

John Peter Oleson

Strategies for Water Supply in Arabia Petraea during the Nabataean through Early Islamic Periods: Local Adaptations of the Regional ‘Technological Shelf’

Summary

Excavation by the author at the site of al-Humayma, ancient Hawara, allowed detailed reconstruction of the water-supply system that supported this isolated settlement in the hyper-arid Hisma Desert of Southern Jordan. A re-evaluation of the regional water-supply systems in Arabia Petraea from the Nabataean through the Early Islamic phases, shows that some aspects of the systems at Nabataean sites, such as Petra and Hawara, had precedents in the technologies of the Late Bronze Age and Iron Age settlements in the region, while others can be traced to developments in the Hellenistic Aegean. Sites such as Petra, Hawara, Iram, and Hegra show that the overall flavor of the water-supply systems remain strictly regional, mostly due to climate, topography, and hydrology.

Keywords: Nabataeans; hydraulic technology; technological shelf; cistern; aqueduct

Die vom Autor geleitete Ausgrabung in al-Humayma, dem antiken Hawara, ermöglichte eine detaillierte Rekonstruktion des Wasserversorgungssystems, das die isolierte Stätte in der extrem ariden Hisma Wüste im südlichen Jordanien versorgte. Eine Neubewertung der Wasserversorgung in der Arabia Petraea von der nabatäischen bis in die islamische Zeit zeigt, dass die in nabatäischen Siedlungen wie Petra und Hawara gebräuchlichen Systeme technisch teils aus der regionalen Spätbronze- und Eisenzeit hervorgehen, teils in die hellenistische Ägäis zurückverfolgt werden können. Es kann gezeigt werden, dass der generelle Charakter der Systeme in Siedlungen wie Petra, Hawara, Iram und Hegra regional bleibt, hauptsächlich aufgrund von Klimabedingungen, Topografie und Hydraulik.

Keywords: Nabatäer; Hydrauliktechnologie; technologisches Repertoire; Zisterne; Aquädukt

A Survey and excavation conducted by the author between 1983 and 2005 at the site of Humayma, in the Hisma Desert of Southern Jordan, produced an enormous amount of data about the details of the water-supply system that allowed this isolated settlement to flourish in a hyper-arid environment.¹

Humayma, ancient Hawara, was founded by a Nabataean King, Aretas, either the third or fourth of that name, sometime in the first century BC. An oracle told his son Obodas to, “seek a place called ‘White’”; a punning reference to the literal meaning of the name Hawara, and the vision of a white camel led him to the site (Fig. 1).² Essentially a colony of Petra, Hawara was located at a spot on the King’s Highway in the Hisma Desert, which was well suited to pastoralism, agriculture, and trade, and the small Nabataean settlement continued to flourish under subsequent Roman, Byzantine, and Abbasid occupiers.

The regional water-supply system included 27 km of aqueduct, five reservoirs, 57 cisterns, and three containment dams, along with a few wadi barriers and terraced fields (Fig. 2).

A complete analysis of the local and regional water-supply system of Hawara for the first final report of the Humayma Excavation Project, published in 2010, made a full evaluation of the historical and technological context from the Nabataean through the Early Islamic periods possible. The regional system, in fact, is almost entirely Nabataean in origin, and the original design functioned almost without change across 800 years. This remarkable stability and effectiveness raises questions about Nabataean hydraulic technology. Was there a distinct repertoire of techniques and structures that is recognizably Nabataean? If so, did all these techniques originate with the Nabataeans themselves as they gradually sedentarized in the course of the second century BC? In particular, did this technology evolve at Petra, which seems early for it to have had special economic, religious, and political importance? Did engineers trained or experienced in some normative tradition of water supply carry this knowledge outward from Petra in the same way that much of the Nabataean painted fine ware was exported from that central place? Was there a Nabataean Vitruvius or Frontinus, some paragon of hydraulic engineering or administration who spread his ideas in written form? Finally, how do the chronology and technology of the water-supply systems at Hegra, or in the flourishing cities of the Negev, compare with the systems the core settlements of Arabia Petraea, such as Petra and Hawara. Naturally, I want to develop this discussion of Nabataean water-supply technology in a way that will contribute to the workshop theme of *Water Management in Ancient Civilizations*, and to the session theme of *Water, Climate, and Society*.

1 See the bibliography and account of the excavation in Oleson 2010.

2 Oleson 2010, 50–53.



Fig. 1 Locator map of Humayma.

At the start, I have to emphasize that the variety of environmental conditions across Nabataean territory presents some problems for any hypothesis of a unitary Nabataean technology.³ The northern portion of the kingdom, which I can only touch upon in this context, was relatively well watered and well endowed with agricultural land. For these same reasons, this region was also rich in traditions of water management and water supply that originated as early as the Bronze Age, and were modified or supplemented by various regional cultures through the Hellenistic period. At present, the annual precipitation at Damascus averages 202 mm, which is below the threshold for grain production, but the Barada River, originating in the Anti-Lebanon mountains, has emptied into the al-Ghutah oasis since antiquity, on the edge of which Damascus was founded long before the Nabataean hegemony, allowing irrigation agriculture. The site of Bosra to the south, in contrast, receives only 150 mm of rainfall a year, and must rely on reservoirs

