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‘Still waters run deep’: cisterns and the hydraulic infrastructure of Constantinople and Alexandria

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Abstract

The two great eastern Mediterranean cities of Constantinople and Alexandria are noted for significant numbers of ancient and medieval cisterns which survive in both places. Using the results of recent research projects in Alexandria and Constantinople the study aims to provide greater awareness of the underground resources and how this can inform a better understanding of the urban history in late antiquity and later times. The unique character of the Alexandrian hyponomes are described in the context of the hydrogeology of the city’s situation. Recent studies note the significance of long term changes in the water quality and responses in the form of new larger cisterns between the 5th to 7th c. The large number of cisterns known from previous descriptions of Alexandria and current studies are considered to date from the 10th c. or later. For Constantinople recent research has established that 209 cisterns are known from the historic peninsula, their distribution is considered and the cistern at the Studios monastery forms a new case study since it can be shown to be structurally earlier than the basilica, dated to 463. The design of this cistern and others from the same era adopt a new innovative form common across the city. Comparison with recent studies from Salamis on Cyprus and Resafa in Syria enable an evaluation of the construction processes in the context of earlier Roman cisterns from North Africa. Geochemical studies from the aqueduct channels offer new insights into the water quality of the Thracian channels and this is considered in the context of the function of the large open cisterns. The conclusion reflects on the differing responses of cistern use from the two cities.

To justify their future aggrandisement, new cities need to create a past. For Constantinople the process was one of continuing fictive renewal from the sixth century onwards: Hesychios, the Parateisis and then in the tenth-century the compendious Patria. At each stage the City’s water provision plays a prominent role, although by the time of the Patria almost everything came to be attributed to its eponymous founder, Constantine the Great. For Alexandria there was a comparable tradition of popular literature, especially The Romance of Alexander, which tells how Alexander brought together masons, builders and engineers for his new foundation. One of them, a “stonemason called Noumenios had a brother called Hyponomos, this man advised the king to build the city on a proper foundation and to install water channels and sewers discharging into the sea and it is called hyponomos because he devised it”. Like most derivations in this genre, the etymology is fanciful, since the name in Greek simply translates as “below ground”, a synonym for channels and sewers. In a collection of papers dedicated to Water in the Late Antique city this chapter aims to consider underground urban water in the eastern Mediterranean’s two greatest city’s – despite the claims of Libanios, Antioch neve quite achieved the same scale. Beneath both city’s packed streets and houses were cool, dark, unseen spaces, hewn from the native soil and rock, filled with water. These cisterns and hyponomes could not match the ostentation of arcaded aqueducts leading travellers to the cities of Rome or Carthage. Constantinople had great bridges

1 Dagron 1984.
deep in its hinterland masked in deep forests, with only one long bridge, the aqueduct of Valens within the city itself, a physical reminder of imperial euergetism still in use into the early twentieth century.

For Alexandria research into the city’s underground waters goes back at least four centuries although in many accounts their presence across the city makes only brief mentions. However a recent project by the Centre d’Études Alexandrines has drawn together in a richly illustrated volume studies by a number of scholars describing a broad range of hydraulic endeavours and contexts. The underling geology and the porosity of the rocks determined two types of hydraulic infrastructure in Ptolemaic and Roman Alexandria, wells and hyponomes. These sources relied on aquifers that were sustained both from natural groundwater and artificially by the canal of Alexandria. First dug by the Ptolemies the broad channel was an off-shoot of the Nile and the water table was sustained by the annual Nile flood. Originally about 80km long, by late Roman and Byzantine times the canal was 130km in length and looped around the southern landward side the city. Because of the porosity of the underlying sandstone bedrock waters from the canal were able to sustain sufficient underground flow for natural wells and hyponomes; The Alexandrian hyponomes (similar to qanats) are drainage galleries, capturing water circulating in rock fissures in an apparently random manner, which explains their irregular pattern. Hirtius’ account of Caesars fighting in Alexandria in 47BC, presents a description of the situation of the city’s water supply before the Roman occupation:

Practically the whole of Alexandria is undermined with subterranean conduits running from the Nile, by which water is conducted into private houses; which water in the course of time gradually settles down and becomes clear. This is what is normally used by the owners of mansions and their households; for what the Nile brings down is so turbid that it gives rise to many different diseases: yet the rank and file of the common sort are perforce content with the latter, inasmuch as there is not one natural spring in the whole city.

