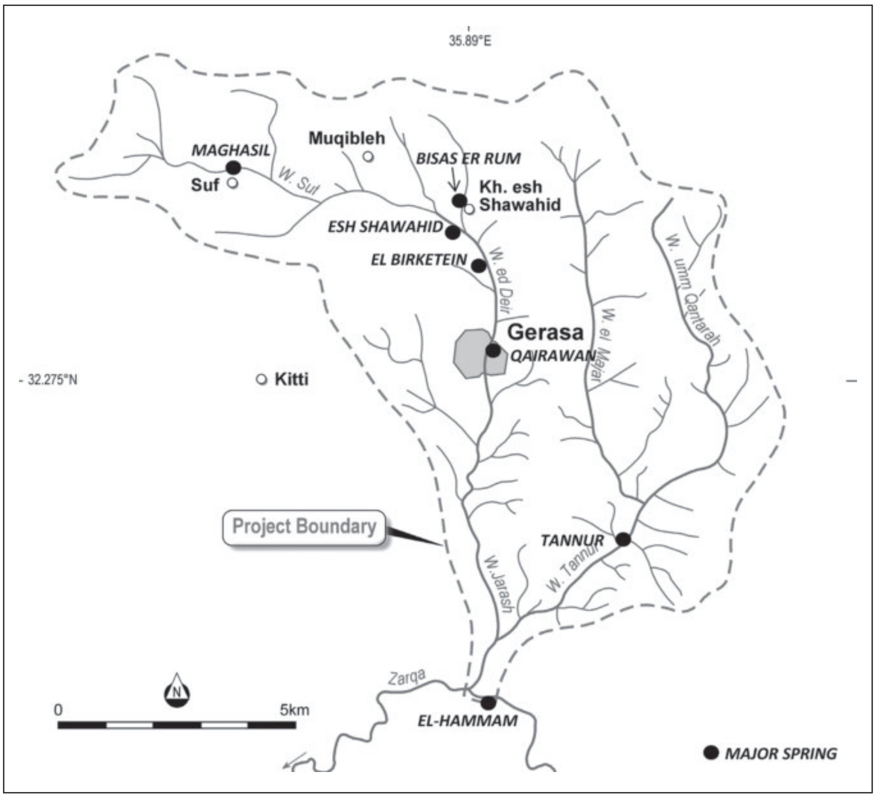
JARASH WATER PROJECT: REPORT ON THE 2014 FIELD SEASON

David D. Boyer

Introduction

The Jarash Water Project is studying the water management system of the Greco-Roman city of Gerasa (Jarash) and its hinterland by combining bibliographic and historical research, photographic interpretation, field survey and landscape analysis. The project was inspired by the water installations recorded outside the city during three seasons of field survey by the Jarash Hinterland Survey between 2005 and 2010, in which the author participated (Baker and Kennedy 2010, 2011; Kennedy and Baker 2009). The project area encompasses the watershed of the combined Wādī Sūf/Wādī ad-Dayr/Wādī Jarash drainage (hereafter the Jarash Valley), and the adjacent valley to the east containing the combined Wādi al-Majarr/Wādī Umm Qanṭarah/Wādi Tannūr drainage (hereafter Tannūr Valley) (**Fig.1**).

Knowledge of Gerasa's ancient water management system has previously been constrained by the absence of a considered assessment of the water supply sources, the nature of the distribution network to and within the city, and the period in which the city's main water installations were in use; key problems that the Jarash Water Project seeks to resolve. Studies of some components of Gerasa's water



1. *Study area boundary, watersheds and major springs (Don Boyer).*

management system have been published, including the public baths (Lepaon 2008) and fountains (Seigne 2008), but there has been no detailed published study of the whole water management system to the city, such as that conducted at Gadara by Döring (2005) and Kerner (2004). Gerasa was also not included in Döring's regional study of the Roman water supply system of northern Jordan (Döring 2004). Seigne (2004) made some preliminary observations on water supply in the context of the city's hinterland, but provided no new evidence.

Until recently, the Jarash Valley carried a perennial stream, whose base flow was sustained by seasonal rainfall and surplus flows from springs. Flows from many former high-yielding springs have been lessened by a reduction in annual rainfall and the lowering of the water table as a result of extraction from water bores; however, a few springs, including Qayrawān within the ancient city and Tannūr to the south-east, still provide a reasonably reliable water supply for domestic use or irrigation. The main springs in the project area draw on water contained in limestone aquifers in the Upper Cretaceous Ajlun Group, particularly in the Na'ur Limestone member, with lesser flows in lower Wādī Jarash coming from aquifers in the underlying Lower Cretaceous Kurnub Sandstone (Hammouri and El-Naqa 2008: 86). Recent flow rate data from these springs show that they react rapidly to periods of high rainfall, nearly all of which falls in the winter months, with a significantly reduced flow during the summer months (Boyer 2017). It is hoped the study of layered carbonate sediment deposits in aqueducts carrying spring water, using the method described by Keenan-Jones *et al.* (2015) for Rome's Anio Novus aqueduct, will provide insight into spring yields and the quantity of water carried by aqueducts[1].

The archaeological evidence points to human use of major springs in the project area from the prehistoric period onwards. Early or Middle Bronze Age sites have been identified near the springs at Sūf, Birkatayn and Qayrawān in the Jarash Valley, with even earlier (Chalcolithic) use suggested at Tannūr (Glueck 1951: 87) and PPNB use at ar-Riyashi (Hanbury-Tenison 1987: 154) in the Tannūr Valley. Roman-Byzantine structures have been recorded at spring sites at Sūf, ash-Shawāhid, Birkatayn and Qayrawān, and use during the Classical period can be inferred from the existence of nearby settlements at the other major springs in the project area (Boyer 2017).

Qayrawān on the east bank of Wādī Jarash, was an important spring within the walled city, but its low elevation (566 m) limited its potential supply area to the lower east side of the city, and the provision of irrigation water to fields on both banks of Wādī Jarash south of the city. The west bank south of the city was supplied by an aqueduct that crossed Wādī Jarash west of the spring. Most of the city lay above the level of Qayrawān spring, including the western side where many of the water consuming public monuments were located. This means that spring-fed water supplies to the west and upper east side of the city would have needed to come from other sources. The prevailing view among archaeologists since the publications by Schumacher (1902: 167) and Kraeling (1938: 160-162) has been that the Birkatayn spring and reservoir complex north of the city was the principal water source for the city, although little evidence has been put forward to support it. Seigne, however, concluded that the open reservoir at Birkatayn was an unlikely source for the city's potable water supplies, due to its elevation relative to the monuments in the city and issues related to potential contamination. He suggested that the water supply came from another source or sources further upstream (2004: 176-177).

The 2013 field program included a pedestrian survey of selected areas in the valley and hills to the north, south and west of the city, to locate and trace the historic aqueducts to the city and its hinterland, and a preliminary survey of selected areas within the upper Tannūr Valley, to gain an understanding of water management in the rural context. A number of aqueducts were identified approaching the city from the north along both banks of Wādī ad-Dayr, and sections of an important aqueduct approaching the city from the hills to the north-west were traced for

1. Also known as 'calcareous sinter' in Europe (e.g. Sürmelihindi *et al.* 2014: 293) and as 'travertine' in North America (e.g. Keenan-Jones *et al.* 2014: 293).

over a kilometre. Additional aqueducts, which formed part of an irrigation system for the Bāb Ammān locality and the lower Jarash Valley, were also identified south of the city. This work resulted in the construction of a preliminary aqueduct plan for the near-city area (Boyer 2017). A preliminary pedestrian survey of the upper Tannūr Valley failed to identify evidence for major spring sources or ancient aqueduct systems; however, evidence of an aqueduct-fed irrigation system sourced from the Tannūr spring was found in the lower Tannūr Valley. The 2013 results verified that Birkatayn was not the sole water supply source for the water monuments on the west side of the city; in fact, although likely, a direct connection between Birkatayn and the city could not be confirmed. Many uncertainties remained, however, including knowledge of when the main aqueducts to the city were in use, their ultimate destinations, consumption requirements of the main water installations within the city, and the importance of irrigation requirements in the overall water management system. While many of the aqueducts identified in 2013 are probably of Roman-Byzantine date, none have been dated with any confidence, and advancement of this and related issues were considered a high priority for the 2014 field season.

An Outline of Settlement in the Hellenistic-Byzantine Period

The ancient site of Gerasa lies in a fertile, well-watered valley in the eastern ‘Ajlūn highlands in north-west Jordan. There is evidence of prehistoric occupation on the site dating from the Bronze and Iron Ages (Braemer 1987: 525; 1989: 318), with evidence of earlier occupation south of the city in the Bāb Ammān locality dating to the Lower Paleolithic (Kirkbride 1958: 9-11) and Middle PPNB/ Pottery Neolithic (al-Nahar 2013). There is archaeological evidence from many sources for the establishment of a Hellenistic settlement on the site by the end of the 2nd century BC (e.g. Braemer 1989: 318; Kehrberg and Manley 2002: 197); one of a number of similar colonies in the region that formed the Decapolis. There are few locations within Gerasa where excavations reach pre-Roman levels, and many early levels were destroyed in later construction phases, so the size and location of this early settlement is uncertain. Some scholars question whether occupation of the site during the Hellenistic period was permanent (e.g. Pierobon 1984: 31; Raja 2012: 148) or whether occupation was continuous between the Hellenistic and early Roman periods (Lichtenberger 2014: 2067). However, the available evidence points to a settlement centred on the west bank of Wādī Jarash in the area between the Zeus Temple, Museum Hill (= Camp Hill) and the South Decumanus, probably close to an earlier Iron Age settlement, with a necropoleis established on the adjacent slopes of both banks of Wādī Jarash. While cisterns and possibly aqueducts would have been used in the Hellenistic settlement, no water installations of Hellenistic date have yet been definitively identified.

