The monumental Late Antique cisterns of Resafa, Syria as refined capacity and water-quality regulation system[1]

Catharine Hof

Although Resafa's four large cisterns were built consecutively, they constitute an associated sophisticated system. This monumental system contributed not only to the amount of storage capacity but also divided the various basic needs by quality, thereby avoiding any waste. This approach was an outstanding hygienic measure to cope with the poor quality of the run-off wadi water.

This paper analyses the hydraulic system and hints at the efforts exerted by the local community to deal with life in a basically uninhabitable place.

Conditions and town development

Two conditions dictated settlement activities in Resafa. First and foremost was the climate of the desert-steppe with its meager average annual rainfall of 100–200 ml (Wirth 1971: 92–93 maps 3–4; Jaubert et al. 1999: 15 map 3). The environmental conditions have changed little since antiquity, so that modern weather data are used in hydrological modeling for ancient Resafa (Beckers 2013: 34–84, 46). Additionally, the lime-gypsum earths between the Euphrates and the Jabal Abu Rajmayn, as part of the Palmyra folds, determined the quality of the groundwater. It is brackish in the entire region and of exceptionally poor quality, and thus non-potable near Resafa where groundwater salinity is 3000–6500 mg/l TDS (Wagner 2011: 168, 175; cf. Al-Charideh/Hasan 2013: 74, Tab. 1). Resafa had no fresh groundwater (contra Wagner 2011: 144) and, accordingly, the seasonal rainwater had to be collected in cisterns and this supply had to last over the year.

1 Work on the Great Cistern of Resafa is part of the general Resafa Project 2006–2012, led by Dorothée Sack of the Berlin University of Technology. With the support of a fellowship from the Free University of Berlin (Topoi Excellence Cluster 264) in 2016, I have been able to explore the raw data of the laser scans and establish the plans of the cistern presented here. The laser scans were performed in 2010 by Ingo Neumann and Hansbert Heister and their team from the Bundeswehr University Munich.

Figure 1: Situation plan (C. Hof)

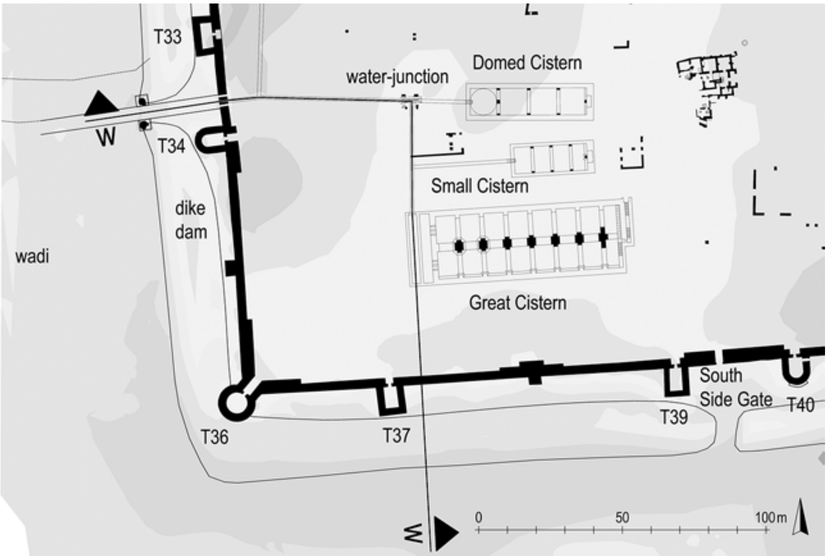


Figure 2: Resafa, southwestern city area (C. Hof)

Resafa started off as a military fort and in the early stages of settlement (approximately from the 4th to the late 5th century CE), the fresh water was collected in individual, small, and usually pear-shaped cisterns (Brinker 1991: 123–124, 132–137).

