Water supply infrastructure of Byzantine Constantinople

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Introduction

Modern water supply systems – hidden beneath the ground, constructed, expanded, adapted and repaired intermittently by multiple groups of people – are often messy and difficult to comprehend. The ancient water supply system we consider here is no different, and perhaps more complex as it was developed over 1200 years, then had a modern city built on top. Despite this, we are beginning to understand how one of the Roman world's most important cities provided its population with water.

The remains of water infrastructure in Constantinople attest to a complex system of water management and distribution. Over 1200 years, from the colony of Byzantium, through the growth and eventual decline of the new capital of the Roman Empire until conquest by the Ottomans, the water supply system developed. Aqueducts, the system of channels, bridges and tunnels designed to carry water through the landscape were the focus of infrastructure investment in earlier periods, but cisterns, for the storage and distribution of water, were constructed throughout the era of Byzantine Constantinople. Recent archaeology studies have ensured a better understanding of the key elements of the system but have not investigated how the water was distributed within the city.[2]

The present study is part of the current research programme "Engineering the Byzantine water supply: procurement, construction and operation", and aims to apply contemporary civil engineering techniques to elucidate the hydraulic infrastructure of the city.[3] Much of our knowledge of hydraulic delivery and distribution in ancient urban settings derives from the classic ruined cities such as Pompeii and Ephesos, where the infrastructure is accessible,[4] rather than Rome and Istanbul because modern development obscures the ancient city.[5] By adopting an engineering perspective, we aim to counter the fragmentary nature of the archaeological evidence. This approach integrates the scattered evidence into a functional whole.

The water supply in Constantinople had three distinct elements – two aqueducts, the Hadrianic Line and the Valens Line, and the third element, cisterns of varying sizes throughout the city. The use of

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[2] Mango 1995; Çeçen 1996; Crow, Bardill, and Bayliss 2008.

[3] A parallel study is considering the application of construction management techniques to determine the processes of construction and questions concerning procurement and workforce; see Snyder *et al.* 2016. The authors express their gratitude to the Leverhulme Trust for financial support for this work under grant agreement RPG-2013-410.

[4] Keenan-Jones 2015 for a recent study of Pompeii; and Pickett 2016 for analysis the ceramic pipe network from Ephesos and how distribution changed over time; the latter in contrast to other more traditional aqueduct studies in Wiplinger 2016, for southern Turkey.

[5] See the integrated study from Roman Barcelona, albeit on a lesser scale, Orengo and Miró i Alaix 2013.

cisterns as a major component of the supply system is singular, if not unique, in Roman municipal water supplies.[6]

The available evidence varies across the three elements. The Hadrianic Line has no physical evidence and very few references in historical texts; we have to build up our picture of the line using what can be inferred from the topography of Constantinople and the known and likely users of this water line. Additionally we can make inferences from the Ottoman water supply system which is thought to have made use of the same water source in the Belgrade Forest. There is more physical evidence of the Valens Line, though its interpretation is uncertain, particularly along the ancient main street of Constantinople, the Mese. For the cisterns, evidence is both physical and textual, with previous studies providing detailed descriptions and dating of some cisterns. However we can show that there are considerably more cisterns than has been supposed by comparing and combining the two most recent and comprehensive studies.

Our understanding of how the elements of the water supply system evolved and operated is still at an early stage but the work detailed in this paper provides a platform for further investigation and clarifies the questions that can be asked about the Byzantine water supply of Constantinople.

Background

Constantinople was an important new city with a water problem. Despite the strategic advantages of its location, the city that became the capital of the Roman Empire was soon compared to a beautiful woman bedecked with jewels but thirstier "than those who are dressed in rags".[7] To tackle the issue, the city undertook several challenging construction projects which added water supply infrastructure to the existing 2nd c. A.D. Hadrianic Line of Roman Byzantium.

Within a few decades of Constantinople's foundation, engineers constructed the Valens Line to tap distant springs in the Thracian hinterland. An initial study, identifying and mapping this far-reaching aqueduct, estimated the length of channel to be 292 km but more recently, studies have calculated much greater distances.[8] The initial research on the Valens Line was further developed with extensive fieldwork which identified two distinct phases of aqueduct building.[9] The first phase, dated to the mid 4th c. A.D., collected water from sources some 65 km from Constantinople, and the second phase, dated early to mid 5th c. A.D., from sources around 120 km from the city. The straight-line distances do not give a clear picture of the scale of construction. The most recent investigation calculates the length to be at least 426 km and possibly as much as 564 km.[10]

However, it would appear that even these substantial infrastructure investments were insufficient to supply the growing city. In the mid 5th c. A.D., with the construction of the second phase of the Valens Line underway, the city altered its water supply strategy and started to construct major cisterns within the city walls.[11] The city, with at least 8 large public baths,[12] may appear to follow the Roman

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[6] See Stewart 2016 for a review of Roman and Byzantine cisterns in the eastern Mediterranean including Constantinople; Hairy 2011 presents an important study of the river-filled cisterns of Alexandria ranging in date from the Roman to the Islamic periods.
[7] Themestius *Oratio* XI.151a-152b quoted in Crow, Bardill and Bayliss 2008, 224.
[8] Çeçen, 1996; Snyder 2013, 199, based on reanalysis of the line drawn in Crow, Bardill and Bayliss 2008, states 454km.
[9] Crow, Bardill and Bayliss 2008, 26-27.
[10] This investigation uses current satellite elevation data and all the data from Crow et al's previous studies. Ruggeri *et al.*, forthcoming.
[11] The first major cistern recorded was earlier, the Modestiaca Cistern in AD 363-369. The location of this cistern is uncertain, although it is possibly associated with the Saraçhane cistern identified by Forchheimer and Strzygowski 1893, 52.
[12] Mundell Mango 2015, fig. 12, 138-144.

model of extravagant water use, but the way the water supply system developed and evolved points to a shortage in local water supplies. The investment in and protection of the water supply system should be viewed as critical to the success of the city.

Current understanding of the three main elements of the water supply system

Prior to this study, little work had been done considering water supply at a system-wide level. The first attempt to map the two aqueduct lines within the city was by Crow, Bardill and Bayliss.[13]

In that study, Bayliss projected the Hadrianic Line based on access to the Basilica Cistern.[14] The modern contours of the city were used to trace the line back towards the Theodosian Wall. The route followed the north flanks of Hills Two, Three, Four, Five and Six and crossed the Wall at an elevation of about 35 metres above sea level (masl).

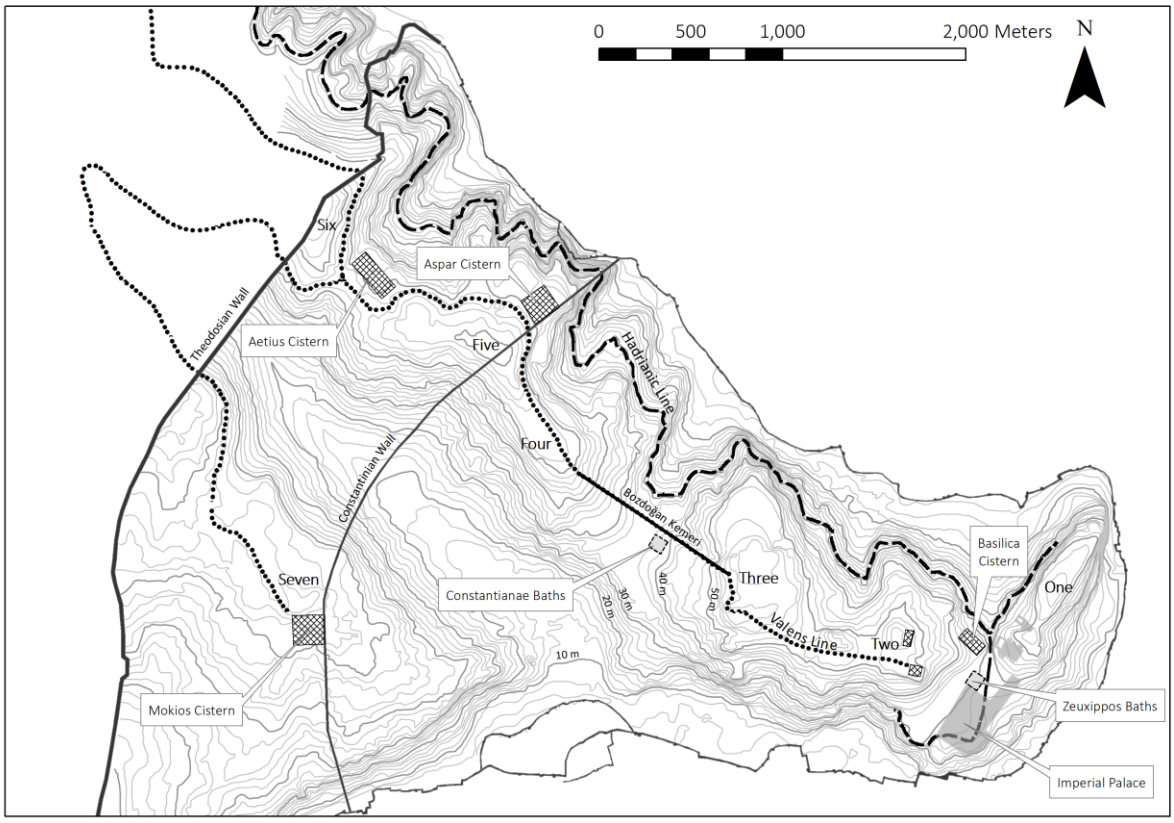

Figure 1: Original aqueduct routes proposed by Crow, Bardill and Bayliss 2008. The Hadrianic Line is dashed and the Valens Line is dotted. This image is adapted from the original data.