The settlement grew rapidly under Roman hegemony in the 1st and 2nd centuries AD. The naturally terraced landscape of the west bank of Wādī Jarash was remodelled, to accommodate an orthogonal street plan with a principal colonnaded street, the Cardo, and two colonnaded cross-streets, the Decumani. The settlement was divided into two parts by the deeply incised Wādī Jarash, and at least two bridges were built across the wadi to link them. Public bathing complexes (*thermae)* were erected on each side of the wadi and public fountains, including a monumental *nymphaeum*, were established along the Cardo. Very little is known of the Roman settlement on the east bank in the 1st and 2nd centuries AD, which now lies beneath the modern town. However three sites, the large East Baths (Lepaon 2008: 60-65), a high status residence evidenced from mosaic flooring (Kraeling 1938: 351-2), and possibly the monumentalisation of the Qayrawān Spring area (Seigne 2004: 175), all date to this period.

Building activity associated with major public works seems to have largely ceased by the end of the 2nd century AD, but two *balneae* were built in the 4th century (the small East Baths and the Central baths) and two more (the Placcus Baths and the Glass Court Baths) in the 5th century. The appointment of a bishop and the construction of the cathedral indicate the emergence of a significant Christian community in the city by the late 4th century AD, and at least another 21 churches were built in and around the city prior to the Islamic conquest (Darabseh 2010: Table 6.1; Shiyyab 2013).

Objectives of the 2014 Season

The objectives in 2014 were to build on the results from the 2013 field program. There were three main goals: (1) pedestrian field surveys, (2) to collect samples of mortar/plaster and layered carbonate sediment deposits lining some of the water installations, for absolute dating and stable isotope analysis, and (3) a preliminary paleolandscape study.

Field Survey

The field survey was divided into several geographic sectors. A number of possible sites, which had been identified in the eastern part of the walled city from photographic analysis, needed to be ground-checked. North of the city, additional work was required to clarify aqueduct sites on the small plain south of Birkatayn, and the important Birkatayn reservoir site needed to be recorded in some detail; the last published survey of the site being that by Schumacher (1902: 165-171). South of the city, an important complex of rock-cut aqueducts on the west bank of Wādī Jarash in the Bāb Ammān locality (first recorded by the Jarash Hinterland Survey), required more detailed recording and analysis, and a detailed survey of a complex site 1 km south of Jarash was required. Immediately south of the city, the water mill complex near the city's south Watergate also required more detailed recording. More broad-ranging surveys were planned for the area north-west of the city, to locate more sections of the important north-west aqueduct to the city (particularly the location of its source), and east of the city, where further surveying was planned in the lower Tannūr Valley, to record any significant rural springs and water installations.

Sampling

Prior to the 2014 field season, none of the aqueducts which supplied the city had been accurately dated, and a key objective of the 2014 field program was to:

1) Collect representative samples of the mortar or plaster that line many of the water installations for the purpose, ultimately, of establishing a typology of such materials (similar to that already done on buildings within the city (Yaseen *et al.* 2013)) and for dating using C^{14}/ C^{14}AMS isotopic techniques (Al-Bashaireh 2013).
2) Collect representative samples of layered carbonate sediment deposits from aqueducts and other water installations for analysis. There has been considerable success in recent years in the collection of climate proxy data from stable isotope determination ($\delta^{18}O$ and $\delta^{13}C$) and Uranium/Thorium dating of such material in Roman aqueducts (e.g. Sürmelihindi *et al.* 2013). Of particular interest in this regard is site JWP-128 on the north-west aqueduct, recorded in 2013, that contains a layered carbonate sediment deposit indicating perhaps >100 years of use. From the results of this work, the goal will be to date when the aqueduct was constructed and when it went out of use, its destination within the city, and the dating of any events, such as earthquakes, which may have impacted on it. The outcome of this research will benefit other researchers working on water installations within the city downstream of the aqueduct.

Techniques and Methodologies

The survey focused on locating and recording sites related to water management. Methodology was based on:

1) A pedestrian survey of selected areas previously identified from a study of published material, plans, satellite imagery and aerial photography, in order to identify water-related sites from all periods, because dating site elements is problematic, especially when, as in the case of this project, no excavation is carried out. In addition, it is evident that there was reuse of ancient aqueducts in the late Ottoman period, in particular the period post-Circassian settlement.
2) Location of all sites by hand held GPS (WGS84 datum).
3) Recording of all sites, including allocating a unique project site number for each, providing a brief written description, taking colour digital photographs and measurements for site elements, making sketches and entering the information in the MEGA-Jordan database.

Results

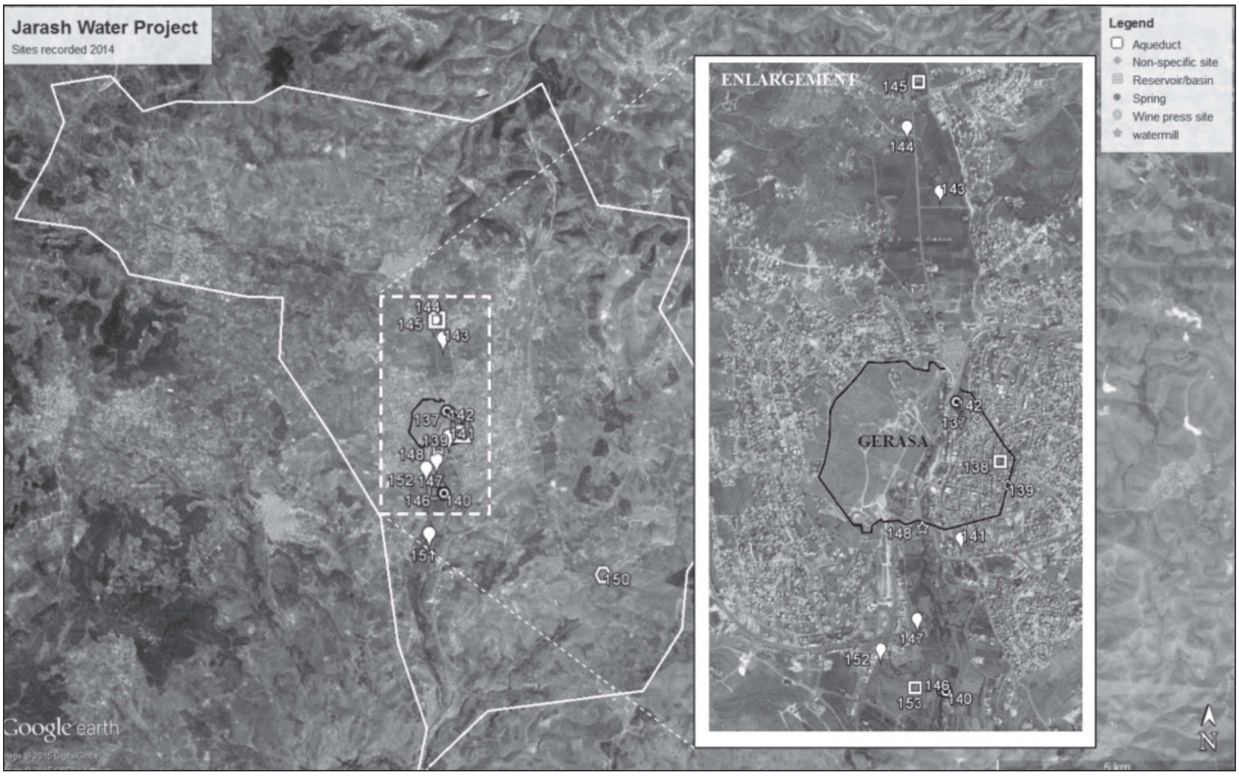
The 2014 field program was conducted for the most part on the areas immediately north, west and south of Jarash, and in the eastern part of the walled city. Visits were also made to the area near the junction of the Wādī Jarash with the R. Zarqā and the Tannūr Valley.

Site Types

Given the focus on water-related structures, only a limited number of site types were recorded. A total of 44 elements were recorded at 17 sites; the breakdown of site type is shown in (**Table 1)** and site locations are shown in **(Fig. 2).**

Table 1: Site Details.

Site No (JWP_)	Lat (N)	Long(E)	Aqueduct	Reservoir-basin-cistern	Wine press	Spring source	Fountain	Mill	Unspec.	Total
137	32.28193	35.89678		1						1
138	32.27964	35.89818		1		1				2
139	32.27839	35.89868							1	1
140	32.26746	35.89436				1	2			3
141	32.27483	35.89572	1							1
142	32.28287	35.89548	2			1				3
143	32.29321	35.89441	1							1
144	32.29659	35.89233	1							1
145	32.29973	35.89307		1		1				2
146	32.26730	35.89463	5			1	1			7
147	32.27053	35.89297	8							8
148	32.27616	35.89334						4		4
149	32.21453	35.89096						1		1
150	32.25209	35.92986		2	1					3
151	32.25667	35.89135	2	2						4
152	32.26892	35.89070	1							1
153	32.26766	35.89286		1						1
Subtotals			**21**	**8**	**1**	**5**	**3**	**5**	**1**	**44**



2. 2014 field season site locations (Don Boyer and Google Earth).