Despite the unfavorable conditions of water provision, Resafa experienced exceptional development because it was on the crossing of long-distance trade routes, and more so, because it turned into the pilgrimage center of Saint Sergius. Both aspects were attractive to visitors, who were the main source of the city's growing wealth.

The need for expansion led to a large-scale urban development project. This enterprise was launched at the turn of the 5th to the 6th century CE, comprising a new extended town wall, several churches, and a monumental hydraulic system (Hof 2016: 399–404). The provision of this first cistern must have been a basic requirement for running the large-scale city expansion building site in the desert steppe (Hof 2017: 68–69 with Figure 2).

The water catchment structure in its final stage comprised dikes, partly embanking the wadi as-Sayla, a transversal earthen barrier damming the wadi-floods, a canal leading the water into the city, and four capacious cisterns.[2]

The smallest of these tanks lies isolated in the northwestern city area, while the three others, the Domed, the Small, and the Great Cisterns, form a group near the southwest corner of the city wall (Figures 1–2).

Short description

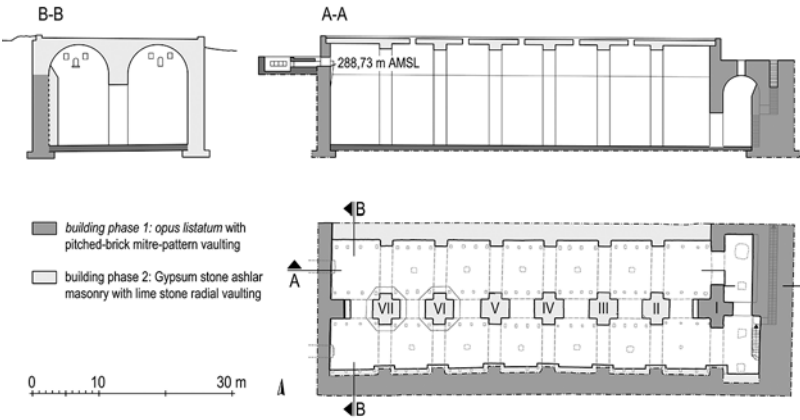
The Great Cistern (Figure 3) rises over a rectangular plan with internal dimensions of 64.56 m in length and 19.58 m in width (Figure 4) (cf. Spanner/Guyer 1926: 45–46, 69; Brinker 1991: 126–127; Brinker/Garbrecht 2007: 132–133). Seven massive, cruciform pillars (I-VII) form an arcade dividing the chamber into two naves and eight bays.

The easternmost pillar (I) marks the intersection of the arcade wall with a transversal wall. This transversal wall divides the seven-bayed main reservoir from a double-chamber with a flight of stairs along the east wall. This entrance bay is narrower than the other seven bays, lower, and covered by a transverse barrel vault made of brick ('mitre-pattern vaults', Hof 2018) rather than the gypsum and limestone vaults of the main naves (Figure 4). On the western end of the cistern, two inlets are placed slightly higher (288.73 m AMSL) than the springing of the main vaults.

2 The barrage-canal system damming the wadi is presented in Brinker 1991; Garbrecht 1991; Brinker/Garbrecht 2007. For the dike structures running alongside the flow direction to the south of the city's enclosure, cf. Beckers 2013: 55–56, 67–68, 76–77. The western rampart of the city wall and its original sole function also as a dike is discussed in Hof (forthcoming). Major studies on Resafa's cisterns are Brinker (1991) and Westphalen/Knötzele (2004).