3 National 1984; Shehadeh 1985; al-Kurdi 2008.

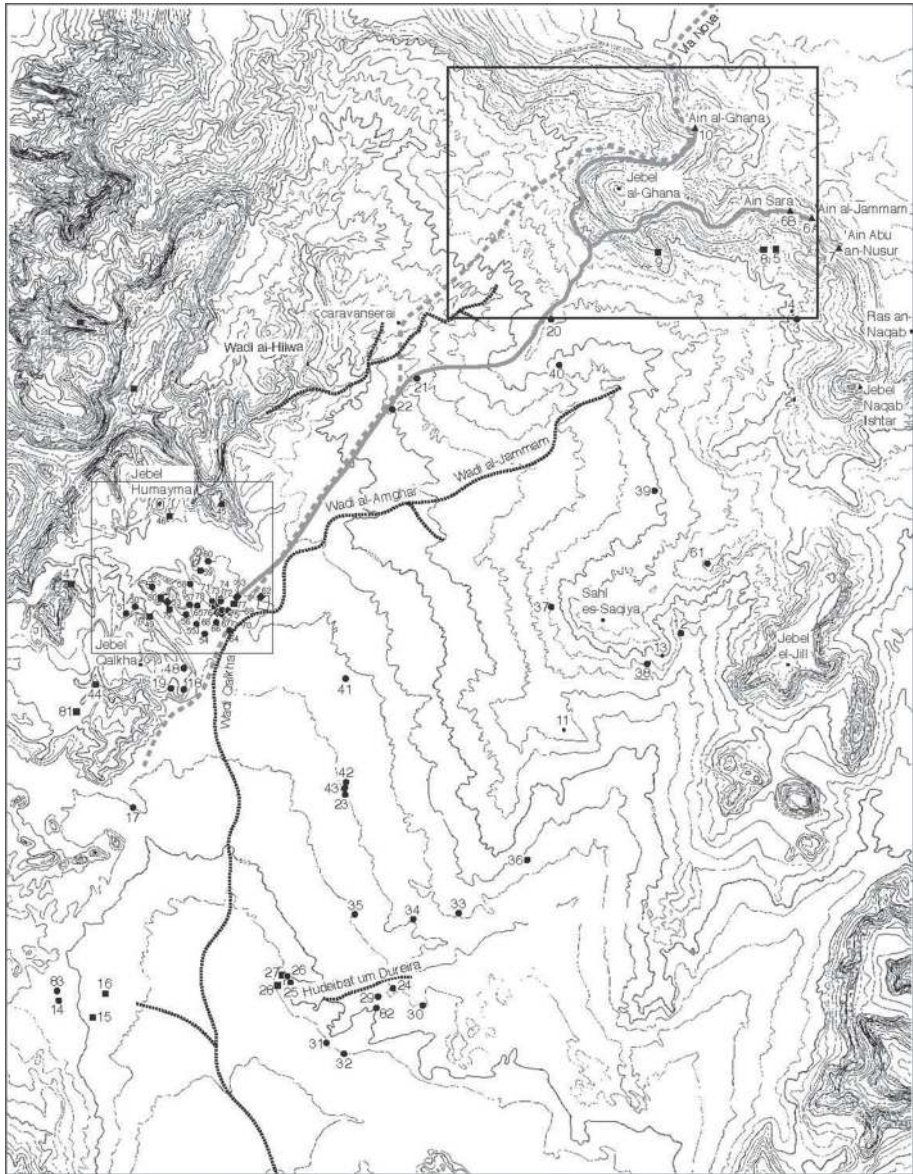


Fig. 2 Map of Humayma region with hydraulic installations.



Fig. 3 View of 'Ain Brak, Petra.

and cisterns to store the run-off. This run-off water was directed to reservoirs and agricultural fields by shallow earthen channels. The same goes for Umm el-Jamal and the other sites that flourished in the Hauran during the Nabataean period. All of these techniques were in use in the region since the Bronze Age.

Between Bosra in the north and Ras en-Naqb far to the south, on the high el-Sherah escarpment that forms the boundary of the Hisma Desert increased rainfall coincides with higher elevation. The settlements at the higher elevations, such as Jerash, Madaba, and Kerak and the lands around them receive between 200 and 400 mm of precipitation, sufficient for growing grain. The lower, dry steppe regions to the east receive between 100 and 200 mm, which allowed an active pastoral economy but restricted agriculture.

Farther south, the capital city of Petra gave its name to stony Arabia Petraea, but enjoyed water resources far exceeding those elsewhere in the region. The site of Petra receives only 40 mm of precipitation a year, but Wadi Musa higher up to the east receives 177 mm, and the run-off flows, for the most part, through Petra. In addition, the abundant spring of 'Ain Musa and several lesser springs flow from the high stratum of limestone down towards the settlement center (Fig. 3).⁴

Conditions to the southeast around the Jafr depression, to the south in the Hisma Desert, and in the Hejaz, qualify as hyper-arid, with more or less 50 mm of precipitation annually and very high evaporation rates. The cities of Nabataean origin in the Negev enjoyed both higher rainfall – between 100 and 300 mm annually – and more fertile soil than Arabia Petraea, although conditions were not as favorable as in the northern Nabataean territory.⁵ Nevertheless, despite all these regional anomalies, modern scholars often assume that all the settlements between Avdat and Bosra that shared in the Nabataean cultural veneer formed part of a unitary technological system. Was this really

4 Bellwald 2008; Oleson 2010, 417–446.

5 Evenari, Shanan, and Tadmor 1982, 95–119.

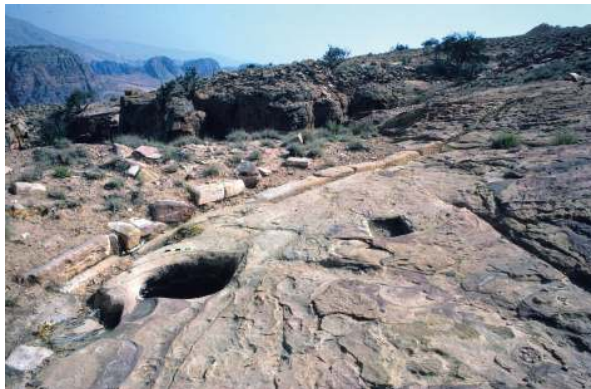


Fig. 4 Iron Age Cistern, Umm Biyara.

the case? What is the cultural flavor of hydraulic technology in this large and varied region, and what does it tell us about Nabataean culture in general? First, we must consider the origins of these techniques.