The earliest masonry cisterns date from Roman times and most were modest in size. The largest of the Roman baths at Kom el-Dikka included an upstanding cistern which required an external aqueduct, the source of which is unknown. In its first phase the structure is dated to the mid-4th century with an extension in the 5th to 6th centuries. Research has identified that the city faced problems of increasing water salinity during the 4th century, but the tipping point in the organisation of water resources followed the tsunami of 365 which salinated areas of the coastline and deposited tons of debris along the city’s shore line. This event exacerbated an already poor situation brought about by increasing urban population and consequent intervention in the existing underground infrastructure of hyponomes. Increased salinity was especially a problem at periods of low water before the annual Nile flood. However it was recognised that as saline water is heavier than fresh water storage in cisterns could help overcome the problem and from the fifth century a number of spacious new cisterns were constructed. These are situated in a line parallel and close

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3 See however Empereur 1998, pp. 125-144; McKenzie 2007; Yves Empereur’s personal account of the city includes a chapter titled “City of Cisterns”, with an evocative account of the history of their rediscovery, he sensibly avoids attempting any chronology.

4 Hairy 2011, the volume is the catalogue for an exhibition, but includes the most recent synthesis and a range of well-illustrated case studies.


6 Hairy 2011, p. 225; McKenzie and Reyes 2013, Fig 1.

7 Hairy 2011, p. 215, Fig 6


9 Hairy 2011, p. 221, Fig. 17; McKenzie and Reyes 2013, Fig. 2.

10 Hairy 2011, p. 223.
with the ancient shoreline which does not correspond with the known orthogonal street grid. The chronology of these structures from the 5th to the 7th centuries is based on the specific brick sizes employed, plus in one instance a Late Roman 1 amphora reused in the wall construction.\textsuperscript{11} The best preserved of these late antique structures is at the site of the modern Orthodox cathedral of Evangelismos. The cistern has vaults supported by rectangular piers, comparable in size and form to the contemporary great cistern at Resafa in Syria.\textsuperscript{12} It is not known whether these new cisterns were for public or private use, although a number can be associated with Christian foundations.\textsuperscript{13}

In the centuries following the Islamic conquest Alexandria declined in significance. But, in the later ninth and tenth century Egypt became independent of Abbasid Baghdad under the Tulunid dynasty and the city witnessed a revival. While their exact chronology remains uncertain, the city was provided with an extensive network of cisterns a number of which were multistorey including the three storey el-Nabih.\textsuperscript{14} (Figure 1) A number are spatially associated with the new Tulunid walls which significantly reduced the circuit of earlier city.\textsuperscript{15} Like Constantinople many of the new cisterns used spolia from earlier structures, column drums and Corinthian capitals. In the seventeenth century Evliya Celebi speaks of 130-150 cisterns functioning in the city together with 3000 wells of which there were formerly 7000. Even so, he claims this was insufficient to supply the city’s needs. Later observers nearly doubled this number and in 1798 Gratien le Père, an engineer and part of Napoleon’s scientific mission to Egypt estimated that a population of 20,000 could survive a siege of the city for around 2 years.\textsuperscript{16} Modern archaeological observations identified 144 known and surviving cisterns with a total capacity of 38143.5m\textsuperscript{3} and an average size of 265 m\textsuperscript{3}. The el-Nabih cistern has a maximum internal volume of 1000 m\textsuperscript{3}. Despite the lack of resolution about the chronology of the Alexandrian cisterns the study by the Centre d’Études Alexandrines concludes that for the development of the medieval city ‘sans citerne, pas d’eau, sans eau, pas de ville’; a phrase that resonates equally through the long history of Constantinople.\textsuperscript{17}