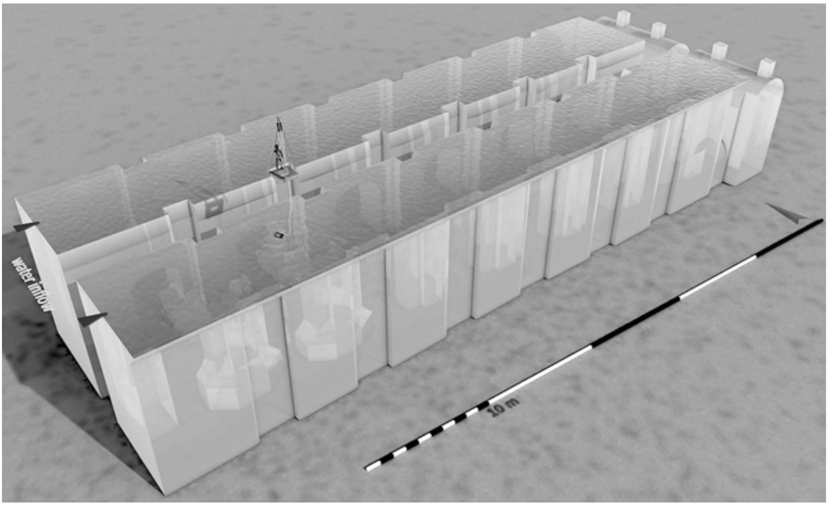
Figure 3: Resafa, Great Cistern, southern nave looking east (C. Hof)

Figure 4: Resafa, Great Cistern, ground plan and sections (C. Hof)



The highest possible filling height was 12.20 m. Former works have estimated the volume to 15–16,000 m³ (Spanner 1926: 45) or to 14,600 m³ (Brinker 1991: 126 and Garbrecht 1991: 246 Figure 9). Yet, cistern capacity figures are often too high because the volumes of pillars and walls within the body of the tank are not subtracted in the estimation. According to the volume properties of our 3D CAD model based on the laser scans, the maximum water capacity up to the inlet level was 12,600 m³ (Figure 5).

Figure 5: Resafa, Great Cistern, 3D model of maximum water capacity (C. Hof)



This volume is equivalent to the amount of water that the renowned Piscina Mirabilis near Naples, Italy was able to hold (De Feo et al. 2010). For a provincial structure, this is truly large – although the roughly contemporary Yerebatan Sarnıcı in Constantinople is nearly six times larger. Table 1 provides some reference data.

Table 1: Examples of Late Antique large cisterns

Cistern	Capacity	Date
Cistern of La Malga (Carthage)	~55,000 m^3 *	approximately 1st century BCE to 2nd century CE
Yerebatan Sarnıcı (Constantinople)	~80,000 m^3 *	approximately 540 CE
Piscina Mirabilis (Bascoli)	10,700 m^3 * 12,600 m^3 **	approximately 30 BCE
Great Cistern (Resafa)	12,600 m^3	late 5th/early 6th century CE
All four cisterns in Resafa	ca. 18,800 m^3 ***	late 5th to approximately 8th century CE

* After Döring 2007: 12, Table 1.
** After De Feo et al. 2010: 351, 354.
*** Sum: (Small Cistern 2050 m^3 + Domed Cistern 3400 m^3 + Northwest Cistern 770 m^3 after Brinker 1991) + Great Cistern 12,600 (laser scanning 2010) = 18,820 m^3

The Great Cistern of Resafa already held two-thirds of the total capacity of all four large cisterns of Resafa taken together. According to the typology by Mathias Döring, Resafa's Great Cistern represents "perfection in [Roman] cistern building"

i. e. his 'Typus IV' with several longitudinal and transversal aisles or naves (Döring 2007: 13–14; Döring 2014: 218; cf. Riera 1994: 313–386). Nevertheless, what makes the Great Cistern of Resafa highly significant is not so much its absolute capacity as its role within the overall hydraulic system of the city.