Plaster or mortar samples were obtained from nine sites, and layered carbonate sediment from seven sites. Despite careful search, no suitable sample material could be found at any of the exposed rock-cut aqueduct sites in the Bāb Ammān locality south of the city (sites JWP-146, 147, 152 and 153). The well-preserved section of north-west aqueduct recorded at site JWP-128 in 2013 (Boyer 2017) was found to be more complex when re-examined in 2014. After cleaning, the site was found to contain evidence of a longer period of use than previously suspected, and at least three applications of plaster were evident, the latter indicating repair on at least two occasions. In addition to plaster material collected from the north-west aqueduct, aqueduct plaster samples were collected from *specus* elements at site JWP-143, the masonry aqueduct (DW01) on the plain west of Wādī ad- Dayr. The plaster material at site JWP-143 appears macroscopically to be similar to the uppermost plaster at site JWP-128 on the north-west aqueduct, the mortar samples collected from the Birkatayn reservoir (site JWP-145) and the al-Ḥammām mineral spring site on the R. Zarqā (site JWP-108). This plaster material contains clearly visible charcoal fragments, which should provide an absolute date using the C^{14} dating method.

Geomorphological Setting

No specific landscape studies of the district have been published; however, there is evidence of substantial change to the landscape of the study area over its long settlement history, which spans perhaps >450,000 years BP from the Lower Paleolithic (chronology from Kennedy and Bewley 2004: 11-12). Given that the design and construction of ancient water management systems is in large part a function of the prevailing hydrogeological landscape, (that is, geology, landforms and climate), it is desirable to attempt a reconstruction of this paleolandscape in the period under study.

The most recent comprehensive analysis of the geology within the study area are the notes accompanying the geological map of the area by Abdelhamid (1995). This provides useful basic information on the Cretaceous stratigraphy, which also informs the work by more recent authors on the area's hydrogeology (e.g. Hammouri and el-Naqa 2008), but only limited commentary on the Quaternary stratigraphy and the local geomorphology. The bulk of the study area forms part of a dissected limestone plateau predominantly comprised of flat lying limestone and marl formations of the Upper Cretaceous Ajlun Group. The Jarash Valley has been incised into the Cretaceous stratigraphy, sequentially exposing the entire Ajlun Group sequence and the upper part of the underlying Lower Cretaceous Kunub Sandstone downstream from Sūf.

Field surveys during 2014 identified a previously unrecognised sequence of conglomeratic sediments of probable Pleistocene age within the Jarash Valley, together with a waterfall tufa deposit within the ancient city. A detailed investigation of these conglomeratic and tufaceous sediments is needed, but beyond the scope of the present study; however, some preliminary conclusions may be drawn, which have a bearing on the understanding of the palaeoenvironment and the water management system in the period being studied.

Jarash Conglomerate

A previously unrecognised fluviatile conglomerate formation, informally named 'Jarash Conglomerate' in this report, has been identified by the author during geological surveys of the Jarash Valley between Khirbat ash-Shawāhid to the north and Bāb Ammān to the south; the unit has not yet been studied outside of this area. The basal contact of the unit is exposed at site JWP-142, in a cave just north of Qayrawān Spring (hereafter Qayrawān Cave), where the Jarash Conglomerate lies disconformably on a weathered karstic surface of probable Na'ur Limestone. In the immediate Jarash area, the weathered, uppermost surface of the formation is a hard crust of hardpan calcrete known locally as *nāri*, generally up to 3 m thick, which forms a plateau-like surface incised by modern drainages, and with recent alluvium and colluvium occupying depressions in its surface[2]. The undulating geomorphology of the hardpan calcrete suggests that it may

2. Calcretisation is the precipitation of calcium carbonate in a regolith profile, through the introduction of calcium carbonate in solution and removal of CO2 through various agencies (Chen *et al.* 2002: 9). The process occurs near-surface in soft material (Itkin *et al.* 2012: 223). The process results in various morphological types, with well-indurated 'hardpan calcrete' (Chen *et al.* 2002: 12) being a common form in the study area. Itkin *et al.* (2012: 223) point out that nāri s.s. is a term that relates to calcrete associated with chert.

represent a fossil water table. Hardpan calcrete can be difficult to distinguish from Cretaceous limestone bedrock, which is probably why the unit was not distinguished in regional geological mapping (Abdelhamid 1995), but the conglomeratic fabric is readily identifiable where exposed in caves and tombs below the calcretised crust. Calcretes in the project area have not been dated, but a regional calcretisation event in the Levant has been dated to the late Pliocene-mid Pleistocene (Itkin *et al.* 2012: 223-4).

The Jarash Conglomerate is a variably indurated, unsorted, polymictic sediment, containing clasts of limestone and subordinate chert and flint. Clast sizes are highly variable, and range up to 1 m. Sedimentary structures, clast size and fabric all point to fluviatile deposition, probably as debris flows (Costa 1984: 268), in a high-energy environment (**Fig. 3**). The formation was deposited on an eroded and irregular paleosurface, so its thickness varies, and there are probably multiple depositional phases. The most extensive exposure identified to date is at Bāb Ammān, where a *ca.* 40 m thick section is exposed on the west bank of the wadi and on top of the low hill which lies east of Hadrian's Arch. In aerial photographs, the low hill can be seen to form the crest of an oval shaped plateau (hereafter the Bāb Ammān plateau) oriented north-south, with its southern end forming a spur between Wādī Jarash to the east, a small wadi to the west and Wādī Bāb Ammān to the south.

The age of the Jarash Conglomerate is uncertain. However, the preliminary view is that it is likely be contemporaneous with the Dauqara Conglomerate in the upper R. Zarqā area, 12 km south-east of Gerasa, which is dated to the Lower-Middle Acheulian period of the Lower Pleistocene, around 0.9-1.0 my BP (Parenti *et al.* 1997: 19), and/or the lower conglomerate member of the Ṭabaqat Faḥl Formation near Pella, dated to the Middle Acheulian (Macumber and Edwards 1997: 34). Macumber and Edwards believe the lower conglomerate member of the Ṭabaqat Faḥl Formation probably correlates with the Dauqara Formation. Acheulian lithics were found on the surface of the western and southern slopes of the Bāb Ammān plateau in the 1940s and 1950s (Kirkbride 1958: 9-10): they include one example of Middle Acheulian date, placing it in the Lower Paleolithic (>450,000 – 150,000 BP). These surface finds may have been eroded from the conglomerate, as is the case of the Middle Acheulian lithics recovered from the Dauqara Conglomerate in the upper Zarqā Valley (Parenti *et al.* 1997), or accumulated on the already calcretised surface at a later date.

Tufa

A *ca.*_12 m high deposit of freshwater waterfall tufa is exposed on the east bank of Wādī Jarash, between the South Bridge and the south Watergate, and forms an apron-shaped terrace approximately 200 m long which projects into the modern valley (**Fig. 4**)[3]. The

3. Bāb Ammān: Section of Jarash Conglomerate exposed in cave (scale 2 m) (Don Boyer).

4. 12 m high scarp of waterfall tufa on the east bank of Wadi Jarash, south of South Bridge (Don Boyer).

3. There is no universally accepted term for calcium carbonate deposits precipitated from cool or ambient temperature freshwater sources, and the term 'tufa', as described by Ford and Pedley (1996: 117-118) is used in this paper. The term 'travertine' is sometimes used for such material; however the author restricts this term to describe freshwater calcium carbonate precipitated from thermal/hydrothermal waters, as described by Ford and Pedley (1996: 117-118).

margins of the tufa deposit are obscured by the modern town; however, the visible dimensions point to accretion over a lengthy period. The only published comment on this formation is a brief note by Vita-Finzi (1964: 22). The original water source is unknown, but may have been a spring contemporaneous with Qayrawān Cave spring. The depositional date of the Jarash tufa has yet to be determined.

Paleolandscape

The working hypothesis is that in the early Paleolithic, the floor of the Jarash paleovalley, including the area later occupied by the ancient walled city, was filled with a sequence of fluviatile conglomerates following the onset of a pluvial or interglacial period. In a later, drier phase, after a period of erosion, the near-surface portion of the unit was strongly calcretised to form hardpan calcrete. Subsequently, pluvial conditions returned and the plateaued surface of the Jarash Conglomerate was modified by landslips and the incision of the modern Jarash Valley.

Within the walled city, the creation of the terraced area that extends from the Qayrawān Cave to the south city wall on the east bank, and the wadi-like depression in the city's north-west quarter on the west bank, probably date to this erosional period. Given the steep slopes and scarps that exist on the hillside above it, this gently sloping terrace with large adjacent springs would have been an obvious location on which to build a settlement on the east bank. It is here that the Circassian village was established in the late 19th century and, from the available evidence, it was where most east bank buildings in the Greco-Byzantine were built. However, Iron Age I sherd scatters on its surface (Braemer 1992: 198) indicate even earlier human activity on the terrace. A spring line was created at the contact between the Jarash Conglomerate and the underlying Na'ur Limestone in the area south of Qayrawān Cave at the foot of a low scarp on the eastern edge of this terrace. Colluvium and modern housing now obscure this contact, and Qayrawān Cave spring is the only visible remnant of this ancient spring line system that probably tapped an aquifer in the adjacent Na'ur Limestone. Spring flow onto the terrace south of Qayrawān Cave deposited tufa that eventually formed the prominent waterfall tufa apron terrace visible today in the city on the east bank south of the South Bridge.

