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Water Management in Northern Jordan: The Example of Gadara Umm Qays[1]

Natural Conditions and Needs of the City

The old city of Gadara is situated on a spur high above the rivers Yarmuk and Jordan. The area is inside the 400-500 mm rainfall isohyet (winter and spring rains), which makes agriculture possible without irrigation. But it does not sustain the needs of a city of several thousand people, as a Roman Decapolis city would have been.

A Classical city with several thousand inhabitants, bath houses, fountains, nymphaeums and possibly even an artifical lake needed a constant and safe water supply.[2] The different Decapolis cities have managed their water-supply according to their setting: Philadelphia and Gerasa had been built around a river or wadi, which provided them with water, Pella was located in an area with strong springs, but cities like Capitolias and Gadara needed artificial supply for their public and private needs.

Only a few 100 m south but also 50 m below Umm Qays is a natural spring, which might have been used additionally in the same way it was used until modern times (people went there to get a supply of fresh water). The outlit of the spring has most probably moved, and was possibly closer and inside the city wall in Roman times.[3] But this spring was neither strong enough for the needs of a whole city nor would it have been possible to bring large amounts of water up into the city from a spring which is situated so far below the city.

Umm Qays is surrounded on three sides by steep slopes (towards the Jordan Valley/Lake Tiberias in the west, to the Wādī ʻArabah in the south and to the Yarmuk river in the north). This is for strategical purposes very convenient– but it is rather unfortunate for water transport. The only easy access to the site is from the east. In the next 12 km east of Umm Qays are three larger springs, but only one seemed appropriate in height and strength. Other, smaller springs were found during our research. The large spring is ʻAyn Turāb, which is situated 11.5 km east of Umm Qays in Wādī Samar and has today (when it hosts a small military camp) a waterflow of 7 l/s. But this spring would not have been enough to account for the amount of water, which was transported to Gadara.

The Gadara Water-System

Technique

Already some years ago water tunnels were found under the Ottoman village of Umm Qays (Kerner 1992: 409ff.; 1993: 369f.; Weber 1991: 127ff.). Two tunnels cross the limestone hill in order to bring water from east of the city to the west side of the hill, where the larger part of the city buildings were. They are ca. 410 and 400 m long, up to 2.50 m high (although the minimum height seems to be 1.60 m) and between 0.80 and 1.50 m wide (FIG. 1). Oil-lamp holes are cut in the walls at different heights with widely varying distances between them. The course of the channels is extremely curved and bent, which was difficult to explain, because neither geological reasons (for the course of the stone would have led straight from entrance to exit), nor technological reasons such as waterflow or inability[4] were responsible for the course. The reason lies in the combination of two well-known building techniques: At regular intervals shafts are dug down to the underground channel (qanat technique) and then the water channel is built from these shafts,[5] not straight from A to B, but from both points towards each other (FIG. 2). To make sure that both parts meet, both lines diverged in the same direction from the theoretical line and, therefore, must meet (this system is described for other tunnels like the Eupalinos-tunnel in Samos).[6] In Umm Qays it is clearly visible in the upper tunnel between E2 and E9 as well as between E9 and E10 and in the lower tunnel between KE5 and KE6 (FIG1).

In some cases the meeting-point in the middle was missed by a few metres and the tunnel course needed correction (like between E5 and E6), which can be recog-