Building phases

According to our present knowledge, the water infrastructure in Resafa seems to have developed as follows (Sack Resafa 8 forthcoming, for former deviating estimates cf. Brinker 1991; Westphalen/Knötzele 2004). In the last quarter of the 5th century CE, the large church building of Basilica A was under construction. The brackish groundwater might have been sufficient, albeit not ideal, for construction needs, but the first cistern, called the Domed Cistern, had probably been built to meet the needs of the workmen (Hof 2017: 68–69). In the next phase of the urban building project, which expanded from approximately 500 CE onwards, the monumental new town wall came under construction. Therefore, far larger amounts of water had to be provided and with some certainty the Great Cistern was built next. Still in the course of the earlier 6th century, the Small Cistern seems to have been added and the Great Cistern was almost completely rebuilt, again meeting the needs of a thriving town and its further development projects.[3] The entire system was maintained in the second quarter of the 8th century and from then on appears to have fallen into disrepair.

Hydraulic concept and strategy of provision

The terrain section (Figure 6) follows an angled line from the axis of the water canal *extra muros* in the west to the four-pillared canal junction where one branch turns sharply south, passing the intake canals of the Domed and Small Cisterns, continuing through the settling tank in front of the Great Cistern, and ending at the terrain to the south of the city wall.

In the profile exaggerated vertically by 2:1, the subtle inclination changes of the bottom line of the canal are hardly apprehensible. Thus, a second, more schematic graph of the same section but with a vertical exaggeration of 100:1 further illustrates the situation (Figure 7).

Coming from the wadi to the west, the floodwater passes a shallow settling basin (288.70 m) at the two pillars roughly 30 m outside of the city wall. From there,

3 The construction or rebuilding of an unspecified cistern is known due to an inscription dated to the time after 528 CE (Gatier 1998: 237–240; Chaniotis et al. 1998).

Figure 6: Resafa, Terrain section w-w, vertically exaggerated 2:1 (C. Hof)

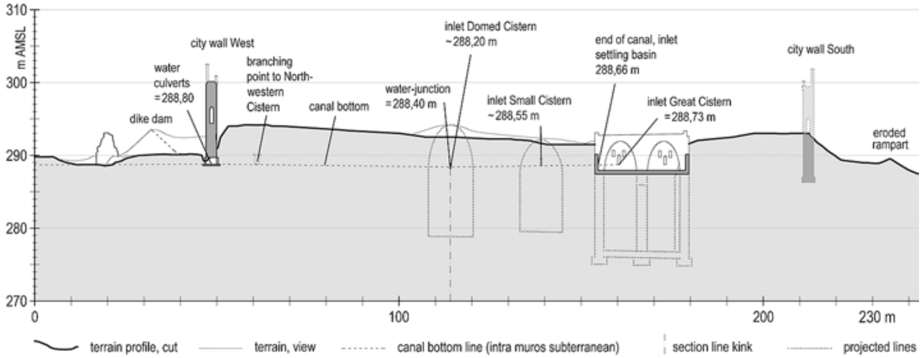
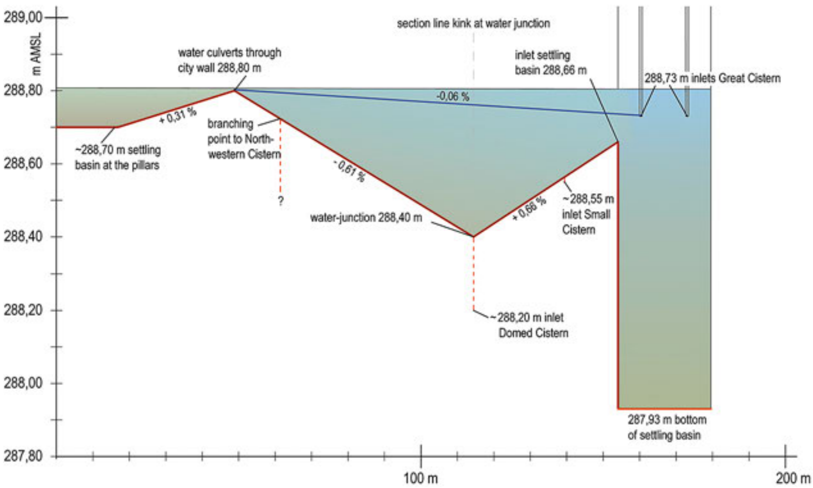