The terrain inside the walled city in the Greco-Roman period would have had a distinct terraced appearance, with the terrace treads separating calcrete scarps up to 5 m high, which were utilised as tomb sites from the Hellenistic period onwards. Over the centuries, the accumulation of colluvium and slope wash has modified the landscape to the smoother profile that we see today.

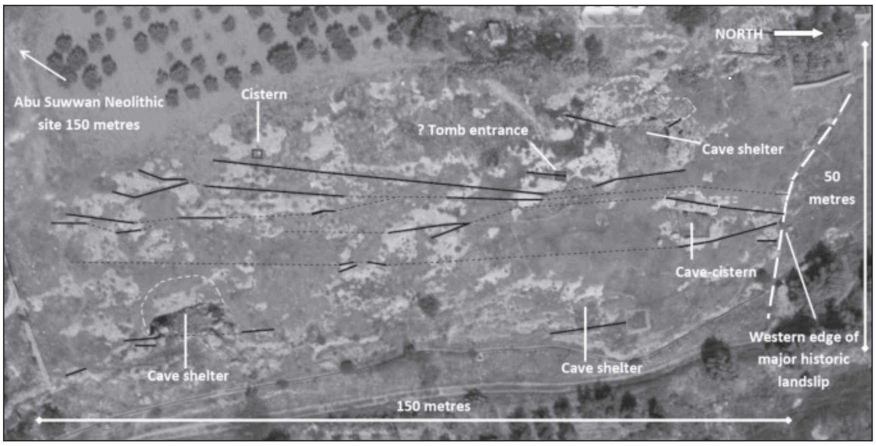
Aqueducts

Half of the site elements recorded during the survey were aqueduct components. The aqueducts fall into three groups.

(1) Masonry construction; with a 'U' shaped canal or *specus* cut into a dressed limestone block. There is some variation of the size of the *specus*; the major masonry aqueduct (DW01) of likely Roman-Byzantine date, which crosses the valley floor to the west of the bed of Wādī ad- Dayr was constructed of dressed limestone blocks up to 1000 mm long, 800 mm wide and 700 mm high. A *specus* 300-450 mm wide and 300 mm deep has been cut into these blocks (site JWP-143 (**Fig. 5**). A single block from the Qayrawān aqueduct in the eastern part of the city has the same dimensions (site JWP-141). There were also blocks with a smaller *specus* width (150-200 mm) associated with aqueduct DW01, which are interpreted to be from side canals supplying local agricultural users in the valley.

(2) Rock-cut construction; the canal is cut directly into bedrock. This is the most common form of construction. Although single canals

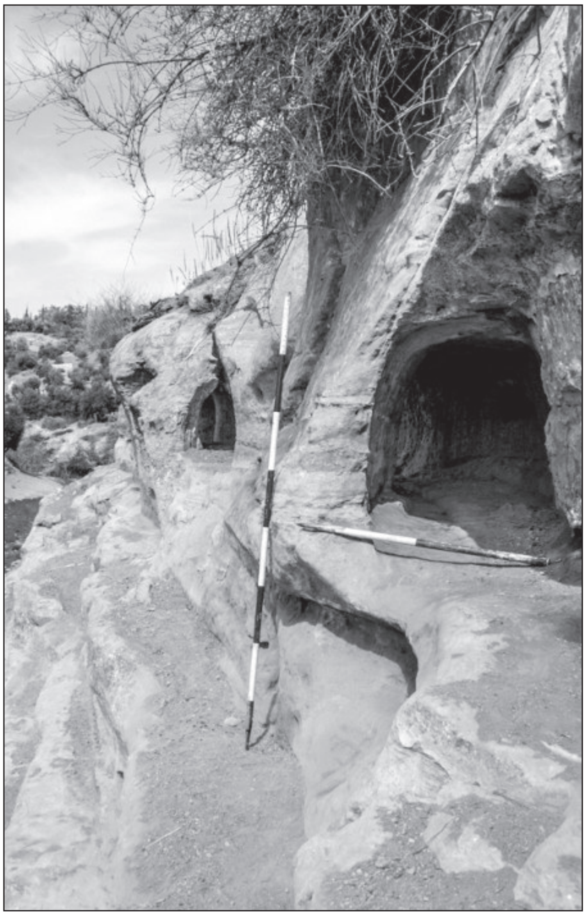
5. Site JWP-143: Blocks from masonry aqueduct DW01 (scale 2 m) (Don Boyer).



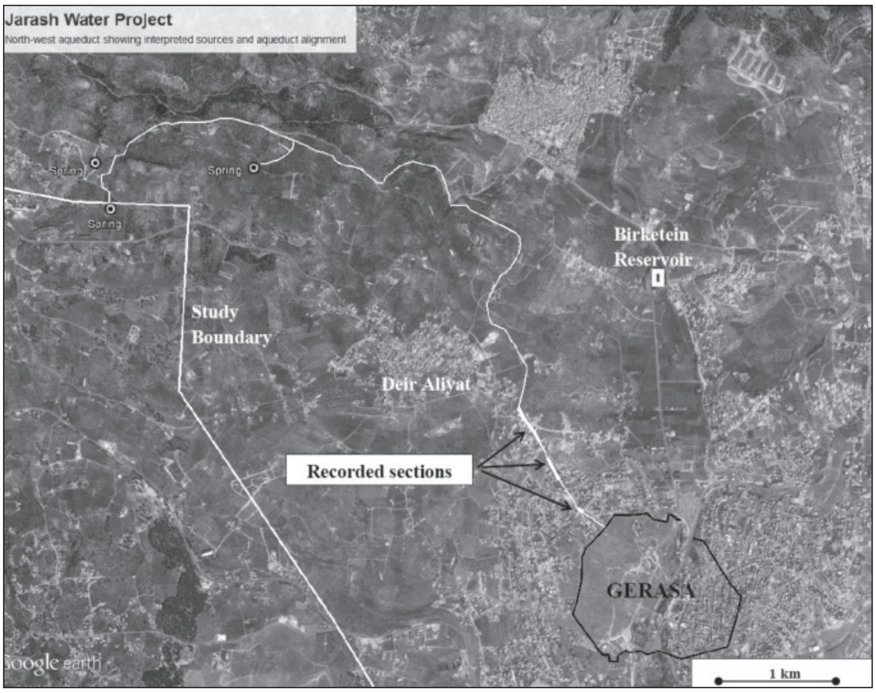
6. *Site JWP-147, Bāb Ammān: Aerial photograph of a group of rock cut aqueducts on the eastern slope of Bāb Ammān plateau (Photo: APAAME).*

exist (examples include sites JWP-144 and 151), there are also examples of canal clusters. At site JWP-147 on the eastern slope of Bāb Ammān plateau, up to eight rock-cut canals are cut into the exposed surface of hard, calcretised Jarash Conglomerate, on a 20 degree slope over a distance of 150 m. They are arrayed over a vertical interval of 7-10 m (**Fig. 6**). The northern (upstream) continuation of this aqueduct complex is abruptly terminated by a small 2-3 m high scarp, which represents the northern edge of a large historic, but undated, landslip some 200 m in length along the west bank of the wadi. This means that the aqueducts at site JWP-147 cannot be traced directly back to their source, which is believed to be a spring located at the northern end of the Bāb Ammān plateau, 350 m north of site JWP-147. At site JWP-146, at least three canals have been cut into outcropping Kurnub Sandstone directly beneath the main tunnel aqueduct (see below) on the east bank of Wādī Jarash. The relative age of the canals with respect to the upper tunnel aqueduct is unclear, but the lower tunnel aqueduct at the northern end of the sandstone outcrop appears to postdate the rock-cut canals.

(3) Tunnel construction; two examples were recorded in 2014, both cut into Kurnub Sandstone at site JWP-146 1 km south of Jarash. The longest is a 100 m long section cut into the edge of the sandstone cliff, and was first recorded by the Jarash Hinterland Survey (site JHS-666; Baker and Kennedy 2011: 459). The tunnel is typically 1.0 m high and 0.7 m wide, with a gutter cut into the floor, and is the highest of a series of at least three aqueducts cut into the west-facing rock face (see **Fig. 7**). The water source for the tunnel aqueduct is uncertain. The second tunnel element is at a slightly lower elevation, and is located at the northern end of the sandstone outcrop. It has a similar cross-sectional profile and appears to post-date the rock-cut canals cut into the outer face of the outcrop. The supply source for this aqueduct is also unknown, but lay to the north of the site.



7. *Site JWP-146: 3 canals cut into the rock face below the tunnel aqueduct (vertical pole 2 m) (Don Boyer).*

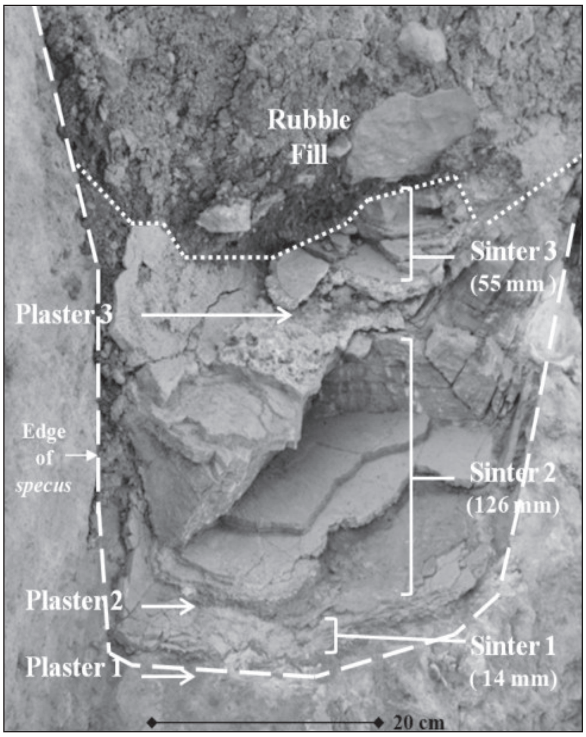


8. North-west aqueduct: trace of aqueduct from source to city (Don Boyer and Google Earth).

North-West Aqueduct

At the conclusion of the 2013 season, the source of the north-west aqueduct to the city was uncertain. Further analysis of early aerial photographs has been conducted, and two probable sources have been identified in the hills between Sūf and Dayr al-Layyāt, including a source that was visited in 2013. A total of seven sites on this aqueduct have been recorded, and the likely trace of the aqueduct is shown in the updated preliminary aqueduct plan of the area (**Fig. 8**).

