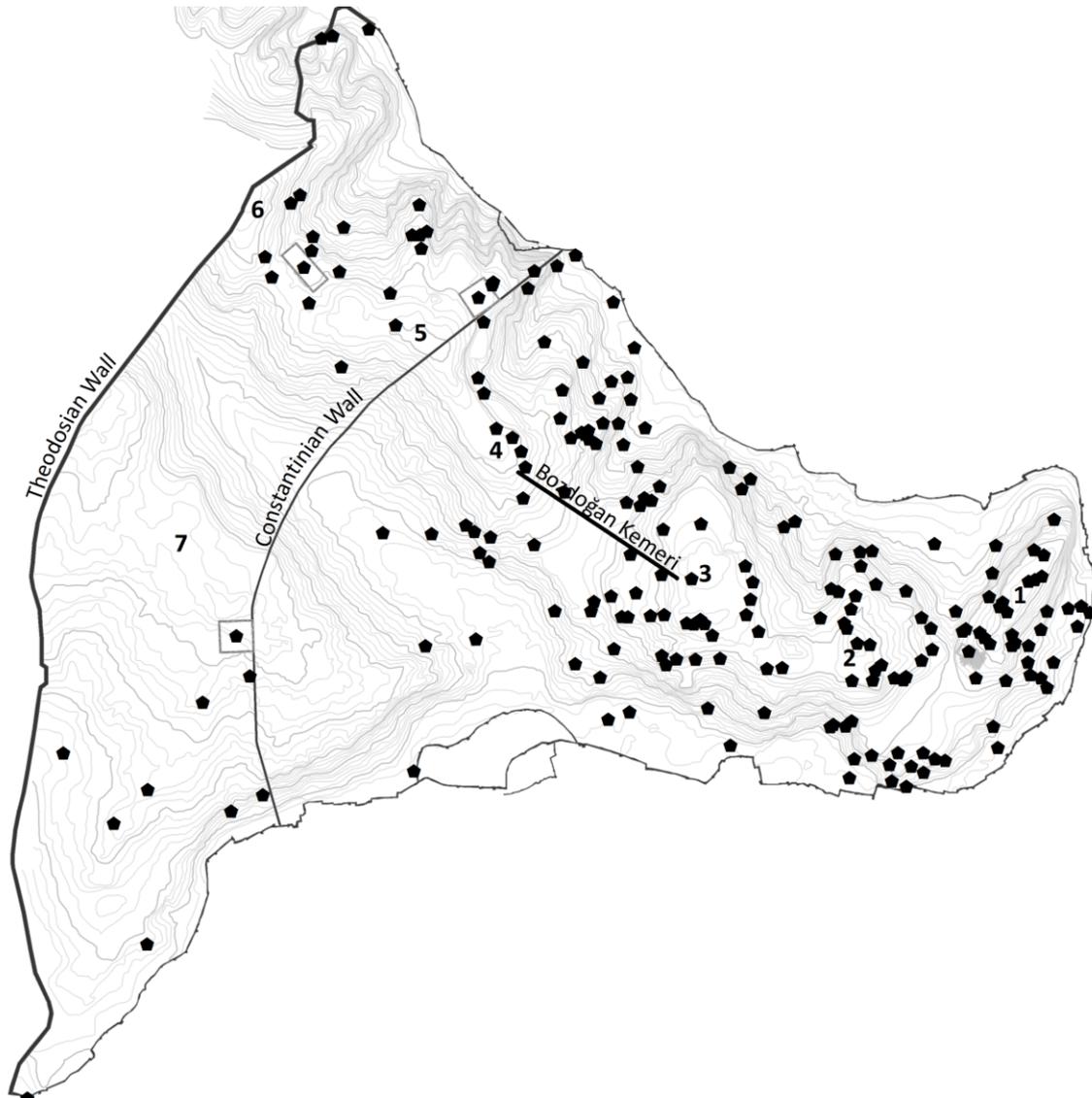
Constantinople; Water supply; Cisterns

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

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



9

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

12 In modern times, the number of cisterns found and recorded has grown considerably. Gilles
13 (Byrd 2008) described nine cisterns, some still in use, during his time in the city in the 1540s.
14 The first attempt to systematically catalogue the cisterns was by Forchheimer & Strzygowski
15 (1893). It listed, within the City, three open-air reservoirs and 40 closed cisterns, and reported
16 descriptions of 27 sites that were unable to be confirmed. Müller-Wiener (1977) records about
17 75 cisterns in his study of the topography of Byzantine and Ottoman Constantinople. The most
18 recent works are Bardill's bibliographical concordance within Crow *et al.* (2008) which lists