Figure 7: Schematic profile w-w, vertically exaggerated 100:1 (C. Hof). The red line indicates the bed of the canal. The blue line is the gradient between the bed of the water culvert through the city wall and the inlet of the Great Cistern. The colored area simulates a floodwater level at 288.82 m AMSL, thus 2 cm above the canal bed within the culvert



the canal suddenly has a positive slope (+0.31 per cent) until it reaches the culverts in the city wall (288.80 m). With again a negative slope, now of –0.61 per cent, the canal continues to the junction (a four-pillared building structure) with its bed at 288.40 m. The original old branch of the canal continues straight to the Domed Cistern, the inlet of which lies at approximately 288.20 m. The presumably younger branch bends south to feed the Small and Great Cisterns. The surprising finding is that this branch of the canal has an ascending slope (+0.66 per cent, the steepest) until it reaches the inlet (at 288.66 m) of the settling tank in front of the Great Cistern. After roughly half the reach, the canal again splits and a branch turns east to feed the Small Cistern.

The uphill gradient was not an accident but was achieved deliberately. Both measures, the positive slope of the canal and the settling tank resulted in inlet throttling and thus, particle settling. The overall slope of the system from the culverts through the city wall to the inlets of the Great Cistern (blue line) is extremely small. Over a length of 112 m, the height difference is only 7 cm, which is equivalent to 0.06 per cent, an angle of 0.04°.[4] This slope may seem very small, as a modern-day architect would certainly suggest a 1–3 per cent drainage slope for a water run-off device or structure such as a rain gutter or flat roof. Nevertheless, the value is by no means unusual, as comparison shows.

For example, in the vicinity of Androna (al-Andarīn), not far west of Resafa, the *qanat* (Lightfoot 1996; Jaubert et al. 1999: 32–35) system supplying the so-called Northwest Reservoir has been surveyed (Mundell Mango 2011: 104–107, esp. Figure 10 from which the gradient can be calculated). Its mean gradient is 0.08 per cent with a maximum slope of 0.17 per cent. The system of Valens aqueduct, which directs water from the northwestern hinterland to Constantinople, has almost the same total gradient, i. e. 0.07 per cent, as those in Resafa and Androna (Crow et al. 2008: 121). The complete hydraulic system comprising the famous Aqueduct of Nimes in France has an average slope of only 0.034 per cent, which seems to mark the minimum for Roman systems (Hodge 1992: 186).[5] The mean gradient of Roman aqueducts ranges between 0.15 per cent and 0.3 per cent (Hodge 1992: 218).

Altogether, the hydraulic system in Resafa shows several measures aimed at flow throttling. We can assume that during seasons of heavy rain, large amounts of floodwater rushed through the system and had to be tamed. The measures taken show the need to address not only the incoming water but also the refuse and solvents it brought along.

4 This clearly contradicts Garbrecht's statement that the inlet of the Great Cistern lies 0.60 m below the bed of the canal near the pillars *extra muros* (Garbrecht 1991: 245). Garbrecht provides no level measurements, but the same difference can be derived with some transformation from Brinker's (1991) levels given in his Figure 11 (canal between the pillars) and Figure 12 (culverts through the city wall). According to present knowledge, the heights presented in Figure 11 must be wrong. A complete discussion will be presented in Sack Resafa 8 (forthcoming).

5 Hodge's dimensions for slope are meter per kilometer; thus, he speaks of a gradient of 0.34 which is equivalent to 0.034 per cent.

Cisterns in serial connection

The question arises as to why the three large cisterns in the southwest of Resafa form a group. If we look, for example, at Constantinople or Dara, the cisterns are built as close as possible to the neighborhood where there is an actual demand for water. One reason for the series connection can be deduced from a recommendation by Vitruvius in approximately 20 BCE:[6]

> If such constructions [cisterns] are in two compartments or in three so as to insure clearing by changing from one to another, they will make the water much more wholesome and sweeter to use. For it will become more limpid, and keep its taste without any smell, if the mud has somewhere to settle; otherwise it will be necessary to clear it by adding salt. (Vitruvius 1914: 8. 6. 15).

