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The Technology of the Hydrological System at Abila of the Decapolis

A Jordanian city of 8000 to 10,000 population like Abila in the Roman-Byzantine periods needed an adequate water supply as an essential element in its infrastructure. The ancient Near East and Rome had already developed an intricate set of hydrological systems which Abila could take advantage of.

This paper will study the following aspects of the ancient hydrological systems, particularly that of Abila of the Decapolis: a brief survey of the earlier development of a variety of ancient Near Eastern and Roman water systems; an analysis of how these systems were established and developed at Abila; a study of how these Abila hydrological systems were financed and controlled, based on analogy from Rome and other cities in the Roman Empire; and an analysis of how the water of hydrological systems, such as the systems of Abila, was tested and kept chemically pure.

Survey of Earlier Ancient Near Eastern and Roman Water Systems

Forbes adequately outlines the development of early water systems in the Near East, Greece and Rome, observing that in the Upper Palaeolithic and Mesolithic periods, European and Near Eastern food-gathering peoples camped near springs or on the banks of rivers and used them directly as water sources to meet their basic needs, exampled by the Jerusalem Gihon Spring, wells in the Arabian wadis and hand-dug wells found in a number of places (Forbes 1964: 149). Finding where good water sources were located was one of the arts of ancient times. Vitruvius, the Roman engineer, gives the following instructions as to how to find water: "observe the nature of the ground, and the water vapors rising from it; analyze the types of soil; observe the types of vegetation growing in it (bulrushes, willow, alder, etc.); bury bronze or lead vessels for a short period to detect any drops of water remaining on them; and seek water in mountains where the rains fall" (Vitruvius 1962: VIII, Ch. 1 and 2). The very ancient wells were hand-dug (cf. 2 *Chron*. 26:10) and lined with stone, brick or wood, as in the Indus Valley and Mesopotamia; such wells in many cases were quite wide and deep, as in Egypt where they were as deep as 85 m; the well at Lachish was 76 m deep. Water from these wells was often hand-drawn (Forbes 1964: 150, 151).

The ancients also used cisterns for the storage of water; compare *Jer*. 2:13, and *Isa*. 36:16, and also the catchment system for collection of rain water at Capitolias, near Irbid, and the catchment territory around Ḥumayma, ancient Auara, in southern Jordan (Oleson 1990: 292). As needs increased, the ancients began to see the need of bringing water from a distance by gravity flow. Thus, they developed the open duct or conduit system (rock, terracotta, and timber trunk types), often covered with slabs to protect the water from pollution (Forbes 1964: 152, 153). But also very early the ancients began to use earthenware or stone pipes, especially where they wanted to carry smaller quantities of water and to use it for drains, including the use of metal pipes (of copper) (as at Abūṣīr, Egypt), as well as pipes of bronze and lead (as used by the Greeks and Romans). Especially in hilly Palestine and Syria the mining technique of drilling within the rock to expose water sources was adapted for the finding and channeling of water. In this case cities drilled tunnels within their fortifications to the spring source; cf. the *sinnor*, or water tunnel and stairs technique, which consisted of stairs leading down a shaft to a tunnel which led to the spring outside the city (for example, the *sinnor* at the City of David in Jerusalem, 2 *Sam*. 5:8). The water tunnels at Gezer, Megiddo, Hazor, Lachish and Gibeon are good examples of early water tunnel installations in Palestine, which began to appear in the Late Bronze and Iron I Ages. At Jerusalem such a tunnel was Hezekiah's Tunnel from the Iron II, period which brought water from the Gihon Spring to the pool of Siloam (2 *Kings* 20:20; 2 *Chron*. 32:30) and also in a modified way, the earlier irrigation channel which ran down the west side of the Kidron Valley floor, "the gently flowing waters of Shiloah" (*Isa*. 8:6) (Mare 1988: 104-107).