Many aspects of Nabataean hydraulic technology had precedents in the technologies of the Bronze Age and Iron Age settlements that later became part of the Nabataean kingdom.⁶

Cisterns are the most obvious example of this connection since they appear in large numbers at nearly every Bronze and Iron Age settlement, both cut into the bedrock and built of blocks. There are numerous Iron Age examples at Sela and at Umm Biyara above Petra (Fig. 4). The terracing of agricultural fields was another common and effective method throughout the eastern Mediterranean from at least the Late Bronze Age onward. This was a technique designed to capture both run-off water and eroded soil, and transform a difficult slope into a series of narrow but fertile horizontal fields.⁷ There are many examples of these throughout the Nabataean kingdom, including a large number around Petra. Dams are a more technically demanding type of structure, but even so, attempts were made to block the flow of run-off water by the Early Bronze Age at Jawa, and – to move somewhat outside the Nabataean cultural area – at Ugarit by 1300 BC, a masonry dam was put across a flowing stream near the Royal Palace. Earth or masonry dams were a typical method of water control for the Late Bronze Age cultures of Egypt and Mesopotamia.⁸ The Nabataeans made use of both techniques.

Earthen water channels were an essential part of the river valley cultures in the Bronze Age, but shallow, unlined earth channels were also used in dry regions in every period to carry run-off water, although they seldom survived. Rare examples can

6 Oleson 1992; Oleson 2001; Heemeier et al. 2008.

7 Oleson 1992, 890–891; Oleson 2001, 605–608; Oleson 2010, 479–481; Price and Nixon 2005.

8 Helms 1981; Garbrecht 1991; Oleson 1992, 890–891; Oleson 2001, 608; Philip 2001, 173–174.



Fig. 5 Late Bronze Age conduit blocks, Ugarit.

be seen at Nabataean sites such as Umm el-Jimal and Sobota.⁹ By the Late Bronze Age rock-cut conduit blocks were a well-known method that was used throughout the eastern Mediterranean and the Levant (Fig. 5).

These were essentially pre-fabricated channels that conducted the flow of water from springs or other water sources across open land or through settlement centers into water storage structures. The Nabataean conduit blocks are generally more neatly carved than their Bronze Age predecessors, but in terms of design and function, they are identical.¹⁰

9 Oleson 2000, 184–205; Oleson 2001, 467.

10 Oleson 2001, 608–610.

An alternative to the open earth channel or the open stone channel was the terracotta pipe, specially designed with male and female terminations to allow a tight-fitting conduit. Pipes were used from the Late Bronze Age onward where a closed flow was needed, as in removing sewage, protecting water quality, conducting water below ground level, or providing a pressurized head.¹¹ Pipelines appear at many Nabataean sites, notably Petra and Hawara, although they had the disadvantage of becoming easily clogged by debris or water-deposited calcium carbonate.

Other aspects of Nabataean hydraulic technology can be traced to developments in the Hellenistic Aegean. It is likely, for example, that Nabataean engineers or military personnel borrowed the idea of long-distance terracotta pipelines from an outside source, and applied specific principles to the conduits that brought spring water to Petra. Possible nearby models include the pipeline built in the early first century BC to serve the Hasmonean and Herodian Palace complexes at Jericho and Kypros, but these pipelines were buried, small in scale, and not easily seen. They were themselves most likely modeled on the long-distance terracotta pipelines built to serve the citadel of Pergamon in the third century BC. Since the Pergamon pipeline climbed the slope above ground, Nabataean merchants or mercenaries in the area could easily have noted the impressive hydraulic installation.¹²

A particularly striking example of Hellenistic techniques adopted by the Nabataeans is the built or rock-cut cistern roofed with slabs carried on cross-arches, which the Nabataeans adopted enthusiastically sometime in the first century BC. Philon of Byzantium describes this roofing technique in the third century BC in the context of military architecture, and sometime afterwards a clever engineer applied the system to roofing rectangular cisterns on the treeless, arid island trade center of Delos (Fig. 6).¹³

The technique is actually quite rare for cisterns elsewhere in the Hellenistic world, although it had the advantage of allowing roofing without the use of long timbers as supports. This was an obvious advantage for applications both on waterless Aegean islands and in the deserts of Nabataea. Nabataean merchants trading around the Aegean in the first century BC probably saw the design while visiting Delos and borrowed it for both cistern and house architecture at Petra. The design remained in use in the region through the early modern period for roofing both types of structures.

Are there any important methods of water supply already known in the Eastern Mediterranean in the pre-Nabataean period that the Nabataeans did not adopt? The only one that stands out due to its later popularity is the *qanat* system. This involves the

11 Jansen 2000, 104–110.

12 Garbrecht 1987; Netzer, Laureys-Chachy, and Meshorer 2001, 27, 31, 33; Meshel and Amit 2002; Oleson 2010, 489–490. For the presence of

Nabataeans in the Mediterranean world see Roche 1996.