1 161 entries (including two in Sycae (Galata), north of the Golden Horn) and the cistern
2 catalogue by Altuğ (2013) which has 158 entries. Despite these publications, even recent
3 works, such as Mays (2014), state the number of known cisterns in the City at around 70.

4 As the number of cisterns known within the city has grown it has become clearer that the
5 cisterns are central to Constantinople's water supply strategy. In fact the number of cisterns
6 within the city is higher than even the most recent studies concluded. At first glance, the studies
7 of Crow *et al.* (2008) and Altuğ (2013), despite using different methods for compiling their
8 lists, appear to agree that there are around 160 Byzantine era cisterns within the city. The
9 bibliographical concordance in Crow *et al.* (2008, 143-155, Maps 12-15) lists cisterns collected
10 from previous studies going back to the sixteenth century, whereas the catalogue of Altuğ
11 (2013) comprises cisterns that either still exist or have firm records and can be mapped
12 precisely. When these two works are compared, it is clear that not all cisterns feature on both
13 lists, some being unique to one or the other. The combination of the two sources has revealed
14 that there is evidence of at least 211 Byzantine era cisterns in Istanbul. Of the 211 entries, 97
15 were present on both lists, 61 were exclusive to Altuğ's catalogue and 53 were exclusive to the
16 concordance of Crow *et al.* (2008).

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

21 **DEVELOPMENT OF CISTERN TECHNOLOGY**

22 Cisterns are an old technology with examples dating to the Neolithic Age. Typically these
23 cisterns were small in scale and collected rainwater in a domestic setting (Angelakis &
24 Spyridakis 2010; Mays *et al.* 2007). This type of cistern was also used through the Roman era,
25 often built into the structure of a house with the roof acting as a catchment. In the Roman era
26 larger cisterns start to be constructed, often associated with high demand users where the
27 constant flow from the aqueduct would be insufficient to meet short term supply needs, such
28 as the Piscina Mirabilis (12,600 m³), constructed to serve the naval port at Misenum (De Feo
29 *et al.* 2010). In Roman North Africa, the concept of storage and management of water on a
30 non-domestic scale appears to be reflected in the larger cisterns, for example in Carthage the
31 La Malga, Dar Saniat and Bordj Djedid cisterns, all associated with aqueduct or groundwater
32 sources (Wilson 1998). These cisterns can bridge a short-term imbalance between demand and
33 what the aqueduct can supply and prevent waste of this important resource.

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

39 **CISTERNS IN CONSTANTINOPLE**

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

1 **Rainwater harvesting**

2 Although the source of water for the cisterns of Constantinople is unverified, it is highly likely
3 that the cisterns were fed by the two aqueducts rather than by rainwater harvesting (Crow *et*
4 *al.* 2008, 140-141). The majority of cisterns in the city are far larger than those typically
5 associated with rainwater harvesting; only 14 cisterns are known to have a volume less than
6 100 m³ (see the section below on the distribution of volume of cisterns). The collection areas
7 required for the larger cisterns would be colossal, but the topography of the city, with steeply
8 sloping spurs, and the location of cisterns, generally high up the slope, reduce the available
9 collection area. The tendency for cisterns to be found in clusters also reduces the available
10 collection catchment per cistern. Rainwater is likely to have been the primary source of water
11 for the smallest cisterns in the city which we can assume are domestic cisterns not to be
12 associated with the wider network. Rain may also have provided a secondary source of water
13 for some larger cisterns where roofs and courtyards surfaces could be conveniently channelled.