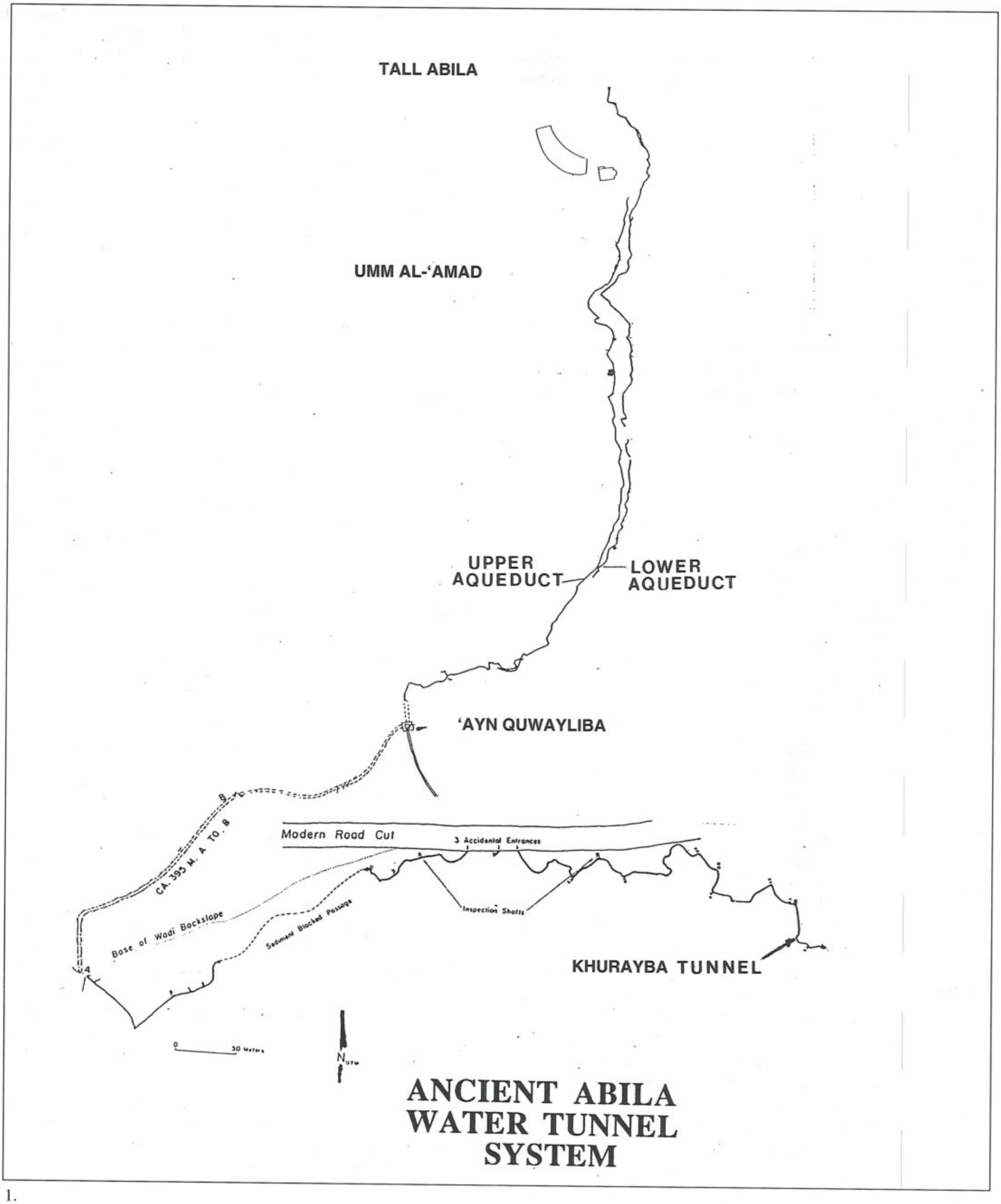
Another related system was the ancient "*qanat*" used in ancient Mesopotamia, Persia and ancient Arabia; the *qanat* technique which originated in Armenia, consisted of "tapping water from the foothill [including the use of the tunnel] to transport it to distant fields by gravity flow," (Forbes 1964: 156-158). The *qanat* technique, widely employed in antiquity, included the use of vertical air shafts (or inspection shafts, called putei by Vitruvius 1962: VIII, VI, 3: 182), spaced at regular intervals, a procedure reminiscent of old mining techniques. The classical Greek water tunnels, although not *qanats* in the strictest sense, also used air-inspection shafts (Forbes 1964: 158). Vitruvius (1962: VIII, VI, 3) comments about this: "If there are hills between the city and the fountain head, we must proceed as follows. Tunnels are to be dug underground and leveled to the fall already described. If the formation of the earth is of tufa or stone, the channel may be cut in its own bed; but if it is of soil or sand, the bed and the walls with the vaulting are to be constructed in the tunnel through which the water is to be brought. Air shafts (*putei*) are to be at the distance of one actus (36 m) apart." In a real sense these water tunnels in essence were the same as the Graeco-Roman aqueducts.

In the first large water supply system used in Nineveh, for the royal palace and for the irrigation of the surrounding fields, Sennacherib, Sargon's son (703 BC) built a dam (weir) across the Khosr River, north of Nineveh, dug a channel (canal) through the "high and low grounds," and brought the waters "across the plain (around) Nineveh and made them flow through the orchards in irrigation ditches"; in addition, to some 18 water courses here, "to arrest the flow of these waters (he) made a swamp and set out a cane-brake within it" (Forbes 1964: 160; Campbell Thompson and Hutchinson 1929: 130-132). Sennacherib also constructed a canal from Bavian to the Khosr River which crossed several small streams and valleys by arched aqueducts, such as at Jarwān (Forbes 1964: 162, 163; Jacobsen and Lloyd 1935: 6-18). In ancient Greece a number of water systems were used, aqueducts such as the Athens *qanat* type aqueduct, with air shafts in the tunnel about every 15 m (which brought water from Mount Pentelicus), and that of Samos, an installation consisting of a stone supported straight-line pipeline with vertical air shafts, 1100 m long bringing water from a copious spring through a hill to the city of Samos. The Greek tyrants and others, especially in Asia Minor, (also Hellenistic kings from Sicily and southern Italy), at an early period, employing a modified example of this system, used the siphon principle, as was the case at Pergamum in the time of Eumenes II. Here the water was brought by gravity flow over 360 m from a mountain spring east of the city to two settling tanks at Hagios Georgios; then with pressure flow by means of two siphons (which ran through 30 cm holes in perforated stone slabs 1.20-1.50 m long, 61-69 cm wide and 20-25 cm thick), which were spaced on their edges c. every 1.20 m, the water was carried through two valleys (over 177 m and 195 m), over a ridge (over 235 m) to Pergamum (over 332 m). What the siphons were made of, and how they solved the problems of the siphon we do not know, but we do know that at least earthenware pipes (possibly installed in Roman times) were used for the distribution of water from the city reservoir (Forbes 1964: 163-165).