Site JWP-128 on the north-west aqueduct, recorded in 2013 (Boyer 2017), was revisited and recorded in more detail. The aqueduct at this site is cut into limestone bedrock, and lies buried beneath 2 m of material that was deposited after it went out of use; this has preserved many original features that allow its history of use to be considered in some detail. The floor of the aqueduct has a gradient of 12%. The record of plaster deposition preserved in the *specus* shows three separate plaster applications (**Fig. 9**). Plasters 1 and 2 appear macroscopically similar, and are separated by a thin layer of laminated carbonate sediment, indicating a relatively short time interval between plaster applications. There is a thick section of carbonate sediment between Plaster 2 and Plaster 3, and the composition of these two plasters appears macroscopically different. The *specus* cross section is much reduced after Plaster 2, indicating a significantly reduced flow rate and sometime later, after a further period of water use, flow ceased entirely, and



9. North-West Aqueduct: Site JWP-128, showing canal construction detail and alternating layers of plaster and carbonate sinter (photo by Don Boyer).

the *specus* was filled with soil and rubble. It is anticipated that C^{14} dating of the plaster will yield absolute dates for the initial plaster application and the two subsequent plaster repairs, which will constrain the chronology of aqueduct flow history represented by the carbonate sediment layers. This aqueduct delivered water to a point close to the North West Gate of the city; however, this gate has not been excavated and the aqueduct's point of entry is not visible. Interpretation of early aerial photographs suggests that the aqueduct delivered water to one or more reservoirs located just inside the wall, before continuing eastwards down slope along the upper edge of a limestone scarp in the city's north-west quarter. The city's north-west quarter is now the subject of an ongoing archaeological study by the Danish–German Jarash Northwest Quarter team that is yielding valuable results, including the first absolute dates from water installations in this area. Mortar from a pressure water pipe excavated on the hilltop inside the city has been dated to 3rd/4th century AD (Lichtenberger *et al.* 2015: 125-Site E). There is no known direct connection between the water pipe and the large rock-cut cistern 150 m to the south near the Synagogue Church, which has a history of use ranging from the 2nd/3rd century AD to the 6th century AD (Lichtenberger *et al.* 2015: 125).

Reservoirs/Basins

Birkatayn

The study included a taped survey and the recording of key elements. The taped survey was necessary because the oft-quoted measurements of 43.5 m x 88.5 m published by Kraeling (1938: 162) lack clarity. The survey demonstrated that these are internal measurements that include the dividing wall between the two compartments, which needs to be taken into account when calculating the effective volume of the compartments. The outer wall of the reservoir is not perfectly rectangular in shape, which perhaps accounts for the variations in published figures; Hawamdeh *et al.* (2015: 3667) for example, report a width of 45.88 m and a length of 89.55 m.

The two-compartment reservoir as viewed today includes some masonry in its original position (generally the lower 2-3 courses), with the balance placed during the 'restoration' that was carried out by the Jordanian army in the 1960's. Although the reservoir floor is currently obscured by rubbish and rubble, it is clear that the south-west corner of the northern compartment was built on limestone bedrock, and evidence from a recent geophysical survey suggests that limestone bedrock may directly underlie the whole reservoir (Hawamdeh *et al.* 2015: 3671). No detailed instrument survey has yet been carried out, but analysis of recent photographs taken when the reservoir was partly full, show that there has been subsidence at the east end of the northern wall, and also of the southern end of the eastern wall, that may date to antiquity. A complete review of the structure is in progress, based in part on the analysis of photographic material published by Schumacher (1902) and largely unpublished material dating to the 1930's in the archives of the Yale Art gallery.

Analysis is incomplete but some preliminary conclusions may be drawn. There is historical evidence that the perimeter wall height may have been close to 4.5 m, which raises the theoretical maximum effective capacity to *ca.* 18,000 m^3 after allowing for the dividing wall, making it one of the largest reservoirs in the Decapolis of northern Jordan after the Jizah reservoir (68,180 m^3) and Umm al-Quṭṭayn 1 reservoir (19,765 m^3) (Kennedy 1995: Table 1). The reservoir is fed from one or more nearby springs *via* inlets at the base of the west and north walls in the northern compartment. The spring source is not visible, but is presumed to lie between the north wall of the reservoir and the Tomb of Germanus. Water was delivered from the source to the northern end of the northern compartment via a canal that is visible in a small underground walled cavity immediately adjoining the north wall. Evidence at the base of the north-eastern end of the northern compartment suggests that water was delivered from the spring supply canal to the basal masonry course in the north wall of this compartment *via* ceramic pipe(s), with an internal diameter of 0.14 m, set in mortar and then into the reservoir compartment *via* vertical slots between face blocks in the masonry wall. The mortar appears to have partially replaced masonry in the lowest course in the northern wall and this arrangement may reflect the general system that supplied water to the northern reservoir compartment through this wall. The removal of the softer mortar as a result of water erosion would account for the cavities visible behind the basal face blocks in this wall at several locations, and provides a possible reason for the subsidence of the north wall already mentioned. While no evidence of water pipes or mortar was found behind the lower masonry course in the west wall of the northern compartment, the existence of large cavities up to 2 m deep behind the lowest masonry course, and the presence of vertical slots between face blocks similar to those in the north wall, suggest that the same water delivery system applied to the west wall.

Water could be drained from the northern compartment via outlets in the eastern wall and the dividing wall**.** Dating of a mortared repair to a water outlet in the north wall and of the mortar surrounding the ceramic pipe described above may clarify the date of construction, considered by Seigne to predate repair work on the nearby Gerasa-Adraa road that is dated to the Trajanic period (Seigne 2004: 177).

Large Cistern in Gerasa's North-East Quarter

Site JWP-137 was identified from analysis of 20th century photography as a possible water installation, based on its dimensions and location on the highest point in the eastern part of the city. It lies 20 m inside the north wall of the city, on top of a tongue-shaped spur at the southern end of Tall Jarash that extends into the walled city, and has views to the south over the eastern part of Jarash and the lower Jarash Valley. Modern housing and gardens now occupy the site, and the oldest observable walls are probably of Ottoman date. A large, rectangular walled structure approximately 31 m x 17 m and aligned east-west is clearly visible on many pre-1930 aerial photographs of Jarash, and a later ground photograph taken by Glueck shows it in more detail (**Fig.10**). The inside of the north wall has a number of variably spaced slots or niches, which may be the location of springers for arches of a vaulted roof; the structure would have been partially above ground. There are no visible signs of an entrance in any of the walls in the Glueck photograph, nor is there any sign of an apse, so the building was unlikely to have been a Christian church. The structure is strong, well-constructed and built of coursed masonry, with some blocks estimated to be 1 m in length. A possible analogue is the urban reservoir at Tiberias (of probable Byzantine date), which has surface dimensions of 32 m x 9.6 m and a depth of 6 m (Winogradov 2002), and a capacity of around 3000 m^3. Large cisterns are located on equivalent high points on the west side of Gerasa, the largest being the rectangular rock-cut reservoir or cistern of Roman-Byzantine date on the hill above the Artemis temple complex

10. Site JWP-137: Possible reservoir or cistern? Historic photograph showing a well-built masonry structure on hilltop (photo © ASOR Nelson Glueck Collection: c027Jerash019).