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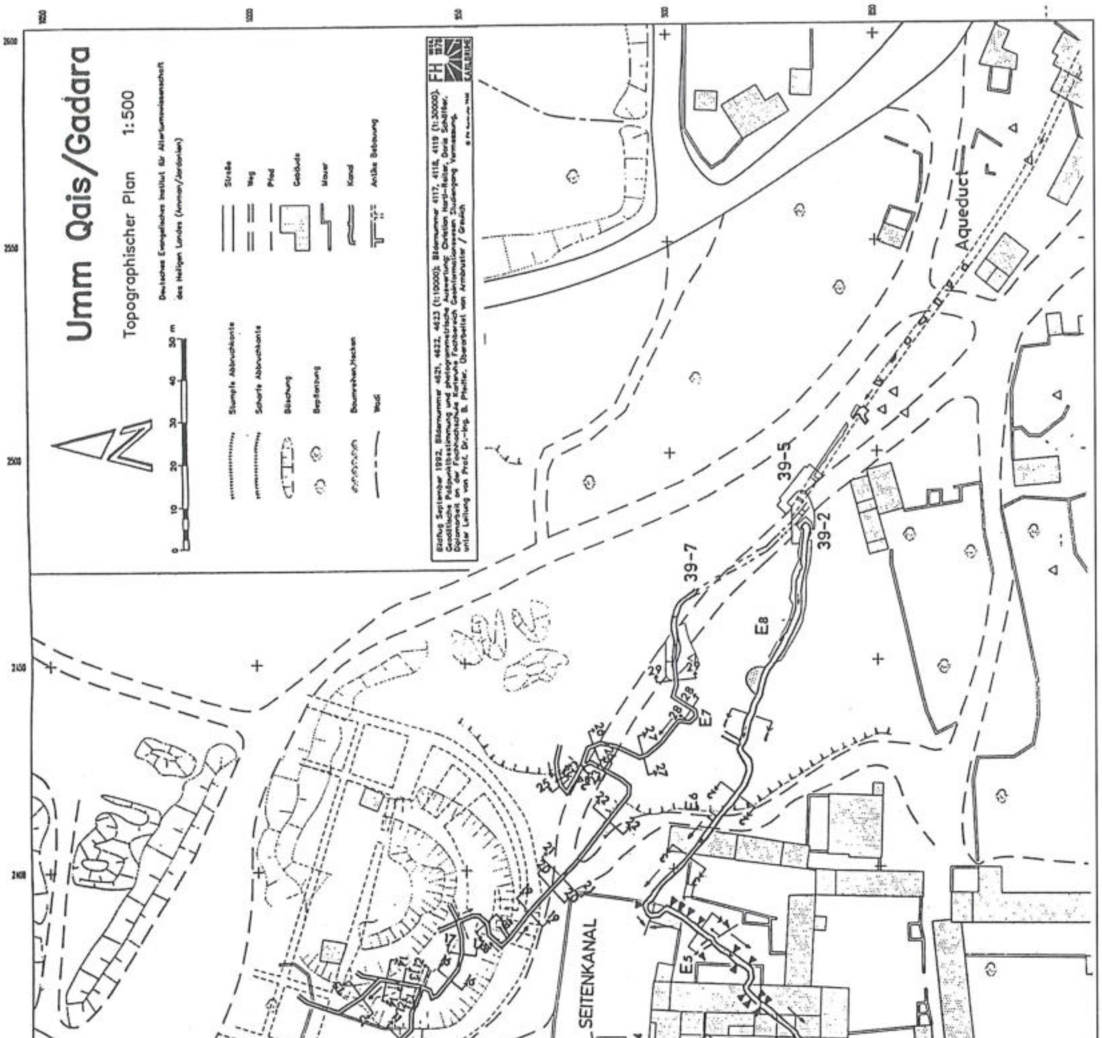
[2] We are best informed about the water-system in Rome, described by Frontinius, a Roman water commissioner.

[3] Perso. comm. A. Hoffmann, who has worked inside the city- wall area along the slope, where the spring would have been.

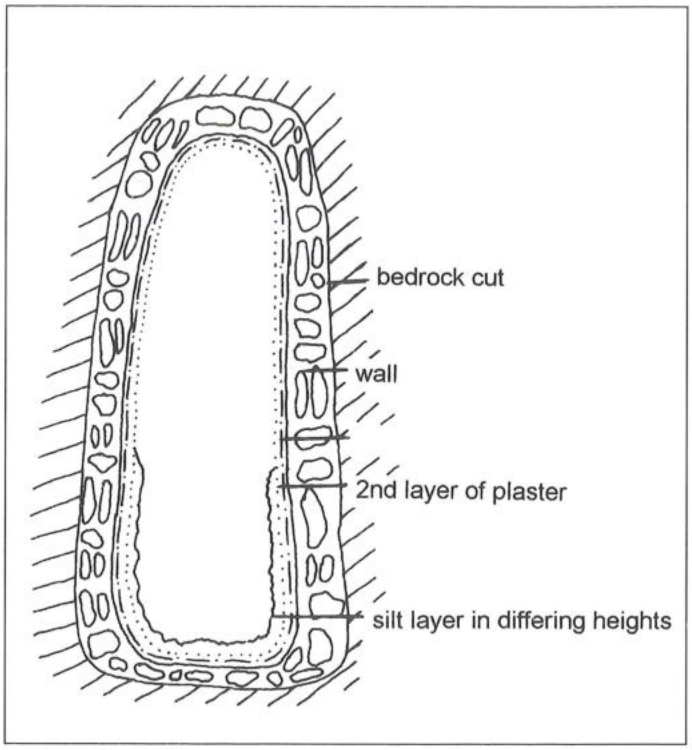
[4] Surveying and measuring instruments were available for Roman engineers (Forbes 1964: 171).