Although Roman aqueducts are generally thought of as consisting of spans of aqueduct arches which transversed many valleys in Spain, France, Italy and the Roman Campagna, the fact is that the greater extent of Roman aqueducts ran underground, providing for the city an abundance of water for households, baths, fountains, public governmental and commercial installations, sewer flushing, other hygienic needs, *naumachia* (water battles or shows), and sometimes providing water for field irrigation (especially in areas where rainfall was not sufficient to meet the need of dry farming). It is to be observed that in the Near East water-lifting equipment, such as the water wheel, also began to be used (Forbes 1964: 166, 172). Rome, in the later Republic and in the Empire, was well known for its aqueduct installations which brought water long distances from the south, east and north of the city. The nine well-known aqueducts at Rome are listed and discussed by the Roman Water Commissioner, Sextus Julius Frontinus, as follows: Appia, Old Anio (*Anio Vetus*), Marcia, Tepula, Julia, Virgo, Alsietina (also called *Augusta*), Claudia and New Anio (*Anio Novus*) (Frontinus 1962: Book 1, 5-22, pp. 339-365; Forbes 1964: 166-168).

How Hydrological Systems Were Developed at Abila of the Decapolis

Roman-Byzantine Abila no doubt used a number of the features from the various ancient hydrological systems of the Near East, Greece and Rome, although basic archaeological evidence is not extensive. As was true in the case of the average ancient Mediterranean and Near Eastern city, Abila was blessed with adequate water sources, including 'Ayn Quwayliba located at the south end of Umm al-'Amad, a class A spring producing a mean average of 7.7 liters per second (according to the Hydrology Division of the Jordanian Natural Resources Authority 1966 study; Fuller 1985: 37). Besides this copious spring, auxiliary water supplies included 'Ayn Khurayba, located to the south of Abila, and no doubt an underground spring located within the heart of the hill to the south of 'Ayn Quwayliba, which the ancient Roman and Byzantine engineers tapped into when they constructed the Khurayba Aqueduct (Fuller 1983: 23) (FIG. 1). A further water source may have come from springs west and southwest of Abila, evidence for which is an air


TALL ABILA
UMM AL-'AMAD
UPPER AQUEDUCT
LOWER AQUEDUCT
'AYN QUWAYLIBA
B
CA. 395 M. A TO. B
A
Modern Road Cut
3 Accidental Entrances
Inspection Shafts
Base of Wadi Backslope
Sediment Blocked Passage
KHURAYBA TUNNEL
0
30 Meters
N
ANCIENT ABILA
WATER TUNNEL
SYSTEM

1.

shaft (*puteus)* located about 1.5 km west of the site (Fuller 1985: 57-58). Compare the ancient underground aqueduct with *putei* and accompanying rock-cut stairs found in the recent archaeological survey activity at the acropolis of Umm Qays, ancient Gadara (Weber 1991: 224-229, and FIG. 1), located several Roman miles west of Abila. All these water supplies would have adequately provided for the 8000 to 10,000 persons living in Roman-Byzantine Abila (Mare 1992: 309-313). In addition, rain water must have been collected on roof tops of public and private buildings to help fill the many cisterns; cf. at Abila the cistern next to and north of the Umm al-'Amad Area D seventh century AD basilica, and the Tall Abila Area A Byzantine plastered water channel which carried water toward the Area A sixth century AD basilica there, presumably to a cistern on the north side of the basilica; this Area A surface water channel must have received rain water collected from the roofs of public buildings located on the acropolis of Tall Abila.

With the adequate spring sources at and around Abila, the ancients then devised a means of bringing water from these sources to the necessary installations in the city (cf. FIG. 1). There were two periods when hydrological systems at Abila were planned and developed: 1) the Iron/Persian/Hellenistic periods when the Lower Umm al-'Amad (south *tall*) Underground Aqueduct was dug and used (and then later repaired/reused in the Roman period). It truncated several small pre-Roman tombs, evidence that it was constructed and used earlier in Early Roman or Hellenistic times, or even in the Iron Age/Persian Period (Fuller 1985: 56). This aqueduct ran north from 'Ayn Quwayliba under the east ledge of Umm al-'Amad toward the central civic center in the saddle depression in the middle of Abila; and 2) in the Roman-Byzantine periods when two underground aqueducts were dug: the Upper Umm al-'Amad Underground Aqueduct which also ran north under the east ledge of Umm al-'Amad, but 1 to 3 m higher than the Lower Aqueduct (Fuller 1985: 39) (both of these Umm al-'Amad Aqueducts ran north-south c. 1400 m — Fuller 1985: 56) and the Khurayba Underground Aqueduct which ran in a winding course 2.5 km through the hill south of 'Ayn Quwayliba. In the case of Umm Qays/Gadara, the hydrological system there is estimated to date back into the Roman imperial times, and possibly as far back as into the Hellenistic era (Weber 1991: 227).

The earlier Iron Age/Persian/Hellenistic Lower Umm al-'Amad Underground Aqueduct has parallels in several Late Bronze-Iron I and II aqueducts in Palestine. These aqueducts consisted of shafts dug within the fortified city, with steps leading down to a horizontal underground tunnel extending out to a spring water source outside the city walls: examples are found at Gezer, Megiddo, Hazor and Gibeon (Gibeon's shaft may have first been used as a cistern and later dug down to a level where a tunnel was then dug extending out to the spring source). One prime example, of course, is found at Jerusalem, which, over the course of time in the Late Bronze and Iron Age periods had three hydrological systems: 1) the earlier Warren's Shaft system of the time of the Jebusites and David (2 *Sam.* 5:6-8); 2) the Siloam Channel, used at least by the time of King Ahaz (735-715 BC, "the gently flowing waters of Shiloah" (*Isa.* 8:6; Mare 1988: 106); and 3) Hezekiah's (715-686 BC) Tunnel (Mare 1988: 100-107; cf. Cole 1980: 8-29; Shiloh 1981a: 169-170; 1981b: 24-39) which carried water from the Gihon Spring outside the city to the Pool of Siloam inside the city (2 *Kings* 20:20).