In their account, there are some inconsistencies between the written description of this route and what is illustrated.[15] In the illustrated route shown by the dashed line in Figure 1, the line is at a low point of 24 masl in the vicinity of the Basilica Cistern before climbing *uphill* to cross the platform between Hills One and Two to the Imperial Palace. We can conclude that the route suggested is too low to supply water to the Imperial Palace and would only be able to fill the Basilica Cistern to a depth of about three metres.

[13] Crow, Bardill and Bayliss 2008, 110-124.
[14] The Hadrianic Line is associated with the Basilica Cistern in both Malalas *Chron.* 18.17 and *Chron. Pasc.* 618-19, quoted in Crow, Bardill and Bayliss 2008, 232.
[15] Crow, Bardill and Bayliss 2008, maps 12-15, 114-117.

The Valens Line, shown by the dotted line in Figure 1 was drawn by Bayliss based on the location and orientation of the Bozdoğan Kemeri (the 970 m long bridge spanning Hills Three and Four which still stands in modern Istanbul), the modern contours, and the location of some of the larger cisterns.

In the 2008 study, Bardill compiled a bibliographic concordance of cisterns, detailing 161 examples that were identified and discussed in the literature. His work is complemented by the recent work of Altuğ who, with the aid of the Istanbul municipal archive[16], compiled a catalogue of 158 cisterns.[17] Both these works considerably expanded the number of cisterns known in Constantinople but even very recent articles continue to underestimate the significance of cisterns in the city.[18]

Aqueduct of Hadrian

Before it became the city of Constantinople, Byzantium was fed by an aqueduct constructed under Hadrian,[19] in the 2nd c. A.D. This aqueduct was the main water provider for the city of Constantinople until A.D. 373 when the Valens Line started bringing water into the city. Although no recognisable traces of the Hadrianic Line survive, it continued to serve an important role within the Byzantine city – around A.D. 440 the law codes restrict the use of the aqueduct to "the public, hot and cold baths and [the imperial] palace" and later, in the 6th c. A.D., the Hadrianic Line is associated with the construction of the Basilica Cistern.[20]

Water Supply to Byzantium

Given that the Hadrianic Line served the city for such a long period of time, it is worth considering the original form of the town the aqueduct supplied. That the aqueduct was operated, repaired and maintained for such a long period indicates that the channel was still relatively accessible despite the enormous changes we know took place around the coastline and topography of the peninsula.

The original town of Byzantium occupied the end of the peninsula that became Constantinople, bounded by a defensive wall that crossed the second hill from coast to coast,[21] with the focus probably in the north-facing valley between Hills One and Two around the harbour and Strategion (now occupied by Sirkeci Station). This area is relatively low lying and could be served by an aqueduct arriving around 31 masl.

Conventionally water provided by Roman aqueducts would be distributed from the highest point of the town, maximising the area supplied. For Byzantium this would have been approximately 55 masl at the point which later became the Forum of Constantine. To achieve this the Hadrianic Line would require a major bridge or inverted siphon to cross the valley between Hills Three and Four (where the Bozdoğan Kemeri stands), but no evidence has been found or is attested in ancient written accounts. If the population of Byzantium was concentrated on the lower slopes, a crossing structure, both costly and, as it exposed a vital lifeline into the town, a potential security weakness, may have been considered unnecessary. Nevertheless, it is likely that the builders aimed for as high an entry point to the town as practical, making the crossing of the valley between Hills Three and Four critical. The lowest ground level of this valley is estimated to have been around 35-36 masl in the Byzantine period[22], so a likely maximum invert level (lowest point of the channel or pipe in cross-section) at this

[16] Koruma Bolge Kurulu.
[17] Altuğ 2013, documents physical remains that he visited and those no longer extant, which others have investigated and recorded.
[18] Mays 2014 states the number of cisterns in Constantinople as 70.
[19] See Crow, Bardill and Bayliss 2008, 10-13 on attributing the aqueduct to Hadrian.
[20] *Cod. Just.* 11.42.6 and Malalas *Chronicle* 18.17, quoted in Crow, Bardill and Bayliss 2008, 227, 232.
[21] Mango 1985, 14.
[22] The level from Muller-Wiener's 1977 map (1920s contours) is 41 masl, sounding 'B' Harrison 1986, 13-14, found the foundations of Bozdoğan Kemeri to be 6.5 m below the existing ground level.

point is 34 masl assuming a cut and cover type construction rather than a method which would expose the channel above ground, making it vulnerable to malicious tampering.

Supplying the Imperial Palace and Zeuxippos Baths

Moving forward to early Constantinople, a law code from A.D. 440 states that the Hadrianic Aqueduct fed, among other sites, the Imperial Palace[23] which was located on the south side of the platform between Hills One and Two. The maximum ground level is approximately 30 masl where the palace is adjacent to the Hippodrome and Zeuxippos Baths with ground levels dropping to the south and east, so if the channel was at a level sufficient to supply the platform level, it would have been capable of supplying the Imperial Palace.

Although there is no textual link between the Zeuxippos Baths and the Hadrianic aqueduct, it appears clear that this is how the baths were supplied with water, which adds further evidence to the route of the aqueduct within the city. The Zeuxippos Baths were a centrepiece of the city, and would have required access to an aqueduct to provide sufficient water.[24] Their origins are unclear, with some texts attributing the baths to Severus and others to Constantine. Either way, the Baths are undoubtedly an early feature of the city and therefore should be linked to the Hadrianic Line, not the Valens Line.[25]

The baths are located adjacent to the Hippodrome at a level of 30 masl[26] and dropping slightly to the east. If this is ground level in the baths, we would expect the water supply to arrive at a higher level, at least 32 masl to allow it to flow through boilers, operate fountains and, possibly, showers.

Supplying the Constantianae Baths

Less clear-cut but still possible, the Hadrianic Line may have supplied, or been intended to supply the Constantianae Baths. The Constantianae Baths are believed to be located near the modern Belediye building[27] in the valley between Hills Three and Four. Construction of these baths started in A.D. 345, and the aqueduct of Valens did not arrive to the city until A.D. 373. It is implausible that construction on a bath would start so far in advance of the water supply on which it was reliant. Even the time to conceive, design and build the enormous Caracalla baths in Rome was no more than 7 years.[28] It seems more likely that the baths were constructed only where an adequate supply of water could be guaranteed- when construction of the baths started, this could only have been the Hadrianic Line.

In the event, the baths were not completed until A.D. 427. The 80-year construction period is extraordinary and casts some doubt on the Hadrianic Line being the eventual supplier to the working baths. Whatever the circumstances of the baths' construction, we must consider the baths being fed by the Hadrianic Line as a strong possibility. The alternative is a bath that was intended to have been completed, unused and empty for 20 years before the arrival of the Valens Line.

Accepting that the Hadrianic Line was capable of supplying the Constantianae Baths confirms that the channel crossed the valley between Hills Three and Four at a relatively high level and opens up the possibility that the channel crossed the saddle of the valley and followed a course on the southern flanks of Hills Two and Three.

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[23] *Cod. Just.* 11.42.6 quoted in Crow, Bardill and Bayliss 2008, 227.
[24] As Hodge 2002 says, many Roman aqueducts were constructed in order to supply public baths, with a more convenient, flowing water supply merely a side benefit. For example the restoration of the Aqua Marcia and construction of the branch aqueduct Aqua Antoniniana for the Baths of Caracalla in Rome, DeLaine 1997, 16.
[25] Mundell Mango 2015, 136.
[26] Casson 1928, 21.
[27] Mango 1985, 41.
[28] DeLaine 1997, 183.

The comparative evidence of the Ottoman System

The generally held view is that the source of the Aqueduct of Hadrian was water from the Belgrade Forest to the north of the city. This region was later used by the Ottomans for the water supply line known as Kırkçeşme. If the Ottoman system exploits the same source and, as possible traces of older structures in bridges on the Kırkçeşme Line suggest, a similar route into the city, an examination of the newer system should provide insight into the older system.[29]

Maps of the Kırkçeşme system show the route the system took within the city and identify fountains and control towers[30] which we can use to examine the water level during Ottoman times and use as a proxy for the Hadrianic Line.

The Ottoman water system operated as a locally pressurised system with water being driven through pipes by gravity between control towers called suterazi – a series of inverted siphons distributed water through the city. This system would allow water to overcome localised obstructions and changes in level.[31] However, as the system was still operating under gravity, the overall water level dropped moving from upstream to downstream. Therefore fountains and other structures with a free water surface (i.e. not under pressure within a pipe) could not be at a higher elevation than the free water surface further upstream.

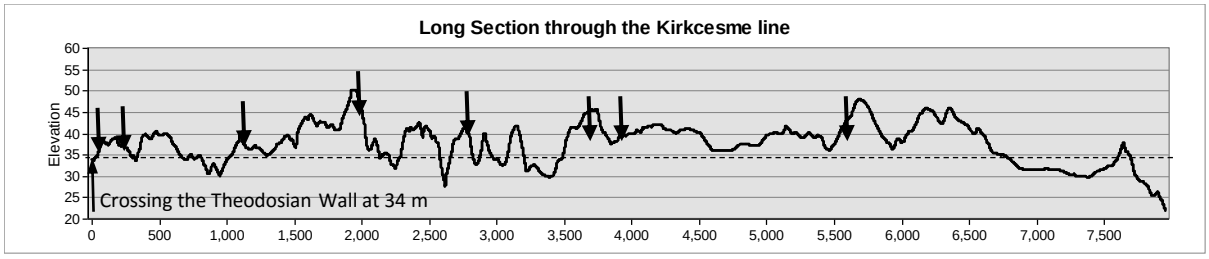

Figure 2: Ground profile through the Kırkçeşme line within the city, from the crossing point at the Theodosian wall (left) towards the Topkapı (right) using a digitised version of Çeçen's 1999 map on a 3D model of the city based on contours from Müller-Wiener 1977 map. Arrows indicate approximate locations of çeşme (fountains) that are positioned above the 34 m crossing level at the wall.