Cisterns are the single most numerous Byzantine structures to survive in Istanbul. With the exception of relatively few churches and walls above ground the built environment of Constantinople fell into ruin and was recycled many times. The latest estimate is that 209 cisterns survive cut into the ground of the historic peninsula and the vast majority are vaulted and lined with water-proof hydraulic mortar. In size they vary from the massive open reservoirs located in the intermural zone between the Constantinian and Theodosian land walls, to small cisterns providing water for individual dwellings. One of the main themes of a recent research project “Engineering the Water Supply of Constantinople” focused on the distribution and demand for water within the Byzantine city.\textsuperscript{18} A primary task was to draw together a concordance of known cisterns from across the city and to create a reliable GIS data base. As part of an earlier project Jonathan Bardill collected a total of 161 cisterns.\textsuperscript{19} A further study by Kerim Altuğ was able to document 158 entries in part based on the archives of the Istanbul Municipality.\textsuperscript{20} Through comparison of the two lists it was

\begin{itemize}
  \item \textsuperscript{11} Hairy 2011, pp. 224-225, Fig 19.
  \item \textsuperscript{12} Hof 2019.
  \item \textsuperscript{13} Hairy 2011, 224-226, Fig 18.
  \item \textsuperscript{14} Hairy 2011, pp. 227-231, Fig 23; for the el-Nabih cistern see pp. 424-461.
  \item \textsuperscript{15} Hairy 2011, pp. 597-604; Figs 13, 18, 19, 20.
  \item \textsuperscript{16} Hairy 2011, p. 228, note that le Père used a quota of 3 litres per person per day significantly less than many modern estimates use of personal water usage.
  \item \textsuperscript{17} Hairy 2011, p. 228; Empereur 1998.
  \item \textsuperscript{18} Crow 2018.
  \item \textsuperscript{19} Bardill 2008 Map 12-15.
  \item \textsuperscript{20} Altuğ, 2013.
\end{itemize}
possible to identify 209 unique examples on the historic peninsula, including some examples documented from the 19th and early 20th centuries.\textsuperscript{21} (Fig 2) Although the smallest may have benefited from rainwater collection, the vast majority represent a network of water supply and distribution ranging in scale across the city.\textsuperscript{22} (Figs 3, 4)

The preponderance of cisterns occupy the higher ground in a band north of the Valens line, but with clusters around the Column of Marcian and more marked towards the Forum Taurii, and then more or less uniformly across the east end of the peninsula, especially on the 1st hill later occupied by the Topkapi Palace. The latter group have been subject to a specific study and remain among the best documented in the city. Their preservation reflects the privileged nature of the setting, an imperial domain since the late 15th c.\textsuperscript{23} By contrast it is notable that that there is a relative blank space on the 3rd hill, now occupied by the Süleymanye Camii and its külliye which occupies an area of nearly 6 hectares. This was the district of Oxia, the focus for the 7th century miracles of St Artemios and although it is relatively high in elevation the absence of cisterns may be attributed to the extensive Ottoman monuments, including as well Bayezit and the Covered Bazaar from the later 15th century.\textsuperscript{24} Overall it is clear that more cisterns are known/preserved along the city’s northern hills (1-6) which also corresponds to the projected course of the two main aqueduct channels.\textsuperscript{25} In addition there are significant clusters east of the Harbour of Julian and south of the Great Palace. Kate Ward’s concordance used Kerim Altuğ’s classification by date, and from the total 209 it is possible to estimate a date for 60%. The majority are late antique (before the 7th c.) and are less common outside the Constantinian walls with exceptions which will be discussed later. The middle Byzantine examples date before 1204 are found predominantly in the northern half of the city and also significantly in the north-west corner of the Blachernai, which reflects known developments in this quarter. From the few in the late period after 1204 to the final fall in 1453 they are again mostly found in the north-west, with a few to the south on the 7th hill. While these distributions must remain tentative they give some insight into the most densely occupied parts of the city, and can reflect changes in focus which complement other known sources.