13 Philon, *Mechanike Syntaxis*, pl. 87. 11–18; Oleson 2010, 481–487.



Fig. 6 Theater cistern, Delos, 3rd century BC.

tapping of a water source below ground by means of an excavated shaft, then digging a tunnel at a carefully regulated slope below a downward sloping ground surface, until the tunnel meets the surface and flows into the open to its destination. The surface indication of a *qanat* is a series of shafts that were used to plot the direction and depth of the channel, to remove the spoil from digging the tunnel – which forms characteristic mounds around the shaft openings – and to allow periodic access for maintenance.¹⁴ This technique probably first appeared somewhere in the area of Persia or eastern Anatolia in the early first millennium BC, and it seems to have arrived in the Levant by the Late Roman or Byzantine period. In my opinion, *qanats* only became common in the region in the Early Islamic period. Although dating a *qanat* is difficult, none so far can be connected with a documented Nabataean context. There are two *qanat* sites in the southern Nabataean homeland; the one at Yotvata is probably Early Islamic and the extensive *qanat* systems between Udhruh and Tahuna are Byzantine or Early Islamic in date. There are eight *qanat* sites in northern Jordan, some of which originated in the late Roman period, but with significant Early Islamic intervention. This technique was not taken up by Nabataean engineers in Arabia Petraea simply because the topography and hydrology usually did not allow it. In the north, it may not have been used during the Nabataean period because the other systems we have reviewed were sufficient.

From this repertoire of designs, or – as historians of technology call it – this technological shelf, Nabataean engineers developed a suite of techniques and materials appropriate for urban water-supply systems and rural run-off agriculture in the regions under their control. That this suite of designs seems so characteristically Nabataean results from the enthusiasm with which their engineers applied the various borrowed designs

¹⁴ Goblot 1979; Lightfoot 1997; Abudana and Twaissi 2010; Oleson 2010, 447.



Fig. 7 Aqueduct channel in the Siq, Petra.

to a uniquely arid and stony landscape in Arabia Petraea and the Hejaz, with transformative results. The dry environment and low population have also fostered remarkable preservation of the structural remains.

How does Hawara, ancient Humayma, fit into this system? Does it closely reflect developments at Petra, the central place of Nabataean culture, or did the inhabitants of Hawara develop their own strategy and techniques for water supply? Petra and Hawara are good test sites for the relationship between the cultural capital and a rural offshoot, since the water-supply systems at both have been thoroughly studied and published. We can then have a look at the more distant Nabataean settlements in the Hejaz and Negev. We have to examine Petra first.

By the mid-first century BC, and possibly more than a century earlier, the inhabitants of Petra enjoyed a sophisticated and adaptable water-supply system.¹⁵ The regional springs were harnessed to supply at least five separate conduits or pipelines, following a variety of routes, using a variety of techniques, and supplying drinking water to various parts of the settlement (Fig. 7).

The multiplicity of channels and routes reflects both the number of sources and the number of areas supplied, but this approach also provided redundancy in the event of renovations, natural disaster, or enemy action. In addition, there were numerous large and small cisterns in and around Petra filled by run-off water. These served a variety of ongoing public and private functions but also supplied back up in the event of the disruption of the aqueducts. Some of these cisterns were formed by blocking a large crevice or small wadi with a substantial barrier wall in order to retain a pool of run-off water. This type of arrangement saved most of the effort of excavating an entire cistern tank.

¹⁵ Bellwald 2008; al-Muheisen 2009, 31–129; Oleson 2010, 417–446.

The Nabataeans occasionally built diversion dams, as at the entrance to the Siq. Another type of blocking wall was apparently unique to Petra. Several dozen small dams block watercourses that drain into the Siq, the narrow passageway into Petra from the east, but they do not retain the water for use. There are discharge openings at the base of these dams that allow the water to run out slowly. In this way the small dams *detain* the water, rather than *retaining* it, preventing the sudden large rush of run-off that would fill the Siq and endanger people and property.¹⁶ This unique feature, now in use in many modern water-control systems, was produced by the special topography of Petra and local patterns of precipitation. Finally, the landscape in and around Petra was transformed by hundreds of terraces and wadi barriers that enhanced local agricultural productivity by holding back both soil and water.

How does this sophisticated and successful hydraulic technology relate to that found at Hawara? The very concept of a long-distance conduit fed by a spring, as seen at Petra, undoubtedly provided both the inspiration and the engineering skills that contributed to the construction of the Hawara aqueduct system sometime in the first century BC (Fig. 8).¹⁷

The same aqueduct technology was applied at both sites, with the exception of the long-distance terracotta pipelines, which were present at Petra but absent at Hawara.¹⁸ While short local pipelines were used within the settlement of Hawara, some of them apparently pressurized, they do not appear outside the settlement center. The much longer distances to be travelled, the lower average slope, and the lower output of the available springs were probably all factors that made use of a long-distance pipeline impractical. It is possible, however, that the occasional use of pipes within stone gutter blocks at Petra inspired the use of inverted roof tiles in the gutter blocks of the Jammam aqueduct in the fourth century AD, perhaps after the earthquake of 363.¹⁹ This curious and unparalleled modification, which involved the recycling of approximately 18 000 terracotta cover tiles taken from structures in the Roman fort at Hawara, probably was meant to solve a supply problem caused either by the settling of the foundations of the aqueduct, or a substantial decrease in the water flow from the springs (Fig. 9). The use of tiles may also have helped solve the problem of the build-up of sinter, calcium-carbonate deposits, in the aqueduct channel, since the tiles could be replaced or cleaned periodically without dismantling the aqueduct structure.