The maps of the Kırkçeşme system are puzzling – the crossing point near the Theodosian wall is at approximately 34 masl, with photographs indicating that the water has a free surface at this point[32] (i.e. not under pressure) yet much of the downstream network on the Kırkçeşme line is higher than 34 masl. The long section in Figure 2 shows the variation in ground level along the route of the main Kırkçeşme line from the Land Walls to the east of the Topkapı Palace. There are several fountains along the route that are higher than the established 34 m baseline, an arrangement that is physically impossible and leads us to question some of the assumptions made regarding the system.

Given that much of the route within the Land Walls is above an elevation of 34 m[33], we must conclude that the structure at the crossing of the Land Wall is either a branch off the main line or has been located on maps incorrectly. The water must arrive at a higher elevation than previously believed. This removes the constraint of assuming that the Hadrianic Line also arrived around this

[29] Tursun Bey, *The History of Mehmed the Conqueror* and Gilles *De Bosporo Thracio Libri III 2.3* both quoted in Crow, Bardill and Bayliss 2008, 242-243.
[30] Maps of all the Ottoman systems are reproduced in Çeçen 1999.
[31] Andréossy 1828, pl. 2. Crow 2015.
[32] Çeçen 1999, 104.
[33] Ground level along the route is an imperfect proxy for pipe inverts as pipes could be buried, but the presence of fountains on, or close to, the Kırkçeşme route and above 34 m in elevation indicates that the pipes are running near to surface level at these points.

level. We can progress with the assumption that the Hadrianic Line reaches the city at an elevation above 34 m.

City routes – Hill Three – North, South or both – the Tezgahçılar Kubbesi structure

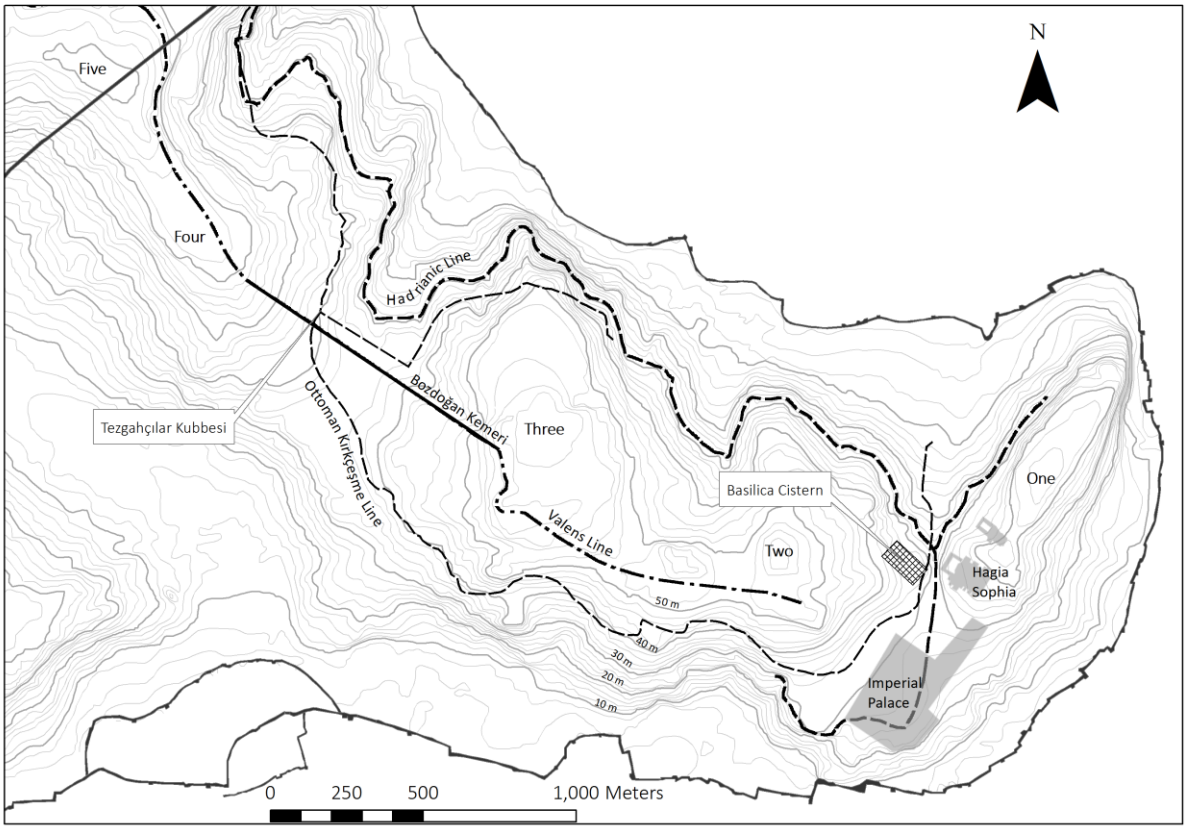

Figure 3: Hills Three and Four, the Bozdoğan Kemeri and the Tezgahçılar Kubbesi. The Ottoman Kırkçeşme line is after Çeçen 1999, maps 30-33; and the Hadrianic and Valens Lines shown are from Crow, Bardill and Bayliss 2008, maps 12-15.

The next key question is the route taken after the channel crosses the valley between Hills Four and Three. Previously,[34] the Hadrianic Line was drawn at a low elevation (already sitting below 30 m elevation at the valley), and could only follow the northern path, taking a sinuous route around the spurs of Hills Two and Three. However, the Ottoman Kırkçeşme system, positioned significantly higher, splits at this valley with a branch to the north and the main line to the south, arriving at the platform between the first two hills near the middle of the Hippodrome.[35] The shape of Hills Two and Three makes this southern route shorter and the gradient of the slopes traversed is shallower, which from an engineering perspective would be easier to construct (compare the original route in Figure 3 and the new route in Figure 4).

The split point of the Ottoman Kırkçeşme system, shown in Figure 3, is the Tezgahçılar Kubbesi. It has been identified as originally Roman[36] with Ottoman repairs and alterations. Although adjacent to

[34] Crow, Bardill and Bayliss 2008, maps 14 and 15.
[35] Çeçen 1999, maps 30-33.
[36] Çeçen 1996, 215; Çeçen 1999, 105-106; and included in Altuğ 2013, 426-27, as belonging to the early Byzantine period. Although Crow, Bardill and Bayliss 2008, 116, indicate that the early dating of this structure should be treated with caution. Dark and Özgümüş 2013, 127 and pl. 2, identify this structure as a Byzantine cistern that has been uncovered by modern work rather than a control structure that has been buried over time.

the Bozdoğan Kemeri it is 15 m lower, indicating that this structure was not part of the Valens Line, so if the original structure was Roman, it would be associated with the Hadrianic Line. The structure, sitting on the modern 40 m contour, is buried up to its roof and is approximately 5 m deep, putting the channel invert at an elevation of 35 masl.

We believe that the Kırkçeşme system can be used as a reasonable proxy for the Hadrianic Line; as it could take the northern or southern route around Hill Three, the Hadrianic Line was also capable of taking either route. This assumption is strengthened by the indication that the Ottoman Kırkçeşme system may reuse an older structure that belonged to the Hadrianic Line[37].

It is difficult to conclude if the Hadrianic Line split in two like the Ottoman system, or merely crossed to the south route. The original town of Byzantium was not that extensive and did not extend over the northern slopes of Hill Three, so there would be little to justify the more complicated construction. However, this area was densely populated during the era of early Constantinople, which may have justified alterations to the existing arrangements, perhaps associated with the rebuilding of the line towards the end of the 4th c. A.D. Two of the city's 4 Nymphaea are located in regions IV and V (on the northern slopes of Hill Two), and could perhaps have been supplied by the Hadrianic Line. However, even though they are located on the northern slope of the hill, it would be possible for a southern branch line to feed this area, as the Ottoman system illustrates.[38]

The Basilica Cistern – endpoint of the Aqueduct of Hadrian

If the water supply entered the city from the north side of the peninsula and did not cross to a southern route in the valley between Hills Three and Four, the position of the Basilica Cistern becomes important – either the aqueduct ran on the slope above it, which would push the elevation up towards 40 masl, or the Basilica Cistern was constructed on the line of the Hadrianic channel, meaning it would have run around 32-36 masl at that point with the Basilica Cistern becoming the terminal point of the Hadrianic Line.

There are implications for the structures we believe were fed by the Hadrianic Line – both the Zeuxippos Baths and the Imperial Palace are situated beyond the Basilica Cistern. Its construction as a terminal point of the Hadrianic Line would effectively cut off the supply to these structures. We know that the Zeuxippos Baths continued to operate as baths until at least A.D. 713 and the Imperial Palace continued to be occupied, so if the water supply was cut off, considerable work would be required to reroute supplies from the Valens Line. However, this only applies if the Hadrianic Line took the northern route into the city. The southern route allows supplies to be maintained to relevant structures including the Basilica Cistern.

