Nabatean Water Supply

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Our comprehension of Nabatean society, economy and settlement strategies depends on an understanding of the way the Nabateans dealt with problems of water supply. Hydraulic technology and agricultural practices varied across time and space within the Nabatean kingdom. In much of the northern territory or at higher altitudes, as near Wadi Musa or around Amman, annual precipitation was sufficient to allow dry farming without extensive human intervention. But elsewhere, as at Petra or around ancient Hawara (modern Humayma), all crops required direct irrigation or the harvesting of local run-off water. In the Negev, the productivity of a very marginal agricultural environment was enhanced by the same techniques. The provision of water for humans and domestic animals depended everywhere on some combination of cisterns, wells, springs and aqueducts, depending on local topography and water resources. Nabatean hydraulic technology was based in part on regimes inherited from Bronze Age and Iron Age predecessors, and on some Hellenistic Greek techniques, but the final systems have an unmistakably local flavor. Local topography, geology and hydrology were the most important factors, along with size of population, character of the economic system, choice of crops and domestic animals, and political and cultural forces. Unfortunately, we still know little about many issues associated with Nabatean water supply, such as planning, sources of funding, design and construction procedures, local administration or allocation of water supplies, ownership of run-off potential or of springs, responses to variation in precipitation, run-off or spring flow, and religious beliefs or rituals surrounding consumption.

The early Nabateans were wandering pastoralists who lived largely off the land and were sustained by run-off water stored in plastered cisterns cut in the bedrock. There were no rivers in Edom, the arid Nabatean heartland, or the Negev, and the infrequent springs seldom flowed in significant volume. Except for the western Negev and a few small areas around the peaks of the mountains towering over the Wadi Arava, precipitation is less than 100 mm per year, and for most of Edom it ranges between 25 and 75 mm. Despite these drawbacks, the dramatically beautiful desert landscape supported a significant human population and its animals. By the mid-1st century BCE significant sedentarization had taken place, associated with a developed monarchy, permanent settlements with stone houses, agriculture (including fruit trees and vineyards), more diverse animal herds (including cattle), and luxurious possessions indicative of sophisticated manufacture and long-distance trade. This settled life depended both on the more intensive application of traditional Iron Age water-harvesting techniques and on the introduction of new techniques from the Hellenistic world.

Early Techniques of Water Management in the Nabatean Cultural Region

In antiquity as today, water management involved collection, transport and storage. For the extensive desert areas of the Nabatean kingdom, collection of water was the most important consideration. Although meager and localized, precipitation occurs predictably in the desert areas of the Negev and Southern Jordan. In this landscape rainfall runs off the surface largely unimpeded and collects in short-lived torrents that fill the wadis, so survival depends on the knowledge of how to harvest it. The obvious techniques had been discovered by the Late Bronze Age and put to work throughout the Near East. The terracing of hillsides is the most visible of these early methods: heavy stone walls built across the slope of a hill to capture both run-off water and the particles of earth it carried. In a variation of this technique, walls were built across wadis that carried the occasional run-off from a catchment area. Although vulnerable to damage, walls and fields in such a location were more likely to receive significant run-off and alluvial soil than terraces on the slopes above.

In contrast to the wadi barrier that merely slowed down water flow, the containment dam was designed to trap and hold a pool of water. Despite the engineering problems involved, this type of dam appeared in arid regions of the Near East by the Early Bronze Age at Jawa, the Middle Bronze Age at Tell el-Handaquq, and in the 8th century BCE at Khirbet el-Maqari. Since the large pools were subject to evaporation, pollution by bird and animal droppings, and infestation by plant, insect and animal life, plaster-lined, rock-cut cisterns were the standard method for storing water for human use. Run-off was conducted to them in channels, and the captured water was protected from evaporation and pollution. The Iron Age Edomites, who gave their name to the Nabatean heartland, cut large numbers of bottle-shaped cisterns 3–4 m wide in the sandstone bedrock at the habitation sites of Umm Biyara above Petra and es-Sil' near Buseirah.