Although the Hawara aqueduct conduits were cut into the bedrock where that was possible, about 95 percent of the course was built of stone gutter blocks.²⁰

16 Bellwald 2008, 67–69; Bellwald and Ruben 2003, 71–76; Oleson 2010, 421–422.

17 Oleson 2010, 74–115, 386–394.

18 Oleson 2010, 181–187, 255–288, 330–331, 394–396.

19 Oleson 2010, 102–107, 112–115, 328–330.

20 Oleson 2010, 74–115.



Fig. 8 Nabataean aqueduct channel to Hawara.

Gutter blocks of the same design appear where necessary in the Petra system, but the main channels were often slightly larger than at Hawara, to accommodate the greater flow of the springs. In all the cases where the capacity of the conduits or pipelines serving Petra has been calculated, the potential maximum flow seems far in excess of the probable available spring flow. The calculated capacity of the conduits in the Siq alone (208 cum/hr), for example, is 34 times the recent discharge of the 'Ain Musa. The same disparity was noted for the Hawara aqueduct system as well (2.2–19.6 cum/hr), although only at a factor of 4.5.²¹ Since it is unlikely that either spring was correspondingly more abundant in antiquity, several technical explanations for this over-building are possible.

21 Oleson 2010, 365–368, 434–435.



Fig. 9 Nabataean aqueduct with inverted roof tiles added, Hawara.

First, the excess capacity gave the engineers greater leeway for errors in leveling and calculation of gradient when dealing with constantly changing slopes; a larger channel area made it less likely that poor leveling would cause an overflow of water that would damage the aqueduct structure. Alternatively, the excess capacity could have been meant to compensate for the formation of calcium carbonate deposits in the channels and pipes over the decades. Sinter seems to have been removed regularly from the Hawara conduits, since the deposits surviving in the conduits usually show only four to 10 annual growth rings, and chunks of discarded sinter are found there and along the course of the aqueduct. It was more difficult to clear pipes, and one pipeline in the Siq at Petra finally became so clogged with sinter that the pipes were broken open to allow unconfined channel flow.²²

In the 'Ain Musa system, it is likely that a distribution basin at the Zurraba reservoir allowed the flow from the spring to be directed to any one of the three outflow conduits as special needs arose in various parts of the city. Diversion of the entire spring discharge to a single channel, naturally required careful attention to capacity. Intentional over-engineering by individuals uncertain about flow rates, slopes, and levels is probably the most likely solution. Roman engineers, such as Frontinus, often took the same precautions in their calculations of water flow in the aqueducts.²³

There are other parallels between the Petra and Hawara aqueduct systems.²⁴ For example, both make use of occasional settling tanks within the flow regime to remove sand and silt. Both systems also provided draw tanks or drinking tanks isolated from the flow by short branch lines. Large stone basins with multiple exits and sluice gates allowing the diversion of water into various subsidiary channels have been found at both

22 Bellwald and Ruben 2003, 58, 87–90.

24 Oleson 2010, 444–446.

23 Hodge 1992, 215–245.



Fig. 10 Nabataean pool fed by aqueduct, Hawara.

sites. Both systems also fed reservoirs or pools that made the water directly available or serviced local pipe systems. The aqueduct system at Hawara discharged its water into a large shallow pool (27.6×17 m, depth 1.34 m) with a capacity of 629 cubic meters (Fig. 10).

The overflow water then spilled into a downstream conduit that supplied a bath building and possibly some cisterns in the town center. The pool was designed to display, rather than to store, the water or to make it accessible. It seems very likely that the Hawara pool was modeled on the Garden Pool complex in Petra, which was the centerpiece of a garden complex, a Near Eastern *paradeisos*. There was even an island in the Petra pool for banquets.²⁵ This comparison, however, has the remarkable implication that the major motive for the construction of the 27 km long Hawara aqueduct was royal or cultural prestige, meant as a dramatic proof of the Nabataean ability to control the desert. The intended audience may have been the caravans travelling the King's Highway, particularly those heading north through Hawara towards Petra. Many of the monuments in the Siq were also meant to impress visitors arriving by that entrance: the arched entrance, water basins, betyls, inscriptions, bas-reliefs of camel caravans, and the spectacular al-Khazneh tomb facade. Once inside the city, visitors might have gaped at the waterfalls at the termination of the 'Ain Brak and North Khubtha conduits, and at the *paradeisos* associated with the Garden Pool. Although compromised in quality, the overflow from both the Petra Garden Pool and the Hawara aqueduct pools was suitable for baths, industrial purposes, and agriculture.

The basic technology of the reservoirs and cisterns at Hawara also resembles the equivalent structures at Petra. At both sites most cisterns were cut down into a leveled rock surface and provided with slab roofs carried on cross arches (Fig. 11).

25 Oleson 2010, 181–187, 381–383, 439–443.



Fig. 11 Nabataean arch-roofed cistern, Hawara.

One disparity is that only one cistern and one reservoir at Hawara were provided with stairs into the pool to facilitate periodic cleaning, a feature that was common at Petra. It is possible that the settling basins commonly associated with cistern intakes at Hawara represent a local practice that made frequent cleaning less urgent. Settling basins were only rarely associated with cisterns at Petra.