During the Avar siege of the city in A.D. 626 the Valens Line was cut, preventing water from flowing until its repair in A.D. 765/6.[39] That the city survived for 140 years without this major water source suggests that the flow in the Hadrianic Line was significant but also that it was accessible and capable of supplying key structures. The Hadrianic Line was not a channel that had been truncated and relegated to solely a backup in time of severe summer drought but was a fully functioning system that enabled the city of Constantinople to survive a major attack on its infrastructure.

The plan included in Altuğ 2013, 427, indicates an access to the structure about 2.5 m below current ground level.

[37] It is also worth noting that the northern and southern branches of the Ottoman Line are unequal – the northern branch, wrapping around the steep slopes of Hill Three is relatively short. On the other hand the southern branch wraps around the southern slopes of Hill Two and Hill Three and continues round also supplying the northern slope of Hill Two. This may be an indication of the difficulty of construction on this northern slope.

[38] For recent studies of the *Notitia Urbis* and the city's districts see, Anderson 2016; Magdalino 2016.

[39] Theophanes, *Chron.* AM 6258 quoted in Crow, Bardill and Bayliss 2008, 236.

It would appear that at least in later years, the Basilica Cistern was connected to the water system at its southeastern edge, close to the Hagia Sophia. A sluice control, connected to the Basilica Cistern was reported in front of the Hagia Sophia[40] and a channel was revealed during the construction of the tourist exit from the cistern in the 1980s.[41] Today, no inlets or outlets to the cistern are known. None of this evidence is conclusive but builds a picture of the advantages of a southern route into the city.

Channel in grounds of Hagia Sophia

During excavations in the western courtyard of the Hagia Sophia, remnants of the earlier Great Church were discovered along with a street, running approximately southeast-northwest which had a large 2.2 m wide channel running beneath.[42] Recent explorations of the tunnels and chambers beneath the Hagia Sophia and its surroundings have revealed a complex network of channels, including the 2.2 m channel, although the original function of these structures remains uncertain.[43]

The channel running beneath the street in the western courtyard of Hagia Sophia is generally assumed to be a sewer[44], but our newly suggested southern route makes it feasible to identify the channel with the Hadrianic Line, flowing northwards along the northeast slope of Hill One.

Suggested route of the Hadrianic Line

To summarise what we can conclude from the evidence about the Hadrianic Line:

- The line is probably higher than previously thought when crossing the Land Walls, as the Ottoman system levels previously used as a proxy are inconsistent.
- At the valley between Hills Three and Four, the Hadrianic Line was at a level sufficient to cross the saddle of the valley, opening up the possibility of a southern route into the city.
- The differences in topography of the northern and southern slopes of Hills Two and Three make a southern route into the city shorter and more straightforward to construct.
- At the platform area between Hills One and Two, the Hadrianic Line was high enough to feed into the Zeuxippos Baths.
- The location of the Basilica Cistern and the structures known to be fed by the Hadrianic Line make a southern route into the city more favourable.

As shown in Figure 4, the route proposed for the Hadrianic Line crosses the Theodosian Wall at a level of about 39 masl. At the valley between Hills Three and Four, the line hugs the flank of Hill Four, passing through the structure later called Tezgahçılar Kubbesi. From here, the channel may branch, with the main branch being the southern branch which traverses the valley and follows the contours on the southern flanks of Hills Two and Three bringing water to the head of the north-facing valley around the Harbour. When the town became the city of Constantinople this southern branch continued to supply many of the key sites in this area of the city and a northern branch may have been added, extending from Tezgahçılar Kubbesi into the densely populated flanks of Hill Three.

[40] Forchheimer and Strzygowski 1893, 55. Gilles in Byrd 2008, 101, reports seeing the inflow to the cistern, described as a large pipe and clearly high up the cistern wall but he does not indicate the location of the inflow.
[41] Çeçen 1996, 25-27, photographed the channel, described as coming from the Hagia Sophia distribution centre, and associates the same channel with two deep wells in the grounds of the Topkapı Palace. These Ottoman structures may have been constructed around an older Byzantine era well as reported in Tezcan 1980, 241-246.
[42] Schneider 1941, pl. 2. It is not clear if this channel should be linked to the channel described in n. 41 above.
[43] Özkan Aygün 2010.
[44] By Schneider 1941, 3-4; Bardill 2004, 27-28; and Lavan (forthcoming).

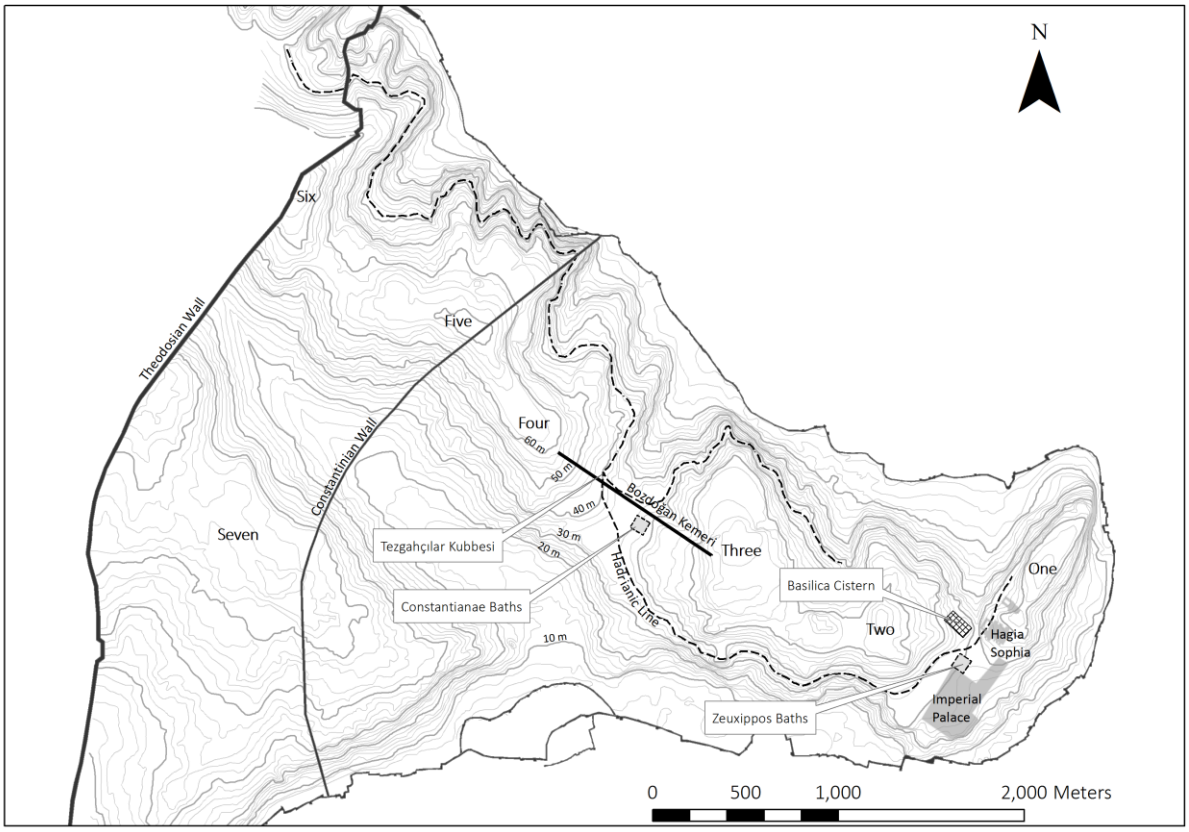

Figure 4: Suggested route of the Hadrianic Line within the city.

Aqueduct of Valens – water supply to the new city

The Aqueduct of Valens was built in two phases during the early period of the new city when not only the population was increasing but also the area the city occupied was expanding. This expansion was generally upwards and outwards from the old city of Byzantium, incorporating a number of hills that could not be served by the Hadrianic Line.

Maximising both the elevation of the channel and the area served would have driven the choice of route for the new line. The engineers would aim for a route that minimised the length of channel and complexity of construction. The Valens Line was constructed before the cisterns associated with it – the line arrived in the city in A.D. 373 and the first major cistern, the Aetius Cistern was constructed in A.D. 421. We do not know whether the cisterns were planned in advance and influenced the aqueduct route, but as they had to be connected to one of the aqueducts in order to be filled,[45] it is reasonable to assume some degree of proximity between cistern and aqueduct. However, siting cisterns would have been influenced by a number of factors, including available space, topography and downstream connections, so we should exercise caution in using the location of a cistern to define the location of the aqueduct.

[45] The volume of most cisterns is too large to be exclusively fed by a rainwater harvesting system, as the catchment area required to provide non-trivial amounts of water is so large as to be unfeasible.

Evidence for the route

Although there is more physical evidence that may be associated with the Valens Line than there is with the Hadrianic Line, the interpretation of some of this evidence is difficult. The most obvious, and still visible, evidence is the aqueduct bridge crossing the valley between Hills Three and Four. Now called Bozdoğan Kemeri, it is a clear indication that the aqueduct followed a route along the high ridge of hills within the city. The bridge, once thought to carry the Hadrianic Line, has been confirmed as belonging to the Valens Line.[46] Although the ends of the bridge have been lost we have its alignment and channel elevation (57 m at the western end).[47]

The remaining physical evidence is scarcer and less conclusive. A recently discovered channel upstream of Bozdoğan Kemeri might be associated with the line and a number of observations of brick channels, stone channels and marble pipes have been made along the modern day Ordu Caddesi and Divan Yolu Caddesi, which are closely aligned to the ancient main street of the city, the Mese. These structures have not been subject to detailed study with some identified as water channels, and some as drainage structures.