The infrequent springs and seepages of Edom, for the most part issuing from the strata exposed by the al-Shera escarpment or the Dead Sea rift, were always a focus for human activity. At 'Ain al-Jammam and nearby 'Ain Abu an-Nusur north of Hawara, occupation dates from the Pre-Pottery Neolithic B. As pools became muddy from frequent use, they were cleared out, lined with stone, and earthen channels or stone gutter blocks were provided to carry the overflow to adjacent artificial access basins or fields. The *qattar*, or site where water seeps from an exposed aquifer, was exploited by trimming back the original face and by cutting runnels and basins to concentrate and collect the water. The numerous pictographs and inscriptions carved in the bedrock around seeps, springs and natural basins at Muqawwar and other sites in the Hisma highlight the high level of human and faunal activity such water sources attracted. The Old Testament and other early sources mention the use of wells at sites later occupied by Nabateans, such as Rehovot (Genesis 26: 22) and Be'er Sheva ("Well of Seven" or "Well of Oath", Genesis 21: 28–31, 26: 33).

Water channels were less well developed among the pre-Nabatean cultures. Stone conduit blocks with a longitudinal channel were sometimes used for local distribution of spring water, but extensive aqueduct systems did not exist in the area of the Nabatean kingdom prior to the 1st or 2nd centuries BCE.

Nabatean Water-Supply Techniques and Systems

The simple techniques for water supply described above were utilized by the early Nabateans as they established themselves in the region around Petra after the 5th century BCE. In the course of the 2nd and 1st centuries BCE, new structures and management techniques evolved in response to territorial acquisition, growing population, the organization of caravan routes, and the shift to a more settled, agricultural economy. The 1st century BCE, a period of particularly rapid innovation in hydraulic technology, also saw the appearance of Nabatean coins, inscriptions, and Hellenized art styles.

Although few details are known, the Nabateans developed administrative systems for the crucial water supply. An inscription dated 6 BCE found at Khirbet et-Tannur mentions an individual with the title "Master of the Spring of La'ban", an official appointed to supervise water distribution at nearby 'Ain La'ban, where stone conduits can still be seen. On a higher administrative level, it has also been suggested that the titles bestowed on King Aretas IV, "He who loves his People," and on King Rabbel II, "He who brought life and deliverance to his people," originated in their enthusiastic support for agricultural development and water-supply systems. An inscription found at Petra indicates that either King Malichus II or King Rabbel II built the dam and tunnel that diverted run-off water around the Siq, and it is clear that the complex, interrelated water-control and water-supply systems that can still be traced around the large area of the ancient city were the product of careful planning, funding and administration by the elite. Structures still visible include several spring-fed aqueduct systems, numerous reservoirs, containment dams for creating pools of water, retention dams for delaying sudden flows of run-off water, run-off collection fields, *qattars*, wadi barriers and agricultural terraces. Smaller complexes of terraces, run-off fields and cisterns throughout the Nabatean kingdom were the result of individual or family initiatives. A Dedanite graffito in Wadi Ram records the efforts of two individuals who built a structure that "collected rain water at Diwah." A Nabatean inscription near a small dam at al-Kharaza in the Hisma commemorates its owner and construction date (32 CE): "Belonging to Seba, son of Eleh (this dam) was prepared in the year forty-one of Aretas, King of the Nabateans, lover of his people".

Earth or rock slopes were made into water catchments by the construction of containment walls or channels to divert water from the edges or base of a slope towards an agricultural field or cistern intake. Catchments of this type were easily developed on bedrock slopes, and around Petra and Hawara many of them still function today. The enhancement of run-off on earthen slopes, however, required more careful management and frequent maintenance. Traces of earthen conduits have survived at Oboda and Sobata in the Negev. Shallow trenches were cut across the slope and reinforced on the down-slope side with fieldstones (Fig. 84, across the hillside). These features intercepted the run-off water and channeled it at a gentle flow rate (to avoid excessive erosion) to the target field or cistern.

It was also possible to increase the run-off yield of an earthen slope. Large areas of the gravelly slopes around many of the Nabatean sites in the Negev are covered with geometric patterns formed by fieldstones collected and piled in regular heaps or lines (Fig. 85). Exposure of the soil in this way caused the soil to crust over when moistened by rain and thus fostered run-off. It has not been possible to date these features precisely. It is usually assumed they were created during the flowering of the major Nabatean settlements of the Negev in the 1st century BCE or CE, but some may date to the agricultural florescence of the Byzantine period. The ratio of the area of a catchment field to its targeted agricultural field ranged from 17:1 to 30:1, which—allowing for absorption and other losses—might multiply the local precipitation by a factor between 2 and 5. In the Nabatean territories of Jordan, catchment fields enhanced in this way are very rare because of differences in local rainfall patterns and topography in the arid south, combined with the absence of a Byzantine agricultural boom.