Historically cisterns are known to have been constructed in the city from the 4th century onwards, the Modestiaca Cistern predates the arrival of the main Thracian aqueduct in 373 and was constructed by the city prefect Modestus. Libanius in Letters 251, wrote to the city prefect Honoratus (359-61) and spoke of “the abundant reservoirs (in Constantinople) by which it is possible for you to rival even us”.\textsuperscript{26} The new Thracian aqueduct brought increased volumes of water and was able to reach those parts of the new city at a higher elevation. It crossed the city’s main aqueduct bridge on the aqueduct of Valens (Bozdoğan Kemer) and filled the great nyphaeum which was to be part of the forum of Theodosius (Tauri).\textsuperscript{27} From that point major cisterns are known either side of

\begin{footnotesize}
\item[21] The most recent study is Ward, 2018, pp. 323-338, Appendix Map B (foldout).
\item[22] Ward, Crapper, Altuğ, and Crow 2017b, Ward, Crow and Crapper 2018 Fig.3
\item[23] Altuğ, 2013, Fig. 5.1, the plan shows how the cisterns on the summit of the hill relate to a road layout and the church of Hagia Sophia and Hagia Eirene, to the east the cisterns are related to terrace walls, probably associated with residences, see also Crow \textit{et alii} 2008, Map 15.
\item[24] Crow \textit{et alii} 2008, Map 14, E/6 as defined by later terraces, compare with Fig. 2.
\item[25] The course of the two channels as shown in Crow \textit{et alii} 2008, Fig. 2.2 has been revised in Ward \textit{et alii} 2017a.
\item[26] The history is outlined in Crow \textit{et alii} 2008, pp. 15-16; 126-140, Appendix 1; Libanius letter is quoted on p. 223; see also Mango 1995, pp. 15-16. The reference to cisterns in Antioch is not matched in the archaeological record.
\item[27] See discussion in Sodini \textit{et alii} 2016, 168-169 for discussion of the great nyphaeum and the Forum Tauri in a wider context.
\end{footnotesize}
the main colonnaded street, the Mese.\textsuperscript{28} FIG S One of these was a large open cistern north of the Mese at Babıli Caddesi. It has been identified with the cistern of Philoxenus and possibly the cisterna Theodosiana; since the latter is noted in the Notitia Urbis it should date before c. 425.\textsuperscript{29} This cistern or others in the area will have functioned as castellum aquae to distribute water from the long-distance line from Thrace.\textsuperscript{30}

The architectural form of the covered cisterns constructed before 400 cannot be determined, but one cistern can be dated archaeologically before the middle of the 5th c. This is the cistern beside the Church of St John Studios, the Imrahıor Camii. The plan published by Forchheimer and Strzygowski shows the north wall of the cistern parallel and distinct from the church/mosque;\textsuperscript{31} although a later plan indicates that the south wall of the main church is partly over and more significantly shows the cistern was at a different alignment from the basilica.\textsuperscript{32} Since the church can be dated from 463, this structural relationship provides a terminus ante quem for the construction of the cistern. The different alignment between the cistern and church implies that they are not part of the same project and that the cistern was part of an earlier estate on the southern edge of the city close to the Golden Gate. It provides rare evidence for part of the estate (originally extra-mural before the construction of the Theodosian land walls) of the prefect Studios (404)\textsuperscript{33} whose name survives in the later 5th century monastic foundation. The early cistern had internal dimensions of 26.4m in length and 18.6-16.65m in width. The vaulted brick roof was supported by 24 granite columns with Corinthian capitals and impost blocks, creating a total of 28 bays with domical brick vaults.\textsuperscript{34} (Fig 6) Since the destruction of the cistern the best evidence is the description by Forchheimer and Strzygowski, their elevation shows windows in the lateral arcades on all four sides, not visible from the photographs, these are a common feature of Constantinopolitan vaulted cisterns. To the east and abutting the east side of the cistern was a chapel described by Forchheimer and Strzygowski and as an ayasma, or holy spring.\textsuperscript{35} A well head is recorded in one of Artmanoff’s photographs apparently west of the cistern.\textsuperscript{36} No inlet into the cistern was observed by Forchheimer and Strzygowski, however a description by Andréossy from c. 1814 provides further details. He records the dimensions as before but notes a rectangular support in place of a column and a staircase, possibly that seen in the Artmanoff photograph (Fig 6) and shown on the 1893 plan. Andréossy noted that in the same corner three feet above the floor was an opening to control the outflow. He also observed the opening where water entered at the level of the springing of the vaults, as well as an outflow channel in the adjacent ayasma.\textsuperscript{37}