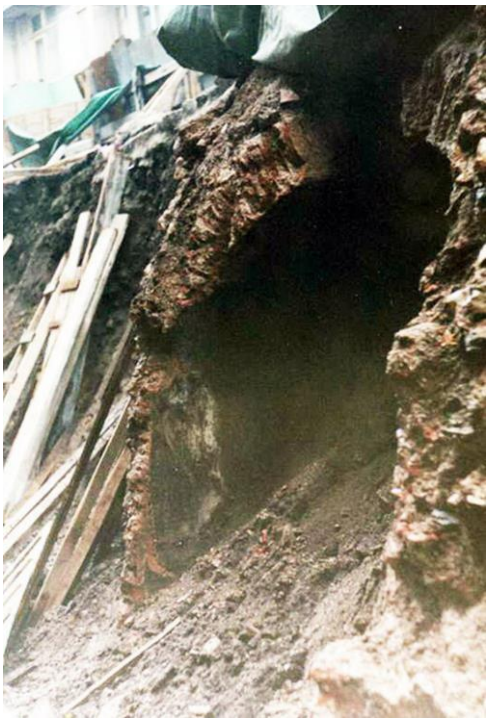

Figure 5: Channel found beneath Baş Müezzin Sokak. Photo: Istanbul Municipal Archive.

Channel in Baş Müezzin Sokak

A large vaulted brick channel, shown in Figure 5 and Figure 8, runs perpendicular to the modern Baş Müezzin street and is a strong candidate for the Valens Line upstream of Bozdoğan Kemeri[48]. The channel is at the highest point of the street, close to where it crosses with Boyacı Kapısı Street. At just over 2 m wide and approximately 2.5 m tall, the brick channel was capable of carrying high flows. The presence of hydraulic mortar, which would be evidence of the channel being part of the aqueduct, is not recorded but the channel position on top of the ridge effectively eliminates the possibility of the structure being a drain.

The location indicates the aqueduct would follow a route on the peak of the ridge or its southern side rather than the northern side as previously shown (see Figure 1). The northern route around Hill Five is longer than the southern route but does pass alongside the Aspar Cistern. We propose that the main channel took the southern route around Hill Five and that a branch was constructed at the time of the construction of Aspar.

The ground level at the point the channel was found is high, about 67.5 masl. From Figure 5 it is apparent that the channel is positioned just beneath the road surface, allowing us to estimate the channel invert level at 64-64.5 masl. One km upstream the channel must pass the saddle between Hills Six and Five, adjacent to the Aetius Cistern. The modern ground level at this saddle is about 62-63 masl so the channel must have crossed on a raised substructure or used an inverted siphon. Downstream from the channel in Baş Müezzin Sokak, the land drops to Bozdoğan Kemeri, requiring the channel to drop about 7 m over 500 m. This is a rapid drop which could create undesirable flow

[46] Following Dalman 1933, Mango 1985, 20 suggests attribution to Hadrian but is more cautious in Mango 1995, 12. See Crow, Bardill and Bayliss 2008, 13-14 for dating and attribution.
[47] Measured at arch 1 by Dalman 1933, quoted in Crow, Bardill and Bayliss 2008, 120.
[48] Baş Müezzin Sokak is northwest of the Fatih Camii, the site of the Holy Apostles

conditions that should be avoided, particularly immediately upstream of a bridge. The sizeable cistern (38 m x 26 m) found on the north flank of Fatih Camii[49] points to a solution – the channel could use this cistern as a settling basin, entering at a relatively high gradient but exiting at a gradient and level suitable for crossing the bridge. The large volume of water would provide a buffer to allow the transition from a relatively steep channel to a relatively shallow channel.

Sewers, storm drains or water channels – resolving the evidence in proximity to the Mese

Although there were vaulted channels and pipes running below the line of the ancient Mese, their exact purpose is not clear. Evidence of the pipes and channels found between Forum Tauri (Bayezit) and the Milyon are outlined in Table 1, with their locations illustrated in Figure 7.

Table 1: Evidence of pipes and channels in the vicinity of the Mese. Refer to Figure 7 for precise locations

Ref	Location	Description
1	Forum Tauri	The excavations of the Theodosian Arch in the 1920s uncovered two parallel channels running approximately east west through the arch of Theodosius. The channels were described as possible water channels.[50] These channels are in close proximity to two further discoveries. Two hundred metres to the east of the Theodosian Arch three parallel channels were uncovered and between these excavations, a third found a single channel.[51]
2	Forum Tauri	An excavation slightly north of the arch revealed four channels running approximately north-south.[52] These are not of a size to be associated with the channels crossing Bozdoğan Kemeri but could possibly be drains that discharge into the larger channels beneath the Mese.
3	Tiyatro Aralığı Sokak	Offset to the south of the line established by the channels at Forum Tauri are a series of pipes shown in a photo of an excavation in Tiyatro Aralığı Sokak[53], which shows large marble pipes, described as running in an east-west direction. The two-part photo also shows what may be two parallel channels (described in the caption as galleries) which could also be associated with the water supply. From the photograph, the pipes are similar to those now found in the grounds of Hagia Sophia. The relationship between the pipes and channels is not clear from the photograph.
4	Near Kara Mustafa Paşa Medrese	East of Tiyatro Aralığı Sokak, the excavation in Figure 6 found more marble pipes west of Kara Mustafa Paşa Medrese, running in two, possibly more, parallel lines.[54] There are no indications of channels in this excavation, although it is not clear whether the excavation extended across the full width of the road.
5	Forum of Constantine	Two sets of two parallel vaulted channels discovered to the north and south of the column of Constantine. One set of channels described as constructed in brick, the other in stone.[55] The brick built channels could perhaps be associated with the channels seen passing under the arch of Theodosius.

[49] The partially collapsed cistern is at least 38 m x 26 m with some evidence of an inflow channel in one corner. Altuğ 2013, cistern 137, 414-15.
[50] Casson 1929, 40.
[51] Müller-Wiener 1977, 261, fig. 294, unmarked on the diagram but noted as D in the caption, midway between A and E.
[52] Naumann 1976.
[53] The excavation occurred in 1975 and the photographs are included in Altuğ 2013, 42, fig. 3.15.
[54] Müller-Wiener 1977, 268-269, figs. 303 and 305.
[55] Mamboury 1936, 254.

Ref	Location	Description
6	Milyon	Müller-Wiener and an excavation near the site of the Milyon, comprising a single vaulted channel with a branch in the direction of the Hippodrome.[56]
7	Various	Bricks with brickstamps removed from vaulted structures along the eastern end of the Mese, between Atık Ali Paşa Mosque and Firuz Ağa Mosque.[57]

Figure 6: Pipe excavation west of Kara Mustafa Paşa Medrese. DAI (Istanbul) KB 2871

Drainage and water supply are gravity fed but design features differ. As smaller channels feed into progressively larger ones, drainage accumulates flow like a river system whereas water supply distributes flow from larger into smaller channels. Ideal flow conditions also differ. In water supply maximising elevation is crucial so shallow gradients and slow velocities are normal. Drainage requires steeper gradients and faster velocities for the rapid removal of wastewater to prevent deposition and odour.

Sewers

We know that the channels discovered at the Forum of Constantine and under the Arch of Theodosius were at approximately the same elevation. If they were connected, the gradient between them was extremely shallow.[58] These poor flow conditions exacerbated by the parallel channels being interconnected make it unlikely that they were sewers carrying human waste.

[56] Müller-Wiener 1977, 216, fig. 245.
[57] Reported in Bardill 2004, 77-78 from the notes of Mamboury.
[58] Mamboury 1936, 253, assumes that the channels were drains and continuous from the Augusteon to the Lycus near Forum Bovis and uses this as a proxy for the line of the Mese. Because of the change in elevation, the only intelligible interpretation of this is that the line of the sewer was continuous but actually sloped in two

Water supply

Both the flat gradient of the channels – if they were interconnected along the Mese – and the interpretation of the double channel as redundancy, allowing access for repair whilst maintaining an essential flow of water, support the hypothesis that the channels form part of the water supply.

Conversely, the position and arrangement of the channels suggest they are not water supply infrastructure: they do not take the highest route available; they flow beneath the Mese, making supply to street level difficult; and the connection with Bozdoğan Kemeri entails a 90° bend at the end of the bridge and again at the Arch of Theodosius, a needlessly complex arrangement.

We can be more certain about the pipes found at Kara Mustafa Paşa Medrese (Ref 4 in Table 1). Their location, slightly to the west of the lowest point of the ridge between Hills Two and Three, could indicate that they formed a flat inverted siphon, using pressure flow either to overcome the drop in elevation or to pass through an area with insufficient ground cover to incorporate a channel. This is unnecessarily complicated and costly[59] for a storm drain, particularly when there is a clear option to drain down the slope towards the sea. However, as Roman water supply situates the channel to minimise loss of elevation, additional costs for pipes and siphons are justifiable. Therefore we can identify the pipe finds at Tiyatro Aralığı Sokak and west of Kara Mustafa Paşa Medrese as part of the water supply.

Storm drains

The channels beneath the Mese are not sewers and are unlikely to be water supply. While their generous proportions are consistent with storm drains, the street collection and guttering, of which there is very little evidence, would need to be large, regular and efficient for the channels to be used at capacity.