The salt mentioned probably refers to potassium alum, which was used in antiquity for purifying water (Syvänne 2007: 71–74).

Vitruvius describes the purpose of two to three tanks in series to improve water quality. In theory, an arrangement in series allows the water to seep between the partitions of the cisterns thereby filtering it. Although the statement by Vitruvius is not clear on structural details, the key message is that a series of cisterns can be used to improve water quality. Vitruvius seems to describe two phenomena as one: on the one hand, the filter effect of the soil or rock and, on the other hand, the problem of pollution by suspended solids.

The general objective of Vitruvius' book 8 on water is a three-part, hierarchical distribution; the highest priority is given to public basins and fountains, then to public baths, and finally to households that pay for private supplies (Vitruvius 1914: 8. 6. 1-2; cf. Evans 1997: 7). Archaeological evidence has not been provided to demonstrate this strict division in the form of practical implementation, but the hypothetical approach illustrates the importance of a general water supply policy in communities.

A filtering effect of the spaces between the cisterns could not have been intended in Resafa because each cistern is sealed by hydraulic plaster. In addition, they are too far apart to achieve a communication system by leachate. However, sophisticated water purification could have been intended otherwise, as indicated by the fact that the supply line rises along the cisterns and that only the Great Cistern has its own settling basin. With this arrangement, the first flow of unsettled water with high concentrations of turbid substances can be directed into the

6 As a starting point for the wider discussion of water treatment in antique scripts cf. Vuorinen 2007a.

Domed Cistern. This water of inferior quality was suitable as process water and was not dispensable as in other sites with abundant water.

The Domed Cistern was not necessarily filled to the brim; rather the canal to the Great Cistern was opened as soon as possible. Beyond the canal junction, the flow speed was reduced and particles settled out before entering the Great Cistern. There, the inlet was kept open as long as water of sufficient quality arrived, preferably until the Great Cistern was full. The water in the Great Cistern was purified and primarily served as drinking water. Thereafter, the final weakening flow of the precious water could be redirected to further fill the Domed Cistern. The Small Cistern between the two others could have served as a buffer for both demands with medium-quality water.

A good 120 years after Vitruvius, Sextus Iulius Frontinus wrote his work, which deals with the water supply of Rome and emphasizes the improvements in this area made by Emperor Nerva (r. 96–98 CE) (Frontinus *Aquaeductu:* 87–93 quoted after Evans 1997: 37–39). Rome hardly had any problems with water availability, but its blessed inhabitants would at times complain about the presence of turbid water. Frontinus describes the problems regarding the fluctuating water quality in the collection plants. A situation that pleased the residents of Resafa, namely, rainy weather, was a nuisance to the consumers in Rome. Precipitation and surface run-off water in aqueducts that were fed from open-water plants contaminated the water at the source of the aqueduct, the external collection points (Frontinus *Aquaeductu:* 89 quoted after Evans 1997: 38; for Frontinus on water quality cf. Rodgers 2004: 23–24). Settling tanks were not sufficient to clear the water enough to satisfy consumer's taste. Some aqueducts, such as the Aqua Claudia named by Frontinus, and especially the Aqua Marcia, were appreciated for their cold and pure water even in bad weather conditions. Promoting the same high quality of all aqueducts was not possible, so Frontinus makes the theoretically understandable, but in practice hardly feasible, proposal to use the reservoirs according to their water quality: pure water such as that from Aqua Marcia as drinking water, other conduits with medium-quality water for other purposes, and finally polluted water, such as from the Anio Vetus, for garden irrigation (Frontinus *Aquaeductu:* 92 quoted after Evans 1997: 39) and probably livestock (Evans 1997: 81; Rodgers 2004: 255). In practice, this approach would have meant that three lines would have had to arrive in every water-supply quarter.