\textsuperscript{28} The sources are quoted in Crow et alii 2008, 223-225; Ward et alii 2017, pp. 187-190, Fig. 7.
\textsuperscript{29} Bardill 1997, pp. 69-75, 83, Fig. 2; another possible open cistern is tentatively identified with the cistern Modestiana at Saracihane, Crow et alii 2008, 127.
\textsuperscript{30} Crow et alii 2008, 15; for the long distance channels see now Ruggeri et al. 2017; Ruggeri 2018; Snyder 2017; Crapper (Forthcoming), and Crow (Forthcoming) for the bridges.
\textsuperscript{31} Forchheimer and Strzygowski, 19893, pp. 66-67.
\textsuperscript{32} Müller-Wiener 1977, p. 147, Fig. 138; his plan is dated 1973. The cistern was used as a plastic factory but was destroyed by fire after 1972 (when the author visited it). Excavation would be needed to resolve the question.
\textsuperscript{33} Dagron 1974, pp. 262-263; I am most grateful to Dr Olivier Delouis for drawing my attention to this structural relationship.
\textsuperscript{34} Forchheimer, Strzygowski, 1893, 66; Artmanoff Collection, Varinoğlu 2013, nos 41-43. http://images.doaks.org/artamonoff/items/show/516-517
\textsuperscript{35} See also Tetriatnikov 2018 for a discussion at Hagia Sophia.
\textsuperscript{36} Varinoğlu 2013, 41; the exterior of the chapel is shown in http://images.doaks.org/artamonoff/items/show/508
\textsuperscript{37} Andréossy 1828, 452-453.
In many details the Stoudios cistern conforms to the group of medium sized cisterns from the city (Fig 4). In volume it is larger than the majority from Alexandria, including the el-Nabih (at least two and half times in volume) and more particularly it exhibits a distinctive system of roof supports and vaulting. The near contemporary cisterns from Alexandria conform to the Roman tradition of cistern building, seen across North Africa and at the so-called Piscina Mirabilis at Puetoli or La Malga in Carthage.\(^{38}\) These were barrel-vaulted structures with large rectangular and cross-shaped piers. The same pattern is found not only in Alexandria at the Evangelismos, for example, but also at Resafa and Dara on the Eastern frontier, dating from after 500.\(^{39}\) The most recent discussion by Catherine Hof of the great Cistern at Resafa provides a detailed account of water capture and storage in a challenging arid environment. Her carefully argued account notes the importance of cisterns as covered spaces to allow water to settle where it is turbid or filled with sediments. Furthermore she also notes that in estimating the volume of such cisterns it is important not to calculate a simple volume from basic internal measurements but also to consider the space taken by the internal supports, which in the case of the North African model is not insignificant. Even if the ground-water sources differ, Dr Hof’s conclusions for water quality are especially relevant for Alexandria and raise issues for Constantinople.

At the Stoudios cistern as we have seen the domical brick vaults of the roof are supported by monolithic granite columns on capitals and impost blocks. The volume of the columns represents only 2.3% of the total volume of 2700m\(^3\). This pattern of modular internal organisation with either domical or groin vaults rather than the more traditional longitudinal barrel vaults noted before was a radical change and Charles Stewart has recently argued that “these vaulted bays were modular units that facilitated volume calculation during the design process.”\(^{40}\) His study is based on the large 7th c. cistern, the Loutron, at Salamis on Cyprus where rectangular stone piers replaced monolithic columns, like the contemporary rebuilt aqueduct at Salamis the arcades take the form of two-centred arches. This interpretation of the Salamis cistern and its Constantinople paradigms stresses the innovative character of water engineering that responded to the specific hydraulic demands of the new Rome. We are familiar with the complex geometrical inspiration for the greatest architectural achievement of the 6th c. Hagia Sophia.\(^{41}\) designed by leading mathematicians of the age Anthemius of Tralles and Isidore of Miletus. Indeed both the recent studies by Stewart and Hof remind us of the significance of engineering and mathematics. The city prefect Domitius Modestus who as noted before was the first documented builder of cisterns in the 360s was later praetorian prefect of the East and the surviving text of Hero’s Stereometrica, a work concerned with the practical geometry of weights and volumes, specifically mentions him as prefect.\(^{42}\) Although the architect of the Resafa cistern is not known, the mechanikos Chryses of Alexandria was responsible for most of the structures in the city Dara and the surrounding country and was called back to help resolve the disastrous flood in the city. Given the similarity between the covered cisterns at Dara and Resafa, Catherine Hof suggests it was his expertise that contributed to the Resafa cistern, observing also his origin in Alexandria.\(^{43}\)