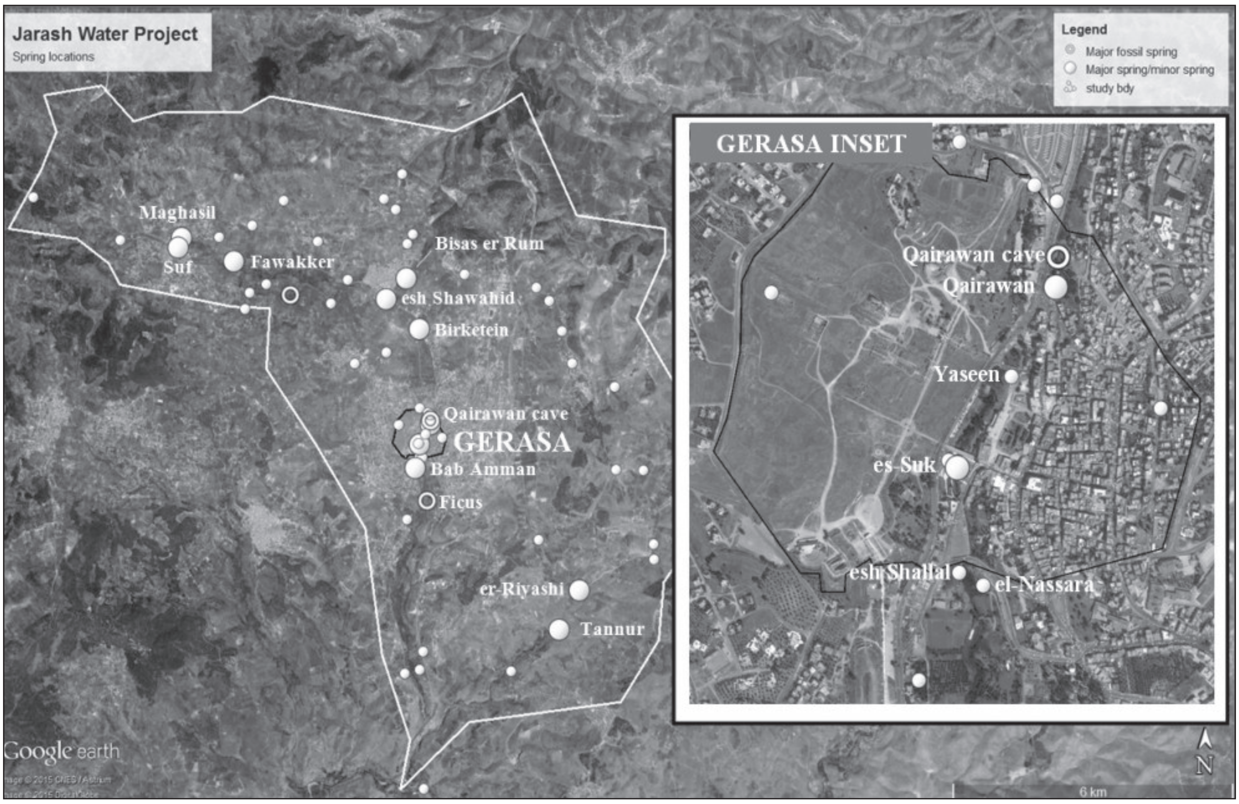
(Lichtenberger and Raja 2014: 643); which, taken together with the size and robust nature of the construction, leads to the conclusion that the structure in Glueck's photograph is a large reservoir or cistern with a capacity >1000 m^3.

The area of the interpreted cistern at site JWP-137 is now occupied by houses and gardens. Inspection revealed a number of interesting architectural fragments and components, said by the residents to have been found locally, including fluted columns, small arched structures (possibly from doorways or windows) and an altar rail colonnette. Additional column fragments were noted in a property 20 m to the south, and tesserae are reportedly common in the immediate area. These are all believed to have come from a second ruined building, no longer extant but clearly visible in the early aerial photographs, which may have been a church. Round hypocaust tiles 21-25 cm in diameter were also noted in the gardens and had reportedly also been used to infill holes in a section of the city wall that forms the boundary of one of the properties. The source of these is unknown, but the high status 2nd or 3rd century AD Roman building identified from an exquisite mosaic discovered under a Mudir's house in the early 20th century (Kriseleit 1984) and located <200 m to the southwest of site JWP-137 is one possibility.

Sources (Fig. 11)

Fossil Spring Sites

Major ancient fossil spring sources were identified at two locations. The northernmost site, JWP142, is associated with Qayrawān Cave 60 m north of the current Qayrawān Spring at an elevation close to 580 m, approximately 14 m above that of Qayrawān spring. Within the cave, prominent spring outlets lie at the contact between Jarash Conglomerate and underlying Na'ur Limestone. Other fossil spring outlets are evident at various points in the cliff face above and adjacent to the cave, at and above the level of the limestone contact. The size of the outlets suggests high discharge rates which, given the high elevation of the site and the perched nature of the water table, points to wet climatic conditions. The central outlet in the cave has the remnant of a 1 m high plaster facade constructed over it (**Fig. 12a**). The facade is poorly preserved and the original



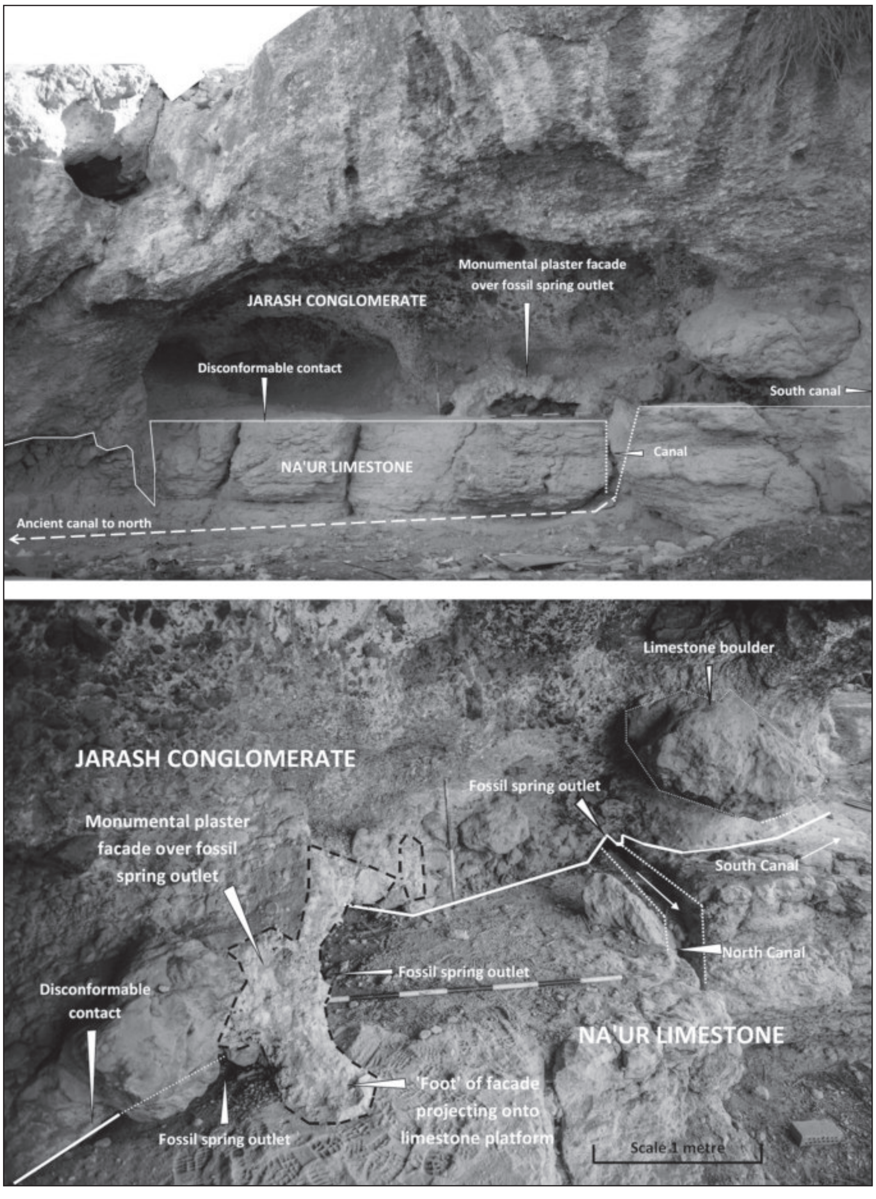
11. Spring locations within the project area (Don Boyer and Google Earth).

shape cannot be accurately discerned; however, the shape of the projection of the northern end of the facade onto a limestone platform facade is reminiscent of the paw and leg of a lion when viewed from the north (**Fig. 12b**). There is evidence of a plastered rock-cut canal leading from the southernmost outlet in the cave to the south, which was later cut by another rock-cut canal that carried water along the base of the conglomerate cliff to the north. To the south of the cave, it is likely that a spring line developed along the conglomerate/limestone contact.

The plastered facade around the main spring outlet in Qayrawān Cave represents a modest level of monumentalisation when compared with the more substantial monumentalisation of Qayrawān Spring 60 m to the south, dated tentatively to the 2nd century AD (Seigne 2004: 175). The Qayrawān Cave spring site is probably one of the two springs mentioned by John Fuller, an English traveller who visited Jarash in October 1819.

"Crossing the bed of the stream, which was now dry, we soon arrived at a pool of water overhung with fine shady plane-trees (sic) and surrounded by various plants and shrubs. It is supplied from two springs, at both of which are considerable remains of ancient buildings and some blocks of marble." (Fuller 1830: 336).