[5] This technique is called " Gegenort" in German (Fahlbusch, 1987:142). The qanat technique is well known in history, and probably developed in Urartu.

[6] Kienast 1983.



1. Plan of Gadara with both tunnels (survey and drawing: Fachhochschule Karlsruhe).



2. Sketch of tunnel construction (design: authors, drawing H.Barnes).

nized in the work-marks along the tunnel.[7] The starting points for the work are generally narrow shafts, which have steep stairs (between 50 and 60 degree) leading down from the town surface. They occur at regular intervals (ca. every 35 m) – as Vitruvius had suggested in his descriptions of tunnel – work (Vitruvius, VIII, 6.3), and, as well as having been used for the construction, might have been planned as maintenance entrances or well-shafts. These "putei" lead down to a landing above the supposed water level or to the tunnel floor.

Lower Tunnel

The older construction (channel A) is of late Hellenistic/ Early Roman origin and was built in at least three different stages. The oldest part is roughly 140m (subareas 7-10) long and has on both sides newer additions, which are slightly differently built. The point where the eastern addition meets the original tunnel is immediately recognizable (subarea 11/10), because of the rather odd angle.

The original building techniques were the following: first the tunnel is cut out from bedrock, the work starting at different entrances, then a covering is built on floor, sides, and ceiling to provide an entirely artificial surrounding for the water. This is a well-known practice mainly for Roman water tunnels like in Lyon or Pergamon.[8]

The eastern addition is very similarly built, and seems to have come in use at the same time or only a little later as the older part of the channel. The western continuation is generally less carefully done (no walling all the way around, less meticulously smoothed surfaces, i.e. the plaster sits straight on the bedrock etc.) and might have been done some time later than the older parts. It takes the water further to the west and into the Roman and later parts of the city.

The plaster consists of at least two different layers of Roman concrete *"opus signinum"*, which were able to hold water with hardly any loss (Lamprecht 1988: 141).

Several outlets from the main channels are made towards the north, all of these side-channels are smaller in diameter and have pipelines for the transport of the water.

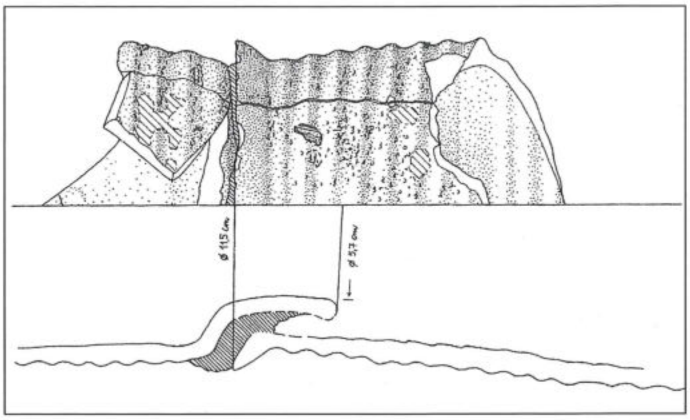
The average gradient was 8.8 % in the entire system, while it fluctuates between 8.3 and 9.1%. The waterflow needed to be controlled in order to divide water in the side-channels. The control was achieved by different means: In one case (subarea 4) the waterflow was slowed down by a weir and could flow through a complicated bent pipe (Krümmer), which was supported by an enormous basalt slab, into a northern side-channel (FIG. 3). At subarea 8/7, where the original course of the channel was later changed, the waterflow into the side-channel was diverted by several basalt blocks, which were pierced to hold a clay-pipe. Therefore it was possible to control the outflow all along the line and adjust it according to need in different parts of the city and availability of water.