\(^{38}\) Wilson 1998.
\(^{39}\) Hof 2019.
\(^{40}\) Stewart XXXX, p.1, Fig 8, 12, 13, for discussion of the design of the Constantinople cisterns see pp. 16-19.
\(^{41}\) Ousterhout 2018.
\(^{42}\) Corcoran 1995, 380-381; Hero’s Geodosia 9 in a later edition from the time of Constantine Porphyrogenitos specifically notes methods of calculating the volumes of the open reservoirs of Aspar and Aetius.
\(^{43}\) Hof 2019, 234-235.
The appearance of large reservoirs and covered cisterns in Constantinople is better documented from the 5th and 6th centuries.\(^ {44}\) The three open reservoirs within the walls were all constructed in the 5th century and it is difficult not to associate their construction with the additional water supply from the extension of the Valens Aqueduct to Vize (Bizye).\(^ {45}\) Fig 3 The earliest open-air cistern between the two walls, the Aetius is dated to 421 and lies just to the east of the projected line of the long distance water channel. A second Asper is also close to the line and was situated just outside the assumed course of the Constantinian wall. The third Mocius was situated to the south on the 7th hill probably dating from the time of Anastasius. How they functioned and contributed to the water supply as whole remains uncertain. Because they are not covered it is assumed that they are less hygienic and it has been suggested that the water was dedicated for the gardens and horticulture in the inter-mural zone. There total capacity is at least 607 715m\(^3\)\(^ {46}\) and it is more likely that they were intended as a strategic reserve, although we have no clear knowledge of how they may have been integrated into a wider water network. Beside the cistern of Asper in the grounds of the Yavuz Sultan Selim Camii recent observations may provide a clue to how water was extracted and dispersed from this great reservoir, but investigation and publication remains limited.\(^ {47}\) Another new study of the water quality and flow based on an analysis of the sinter deposits collected from the long-distance channels notes significant deposits of clay in the record of water flow.\(^ {48}\) The geologists involved in that study have suggested that the large reservoirs could have acted as large settling tanks, from where water was then distributed throughout the city. The open reservoirs do however raise the issue of increased water security. The reign of Anastasius saw the beginning of the construction of very large covered cisterns in the heart of the city with the Binbirdirek, (Fig 3, although the chronology of this cistern is uncertain.\(^ {49}\) This is the deepest of the large urban cisterns and reflects the need to create a vast storage space in what was crowded urban region allowing for a limited footprint. Also credited to Anastasius was the creation of the Cold Cistern in the Spendone of the Hippodrome. The Cold Cistern is the earliest example of inserting a cistern into an existing large building. Soon after came the largest of the covered cisterns the Yerebatan Saray, the Basilica Cistern constructed by Justinian, the most spectacular achievement of vaulted bays and modular units anywhere in the Roman or Byzantine worlds.\(^ {50}\)

The vast water infrastructure projects such as the Binbirdirek and Yerebatan Saray were responding to the needs of the city and were not mere vanity programmes like the nymphae and baths of earlier Roman cities. This concentration of water storage at the east end of the peninsula close to the greatest density of habitation (north and south of the cisterns, as well as to the east) may be seen as a response to threats to the city’s hinterland and increasing concern about wider security in the east Balkans. Certainly, it corresponds with Anastasius’ decision to construct a new barrier wall only 61 km west of the Land Walls intended to provide an outer defence for the city,\(^ {51}\) which in turn protected part of the water supply network from Danamadiri and Pinarca, but left exposed all of the outer line to Bizye. The 6th c. is also now recognised as a period of climate change, although the details remain subject to debate. The conclusions of the recent engineering and geological studies