Although a deep shaft like the Palestinian examples has not yet been found in Abila's central saddle depression area which could be identified with the Abila Iron Age/Persian/Hellenistic Lower Umm al-'Amad Aqueduct which extended south to the 'Ayn Quwayliba spring outside the city, the numerous deep well shafts in this tunnel (Fuller 1985: 38, FIG. 1) cut down some 3 to 4 m to the horizontal tunnel floor, suggest that there may well have been such a deep central shaft within the city which connected with this tunnel leading to the water source. The course of the Lower Aqueduct was sinuous, which may have been accidental because of the lack of precise sighting engineering instruments or because of the lack of light in the dark tunnel which made precise excavation difficult (no lamp niches were found in this tunnel (Fuller 1985: 56.); or purposeful, in some cases, to avoid geological faults. As the Lower Umm al-'Amad Aqueduct aged through use and time, officials in the Roman period repaired the structure by coating the walls of the tunnel with a gray lime mortar to cut down on leakage and thus increase water volume; also at a later time, to increase its water flow, the Lower Aqueduct was increased in size by nearly doubling the depth of the tunnel, and widening it in its northern section. Possibly because of damage from earthquake activity in the Late Roman/Early Byzantine periods, a well constructed peaked roof section (the pottery in the construction mortar was Late Roman/Early Byzantine) was constructed near this tunnel's northern end, and a well engineered by-pass tunnel was also built (Fuller 1985: 56, 57).

The Abila hydrological system became much more complex in the Roman-Byzantine periods when the city reached a population of 8000 to 10,000 persons (Mare 1992: 311). Then the water systems dug included at least: 1) the Upper Umm al-'Amad Underground Aqueduct: 2) the Khurayba Underground Aqueduct to the south of Umm al-'Amad; 3) an inter-connecting underground aqueduct segment in the south Wādī Quwayliba, connecting these two aqueducts; and 4) possibly a fourth aqueduct segment 2 or 3 km to the west, southwest of

Abila.

In these Roman-Byzantine times a number of parallel aqueduct installations existed in Palestine, Transjordan and in the surrounding area, as well as many such structures in Rome and elsewhere in the Roman Empire (Forbes 1964: 166-168). A prime Palestinian example is to found in the system south of Jerusalem which supplied the city with water. This system consisted of underground and surface aqueduct segments, including a Low Level segment hewn in the rock (probably built by the Hasmoneans in the first and second centuries BC), and large stone pipe segments of an Upper Aqueduct (constructed by the Tenth Roman Legion in the second century AD), bringing water from c. 25 km (70 km of contours, developed for gradient purposes) from the Pools of Solomon near Hebron and from farther south, from the Kuwayziba Spring, and from the 'Arrūb Spring near Hebron (Josephus, *Jewish War*, II, 175; *Antiquities* XVIII, 60 also mentions an aqueduct built by Pontius Pilate) (Shanks 1984: 46-54). Another example is to be seen at Caesarea Maritima with its high aqueduct (built by Herod the Great and enlarged by Hadrian), extending 21 km to the south from the area of Mount Carmel on the north — half the length ran underground, and half on a series of arches; and Caesarea Maritima had an additional low level aqueduct, carrying water to the city from a river 7.2 km to the north (an aqueduct in use in the fifth century AD) (Bull 1982: 24-32). A further example is found at Antioch of Syria where two Hellenistic aqueducts were built, and two aqueducts constructed later in the time of Caligula (AD 37-41) and Trajan (AD 115) (Fuller 1983: 24). At ancient Auara (Avara), modern Ḥumayma in southern Jordan, an extensive hydrological system of surface aqueducts, channels and dams have been investigated, a system some 27 km long, extending from the springs in the hills to the north down to Auara itself; this Ḥumayma aqueduct system is called by Oleson (1986: 257), "...the most remarkable surviving example of Nabataean hydraulic technology so far reported anywhere. The main structures of this hydrological system were no doubt funded or sponsored by the Nabataean king, Aretas III (87-62 BC), and so this system dates to the Nabataean period, but its use extends into the Roman and into the Late Byzantine, and possibly into the Umayyad periods" (Oleson 1988:168; 1990: 306). At Qumrān a surface conduit brought water from the cliffs to a large retaining basin from which the water flowed into thirteen cisterns (Sanders 1973: 120). At the Herodium near Bethlehem, the complex hydrological system consisted of an aqueduct, bringing water 5.6 km from springs near Bethlehem to an elaborate pool with central pavilion; also a number of tunnels and cisterns were at the site (Netzer 1983: 41-42). Samaria had an elevated aqueduct which, with a gradient drop of 2.54 cm, crossed the low land area, paralleled the sea until the aqueduct delivered its water into collection basins for distribution to public baths, fountains and private dwellings; ceramic pipes brought fresh water from Samaria's domestic water box to the city's homes.

In northern Jordan examples include Gadara (Umm Qays) about which it is said that an aqueduct brought water 48.3 km from the east to the city. About the Gadara hydrological system, Weber (1991: 225) has recorded "25 plots with traces...[of the rock-cut aqueduct] between the eastern slope of the Gadarene acropolis hill...and Wadi ash-Shellaleh," a tunnel which ran "alongside the natural watershed of the northern 'Ajlun range." As noted above, the Gadara underground aqueduct ran in a somewhat sinuous route through the acropolis hill (with intermittent *putei* observable), finding its end "at the artificial basilica terrace...at the western slope of the acropolis hill." (Weber 1991: 228; compare FIG. 1). Weber (1991: 227) also notes that one distributor (*castellum*) had been known at an earlier time at nearby al-Qabū, but he could not ascertain if this irrigation system had drained into the main Gadara aqueduct. An additional northern Jordanian example is to be seen in Umm al-Jimāl, where water accumulated from a dammed area brought water for field irrigation, and the city's ground level aqueduct brought runoff water from the slopes on the north a number of kilometers south to the city where many branch channels brought the water into large open pools distributed throughout Umm al-Jimāl, and also to smaller roofed over cisterns located next to most every house and public structure.[1]