A more striking anomaly at Hawara is the appearance in the settlement center of cylindrical cisterns built of blocks. In the Hawara center, cisterns and reservoirs had to be built of stone blocks rather than cut into the rock, because the bedrock was out of reach beneath the surface soil. It is no particular surprise to see the usual rectangular design constructed entirely of blocks. What is surprising is the appearance of seven built domestic cisterns with the typical arch supported roof, but with a cylindrical form (Fig. 12).²⁶

I have found no close parallels for this design in Nabataea or anywhere else in the contemporary Mediterranean world.²⁷ The design certainly makes sense, since the cylindrical shape not only provides more volume in proportion to the amount of masonry than rectangular plans, but it is also easier to waterproof and is better able to resist pressure from the surrounding soil. Did an innovative Nabataean engineer responding to the local situation possibly introduce the design to solve problems at Hawara? If this is the case, these cisterns provide striking evidence of the adaptability and sophistication of Nabataean hydraulic engineers, and their willingness to deviate from accepted designs. On the other hand, the fact that this design did not spread to other Nabataean

26 Oleson 2010, 199–202, 206–213, 377–378.

27 Bruneau and Bordreuil 1982, 499–502, record a circular well at Delos built of dry stone masonry, with three transverse arches that support a roof like a truncated cone. The design of this structure, how-

ever, is quite different from that of the arch-roofed cisterns at Humayma, and it is not a cistern. The adjacent stairwell suggests that it might have served as a ritual bath (*miqueb*) for the nearby synagogue. I owe this reference to Monika Trümper.

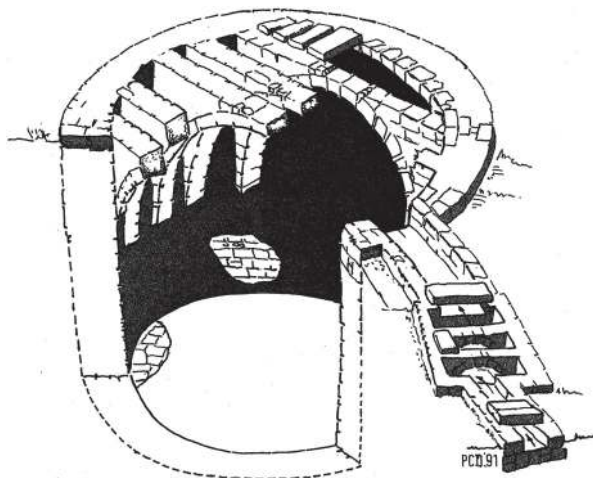


Fig. 12 Cylindrical arch-roofed cistern, Hawara, reconstruction.

sites may indicate that this engineer only worked locally, and the exchange of technical information was limited.

Another anomaly at Hawara is the rarity of agricultural terraces and wadi barriers in comparison with the hundreds seen at Petra.²⁸ The best soil around Hawara is found in the two depressions north and south of the settlement center, below the bedrock jebels, but very few traces of ancient wadi barriers survive there. Perhaps the flow of water in these wadis was either too violent for earth barriers to survive, or too intermittent for earth barriers to be of use for agriculture. Agriculture was practiced around Hawara, but, if the recent Bedouin practices preserve the ancient ones, near the foot of sandstone ridges or jebels that provided reliable and manageable catchments. The fields probably were furnished in antiquity, as today, with earthen barrier walls and conduits rather than with constructions of stone. Earthen features naturally were more likely to disappear over time, but Nabataean examples have survived here and there around Petra and at et-Telah in the Arabah.²⁹

There were at least three retention dams on the outskirts of Hawara, designed to hold back large pools of run-off water (Fig. 13).³⁰ The water would have been of low quality and probably used to water animals. This type of large open pool retained by a barrier wall does not appear at Petra, either because spring water sources were available, or because of the generally steeper topography.

There is a striking contrast between the agricultural practices at Hawara and those in the wadis around the Nabataean through Byzantine mining settlement of Phaino, 35 km

28 Oleson 2010, 161–169, 370–372.

29 Oleson 2010, 448–452.

30 Oleson 2010, 155–161, 372–373.



Fig. 13 Nabataean dam,
Hawara.

northwest of Petra in the Wadi Arabah. Although the function of the settlement was very different from that of Hawara, and much of the water supply in the Byzantine period was intended for use in processing ore, there are some similarities in topography and in soil and water resources. A recent survey catalogued a few structures similar in function to those at Hawara, but later in date and following the Roman design traditions: an aqueduct, reservoirs, a few cisterns, and two dams.³¹ The most prominent surviving remains of the water-supply system of Phaino are the numerous field boundaries built of water worn boulders, barrier walls with spillways, and earthen, stone framed water conduits built on and just above the wide, braided plane of the Wadi Faynan. Barrier walls diverted and guided the flowing water and delayed it so it could soak into the soil. The survey recognized 85 simple field systems, 10 complex field systems, and 6

31 Barker, Gilbertson, and Mattingly 2007.



Fig. 14 Aqueduct channel, Ramm.

side terraces. An area of at least 253 ha was prepared for agriculture in this manner, beginning in the Nabataean period. This irrigation system illustrates techniques that could have been applied at Hawara to make use of the braided flow in the wadis that pass by the site, but which apparently were not.

The well-known temple of Allat at Iram, modern Ramm, was built on a slope of scree at the foot of the precipitous cliffs characteristic of Wadi Ramm. The spring that served the site is tucked back into a recess in the west wall of the main wadi, framed by smaller wadis that climb into the cliffs to the north and south. Hawara lies 43 km to the north, but otherwise there were no Nabataean settlements of any size in the Hisma. The precise character of the sanctuary and settlement is still not entirely clear, but the water-supply system shows some striking parallels with that serving Hawara.³² The design of the spring-fed aqueduct is identical, as is the use of several branch lines to supplement

the main conduit, and the conduction of the water to a pool or reservoir (Fig. 14).