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\(^ {44}\) Crow et alii 2008 pp. 128-137, Map 13.
\(^ {45}\) Crow et alii 2008; Ruggeri et alii 2017.
\(^ {46}\) Crow et alii 2008 p.129.
\(^ {47}\) Sav 2010, p. 10; I am most grateful to Dr Kerim Altuğ for drawing our attention to this structure and publication.
\(^ {48}\) Crow 2018, pp. 234-235, n. 90, Fig. 14; Sürelmihindi et alii Forthcoming.
\(^ {49}\) Crow et alii 2008, 123; see Stewart XXX, pp. 17-18, Figs. 17, 18.
\(^ {50}\) Stewart XXX 19-21, Fig 16; he also notes the importance of timber ties between the pillars as security against lateral seismic shock; see also Pickett 2018.
\(^ {51}\) Crow 2017.
indicate that there was significant range in the pattern of supply determined by local factors rather than changing global patterns. Thus on the two main branches of the long-distance supply line the karstic springs which supplied the Pinarca and Danamandira sources were responsive to seasonal rainfall variations, whereas the springs from Vize and Ergene display greater annual continuity and less seasonal range. In practice local conditions in Thrace along the water supply line and the varying issues relating to maintenance and local water use will have had greater effect on the city’s supply and how the water was distributed and stored.

The 7th c. brought new and greater challenges and changes to both cities. Alexandria declined in status as political centres were reassigned under Muslim domination, although it still retained a role as a naval base against the Byzantines. As its territories contracted Constantinople was defiant within its great defences, but the long-distance water supply, cut in the Avar siege of 626, was not reinstated until 767. The recent research from Alexandria has demonstrated that the large number of known cisterns date for the most part from Tulunid or later times, a critical mechanism for urban regeneration. The form of el-Nabih and other cisterns resembles Constantinopolitan prototypes, although an Alexandrian feature is that lateral support was provided by horizontal stone lintels and not timber beams. We cannot know if there was any inspiration from Byzantium although we are aware of Arab admiration for the city’s renewed water system. Most ancient sources concerning water technology are Roman in origin, however there are hints in Byzantine texts of continuing knowledge of water technology relevant to cisterns, thus the discussion of ‘Besieging a City’ in Leo VI’s Taktika included detailed advice on the importance of aeration and how to keep water fresh in stored containers. New cisterns continued to be constructed and a number followed the practice of creating cisterns within pre-existing structures. Sometimes these were disused like the large cistern inserted in the late antique rotunda at the Myrelaion. In the 10th c. it became part of the palace of Romanos Lecapenos and later a monastery. Other cisterns were constructed de novo as part of the foundations of churches, indeed the site and plan of now lost churches survives in the outline of the basement cisterns. (Fig 4). Many of the new cisterns continued to follow the model set in late antiquity, but whereas formerly many of the columns and capitals were new, and often not fully finished from the quarries, in the middle-Byzantine period everything was recycled from the past. The combination of columns and capitals as roof supports for cisterns was only followed in a few other places. Whilst it was easy to find spolia in Constantinople it not necessarily available elsewhere and this may help to explain the maintenance of the traditional Roman barrel vaults at Dara and Resafa. But the Constantinople type is seen at Ephesus at the end of the aqueduct leading to pilgrimage centre and fortress of St John at Ayasoluk and at the monastery of Vlatadon at Thessalonike.