Our solution is far from certain but offers an arrangement of both water supply and drainage structures that reconciles the evidence available. As shown in Figure 7, the channels referenced as 1, 7 and the southern portion of 5 are assumed to be drains. The channel at 1 flows west into the Lycus or Harbour of Theodosius and the channels at 5 and 7 flow east towards the Augusteon and discharging around the Prosphorion Harbour. The Valens Line is expected to maintain a position on the high ground north of the Mese, distributing water to the Cistern of Philoxenus[60] before doubling back along the Mese, initially in the channels at the northern portion of 5 and then at 4 in pipes whilst crossing under the road, and discharging from pipe into channel at 3 to feed the cisterns on the southern side of Forum Tauri.

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directions, draining to both the east and the west, with the split point located somewhere between the Fora of Constantine and Tauri.

[59] This is part of our current project *Engineering the water supply of Byzantine Constantinople* where manpower rates from Pegoretti 1863-64, are compared for equivalent lengths of hollowed out pipe and masonry channel.

[60] The cistern on Bab-ı-Ali Caddesi identified as the Cistern of Philoxenus by Bardill 1997, 69-75.

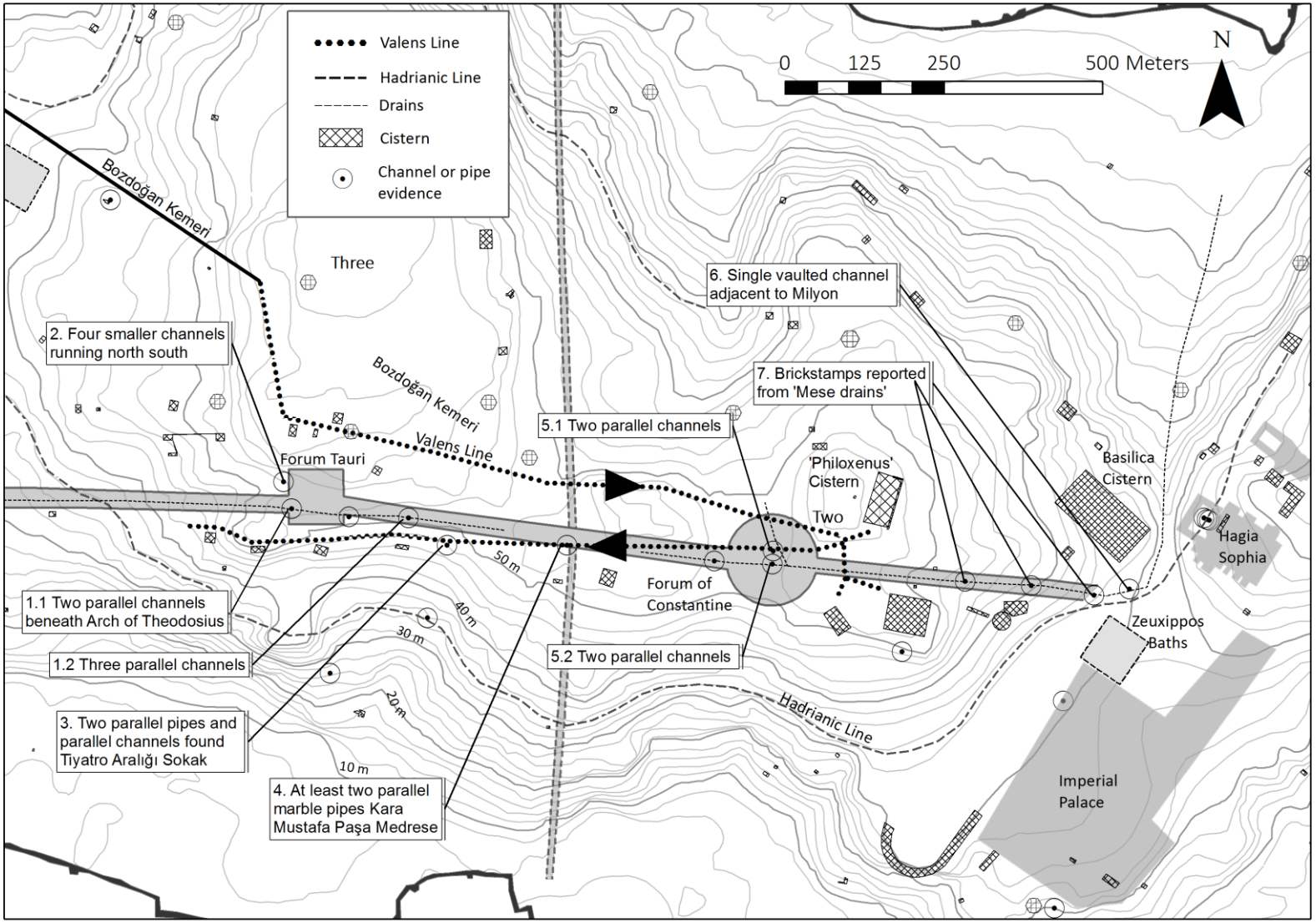

Figure 7: Detail of suggested route around the Mese for the Valens Line and the Hadrianic Line, with suggested drain routes.

Suggested Route of the Valens Line

Although the evidence for the Valens Line is difficult to interpret with certainty, we conclude:

- Based on the discovery of a large channel in Baş Müezzin Sokak, we propose that the main route for the Valens Line was on the south side of Hill Five, although a branch to feed the Aspar Cistern is likely to have been added when the cistern was constructed in A.D. 459.
- The channels running beneath the Mese are unlikely to be the main Valens Line, which probably ran on the higher ground north of the road. However, the large stone pipes found midway between the Forum of Constantine and Forum Tauri, are almost certainly associated with the water supply.

In Figure 8 the Valens Line enters the city on the northern slope of Hill Six at approximately 65 masl, taking the southern route around Hill Five to the bridge between Hills Four and Three. The line follows the highest ground towards Hill Two. Inverted siphons may have been necessary to maintain maximum elevation. The largest cistern north of the Mese is the Philoxenus Cistern, which may have acted as a form of castellum for the Valens Line. It is uncertain whether the Valens Line continued further east towards Hill One, but there was almost certainly a branch which crossed the Mese and fed the cisterns on the southern slopes of Hills Two and Three, including the Binbirdirek cistern.

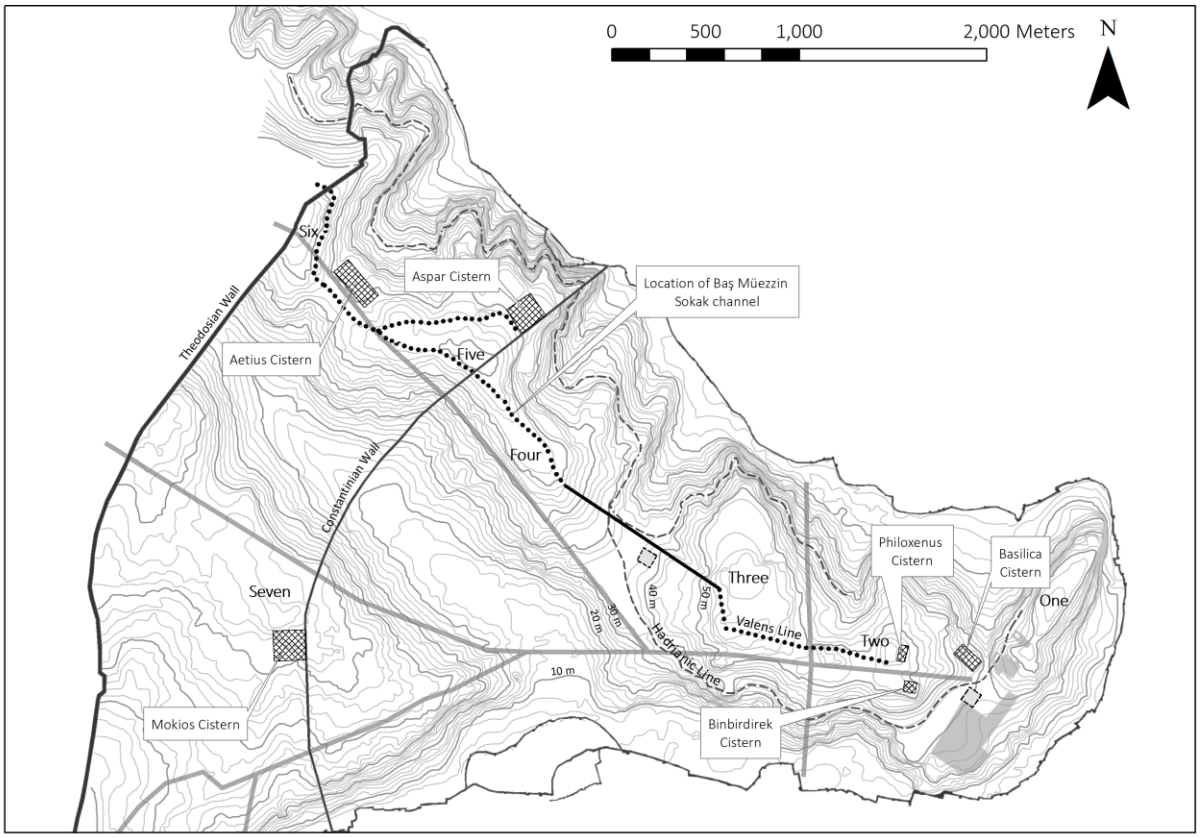

Figure 8: Suggested route of the main Valens Line

Cisterns

People have long been interested in the cisterns of Constantinople, but only relatively recently have studies shown how numerous they were. This is perhaps unsurprising – although present elsewhere in the Roman Empire, cisterns were not a standard tool in water supply nor known to be combined in networks. The advent of so many cisterns marks a significant change in Constantinople's water supply

strategy, which began in a typical way, with an aqueduct bringing water to the city; but after the construction of the colossal Valens Line, water supply investments focused on cisterns within the city. From meeting increased demand for water by obtaining more water (as was the strategy in Rome) they moved to managing and storing available water resources.