There were numerous arch-roofed cisterns and small dams in the region, as around Hawara, providing privately owned water. Although no one seems to have noticed, the modest Nabataean dam at al-Kharaza near Jebel Ratama, between Wadi Ramm and Hawara, may be the earliest well-documented vertical wall dam with an arched plan – a brilliantly innovative design that continues to be used throughout the world today.³³ This structure is also remarkable due to the presence of an inscription that provides both the owner's name and the date of construction: "Belonging to Seba, son of Eleh [this dam; J. O.] was prepared the year forty-one of Aretas [AD 32; J. O.], king of the Nabataeans, lover of his people."³⁴ Could this structure be another example of the innovative genius of the Nabataean engineer who designed the cylindrical cisterns at Hawara? Given the proximity of Hawara and Ramm, there were undoubtedly social, religious, and political bonds between them. In fact, Wadi Ramm may be the site of the oracular shrine referred to in the foundation story of Hawara, the oracle that told Obodas to "seek a place called 'white'".³⁵ Hydraulic engineers probably moved freely among Petra, Hawara, Ramm, and rest of the Hisma.

Although Hegra, modern Meda'in Saleh, lies 400 km south of Hawara, the two sites were connected by an active trade route. The topography of the sites is similar, and the amount of precipitation is approximately the same: 50–80 mm. Some parts of the site were served by rock-cut conduits with settling tanks, collecting run-off water for cisterns, but there are far fewer rock-cut cisterns at Hegra than at Hawara or Petra. Instead, the presence of ground water at a depth of only 18 m apparently fostered a water-supply system dependent on wells, which are not seen at Petra or Hawara.³⁶ The wells are very wide, up to seven meters in diameter, and seem to have served as a type of cistern fed by the percolation of ground water rather than by run-off.

The early stages of the Nabataean occupation of the Negev remain obscure, but the Nabataeans seem to have established trade routes across the region to emporia at ancient Gaza and Pelusium by the late fourth century BC. These routes attracted watchtowers and settlements possibly as early as the second half of the third century BC. Incense and other high value commodities imported from the Arabian peninsula and the Indian sub-continent were carried along this 'incense road,' and they contributed to the development of six main Nabataean settlement centers that by the Byzantine period may have had a total population of 20 000: Oboda, Sobata, Nessana, Mampsis, Elusa,

32 Oleson 2010, 452–456.

33 Farès-Drapeau and Zayadine 2001, 207–213; Oleson 2010, 456. A Roman dam with arch plan at Glanum in Southern France may have been constructed in the first century BC, but its design can no longer be

documented, and the date is approximate; Hodge 1992, 81.

34 Farès-Drapeau and Zayadine 2001, 212–213.

35 Oleson 2010, 50–53.

36 Nehmé et al. 2006.

and Ruheiba. The average annual precipitation around these settlements varies from 100–300 mm. To support the human and animal populations in this arid environment, sophisticated water-supply systems were developed that provide interesting parallels and contrasts with the Hawara system.³⁷

There are several problems in evaluating the relevance of the Negev archaeological evidence to the systems at Hawara and Petra. Most important is the question of chronology. The region remained well populated and prosperous through the seventh century AD, and it is often not clear to which period various water-supply structures such as wadi barriers belong.³⁸ Although the designs are often compatible with a first-century BC or AD Nabataean origin, it is very likely that many of the water-supply systems visible in the region today date to the Byzantine or early Islamic period. At Hawara, in contrast, the Nabataean aqueduct continued to serve the settlement well into the Byzantine period, and none of the five Byzantine churches built there were provided with a cistern. In the Negev, by contrast, nearly all the churches were provided with one or more cisterns fed by run-off from the roof and adjacent courtyard.

A second problem is that, although the Negev is arid, in many areas the soil is generally more extensive and better in quality than that around Hawara or the rest of Arabia Petraea. Furthermore, there are varying ways to calculate the amount of useable run-off generated by the hills, which are earth rather than bedrock.³⁹ As a consequence, even though the ancient cities of the Negev are often cited as close cousins to the Nabataean settlements of Arabia Petraea, the parallels are frequently only approximate and the chronologies are very different.

As in Arabia Petraea, both rural and ‘urban’ cisterns were an important part of the water-supply system in the Negev. Due to the regional geology, however, the most common design in the Negev was a regular or irregular tank carved in soft chalk bedrock, with a natural roof formed by a stratum of limestone. This technique was easier and generally more durable than building roofs over a rock-cut tank. The slab roof supported by cross-arches on block built walls occasionally appears on cisterns in the Negev, and it was ubiquitous for roofing houses.⁴⁰ The first-century cistern at Bor Nekarot on the ‘Incense Road’ looks particularly similar to the type seen at Hawara and Petra, perhaps because of its early date. Where cisterns are associated with houses in the Negev, they usually appear beneath the courtyard, as at Hawara, but they seldom have arch-supported roofs.

As at Petra and Hawara, dams were occasionally employed to retain water where the topographical circumstances allowed. A particularly impressive series of Nabataean dams survives at Mampsis.⁴¹

37 Oleson 2010, 460–478.

38 Shereshevski 1991.

39 Evenari, Shanan, and Tadmor 1982, 95–147,

179–219.

40 Oleson 2010, 464, 477–478.

41 Oleson 2010, 470–474.



Fig. 15 Stone piles, Sobata.