The technique of digging the Roman-Byzantine underground aqueducts at Abila can be described as follows. Once the water sources had been established, the Abila engineers determined the points where water needed to be brought and then laid out the courses they wanted the aqueducts to take and the gradient requirements necessary for an adequate gravity flow of the water. They recognized that a steady gradient needed to be maintained, and, as Forbes has indicated, in the Roman period there were a number of surveying instruments available to enable an accurate digging of tunnels and the maintaining of a proper gradient. The primitive instruments included the plumb bob; the *merchet* (sighting device), *libra aquaria* (simple water level); the *chorobates* (primitive plane table or field service level some 6 m long; the *dioptra* (a water horizon with sights mounted on a divided circle); the *groma* (or Grecian star, to trace 90 degree angles) and leveling rods. Forbes (1964: 171) comments, "Skillful work with these prim-

[1] Beebe 1975: 98-99 (Samaria). In the Jordan Valley between Jericho and Sablata remains have been found of an aqueduct built by Herod in which ceramic pipes carried water to Phasael's palace (Fuller 1983: 24; De Vries 1979: 52).

itive instruments would, however, enable them (the engineers) to maintain a gradient of 1:2000 very closely. Even accurate tunneling was possible with these instruments and only seldom do we hear complaint of careless and negligent work."

Having determined the course of the aqueduct to be dug, the engineers at Abila began their work by digging vertical shafts (*lumina, columnaria,* also called *putei* by Vitruvius [1962, VIII, VI, 3, p. 183; VIII, VI, 14, p. 191]; Forbes 1964: 171), with steps, at a c. 55 to 60 degree angle2 down to a depth of c. 3 to 4 m, to reach the desired level at which the underground aqueduct was to run. At Abila these shafts were spaced somewhere between 20 and 30 m apart.[3] Presumably the Roman engineers started their work by digging the Upper Umm al-'Amad Aqueduct, in order to add to the water volume brought through the earlier Iron/Persian/Hellenistic Umm al-'Amad Lower Aqueduct which, with age and use, had already had to be repaired (see above). To meet the expanding needs of the growing governmental, business, cultural and religious establishment of Abila, the Roman engineers, at about the same time and using the same techniques, dug the Khurayba Underground Aqueduct 2.5 km back into the hill south of 'Ayn Quwayliba to reach spring water deep within that hill (Fuller 1983: 23) — they may also have cut the Khurayba Aqueduct clear through the south hill to reach 'Ayn Khurayba. The engineers may have dug this Khurayba Aqueduct in a winding course to avoid serious geological faults, or it may be that the quantity of winding within the aqueduct evidences less careful work done by local contractors, after the more accurate initial work had been finished by the master engineer (Fuller 1983: 21). As in the case of the Upper Umm al-'Amad Aqueduct, in order to initiate standard tunnel digging procedures, and also to provide ventilation and additional light, and to avoid air lock, the engineers used a number of vertical air shafts (*putei*) to reach the level the horizontal tunnel was to run. To centralize the whole system of aqueducts further, and to obtain a better flow and volume of water, these engineers connected the Upper Umm al-'Amad Aqueduct (whose mean height and width are 1.76 and 0.78 m, respectively) on the north with the Khurayba Aqueduct (whose mean height and width are 1.44 and 0.73 m, respectively;[4] the mean height and width of the earlier Lower Umm al-'Amad Aqueduct are 2.38 and 0.88 m, respectively — Fuller 1985: 41) on the south by means of an additional and intermediate underground aqueduct, the South Wādī Quwayliba Underground Aqueduct; they accomplished this by running this latter aqueduct in a winding pattern from the exit of the Khurayba Aqueduct for c. 750 m northeast across the south Wādī Quwayliba valley (one can trace on the surface of the wadi floor the winding course of the South Wādī Quwayliba Underground Aqueduct, with its easily identifiable *putei*, until it emptied into the Upper Umm al-'Amad Underground Aqueduct at a point somewhere near the Upper Aqueduct's connection with 'Ayn Quwayliba.[5] We do not have any detailed information yet as to how the proposed additional fourth Underground Aqueduct (possible *putei* have been sighted at a point on the southwest edge of Umm al-'Amad, and also in the West Transect 15, 1.5 km west/southwest of Abila) fitted into the Umm al-'Amad-Khurayba system, but we assume that it would have somehow brought water from springs west/southwest of Abila to the central civic center of the city. It is possible that the Abila aqueduct system was somehow connected with the Gadara aqueduct running east to Wādī ash-Shallālah (Weber 1991: 225).

Air shafts (*putei*; many of their blocked entrances have been observed), referred to above, were needed: to check and help maintain a proper gradient for a proper flow of water from 'Ayn Quwayliba; to prevent air lock; to provide personal access to shafts cut into the tunnels (cf. the well shafts spaced at intervals in the Upper and Lower Umm al-'Amad Aqueducts, well shafts which exhibit rope rubbings in their sides); to obtain necessary access for periodic cleaning of the aqueduct (cf. the Abila inscription found on the wall of the Upper Umm al-'Amad Aqueduct not far from the 'Ayn Quwayliba spring head, indicating cleaning was done in AD 568);[6] to assure proper ventilation; and to provide access to water in times of siege. When the engineers had dug the *puteus* to the desired tunnel level, they began to dig from this level in both directions to the determined points where additional *putei* were, or had already been, dug.