14 A full calculation of rainwater harvesting potential is outwith the scope of this paper but with
15 annual rainfall of between 630 and 730 mm estimated for the Antique period (these estimates
16 are from a preliminary unpublished Macrophysical Climate Model study) and an estimated
17 population of 360,000 (Jacoby 1961), the entire historic peninsula at approximately 13.4
18 million m² would only be able to provide 64 litres/person/day. As soon as we start to make this
19 calculation more realistic (by reducing the area available for collection, assuming some losses
20 of rainfall and taking into consideration seasonal variation) the water available per capita
21 becomes unfeasibly small. The enormous investment represented by the cisterns was not to
22 enable the city to just struggle along but in order to let it flourish. To do that, the cisterns must
23 have been fed by the aqueducts.

24 **Cistern distribution – location and volume**

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



1

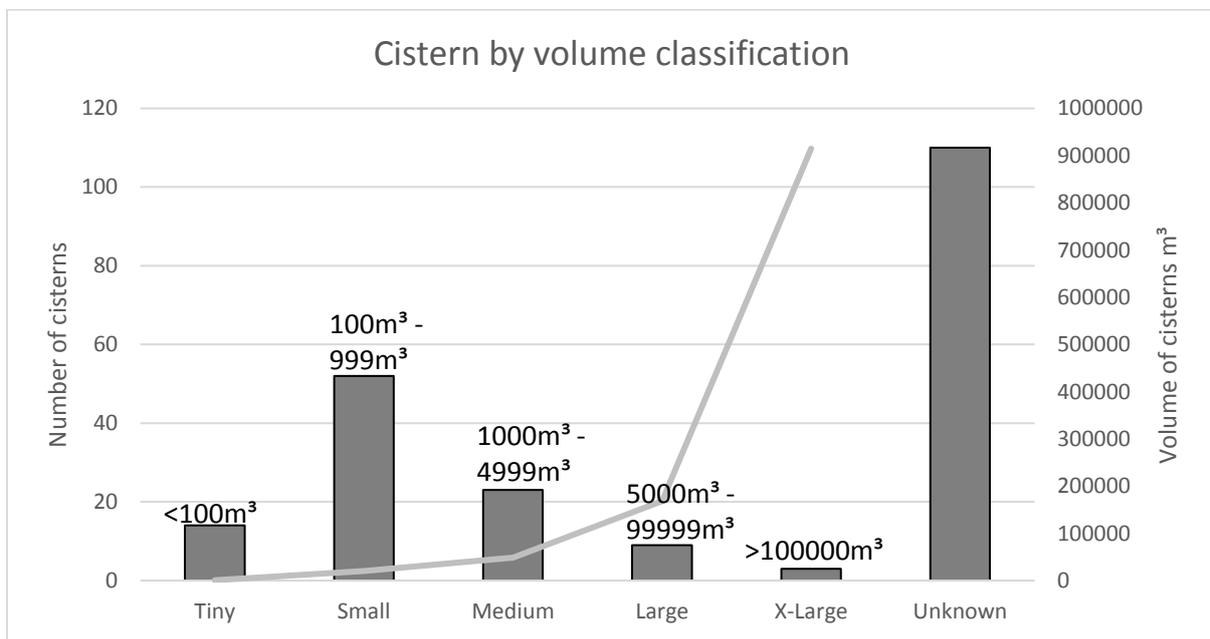
2 **Figure 2.** The City's 211 cisterns categorised by volume. Extra Large >100,000 m³; Large
 3 5,000 – 99,999 m³; Medium 1,000 – 4,999 m³; Small 100 – 999 m³; Tiny <100 m³. Numbers
 4 indicate the Hills of the City.