Another advance of the Middle Nabatean period was the application of wadi barriers to raise the water flow high enough so channels could carry it to fields just above the unpredictable wadi bed proper. This arrangement both expanded the area of watered fields and avoided the loss of soil that resulted when a particularly strong flood scoured the wadi bed. Spectacular examples survive in Wadi La'ban near Sobata and Nahal Zin near Oboda (Fig. 86).

Containment dams represent yet another approach to water harvesting. Small dams built across steep-walled gullies to form cisterns or detainment pools to slow the arrival of floodwater are common in the sandstone topography of Petra and other Nabatean settlements in southern Jordan, but large containment dams are rare. Among the largest dams in the Nabatean cultural region are three at Mampsis in the Negev, 20 m to 53 m wide, which barred the main wadi and created pools holding 10,000 cubic meters of water (Fig. 87). Their date of construction is uncertain, but an origin in the 1st or 2nd century CE is likely on historical grounds. The dam walls, built of mortared blocks, had vertical faces upstream and sloping walls downstream for buttressing. Recent rebuilding has concealed the original spillway arrangement. A smaller dam (10.7 m wide, 4.4 m thick) at Hawara was thick enough and had a narrow enough span that buttressing was unnecessary (Fig. 88). The spillway was cut in the bedrock to one side of the mortared masonry wall to avoid erosion of its fabric. Constant maintenance was necessary to keep this sort of structure functioning properly, and the pools behind the dams at Mampsis and Hawara are filled to the brim with silt and sand.

Water held behind dams or stored in cisterns had to be lifted out manually in containers and carried to its place of use. There is so far no evidence that mechanical water-lifting devices were used in the Nabatean world, although the application of the *shaduf* is very likely. This device, a simple tip-beam with a container suspended from a long stick at one end and a counterweight at the other, would have been suitable for situations such as that described by Byzantine papyri at Nessana, where cisterns and irrigation channels served an agricultural field.

Flowing spring water could be carried down-slope in aqueducts to a location more convenient for use or storage. Nabatean aqueducts, unlike Roman systems, were almost entirely ground level structures, dependent on natural slopes to provide their fall. The water was carried in a channel usually about 12 cm wide and 15 cm deep cut lengthwise into blocks of sandstone, marl or limestone 60 to 90 cm long (Fig. 89). The blocks were placed end to end, held in position by framing walls, and sealed with cover slabs to protect the water from evaporation and pollution (Fig. 90). Nabatean engineers constructed aqueducts in this way at most major springs in that portion of the kingdom east of the Wadi Arava from at least the 1st century BCE, but not in the Negev. The conduit carrying water from 'Ain Shellaleh in Wadi Rum to the adjacent sanctuary was only 1.5 km long, but the system serving Hawara was 26.5 km long. The aqueduct that carried the water from 'Ain Musa to Petra was approximately 8 km long. These conduits fed reservoirs either along their courses or at their termination. Due to the less generous springs and smaller populations, Nabatean aqueduct systems were designed to discharge a tiny fraction of the water carried by a typical Hellenistic or Roman aqueduct. The channel of the Pont de Gard near Nîmes was approximately one meter wide and deep, its flow 20,000 cubic meters per day, while the main aqueduct serving Petra had a maximum flow of no more than 500 cubic meters per day. The long conduit serving Hawara could have discharged at most 470 cubic meters per day, but probably never reached this figure.

Where necessary, Nabatean engineers supported their ground-level aqueducts with heavy support walls, viaducts, slab bridges over small gullies, channels cut across bed-rock cliffs, and—at Petra, arched bridges over gorges or run-off channels. Although the Nabatean aqueduct system at Petra incorporated terracotta pipelines here and there, particularly in the Siq, there is only one section incorporating an intentionally pressurized section: a 60-m stretch at the end of the 'Ain Brak aqueduct. This so-called "inverted siphon" was common in Hellenistic and Roman aqueduct systems and allowed them to cross deep valleys. Due to the relatively small carrying capacity of their conduits, Nabatean hydraulic engineers could lay out channels with sharp bends and down slopes unthinkable to Roman engineers. The Roman architect Vitruvius recommended a slope of 0.5 percent for an aqueduct channel, and surviving Hellenistic and Roman aqueducts typically have slopes between 0.03 and two percent. The overall slope of the aqueduct leading to Hawara is 2.5 percent, but at points where the channel descends the al-Shera escarpment, the channel slope varies from an impressive ten to an astonishing fifty percent! Although the technology is typically Nabatean, the scale of the Petra and Hawara aqueduct projects may reflect a familiarity on the part of King Aretas III—who boasted the title "Philhellene"—or King Aretas IV, with Hellenistic aqueduct systems in the eastern Mediterranean, particularly that of Pergamon.