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52 Based on analysis of the sinter samples by Sürmelihindi et alii Forthcoming; Ruggeri 2018, pp. 123-187, discusses in detail inflow data and the application of paleo-climate modelling for the Thracian aqueducts.
53 For a reductionist view derived from climate studies see the suggestion that the construction of the Basilica cistern was a response to drought, McCormick et alii 2012, pp. 197-198, n. 22; the studies noted above demonstrate that a more nuanced approach is required.
55 Leo VI, Taktika 15.3.90; commentary by Haldon 2013, p. 381, n. 57, also including the advice that water keeps better in large containers.
56 Striker 1981; the largest example known is the cistern east of the Fatih Camii where the outline of a church is comparable in size with the south church of the Pantocrator complex, Müller-Wiener 1985, pp. 333-35, Figs 2, 4; Ward 2018, DS/9 = Altuğ 2013, 136.
57 Altuğ 2018; Crow et alii 2008,
58 Wiplier 2010, Fig 18; Gala-Georgila 2015, Vol 2, p.41.
This paper set out to compare and contrast the water regimes at the two greatest cities of the Eastern Mediterranean. Neither conform to the standard pattern of Roman water distribution as seen across the Roman world and each was able to develop new and innovative methods of water capture and storage. More importantly the comparison reveals that the systems needed to modify and innovate to ensure adequate resources. Up to the end of the 4th c. AD in Alexandria cisterns were small and local, no more than for household use. But in one part of the city close to the sea front new larger cisterns appear responding to new challenges of salinity, resulting from seismic activity but also long-term changes in the water-table. It is not known how far there was public access to these new cisterns, as was certainly the case for some in Constantinople, or only for elite Alexandrian households or specific Christian communities. Water quality is also a theme at Constantinople and new research suggests that the water from one of the branches of the main long-distance supply was turbid, with clay particles. This is a problem in common with Alexandria, and while the Thracian waters were more hygienic than Nile water, to be potable the waters needed time to settle. Cisterns could store, could improve water quality, could distribute through systems of pipes. Although the number of known cisterns from Constantinople seems high, it is far exceeded by reported figures for Alexandria which suggests that there the majority were for local or household use, and not part of a wider network as Kate Ward has modelled for the former city. Studies of the watery underworlds of both cities help to reinforce their three-dimensional quality which responded and changed over time and circumstance. The hydraulic urban networks partly following the thoroughfares and passageways above, synchronously created a forgotten, secret, marginal and hazardous underworld. Rarely do our written sources reveal how this world was experienced. Two texts allow some insight. The chronicle of Theophanes Continuatus reports how Basil I in the late 9th c. cleared cisterns from a number imperial palaces which had been filled with earth and turned into gardens by the emperor Heraclius in the 7th c., because it was prophesied that he would die through water. A correct prediction for his grandson Constans II who was murdered in a bath in Syracuse, not the only Byzantine ruler to die in this manner. But Heraclius’ alleged anxiety reveals the potential and real danger of cisterns as closed, hidden and often inaccessible spaces. Uniquely another source reports an additional function exploiting these hermetic qualities. Skylitses’ history recounts how in 1042 after the brief reign of the emperor Michael V Kalaphates, his uncle the nobelissimos Constantine was recalled from exile and interrogated about public finances. The text describes how “Terrified by what he was threatened with, he showed the 53 kentenaria of gold hidden in a cistern at his house near Holy Apostles’ church”. A huge sum secreted in the oikos (mansion) of a member of the imperial elite. Clearly some private cisterns might have quite different functions beyond the practical. Overall what we have observed is that for both cities cisterns were vital in sustaining the dense urban populations, but the hyponomic infrastructures reveal a world that presented threats and securities deserving consideration beyond the basic estimates of scale and volume.

59 See the discussion of water hygiene in Hof 2019, p.233.
61 Urban landscape studies need to include these ‘underlands’ in their overwritten urban palimpsest, see Yalman, Üğürlu 2019, p. 8, n. 21; the metaphor of palimpsest appears novel in urban studies but was formulated in the landscape archaeology and history over 6 decades ago, and its utility has been questioned see Watteaux 2009, p. 23.
63 The same chronicle reports that the emperor Theophilos filled in a cistern where his infant son had drowned and created a garden to mourn him.
64 Skylitses, History, p. 397, 53 kentenaria is equivalent to 381,600 nomismata, almost 1,75 tonnes of gold.
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Captions:

Fig 1 The interior of the El Nabih cistern in Alexandria (Creative Commons El-Nabih File:GD-EG-Alex-ElNabih012.JPG)

Fig 2 Plan showing the distribution of cisterns in Byzantine Constantinople (drawn by Kate Ward)

Fig. 3 Comparative plan showing the large open reservoirs (drawn by Richard Bayliss)

Fig 4 Comparative plan showing medium to small cisterns (drawn by Richard Bayliss)

Fig. 5 Plan showing the distribution of cisterns and water channels along the Mese, between the Forum Tauri and the Forum of Constantine (drawn by Kate Ward)

Fig 6 The interior of the Stoudios cistern from the Artomanoff Collection (Dumbarton Oaks with permission)

Fig. 7 The interior of the Binbirdirek cistern showing the columns continuing below the modern floor. (Author)

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