To facilitate their digging, they carved out small lamp niches on either side of the tunnel walls, to give necessary light for the task and to identify that there was a proper oxygen supply in the tunnel. The quantity and

2 This was the situation at the exit passage *puteus* in the Abila Khurayba Underground Tunnel (Fuller 1983: 21).

3 From my own investigation in June, 1991. Fuller (1985: 41) calculates mean spacing putei for the three underground aqueducts as follows: Upper Umm al-'Amad, 31.2 m; Lower Umm al-'Amad, 25.7 m; and Khurayba, c. 50 m(?). Fuller (1983: 21) states that the Khurayba entrance passage *puteus* had steep stairs, 22 cm steep and 32 cm high, and indicates that the *puteus* passage at the base was 1.55 m wide, whereas at the entrance, which is blocked, it is 1.7 m to 2.0 m wide.

4 The average height of the main Gadara aqueduct is c. 2.50 m, and its maximum width is c. 1.40 m (Weber 1991: 225).

5 During my investigation in early June, 1991, two individuals trucking water from 'Ayn Quwayliba verified that water ran north (through the aqueduct) from the exit of the Khurayba Underground Aqueduct towards 'Ayn Quwayliba on the north edge of the wadi.

6 Van Elderen 1989: 2-5. This painted inscription (located on the wall of the Upper Umm al-'Amad Aqueduct not far from the 'Ayn Quwayliba end), of which a considerable part has been preserved, can, in the main, be made out to read, "(At the time of.....) the most holy and most blessed bishop, the upper channel was cleared in the month(s) September (and) October, in the second indiction (and) the year 631," i.e. AD 568, according to the Era of Pompey, 64/63 BC, which was the era system used in the Decapolis, especially at Jarash (Welles 1938).

spacing of lamp niches in the aqueducts can be summarized as follows: for the Upper Umm al-'Amad Aqueduct the mean distance between lamp niches placed on the left (west wall, facing north) is 0.93 m and the mean distance between lamp niches on the right (east) wall is 1.29 m; for the Khurayba Aqueduct the mean distance between lamp niches on the left wall is 0.80 m, while on the right wall it is 1.38 m; no lamps niches have been found in the Lower Umm al-'Amad Aqueduct (Fuller 1985: 40; it is possible that in this earlier period they used torches).

The significance of numerous engineering inscriptions and graffiti found in the Upper Umm al-'Amad and Khurayba Aqueducts can be summarized as follows. In the Upper Umm al-'Amad Aqueduct there were painted or smeared on the walls seven Greek letters or combinations of Greek letters, consisting of four short inscriptions in the southern end of the Upper Aqueduct, possibly initials smeared on the walls by the tunnel maintenance crew, and three Greek "painted" letters consisting of single letters, and one inscription of three letters which were painted (red paint) on the ceiling; these may have indicated locations in the engineer's plan for the aqueduct. In addition four engineering graffiti were found, consisting of crude geometric shapes, an engineer's abbreviated notes.[7] In the Khurayba Aqueduct along the north wall of the *puteus* off the exit, were discovered two red painted Greek inscriptions: the Greek alphabet letters seem to indicate *Pi 25* (the upper inscription) and *Pi 9* (the lower inscription), which may well represent elevation-gradient markers and benchmark symbols; the finding of a painted arrow pointing down a short distance above the upper inscription supports this interpretation (Fuller 1983: 21). Also in the Khurayba Aqueduct on the northeast wall of an almost choked *puteus* exposed by the modern road-cut near and to the south of 'Ayn Quwayliba, another elevation-gradient marker was found, consisting of a Greek letter *Pi* painted in red on the wall, with a possible Greek *Theta* to the right of the *Pi*; both letters were painted above a horizontal line cut in the wall. The Greek *Pi* was surmounted by a small tear drop, possibly a Byzantine convention, similar to such a mark above a *Pi* on a painted Byzantine inscription in the Syria National Museum, Damascus (Fuller 1985: 57).

If we had been able to investigate the Abila hydrological installations as they existed in the first and second centuries AD, we would no doubt have found many of the devices, instruments, equipment and installations described by Sextus Julius Frontinus, Water Commissioner of Rome in the late first century AD (Frontinus 1962 Vol. II, VIII, pp. 132-193). Frontinus describes the step by step procedures and necessary equipment needed for a full fledged hydrological system to function completely and efficiently from water source to consumer. Forbes (1964: 172-177) summaries these features as follows. 1) From the water source (spring, river or dammed area) the water was directed to settling tanks (called *piscinae* and *castellae limonariae*) which usually had two compartments with sloping floors for better cleaning. Then, 2) the water was brought through a *specus* (a "real duct") often 15 m underground. These "real ducts"[8] were punctuated with 3) air shafts (called *luminae, columnariae*, or *putei*) every 36 to 45 m (at Abila the distance averaged 20 to 30 m), to prevent air lock and allow inspection and cleaning. Then, 4) the water then flowed to *castella* (water towers, which were only distribution tanks, and not like our modern water reservoirs, since they only had a small storage capacity).[9] Three mains 5) (the *specus*,[10] or water box) tapped water from near the bottom of the *castellum* to provide water for baths, fountains and domestic use[11] — the overflow from the two outer water boxes (which directed water to the baths and to domestic installations) flowed into the central box whose water went to the fountains. To the water boxes 6) were attached ajutage nozzles,[12] which included the bronze *calices* (the *calix* was the water meter) by which the *aquarii* (the water meter officials) charged the customers. And to the bronze calices 7) were attached individual private service pipes (*fistulae*), placed to deliver no more than 1 *quinaria* of water every c. 15 m.[13]

7 Fuller (1985: 46-50). There were also found fourteen crosses incised on the walls of the Upper Aqueduct, including the following varieties: 5 Greek crosses, with equal length of their horizontal and vertical beams (*crux quadrata*); 7 variants of the Greek cross, also with equal beams, but with bi- or tri-lobes, called also the "forked cross" (*crux fourchee*); there was also one St. Andrews cross, one which is in the shape of an X (the *crux decussata*). Some religious significance can be adduced for these numerous crosses incised on the walls of the Upper Aqueduct, indicating the presence of Christian workmen, or some Christian symbolism for testimony, Christian ceremony, or theological statement (three crosses were found in one place together), or for some apotropaic purpose, etc. There were also found in the Upper Aqueduct three early Christian monograms in simple star designs, two of them similar to a six pointed star, possibly abbreviation for the Iota and Rho symbols for Jesus Christ (Fuller 1985: 50-56).