The two most recent and comprehensive works on the cisterns of Constantinople doubled the number of known cisterns in Constantinople to around 160.[61] By combining these works we have a new total of 211 Byzantine era cisterns.[62]

This new list allows us to examine the role of cisterns and develop ideas about how water was distributed across the city.

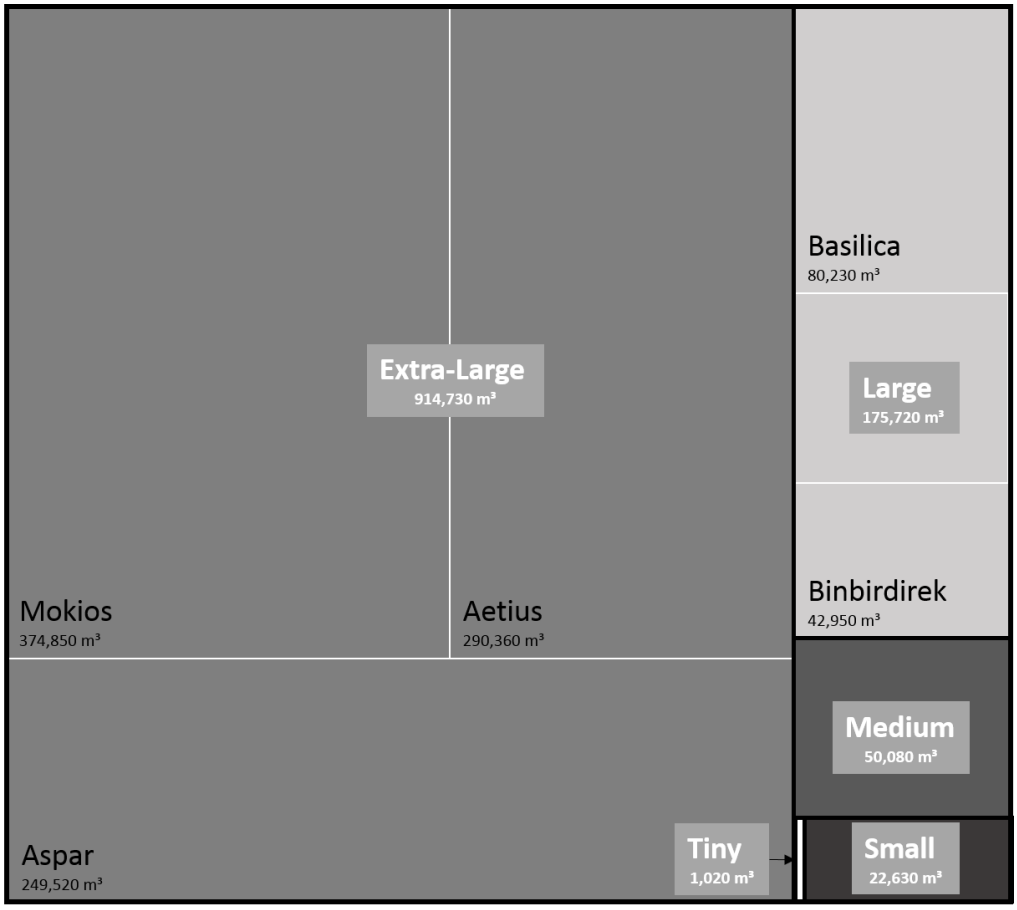

Figure 9: Distribution of known volume of cisterns[63]

The range of cisterns

Cisterns in Constantinople range from the smallest, most traditional structures that were probably rainwater-harvesting systems belonging to individual households, to colossal open-air structures

[61] In Crow, Bardill and Bayliss 2008, 144-155, Bardill created a bibliographical concordance of 161 cisterns, with two of these on the Galata peninsula. Altuğ 2013, 142-457, includes a catalogue of 158 cisterns on the historical peninsula. Prior to these two works the most comprehensive collection of cisterns was probably Müller-Wiener 1977 although the references to about 75 cisterns are scattered throughout the book and maps without an explanatory text bringing all the cistern information together.

[62] Ward *et al.* forthcoming.

[63] Diagram created in R using Tennekes 2016 and adapted for clarity.

capable of holding several months' worth of water supplies. Figure 9 illustrates how the total storage volume of over 1.1 million m³ is distributed among the 101 cisterns with sufficient data to calculate or estimate storage volume. Over 100 cisterns without sufficient data are omitted, including some believed to be large, such as the Modestus and Philoxenus Cisterns. The majority of storage is on the periphery of the city in the three open-air cisterns – Aetius, Mokios and Aspar; then in the heart of the old city, the largest of the covered cisterns, the Basilica and Binbirdirek. Other cisterns add a negligible amount to the storage capacity yet clearly serve an important role in distributing water from the aqueducts and possibly from the larger cisterns.

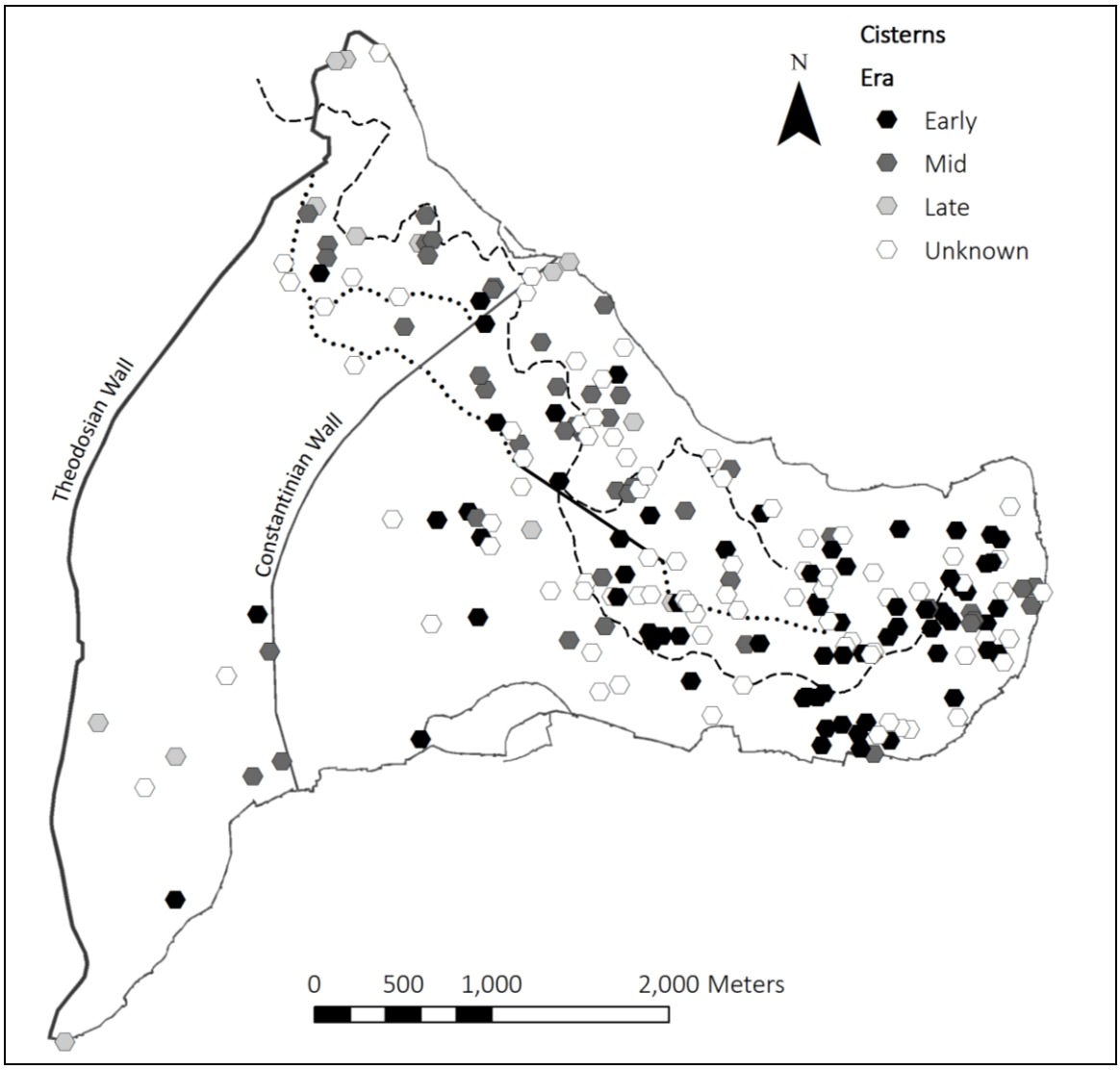

Figure 10: Distribution of early (4th-7th c. A.D.), mid (8th-12th c. A.D.), late (13th-15th c. A.D.) and unknown cisterns.

Figure 10 shows the spread of cisterns across the city. This shows that there must have been a complex network of distribution beyond the main lines of the two aqueducts. The majority were constructed after the completion of the Valens Line, not to replace the aqueducts but to assist in serving the population. We do not fully understand their purpose or how the stored water resource was managed but quantifying and locating the cisterns and the aqueducts that fed them within the city is an important first step.