Neither the technical design according to Frontinus (separate supply lines for separate quality levels) nor the older Vitruvian approach (filtering according to a leakage principle) can be found in Resafa exactly as outlined in the sources. Nevertheless, the basic ideas of quality improvement and quality separation are reflected in Resafa's hydraulic system. Unlike Rome's, Resafa's collection system relied completely on rainfall. However, the alluvial muddy run-off water from the dusty, naturally polluted environment was hardly suitable for drinking. This condition seems to have been recognized only after having experienced water-quality issues with the Domed Cistern as the sole reservoir. The hydraulic system was extended and redesigned to become the subtle and sophisticated operating mechanism described above.

Resafa's cistern system under hygienic considerations

The crucial difference between Resafa's water collection system and most of the other localities that also sourced water from the surrounding area was that the water of Resafa did not come from smooth, rocky plains but from the sandy, dusty soils of extensive pastureland near the confluence of several small wadis with the wide funnel of Wadi as-Sayla. This water was not only clouded by inert soil particles but was contaminated by organic and thus hazardous substances such as animal faeces, insects, plants, and small animal carcasses.

The sanitary problems associated with such so-called surface-water run-off cisterns, which are primarily fed from surface water from unsealed areas, were examined in the early 20th century in two extensive studies on Jerusalem, Palestine, and Syria.[7] The groundwater in Jerusalem is like that in Resafa, i. e. unusually brackish, and thus fresh water was collected in cisterns and consumed until the modern age. Anastasius I (r. 491–518 CE) held such conditions to be appalling and initiated the construction of an aqueduct supply system (Procopius of Gaza 1986: 18).[8] Two aqueducts brought clean water to the so-called Solomonic ponds near Bethlehem and from there to Jerusalem's upper city, but the other urban areas remained completely dependent on locally collected rainwater (Masterman 1918: 57–58).

Until the 19th century, the microbial causes of diseases due to aquatic pathogens were unknown, but the basic causal relationships between water quality and health were well understood in previous times. Clear and cool water was considered not only the best in taste but also the most wholesome. Covered drinking water cisterns were viewed as extremely important, whereas open reservoirs usually served as process water supply (Hellmann 1994; Vuorinen 2007a: 48–49, 53–54, 64; Vuorinen 2007b: 110; van Tilburg 2013; Fahlbusch 2014: 11–14).

In its last stage of development, the water supply and the proposed elementary hygienic concept seemed to have worked satisfactorily. Otherwise, the ancient

7 Mühlens 1913; Masterman 1918. On the problems of surface-water runoff cisterns, cf. Mühlens 1913: 57–58; Mühlens' early work as an engaged physician in Jerusalem, Aleppo, and Constantinople and his later change to become a compliant servant of the regime in the Third Reich are described in Wulf 2005.

8 On the discussion about whether the passage refers to Jerusalem, or Hierapolis in Phrygia, or Hierapolis in Cilicia cf. Pickett 2018: 119 n. 127.

authors Procopius (2002[1954]: 2, 9, 3–9), Yāqūt ar-Rūmī (Kellner-Heinkele 1996: 146) and Ḥamza ibn Ḥasan al-Iṣfahānī (Musil 1928: 267; Kellner-Heinkele 1996: 150–151 as cited in Ibn al-ʿAdīm and Ibn Šaddād) would hardly have claimed authorship for the named builders, respectively rulers, Emperor Justinian I (r. 527–565) or al-Munḏir ibn al-Ḥāriṯ (r. 569–582).[9] Just recently Jordan Pickett has demonstrated how Procopius elevated the technical structures of inconspicuous reservoirs and cisterns to the league of commonly praiseworthy targets of imperial patronage, such as aqueducts and baths (Pickett 2018: 99, 118–122).

Fortuna or luminary?