8 Forbes (1964: 172) says: "The area of the specus [the "real duct"] varied from 0.5 m. to 3.0 m., it consisted of a 50- 60 cm cement lining enclosed and carried by a mass of masonry."

9 Each aqueduct had a number of *castellae* (at Rome Aqueduct Appia had 20, *Anio Vetus* 92; the total *castellae* for all was 247).

10 "Though tapping from the *specus* or main was unlawful, the overflow from reservoirs, fountains and public baths (called 'lapsed water' or '*aqua caduca*') was often free though it was also used for swilling drains or for industrial purposes. The basement of the baths of Caracalla contained mills driven by this surplus. Apartment houses and other buildings had secondary reservoirs in which the water supplied was pumped by water wheels, force pumps and the like." (Forbes 1964: 173).

11 In provincial towns like Pompeii where the water was not so plentiful as at Rome, the officials frequently rationed or cut off water to private individuals during parts of the day to provide a sufficient amount for the baths and public buildings which formed the central part of city life.

12 At Ḥumayma there has been found in connection with one of the reservoirs a large, bronze stopcock valve which may have been similar to one of the ajutage nozzles described by Forbes. Cf. Oleson 1988: 162, 163; PL. XXX 1, 2.

13 "The *quinaria* was a measure not of volume but of capacity, i.e. as much water as would flow through a pipe one and one quarter digits in diameter, constantly discharging under pressure". (Frontinus 1962: I, 25, pp. 366-367). "A *quinaria* was about 5,000 or 6,000 United States gallons per twenty four hours, plus or minus 2,000 or 3,000 gallons, according to circumstances, favorable or unfavorable (Herschel)." (Frontinus 1962: I, 25, pp. 366-367, fn. 3).

Although the archaeological evidence at Abila has not yet provided the artifacts and installations corresponding to all the items that Frontinus and Forbes describe, yet we can assume that Abila, a Roman-Byzantine city under the overall government and direction of the Roman and Byzantine Empires, in addition to having the *putei*, underground aqueducts and Roman and Byzantine engineering symbols which were clearly found in its ruins, had also a number of other technical instruments and installations described by Frontinus. For example, we have found just to the east of the Abila Area C bath/nymphaeum, just north of the theater cavea and in the heart of the saddle depression city civic center, remains of a large vault (Mare 1990: 2, FIG. 1) where, on its south side, water channels coming from the direction of the Umm al-'Amad Underground Aqueducts emptied their contents into the vault; this may have been a distribution tank (*castellum*) or one of the water boxes through which distribution was made to the baths, to the fountains and to the domestic units, an installation similar to the type described by Frontinus and Forbes. Just as smaller equipment items described by Frontinus (such as the ajutage nozzles, and bronze calix water distribution and water meter installations) had difficulty in surviving in ancient Rome, the same would have been true of this kind of equipment at Abila. Interestingly near the vault just mentioned and next to it are remains of another vault which may likewise have fitted into this water system. Also we have found remains of a small covered water channel running north-south along the west side of the proposed Area C bath/nymphaeum ruins; and, in addition, on the south of the Area C ruins, near the front of the theater cavea we have uncovered small water channels running on either side of a north-south street which extends toward pavement stones found in the peripheral sector of Area C.[14] All these installations may have been part of the central water distribution system of Abila.

How the Abila Hydrological Systems Were Financed and Controlled; Analogy from the Roman Model

Fuller (1983: 24) has aptly commented on the importance of the Khurayba Tunnel:

> The significance of the water tunnel - aqueduct [the Khureibah tunnel] at Abila cannot be underestimated. It reflects something of the community's wealth and integration into the Roman Empire. The inferred date for its construction (Roman-Early Byzantine) corresponds to the period of major urban and suburban expansion at Abila. The growth in the urban center probably taxed the flow from Ain Quailibah and an alternate source had to be located. An interesting discovery during the survey of the West Transect is a number of choked shafts which greatly resemble the *puteus* shafts associated with the water tunnel discovered in 1982. We do not have positive evidence for an aqueduct coming from the West, but there are several enticing clues. All of this suggests that Abila was more than a simple farming village or a caravan stopover. It was an urban center with a significant population density, public buildings, and an aqueduct system.

Commenting on the additional evidence of the Umm al-'Amad Aqueducts, Fuller (1985: 57) remarks:

> The construction of the Upper and Lower [Umm al-'Amad] Aqueduct system was an expensive investment which allowed the urban population of Abila to transport a class A spring to the foot (and possibly beneath the base) of Tell Abila. This maximized their resources in terms of water and defensive elevation.