Fuller's description indicates that the spring



12. *(a) Site JWP-142: View of Qayrawān Cave from the west, showing monumentalised fossil spring outlet and the disconformable contact between Jarash Conglomerate (?Pleistocene) and underlying Upper Cretaceous Na'ur Limestone, (b) View from inside Qayrawān Cave looking south, showing detail of plaster facade and canals (photos by Don Boyer).*

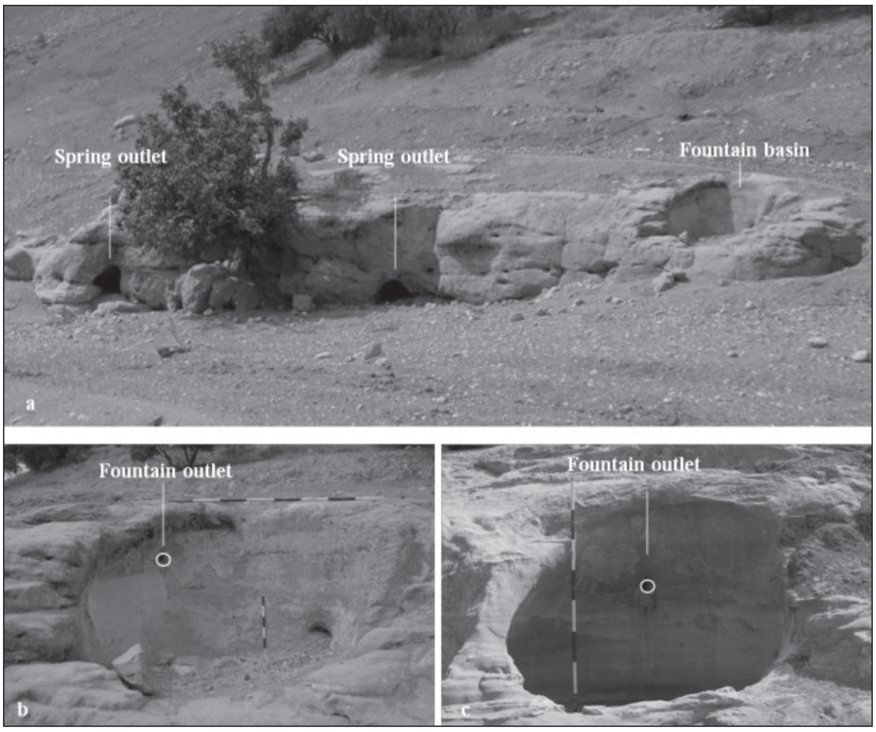
was still flowing in the dry season of 1819 and that there were buildings at the site. At this stage, the possibility that Qayrawān Cave spring and the nearby Qayrawān Spring formed part of a single complex or sanctuary cannot be discounted.

The second major fossil spring site is located 1 km south of the city in the Bāb Ammān locality, where there are substantial outcrops of Lower Cretaceous Kurnub Sandstone. The site spans the bed of Wādī Jarash at one of its narrowest points. It was recorded as two sites; JWP-140 on the west bank and JWP-146 on the east bank (informally named 'ficus springs'). A major fossil spring site is evident on the west bank, with multiple spring outlets close to the current ground level of a wadi terrace (**Fig. 13a**). The east-facing surface of the outcrop shows evidence of tufa deposition. A well-preserved hemispherical fountain basin with a diameter of 2 m has been carved into the face of the outcrop at its northern end (**Fig. 13b**), and a less well-preserved example is located at the southern end. Site JWP-146 on the opposite (eastern) bank of the wadi presents a similar picture, except that the sandstone outcrop is more imposing, being approximately 12 m high and with a prominent tunnel aqueduct cut into the upper edge of the cliff. One and possibly two hemispherical fountain basins have been cut into the sandstone outcrop midway up the slope. The best exposed basin has a width of 2 m and a height of 2 m, with a 0.35 m high lip forming the front of the basin and a small, circular water outlet located roughly midway up the rear wall. The installation is roughly hemispherical in plan and section; an almost identical installation is located 65 m to the south east at site JWP 146 on the east bank. (**Fig. 13c**).

The survey of sites JWP-140 and 146 identified two distinct groups of components; a network of aqueducts of different ages, including the only known examples of tunnel aqueducts in the immediate Jarash area, coming from an unknown source upstream, which carried water for probable irrigation use in the Jarash Valley downstream, and a group of spring sources and rock-cut fountains which may have formed part of a rural water sanctuary. The fountains appear to be unique in the Jarash area. No large settlements are known in the vicinity; however, the Abu Ṣuwwān MEGA-Neolithic site lies 250 m to the west.

Other Spring Sites

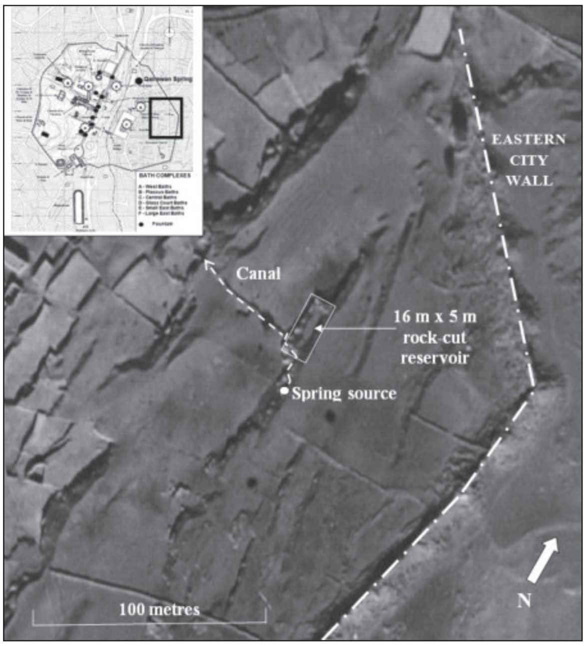
In antiquity, the lower east side of the city below 566 m elevation would have been supplied



13. *(a) Site JWP-140, showing ancient spring sources and fountain on the west bank, (b) Site JWP-140, showing detail of fountain basin, (c) Site JWP-146, showing detail of fountain basin (photos by Don Boyer).*

from Qayrawān Spring, and it is known that the small Byzantine Baths, and probably the large East Baths, were supplied from this source. This leaves the greater part of the eastern side of the city without an obvious spring supply. This problem may have been resolved by the identification of two new springs; firstly by the Qayrawān Cave spring (site JWP-142) at 580 m elevation described above, and secondly by a source high on the eastern slope of the city, located approximately 90 m west of the east wall of the city at an elevation of around 604 m (site JWP-138). Early photographs show that the spring flowed from a source on the upper slopes into a rock-cut basin with a capacity of *ca.* 150 m^3 (**Fig. 14**). The spring was still flowing as recently as the late 1920's and is likely to be a spring described by Burckhardt, who noted during his visit in 1812 "a stream of water descends from a spring in the mountain, and after flowing through this division of town, passes this building (East Baths), and empties itself in the river" (1822: 262).

Visits were made to spring sites in the Tannūr Valley, but recent agricultural activities either mask or have largely destroyed the spring-fed irrigation systems visited and described by Jean Sapin in the 1990's (1998: 112-113). Only the spring-fed irrigation system immediately downstream of Tannūr spring is in any way intact.



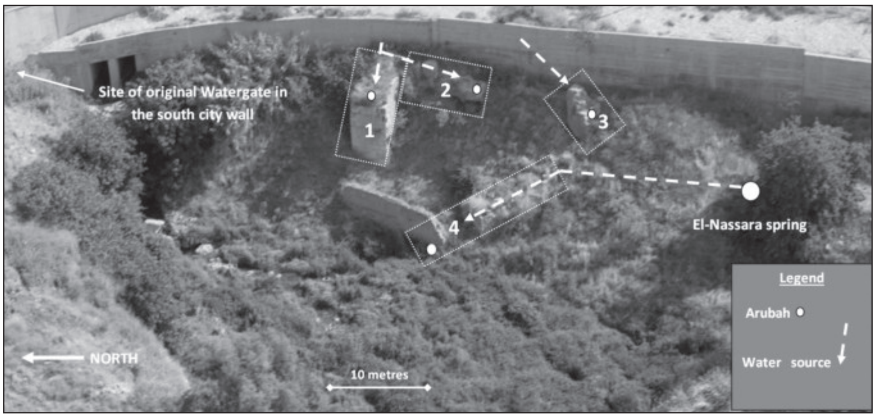
14. Site JWP-138: Spring and basin site, east side of city (Boyer 2016).

Water Mills

The combination of suitable terrain, perennial wadi flow and abundant springs explains why water milling was a feature in a number of the well-watered valleys in the Ajlun district (Liwa Ajlun) during the Ottoman period, including 'Ajlūn, Kufranji and Jarash, as reported in the 1597 Ottoman census (Hütteroth and Abdulfattah 1977: 162-164). The ruins of penstock (*arubah*) water mills in the Jarash Valley are testament to the importance of water milling in the late Ottoman period, and many more can be discerned in early plans and photographs, including a number on the banks of Wadi Jarash within the walls of the city. This type of mill, also known as "Greek" or "Norse", drives a horizontal mill wheel (McQuitty 1995: 746). There is mention of water milling being an activity in an otherwise virtually deserted Gerasa by the Arab geographer Yāqūt in the 13th century (Le Strange 1890: 462); yet, despite the wadi banks within the city providing optimal locations for water mill construction, the earliest attested example of a water mill in the Jarash Valley is the 6th century AD water-driven stone saw discovered in a room in the Artemis complex (Seigne 2002). From its location on the western hillside, this mill must have been supplied from a spring source.

While many of the mill ruins in the district are known to be of late Ottoman date from photographic or written records, none have yet been excavated, and it was decided to include mill sites in the current study, as it is possible that mills from the later Mediaeval and Ottoman periods were built on the foundations of earlier mills that date from the Roman-Byzantine period. Schumacher (1902: 119) mentions water mills from the 'Arabic period' in the valley north of Jarash, but provides no more detailed description other than they had wide water races.