Resafa's sizeable hydraulic system required the highest engineering competencies for execution. Developing and implementing the purifying concept and the additional separation by water quality to the primal basic collecting installation clearly followed a sophisticated plan. This finding not only added further tanks in a row but also refined the methods of settling suspended particles through throttling the feed rate of the cisterns, particularly the Great Cistern. What traces of acknowledged expertise do we know of, whose influence or even direct participation would have been possible?

The most probable authority is known to have been responsible for the hydraulic structures at Dara-Anastasiupolis, which were built around 507 CE under Anastasius I (r. 491–518). That fortified border city dates to the same time as the advancing project of city expansion in Resafa. A short time after Dara had been built, with its enclosure wall encompassing a section of the Cordes stream, a devastating seasonal flash flood damaged the city wall and parts of the town (Procopius 2002[1954]: 2, 2, 13–15). The same luminary who had planned the original system, Chryses of Alexandria, was now consulted to achieve a safer system of dams, canalization, and water storage.[10] The exact dating of the flood event and the following redesign of the hydraulic system in Dara remains unclear but can be estimated to the

9 The sources mention an-Nuʼmān ibn al-Ḥāriṯ ibn al-Ayham, who ruled 434–453, which is too early; thus, a naming error might have occurred. If this mistake effects the given name and the patronising ibn al-Ḥāriṯ is correct, then the name should have been al-Munḏir ibn al-Ḥāriṯ (r. 569–582), the builder of the so-called al-Munḏir-Building just outside the walls of Resafa (Kellner-Heinkele 1996: 146, n. 114 – she also regards the Father, al-Ḥāriṯ ibn Ǧabala r. 529–569 as a candidate; Shahîd 2002: 122–129, esp. n. 194).

10 For the twisted story of Chryses' divine inspiration through a dream, leaving the Emperor Justinian as the true designer of the plan cf. Procopius (2002[1954]): 2, 3, 3–15; for the paradox of the events, cf. Turquois 2015: 228–230. The full description of the rebuilding is covered by Procopius (2002[1954]): 2, 3, 1–26. For Dara's role within the topic of water management in Procopius' Buildings cf. Pickett 2018: 105–110.

first third of the 6th century CE.[11] Chryses was a contemporary of the renowned architects of the Hagia Sophia (532–537) at Constantinople, Isidore of Miletus and Anthemius of Tralles, and according to the descriptions of Procopius, he was responsible not only for the hydraulic structures in Dara but also for those "in the rest of the country" (Procopius 2002[1954]: 2, 3, 2). Chryses must have visited Dara twice, before and after the flood, and his journey may have led him over Resafa which lies on one of the possible routes between Alexandria and Dara. At the later G. Garbrecht finds considerable similarities between the description by Procopius and the still existing remains of the dam, even if the dam wall is polygonal and not crescent shaped (Garbrecht 2004: 117, 119–120). There is no reason to assume that the building developers in Resafa would not have made use of the expertise of Chryses, coming from the "City of Cisterns", Alexandria (Empereur 1998: 125–144).

The traces concerning the motivation to expand the infrastructural facilities of the former military post in Resafa do not indicate the involvement of the emperor or any military personality but hint at a local client (Ulbert 2000: 144–145; Mundell Mango 2008: 78–79). One cistern (as yet unspecified) is attested by inscription and connected to John, the deacon of Antioch, with a terminus *post quem* of 528 CE (Chaniotis et al. 1998; Gatier 1998: 237–240). The civil authorities in Resafa at the time probably made an extra large-scale investment in what was becoming the main economic factor of their community: the well-being of pilgrims and merchants.

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11 The building of the dam still within the reign of Anastasius I (r. 491–518) is suggested by Croke/Crow 1983: 158. M. Whitby (1986: 768) holds the 520s more probable, thus during the reign of Justin I (r. 518–527) or the early Justinian I (527–565), thus following Procopius. The 530s are also mentioned as an extended option (Zanini 1990: 250).

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