While purely Hellenistic tunnels have often pipes all along the way, here pipes are only used for side divisions. The same technique is used in Caesarea (Peleg 1992). Archaic clay pipes (like in Athens, Tölle-Kastenbein 1994: 46ff.) always had openings and strongly stepped ends, the Late Hellenistic and Roman pipes were without these maintenance features and of smoother shape. The single elements were held together by a mixture of lime, ash and oil (Landels 1978: 44). Towards the end of the channel a water-chamber with three different levels controls the outflow. So-called water castles are another common feature in Classical water systems. The construction here is rather small and less complicated than the ones in Pompei or Nîmes (Fahlbusch 1987: S.159). In the water-chamber the water is divided into three different directions. The main channel continues to the north with a nearly unchanged volume, the channel floor has even a small conduit in the middle, to make sure that even the smallest amount of water can be transported. The chamber has then two higher, well-plastered levels to the east and west of the channel. On the middle level, which is badly disturbed, the water most probably flowed through pipes into a small, closed basin, built of walls, where any sediments could sink down. Then the water flowed through other pipes into a much smaller channel towards

[7] Again, this is a very common pheneomenon as it is described for Bologna (Giorgetti 1988: 182) or Saldae (Fahlbusch 1987: 152/3).

[8] The Gier-channel through the Cave du Curée has completely artificially-built walls in the bedrock . The Aksu tunnel in Pergamon is differently built but has also an artificial surrounding (Fahlbusch 1987: 151).

3a. Lower channel (A) in detail (survey FHS Karlsruhe and authors).



3b. Section of pipe-join of lower channel (drawing S.Shreydah).

the west. The highest level to the east was blocked off by a wall with six pipes, through which the water could flow. The main channel and the east channel share the middle wall in the beginning of their course. The water-chamber also has a direct entrance from above. The neccessary level of water (up to 1.60 m) in the chamber was created by damming up the water. The channel was dammed by a weir some 25 m further to the north at the western end of the channel. The weir is built of stone, very well plastered and has four pipe-holes to control the amount of water, which could flow through. The weir had four stepping-stones on the outside, which made control visits possible.

Outside the acropolis hill — after the weir— the water is further distributed in smaller channels with slightly different plaster (Wagner-Lux 1980: 160) and into pipes and lead-pipes. Further down the line even basalt pressure pipes were used (Bol 1990: Figs. 3 and 7).

The younger construction (channel or tunnel B) is built similarly to the western addition of the older channel, but has never been finished. Both constructions, older channel and younger tunnel, are cut all the way from the spring in the east. As far as we can prove, two independent lines were built all the way through the rock. But in spite of all the work, which had been invested to build channel B so far, the finishing touches – levelling the floor, equalizing and smoothing the walls, plastering floor and walls – were never done and the construction was never connected to the aqueduct. Only the first 50 m in the acropolis hill show the first step of smoothing.

Overland Tunnel and Channel

Roughly 23 km of tunnels cut inside the hills (in an area, which is 12 km as the crow flies) were found. The length is due to the fact that the tunnels follow the contour-lines along the hillsides. It is impossible to follow the course inside the hill or excavate it all the way, because the tunnels are blocked up entirely at several points. But the different entrances (horizontal or vertical to a level above the waterflow), the partly accessible shafts and the different inner linings or cross-sections show very clearly, to which of the two constructions the part in question belongs. The younger channel shows rough walls all the way through, while channel (A) is plastered. It is possible to see through holes from one tunnel into the other at several points.[9]

Both tunnels run parallel and follow the contour line of the hills, which means the tunnels follow every valley all the way in and out. The only way to shorten this would have been the construction of an aqueduct, which has obviously been avoided except in Umm Qays itself. The natural stone is relatively easy to cut and in keeping inside the hill one avoids all risk, which an open construction such as an aqueduct might pose. The water is also safe from evaporation and pollution.

'Ayn Turāb is not the main watersource for the tunnel. This tunnel still holds water coming out of an artificially-cut tunnel, which continues for at least 200m to the east. We, therefore, assume at present, that the water of 'Ayn Turāb comes from a spring even further east or 'Ayn Turāb is not a spring in the normal sense but cuts into groundwater. To be certain about this question, further research in 'Ayn Turāb itself is needed.