When an aqueduct arrived at the target settlement, metering tanks—large monolithic or block-built basins provided with three or four discharge holes—divided the water up among various sub-conduits or pipelines. In this way the water was apportioned by amount or time of day among public reservoirs and cisterns, public baths, and possibly private cisterns and agricultural plots. A particularly well-preserved example, possibly Byzantine in date, appears at the end of the water conduit feeding the main cistern at Sobata. A metering tank of slightly different design was installed near the termination of the 'Ain Brak aqueduct at Petra (Fig. 91). One branch fed a large reservoir (23 x 46 m) built in the city center by Aretas IV early in the 1st century CE. Although the water was meant for use, the reservoir was provided with an island retreat and public garden, and possibly a waterfall, providing an intentionally striking spectacle of watery abundance in the centre of this desert city. The contemporary construction of a similar pool at Hawara confirms that Aretas IV was publicly showcasing royal competence in hydraulic technology. At Hawara, the continuous stream of overflow water from the reservoir was carried off in conduits and terracotta pipelines to serve a bath building, private cisterns, a shrine, and possibly small orchards and vegetable gardens south of the settlement.

The *qanat*, a subterranean conduit excavated by means of a chain of access shafts, was occasionally used in this region as an alternative to the aqueduct. Its date of introduction is uncertain and may be as late as the early Islamic period. Examples survive at Udruh (Adru-Augustopolis), southeast of Petra, and at Yotvata in the Wadi Arava.

Since aqueducts were expensive to maintain and easily disrupted, private cisterns and public reservoirs filled by run-off water remained important to Nabatean water-supply systems even alongside an aqueduct. All cisterns needed a settling tank near the intake, which allowed the debris carried by the run-off water to settle out before the water spilled over into the main tank. Reservoirs with constant flow-through did not need roofs, while cisterns with standing water did. The Iron Age bottle-shaped cistern cut into bedrock was well protected from the sun and pollution, but it had to be located where both the bedrock and the run-off catchment were suitable. Sometime in the 1st century BCE the Nabateans adopted a Hellenistic Greek technique for roofing block-built and open rock-cut cisterns without the use of timber or enormous slabs: transverse arches were built across the opening to support short, stone roofing slabs (Fig. 92). This design, probably observed by Nabatean merchants visiting Delos and other arid Aegean islands, allowed the construction of cisterns wherever they were needed and the catchment was most effective. At Hawara the two public cisterns were roofed with 16 arches carrying heavy stone slabs, well chinked and sealed with mortar, so that people and animals could move around and even over them without hazard to themselves or the precious water within. This roof design quickly became typical of virtually every Nabatean site and was also put to use in the stone houses constructed by sedentarized Nabateans, as at Petra, Oboda and Mampsis. Cisterns and houses continued to be roofed in this manner throughout the region until recent times.

In Arabia Petraea the topography and geology did not favor the use of wells, but where conditions were appropriate, the Nabateans did dig them. In the western and southern parts of the Negev, where the sandy soil made the collection of run-off water impossible, wells appear at Nessana, Elusa, and Rehovot-in-the-Negev. At Oboda a very deep well (60 m) was dug through solid rock to reach an aquifer to supplement locally available run-off water.

Conclusions

For thousands of years before and after the period of Nabatean cultural domination, the ways of life in the region encompassed by their kingdom have oscillated between the extremes of desperately poor nomadism and relatively comfortable settled life. The major accomplishment of the Nabatean culture, in both its nomadic and settled form, was its harmonious co-existence with the resources of the unforgiving desert environment. Although the Nabateans do not seem to have been exporters of food stuffs, neither do they seem to have depended significantly on imports of food.