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

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

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

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



14
 15 **Figure 3.** Number of cisterns in each volume classification

16 **Distribution of cisterns over time**

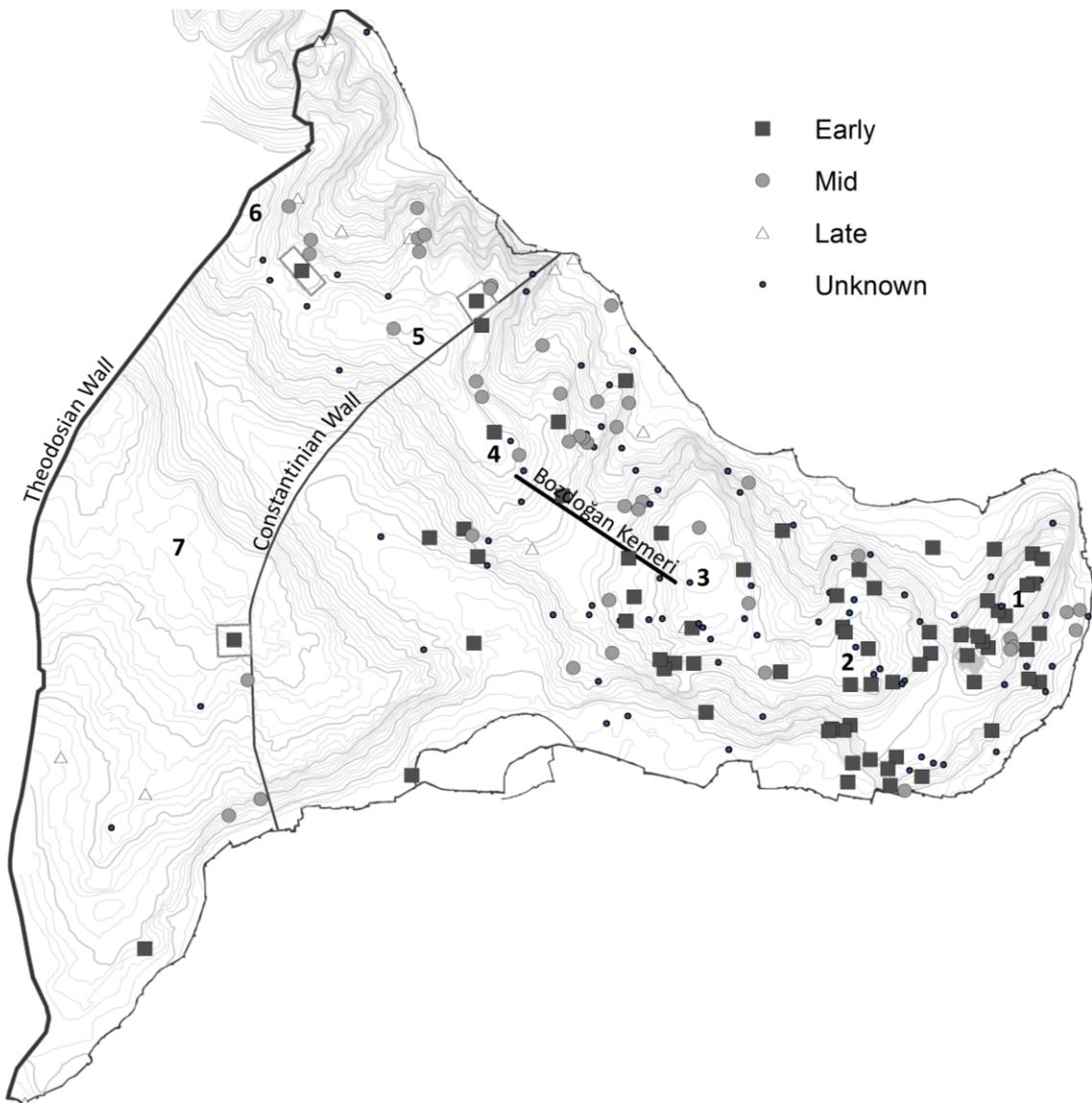
17 Most cisterns are difficult to date with any precision, some, like the Yerebatan Sarayı (Basilica)
 18 cistern, can be dated with some certainty from historical sources, although often these have
 19 different interpretations. Others may be dated from specific forms of construction, and others
 20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

26 **Table 1.** Distribution of cisterns by period

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

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

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



12

1 **Figure 4.** Cistern distribution by era: Early era (4th – 7th century) – square; Mid era (8th –
2 12th century) – circle; Late era (13th – 15th century) – triangle; Unknown era – dot. Numbers
3 indicate the Hills of the City. Dating of cisterns comes from Altuğ (2013).