Some cisterns have been dated into three broad categories: early period (4th-7th c. A.D.), middle period (8th-12th c. A.D.), late period (13th-15th c. A.D.), and period unknown.[64] From this data we can see that although cistern building reduced in later periods, it did continue, suggesting that the water supply system was continuously adapted to the needs of the city as the population rose and fell, population centres moved, and cisterns were damaged.

Cisterns were evidently important to the water supply system and distinguish Constantinople's approach from that of other major Roman cities. Though space precludes detailed study of how they were connected in a distribution network, we consider the possible arrangement of cisterns and channels on a smaller scale with two cases where the need to feed cisterns raises important questions about channel routes, water sources and the use of lifting mechanisms.

Water supply to cisterns on Hill One

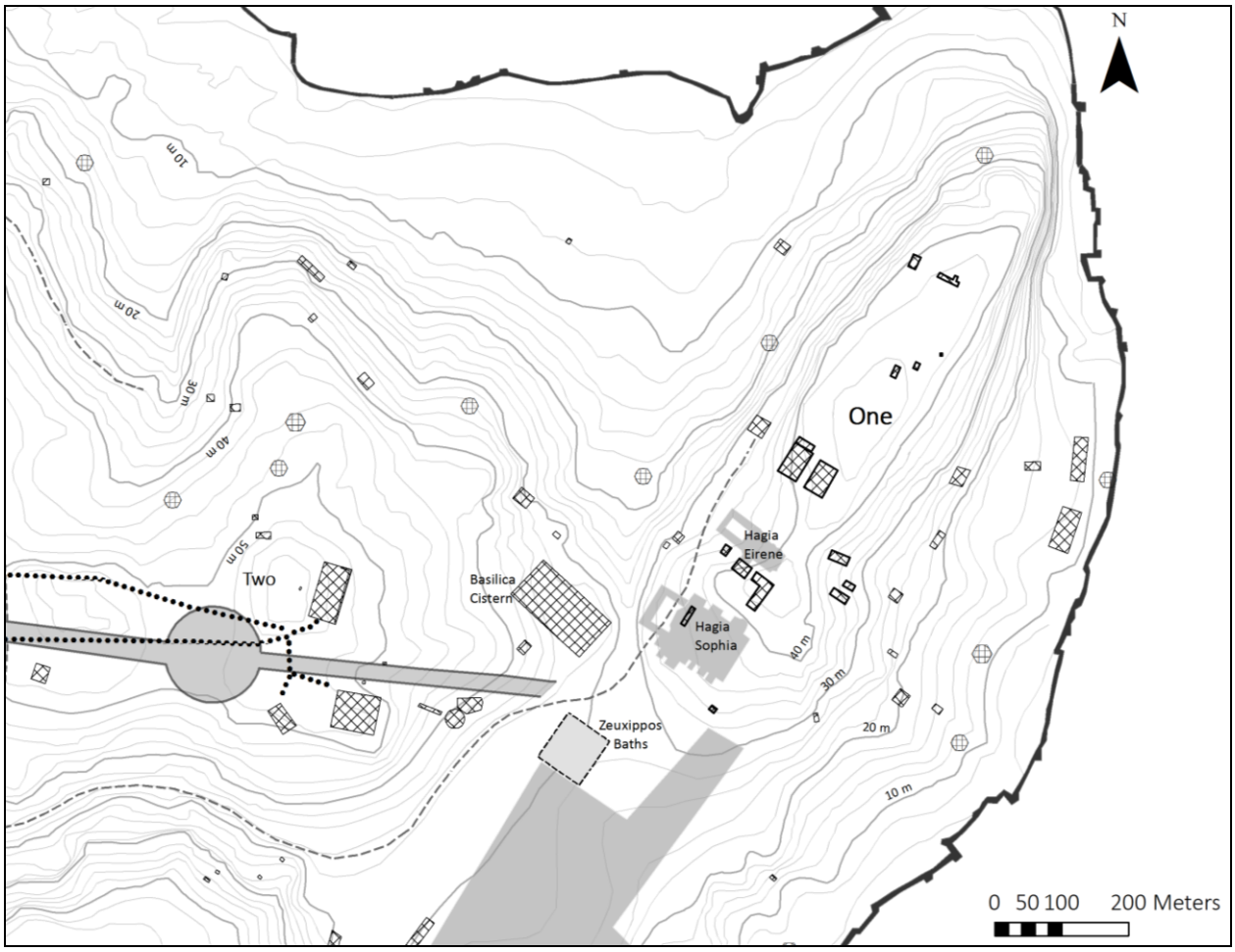

Figure 11: Water supply to Hill One is uncertain. The cisterns highlighted are at an elevation that would require water to be lifted or to cross from Hill Two using a bridge or inverted siphon.

As shown in Figure 11, Hill One is separated from Hill Two by a valley about 10 m deep. Largely within the precinct of the Topkapı Sarayı, it is one of the best-preserved and least developed areas, well endowed with cisterns, some sizeable. The available catchment area is too small to sustain the cisterns using a rainwater harvesting system making it a puzzle how a substantial flow could be delivered to them.

[64] Altuğ 2013 provides dates for some of the 158 cisterns in his catalogue. The additional cisterns from the concordance in Crow, Bardill and Bayliss 2008 have been included in the unknown period category.

The first option is that the Valens Line crossed the valley from Hill Two to Hill One. However, it is difficult to find a clear route between the hills. This area of the city was congested with large buildings and public spaces. The shortest route is blocked by the Hagia Sophia. The northern route is obstructed on Hill Two by the Basilica and on Hill One by the Hagia Eirene and the hospital which sat between the two Great Churches. If the cisterns were fed by the Valens Line it probably crossed to the south of the Hagia Sophia, traversing the Augusteon before turning north by 90°. This route is also congested and the complexity of it suggests a bridge or arcade rather than a siphon.

The second option is that water was lifted from a low level by a mechanised device. This arrangement was used during the Ottoman period in the grounds of the Topkapı Sarayı. A well was linked to a channel at a low level which fed it with water.[65] As discussed above, the Ottoman system may update a similar Byzantine one, with the channel connecting to what we now believe to be part of the Hadrianic Line.

Feeding the Mokios Cistern

Mokios an isolated open-air cistern on Hill Seven, is the largest that we know of in Constantinople. Constructed in the early 6th c. A.D. and measuring 170 m by 147 m and 15 m deep, it provides almost a third of the known storage volume within the city. It must have been fed by an aqueduct, the source of the aqueduct is uncertain. Perhaps Mokios was fed by a branch from the Valens Line, splitting off close to the Aetius Cistern and following a path back out of the Theodosian Wall, crossing the Lycus valley and then re-entering the city on the northern slope of Hill Seven (Figure 1)[66] or else the Lycus valley may have been crossed by an inverted siphon.

Mokios may have been fed by a separate line taking water from the Halkalı springs. These were tapped by the later Ottoman system and are closer to the city than the Belgrade Forest or the numerous mountain springs used by the Hadrianic Line and the Valens Line respectively.

It is difficult to conclude which option was preferred. It seems unlikely that a water source so close to the city would go unused. Modern estimates of the yield of the Halkalı springs are relatively low[67] and the complexity of the Ottoman systems constructed to capture them perhaps shows why the springs were not used as a primary source for the whole city, but does not exclude them as a supply to the area around Hill Seven.

Conclusions

Although the evidence that remains of the water system is fragmented and unclear, by considering it within the framework of a functional water supply system that corresponds to engineering expectations we can offer a fuller interpretation of the city's water infrastructure.

The Hadrianic Line probably crossed from the northern slopes of the peninsula to the southern slopes between Hills Four and Three at a higher level, arriving close to the Hippodrome before passing the Zeuxippos Baths and Basilica Cistern. Beyond, the channel might be associated with the 2.2 m wide channel running beneath the grounds of the Hagia Sophia along the northwestern slope of Hill One.

The Valens Line is expected to take a different route, with the main line running south of Hill Five, rather than alongside the Aspar Cistern. Further downstream, the situation is less clear. The Valens Line was probably north of the Mese, maintaining height before discharging into the Philoxenus Cistern. A number of branches may have crossed the Mese to feed the Binbirdirek and other cisterns

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[65] Özkan Aygün 2010, 58; and, Tezcan 1989, 241-46.
[66] Proposed in Crow, Bardill and Bayliss 2008, map 12.
[67] Dalman 1933, quoted in Mango 1995, 10, notes a yield of only 6000 m³/day for Halkalı. Çeçen 1991, 30, notes 16 separate lines as part of the Halkalı system, with a combined flow of 4212 m³/day.

on the south side; conveyed in the stone pipes found at two points near the Mese. The remaining channels running beneath the Mese could be associated with drains although questions about their size and design remain.

Cisterns are more numerous than previously thought with 211 identified with the Byzantine era of the city. The number and spread of cisterns throughout the city show that they were key to the operation of the system and also indicate that there was a network of considerable complexity connecting the aqueduct routes described above with the cisterns and connecting the cisterns with the people.

This paper has established that examining the archaeological and topographical evidence from an engineering viewpoint can expand the conclusions that can be made. We have proposed new routes for the city's aqueducts and established a higher total of cisterns. The extent of the water supply system is not yet understood and some significant questions remain, particularly on how water was supplied to Hill One and to the Mokios Cistern on Hill Seven. A detailed study of the connections between cisterns, aqueducts and the population is now possible.

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