Reservoirs, usually unroofed because of their size, formed the largest part of the Negev water systems, occasionally built of blocks, but more often cut into the bedrock. Due to their exposure to the sun and wind-blown debris, the quality of the water was likely to have usually been poor. The water was collected from precipitation run-off, lifted from wells, carried in from dammed pools by porters or draft animals, and, in only one case, at Sobata, filled at least in part by an earthen aqueduct that carried in run-off from a nearby catchment. At Hawara, Petra, and Wadi Ramm, in contrast, the largest reservoirs were filled entirely by spring-fed aqueducts. In fact, the only long aqueduct in the Negev with engineering features, such as a built viaduct and distribution tanks, was the dirt channel at Sobata. Nothing has been found that resembles the ten to twenty kilometer long channels built of stone conduit blocks found in Arabia Petraea. Water channels made of stone gutter blocks very similar to those used at Hawara, can be seen in all the Negev settlements, but only to carry water short distances within a house, along a street, or between a reservoir and a bath. Stone distribution basins also appear in these same circumstances. Springs existed in the Negev, but inconveniently deep or distant from the site of the larger Nabataean settlements. Wells 40 to 70 m deep at Oboda, Ruheiba, and Nessana represent the typical regional solution to this problem. Wells were of no use at Petra or Hawara, where groundwater was either too deep or non-existent.⁴²

Despite the similarities in climate and cultural development, and despite a few superficial similarities, the water-supply systems serving the ancient settlements in the Negev are actually quite different from those at Petra and Hawara. Above all, the creation of fields at Oboda and Sobata through the terracing of wadis and the piling up of surface stones in regular patterns on hillsides to enhance run-off did not occur at Petra

(Fig. 15).

There are in fact stone piles on three slopes at Hawara, but not associated with fields suitable for agriculture. They may represent a failed experiment, or they may have had some sort of ceremonial or religious significance.⁴³ There may simply have been enough bedrock slopes in the vicinity of Hawara suitable for channeling water to agricultural fields that it was not necessary to enhance the run-off from a few slopes with rocky soil. The intensive agriculture in the Negev, particularly the bulk production of wine for export in the Byzantine period, was an extension of the needs of the adjacent Mediterranean economy. Arabia Petraea was too distant to have served this trade in bulk goods, and food production very likely was intended for local consumption.

Judging from its foundation story, the nearly exclusive use of ceramics from Petra, and the character of the water-supply system, Hawara was a political, cultural, and technological colony of Petra. Petra provides the closest and earliest parallels for all aspects of the water-supply system, although the system at Petra was more complex and monumental. The neighboring water-supply system at Ramm constitutes the one other close parallel to the arrangements at Hawara. The water-supply systems at the other sites of Nabataean origin differ from one another, since Nabataean engineers naturally responded to local variations in climate, topography, geology, and population. There were also differences in chronology, and possibly in engineering traditions as well.

There was no single methodology for supplying Nabataean settlements with water. There was an established repertoire of techniques, probably carried from place to place by engineers. It is unlikely, however, that any Nabataean Vitruvius or Frontinus composed a written compendium of engineering knowledge. Nevertheless, the cylindrical, arch-roofed cisterns in the center of Hawara are a testimony to the activity of at least one local genius, along with the nearby arch dam at al-Kharaza.

What does all this mean for the concept of Petra as a central place with an admired and imitated technological shelf? It seems likely that hydraulic engineers who worked at Petra also worked at or had some influence on the engineers who worked at Hawara and Ramm; so, here we see the projection of a central technology in a similar environment. Farther afield, however, the systems seem very different, in tune with varied local circumstances. Even allowing for their probable later chronology, the Negev settlements used water-supply strategies and designs different from those seen in the Petra region. The fall-off of central influence with distance did not, of course, imply a decline in effectiveness of the systems. There is much we still do not know about the processes of Nabataean technology. At Hawara and near Ramm, we find the apparently unique technological

42 Oleson 2010, 460–478.

43 Oleson 2010, 167–169. Kennedy 2012, 497–498, reports the presence of ca. 2000 similar cairns at a site

in northeast Jordan that have no apparent practical purpose and thus might have served some ceremonial need.

footprints of the strikingly innovative hydraulic engineer or engineers who created a new cylindrical cistern and an arch-walled dam. Other issues that remain unsolved are the sources of funding, planning procedures, surveying techniques, the composition and organization of the work teams, the local administration of water from springs, and the ownership of run-off flow from natural or enhanced catchments. We still need to throw light on the details of the hydraulic technology for which the Nabataeans were so famous in antiquity.

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JOHN PETER OLESON

an archaeologist and Classics scholar, was Distinguished Professor in the Department of Greek and Roman Studies at the University of Victoria, Canada, where he taught from 1976 to 2015. He is a fellow of the Royal Society of Canada, has been a Killam research fellow, and in 2010 he was awarded the Pierre Chauveau Medal by the Royal Society of Canada for his “distinguished contribution to knowledge in the humanities.” Professor Oleson’s research focuses on ancient technology, particularly ships, harbors, and water-supply systems. He has directed archaeological excavations underwater and on land at a number of sites around the Mediterranean. He has published 12 books and more than 95 articles concerning ancient technology, marine archaeology, the Nabataeans, and the Roman Near East.

Prof. Dr. John Peter Oleson
Department of Greek and Roman Studies
University of Victoria
Box 3045
Victoria B.C. V8W3P4, Canada
E-Mail: jpoleson@uvic.ca
Web: <https://web.uvic.ca/~jpoleson/>