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

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

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

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

22 **CONCLUSIONS**

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

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

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

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

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

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

18 **ACKNOWLEDGEMENT**

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

21 **REFERENCES**

- 22
23 Altuğ K., 2013 *İstanbul'da Bizans Dönemi Sarnıçlarının Mimari Özellikleri ve Kentin Tarihsel*
24 *Topografyasındaki Dağılımı (Architectural Features of Byzantine Cisterns and Historical Topography of*
25 *Istanbul)*. PhD thesis, İstanbul Teknik Üniversitesi, İstanbul, Turkey.
- 26 Angelakis A.N. & Spyridakis D.S., 2010 A brief history of water supply and wastewater management in ancient
27 Greece. *Water Science and Technology: Water Supply*, 10 (4), 618-628.
- 28 Byrd K., 2008 *Pierre Gilles' Constantinople: A modern English translation*. Italica Press, New York.
- 29 Çeçen K., 1996 *The Longest Roman Water Supply Line*. TSKB, İstanbul.
- 30 Crow J., 2012 Ruling the Waters: Managing the Water Supply of Constantinople, AD 330-1204. *Water History*,
31 4, 34-55.
- 32 Crow J., Bardill J. and Bayliss R., 2008 *The Water Supply of Byzantine Constantinople*. Society for the Promotion
33 of Roman Studies, London.
- 34 De Feo G., De Gisi S., Malvano C., De Biase O., 2010 The greatest water reservoirs in the Ancient Roman World
35 and the “Piscina Mirabilis” in Misenum. *Water Science and Technology: Water Supply*, 10 (3), 350-358.
- 36 Forchheimer P., and Strzygowski J., 1893 *Die Byzantinischen Wasserbehälter von Konstantinopel (The Byzantine*
37 *Cisterns of Constantinople)*. Byzantinische Denkmäler 2, Vienna.
- 38 Jacoby D., 1961 La population de Constantinople à l'époque Byzantine: un problème de démographie urbaine
39 (The population of Constantinople in the Byzantine age: a problem of urban demography). *Byzantion*,
40 1961, 81-109
- 41 Mays L., 2014 Use of cisterns during antiquity in the Mediterranean region for water resources sustainability.
42 *Water Science and Technology: Water Supply*, 14 (1), 38-47.
- 43 Mays L., Koutsoyiannis D., Angelakis A.N., 2007 A brief history of urban water supply in antiquity. *Water*
44 *Science and Technology: Water Supply*, 7 (1), 1-12.
- 45 Müller-Wiener W., 1977 *Bildlexikon zur Topographie Istanbuls (Illustrated encyclopaedia of the topography of*
46 *Istanbul)*, Wasmuth, Tübingen.
- 47 Ruggeri F., Crapper M., Snyder J.R., and Crow J., 2016 A GIS-based assessment of the Byzantine water supply
48 system of Constantinople. In *4th IWA International Symposium on Water and Wastewater Technologies in*

- 1 *Ancient Civilisations*, Coimbra, Portugal.
- 2 Snyder J. R., 2011 *Manipulating the Environment: the impact of the construction of the Water Supply of*
3 Constantinople. In: *Man and his Environment in the Byzantine Empire, proceedings of the Byzantinische*
4 *Archaologie Mainz Interdisciplinary Conference*, Mainz, Germany.
- 5 Snyder J. R., 2013 *Construction requirements of the Water Supply of Constantinople and Anastasian Wall*. PhD
6 Thesis, School of History, Classics and Archaeology, The University of Edinburgh, Edinburgh, UK.
- 7 Wilson A.I., 1998 'Water supply in ancient Carthage' in J.T. Peña, J.J. Rossiter, A.I. Wilson, C.Wells *et al.*,
8 *Carthage papers, the early colony's economy, water supply, a public bath, and the mobilization of state*
9 *olive oil*, JRA Supplement Series 28, Portsmouth RI, 65-102.