The question now arises how these expensive installations were financed and how they were financially maintained for large urban populations. In ancient Rome and other town installations there were a large number of consumers. Frontinus (1962: II, 78-87, pp. 407-417) divides the consumers at Rome into three large groups: 1) those who had received special grants from Caesar (*sub nomine Caesaris*); 2) private parties; and 3) public uses or supplies (*usus publici*), which included water for camps (*ex eo castris*), public structures (*opera publica*), ornamental fountains (*munera*), and water basins or cisterns (*lacus*). Forbes summarizes Frontinus' categories and percentages as follows:

Special grants from Caesar (including baths)		17.1%
Private parties (houses and industries)		38.6%
Public uses or supplies:		
19 military barracks	2.9%	
95 official buildings	24.1%	
39 public buildings and theaters	3.9%	
591 cisterns fountains	13.4%	44.3%
		100.0%

All these equipment items and installations for such a large population would have cost a great deal of money, and the system had to be regulated carefully to make the system efficient and financially viable. In Rome the entire hydrological system was under state supervision, and the state or town council purchased the land upon which the aqueduct was to be built (including a reserved strip of 12 Roman feet which was leased for pasture, or hay or for cutting brushwood). Often the purchase included portions that were not needed for the aqueduct; the excess was then sold. The aqueducts at first were financed by

14 "R. Bullard [the Geologist] observes that the travertine accretions on the sides of the channel [on the east side of the street] gives good evidence of use over a long period of time." (Van Elderen 1990: 25-27).

tribute gained from captured countries, and then the cost was shifted to the *viri triumphales*, those Roman commanders who were successful in battle, and then finally the state and many provincial towns imposed a water tax upon the private citizens and businesses who received water piped to them from the main aqueduct. In addition, in places like Roman Syria the aqueducts were financed out of temple revenues, and also in numbers of cases public minded citizens gave aqueducts as beneficent gifts to their own towns.[15] To be sure, definite regulations and restrictions were needed on the use of water. Some of these restrictions were made by the decree of the Senate who permitted water to be drawn only from the reservoirs (*ex castello duci*) (Frontinus 1962: II, 106, p. 441). Frontinus (1962: II, 103, p. 435) gives further details on regulations, as he indicates that no one could draw water from the public supply without Caesar's authority, that is, without a license, and that no one was to draw more than had been allowed. To help him discharge his duties, the Water Commissioner had two lictors, three public servants (*servi publici*), an architect, and an administrative staff consisting of scribes (*scribae*), clerks (*librarii*), assistants (*accensi*), and criers (*praecones*) (Frontinus 1962: II, 100, pp. 429-431). Forbes further comments (1964: 169, 170):

> His [the Water Commissioner's) technical personnel consisted of *villici* (who attended to the pipes and orifices), *castellarii* (for the reservoirs), *circuitores* (line-inspectors), *silicarii* (pavers) and *tectores* (masons). Agrippa [Marcus Vipsanius Agrippa, to whom at an earlier period Caesar Augustus had entrusted the duties of the water supply of Rome] had used a band of 240 slaves of his own, whom he trained and left to the state at his death and Claudius had formed "Caesar's gang" of 460 men. These gangs were then combined and together with the specialists [already mentioned], further architects (*aquarii* [inspectors]) and free labor (hired occasionally), they formed the regular technical staff.

Abila, a city of the Roman Empire, no doubt also had to finance its hydrological system from similar public, religious and private sources, and had to depend on public decrees and public servants to administer its water system as efficiently as possible and to keep the system financially solvent.

How the Water of Hydrological Systems Like Abila's was Tested and Kept Chemically Pure

Besides funding the system and taking care of the equipment as discussed above, there was also the testing and maintaining of the purity of the water carried in these hydrological installations, a detailed and costly process. Forbes talks about ancient concern for lead poisoning, which a number of the ancients, Hippocrates, Galen and Vitruvius, warned against when lead was used as lining for cisterns and pipes; but Forbes (1964: 177), however, argues that this problem was overly stressed, since "the manifold cases of rather intense incrustations of calcium carbonate on the interior of ancient lead pipes suggest that this complaint is grossly overrated." Vitruvius (1962: VIII, IV, p. 177) talks about testing for the purity of the water supply, and suggests that such testing should include sprinkling the water "over a vessel of Corinthian bronze [an alloy of gold-silver-copper]" (Forbes 1964: 177). Vitruvius also suggests that water be boiled in a copper vessel, be allowed to stand, and then poured off to see that there were no traces of sand or mud in the bottom of the copper vessel; another recipe was to test the water by boiling it with vegetables until they were cooked. Of course, he says that good water must not be contaminated with filth or with moss or reeds.

Numbers of ancient procedures were suggested for purifying water, such as exposing it to the sun or air (cf. our modern open reservoirs), boiling it, filtering it through porous pottery made of mixes of zeolite and clay, and filtering it through tufa, wool or wick siphons. Other prescriptions included desalination by percolation of sea water, percolation through sand, addition of salt (Vitruvius 1962: VIII, VI, 14, p. 193; cf. 2 *Kings* 2:21, 22.79) to counteract lime, addition of herbs for purification (cf. *Exodus* 15:25) or the cooking of water with a bag of barley or laurel or crushed coral, or the use of chalk from Rhodes or clay (*argilla*) from Italy, or mixing the water with wine (Forbes 1964: 178).

Whatever the processes used for testing or purifying the water supply at Abila, it was a constant problem and an item of public expense.

The analysis of the hydrological systems at Abila of the Decapolis has brought us to the conclusion that these water systems were large enough and sophisticated enough to meet the needs of the people living here in this Iron to Hellenistic Age city and also to meet the needs of the larger Roman-Byzantine Abila of 8000 to 10,000 people (Mare 1992: 313) as the city continued to grow culturally, industrially, agriculturally and religiously.

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[15] "At Rome the public could draw water freely without paying and even by the end of the first century A.D. the water-tax collected amounted to some 250,000 sesterces per year, hardly enough for the upkeep and repairs. Italian cities usually managed to pay for an excellent supply of clean water. Villages paid water-tax to a neighboring town for the use of a branch line." (C.I.L. IX. 5144) (Forbes 1964: 168).

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