'Ayn Turāb has 7 l/s, while the channel in Umm Qays would have had 124 l/s as a maximum flow. The hydraulic formula for this measurement includes the height, density and thickness of water-residues in the channel. So other springs must have been used as well. The tunnel possibly collected water from 'Ayn Umm al-Laja, springs at Ibdar, in the Wādī Umm Kahraq, and in the wadi at as-Sarif. If one climbs into the modern concrete spring linings, one finds the old channel course directly behind it. And as well as all these springs additional surface water was used: small channels (up to 20 cm wide) ran along the rocky surface and collected surface water over large catchment areas (FIG. 4). The water was directed through small shafts into the underground tunnels.

[9] At the point where the tunnels cross from the north side of the modern road to the south side and at 'Ayn Turāb.

At a certain point the tunnels cut through the hills and continue on the south side of the road, which avoids the large bend around Malka. Only in modern Umm Qays the builders faced a problem, which they could only solve by building an aqueduct. Here, there was no possibility to exploit the natural conditions any more. But having been carried in an aqueduct over the valley the water-course then immediately turns again into tunnels (see above). This combination of different structures is very typical for a Classical water-system (Landels 1978: 40).

Only 11 piers and the last arch are left of the aqueduct; with its 60 m length it would have had only one row of arches and had been one of the smaller aqueducts in Classical history (Gabrecht 1987: 38).

The aqueduct was most probably contemporary to the older of the two water-courses, but could have been used for the younger one as well. The artificially-built beginning of the younger tunnel would have been able to hold an aqueduct 'offspring', but there is no sign of such a construction at all. The older channel was supplied from the aqueduct and again several constructions – most of them lost to us – controlled the waterflow carefully.

Dating

Unfortunately it is very difficult to date a construction cut from bedrock. It is not quite clear when the older line went out of use. Bearing in mind, that at least two baths, one nymphaeum and a whole city needed to be supplied, one wants to assume that it worked all the way to the Late Byzantine period. It definitely was repaired several times, as the plaster layers (sometimes straight over water residue and silt) show. At the eastern end and in the oldest parts of the channel plaster was renewed at least three times. The western end of the channel went through a cistern, which silted up and was filled with rubbish sometime during the sixth century AD (Kerner forthcoming).

The younger system – tunnel B – had a very strange history: it was built, never quite finished, certainly never used and finally given up as a project after the middle of third century AD, which is clear from the midden at its western end.

Tunnel B was probably planned as a supplement to channel A and might have been abandoned not long after its beginning, due to financial problems. The interesting difference between the construction of both tunnels is the fact that tunnel B cuts into several cisterns, while the slightly more northern course of the older tunnel A has avoided that completely.

The building time (for the entire course) is very difficult to assess without any information concerning the size of the working teams. The Eupalinos tunnel took 10 years (1040 m long) to be cut in very hard limestone, while the tunnel in Bologna took between 17 and 38 days per unit (a unit was 7.4 m).[10] The lower tunnel A in Gadara would point to a duration between 2 and 3 years depending on

4. Tunnel in 'Ayn Turāb.

the amount of workmen.

Northern Jordan

The other – roughly contemporary – water systems in northern Jordan include the channels at Abila, Capitolias/Bait Ras and Khirbat Zeraqun. While the tunnels in Zeraqun have more the character of huge tunnel-shaped cisterns (no distribution outside the hills were found), both decapolis cities have elaborate systems. Capitolias has an enourmous cistern, which would have held several tens of thousand cubic metre of water. Surface water from the surrounding bedrock is channelled into it,[11] other sources are unknown. In no obvious connection with the main cistern is the water tunnel of Bait Ras. The tunnel is again cut out of the bedrock but shows an older design than the tunnel in Umm Qays. Here the actual water channel is cut into the floor of the larger tunnel like in the Eupalinus tunnel in Samos.

In Abila are different tunnels directly at the site but also close by at the Quweilbe spring. The excavators assume that they have tunnels from two different time periods: the Iron Age/ Persian/Hellenistic upper water-course and the Roman/Byzantine lower water-course (Mare 1995: 730). The construction technique seems to be remarkably similar to the tunnels in Umm Qays.

In the wider surrounding, Caesarea (Olami and Peleg 1977) and Humeyma (Oleson and Eadie 1986) show other impressive examples of water-systems from Classical times.

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[10] Samos: Kinast 1979.; Bologna, Giorgetti 1988: 182.

[11] The authors visited the cistern once in streaming rain and although the water was absorbed by the modern filling of the cistern, it was still possible to see the surface-collecting mechanism on the bedrock.

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