Two mill sites were recorded in the 2013 field season (Boyer 2017) and a further two were recorded in 2014 (JWP-148, 149), by far the most significant being the water mill complex located immediately south of the city's south watergate at site JWP-148 (**Fig. 15**). Three separate mill penstocks have been identified in the complex at site JWP-148, west of the modern road; a fourth is inferred and a possible fifth



15. Site JWP-148: Aerial view of watergate mill complex, showing the 4 mills identified and their sources (photo by Don Boyer © APAAME_20130428_DDB-0373).

has been identified from historic photographs, but now lies beneath the modern road to the east, making this by far the largest known mill complex in the Jarash Valley. The sites of most of the mill buildings associated with them are no longer visible. The penstock of Mill 1 is of well-built masonry and is very similar in size and construction to the mill immediately east of the city's North Gate (JWP-136; Boyer 2017). It was probably one of the last of the mills to be operating in the late Ottoman period. A detailed 1:500 scale plan (SE B1) in the Yale Art Gallery archives shows that this mill, and possibly adjacent Mill 2, was supplied via a canal that brought water from the wadi stream near the south Watergate. The inferred penstock of Mill 2 is entirely buried beneath a thick deposit of tufa and is not visible. The source for Mill 3 is uncertain, but is likely to have been the as-Suk spring near the South Bridge. Mill 4 is unusual in that it was sourced from an-Nassara spring lying 20 m to the south of the mill complex. This spring is at a lower elevation than the sources for the other mills, and whereas the water races (water delivery canals) for the other mills were roughly horizontal, the water race for Mill 4 appears to have sloped, and delivered water to the top of a penstock that lies at the foot of the slope and close to the current wadi bed. Given that penstocks are typically 4-8 m high, this means that the base of the penstock for Mill 4 (and the mill house at its base) must lie at least several metres below the current level of the wadi bed. The low elevation of the penstock base, the sloping water race design and different source for Mill 4 all point to this being the earliest mill on the site. The water race and the masonry walls supporting it are covered by thick tufa deposits, indicating water flow over an extended period. It is hoped that C^{14} dating of mortar in the water race wall will clarify the date of construction.

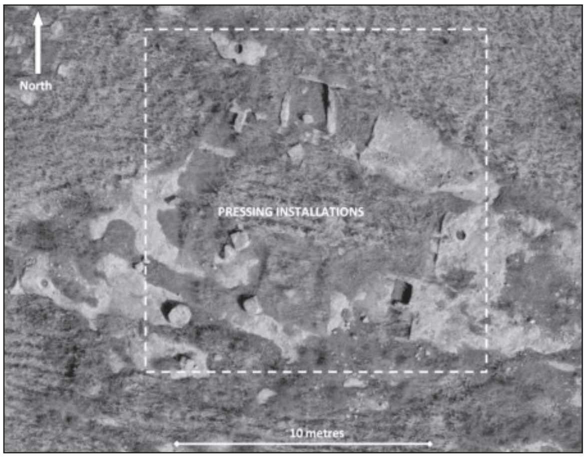
Wine Presses

A large wine press site (site JWP-150) was recorded on the site of Khirbat 'Ayn Riyashi in Wādī Umm Qanṭarah; the site had been previously identified in APAAME aerial photographs in 2013. The installation has been cut into the limestone surface on a south-west facing slope on a terrace north of the spring. The main installation covers approximately 100 m^2 and, although partially covered with slope wash, several pressing floors and plastered vats are visible (**Fig. 16**).

Sherds and Lithics

Site JWP-150: Kh. 'Ayn Riyashi

Flint lithics were found scattered in the slope wash that covers portions of the rural



16. Site JWP-150: Aerial view of Kh. 'Ayn Riyashi wine press installations (photo by Don Boyer © APAAME_20130428_DDB-0212).

installations, sourced from a site upslope to the north in an area where PPNB lithics had previously been recorded (Hanbury-Tenison 1987: 154). Selections of flints are shown in (**Fig. 17**).

Sites JWP-152-153: Bāb Ammān

These lie adjacent to the Abū Ṣuwwān MEGA-Neolithic site, and extensive flint scatter was found at both locations.

Site JWP-147 Bāb Ammān

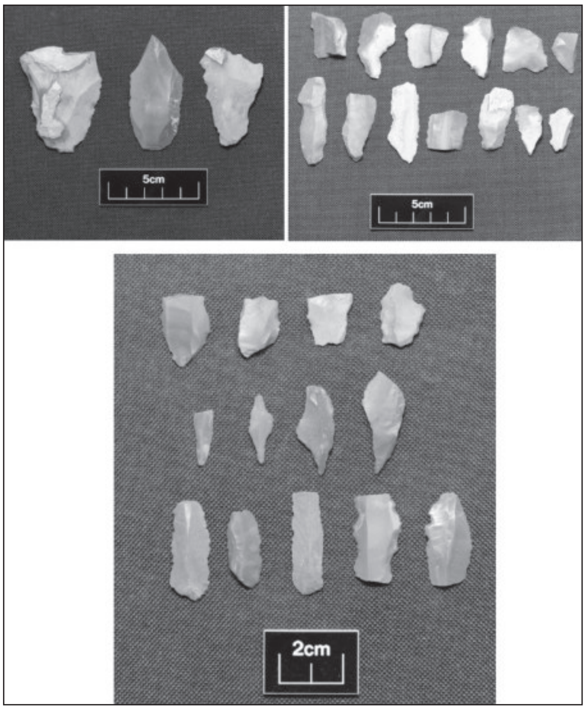
A concentration of sherds was found towards the top of the slope. The site is covered by a veneer of slope wash, and it is presumed that the sherds come from looted tombs on top of the Bāb Ammān plateau. The material has not yet been assessed.

Materials Sampling

Samples were collected from a total of 10 sites for further scientific analysis, including two sites recorded in 2013.

Preliminary Conclusions

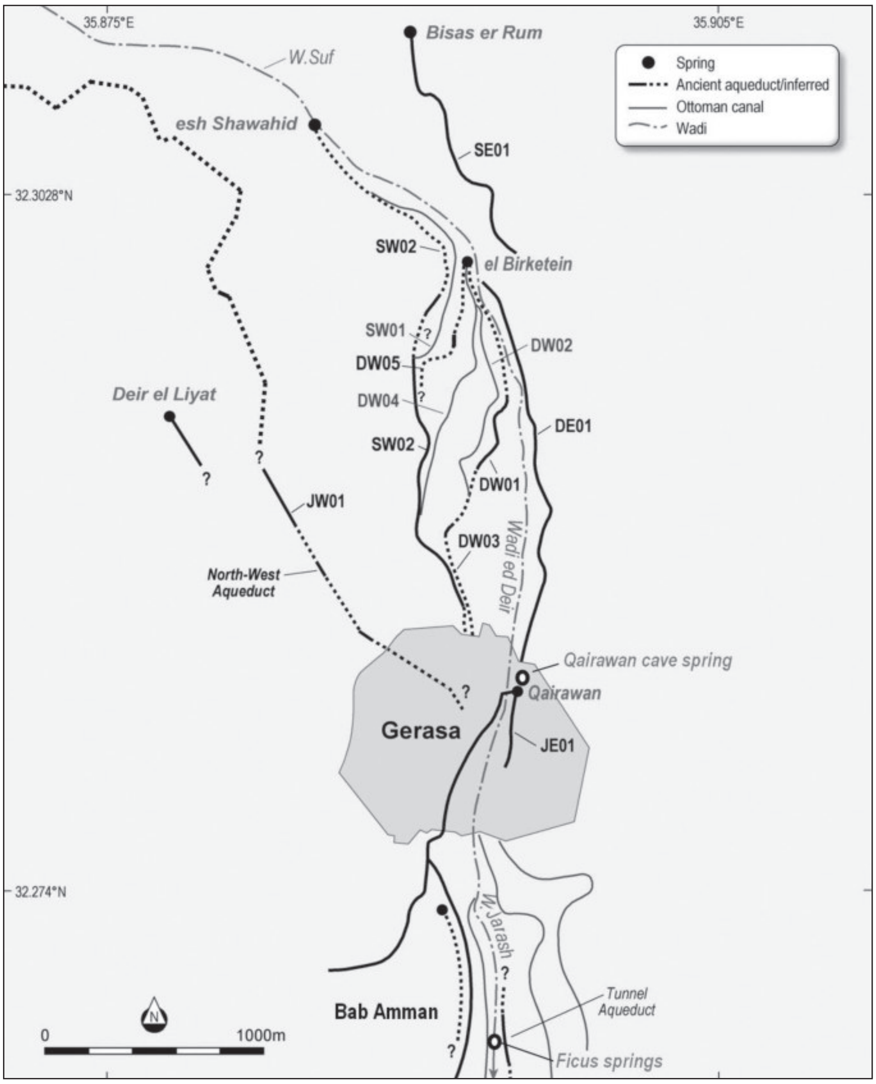
A total of 53 sites have now been recorded over two field seasons. The 2014 field season yielded important new information on the paleoenvironment of the city area, prior to the establishment of the urban centre in the historic period. A wadi-fill deposit of probable early Pleistocene age (the Jarash Conglomerate) has been recognised for the first time at a number of locations within the Jarash Valley. Subsequently, following a period of erosion, major springs were established during a pluvial period, and waterfall tufa was deposited on the terraced east bank of Wādī Jarash, in what later became the east side of Roman Gerasa. The fossil spring site in Qayrawān Cave above the modern-day Qayrawān Spring was part of this system, and evidence from ancient rock-cut canals and a plastered façade point to use of the Qayrawān Cave source in the historic period; possibly concurrently with the Qayrawān Spring. The terraced east bank provided an attractive natural platform on which later settlements were located from the Roman-Byzantine period to the present day.



17. Site JWP-150: Flint lithics, Kh. 'Ayn Riyashi (photos by D. Boyer).

Surveying in 2014 provided additional information regarding the extent of the ancient aqueduct network in the vicinity of Gerasa (**Fig. 18**). The sources for the major aqueducts recorded have now been identified; the only exceptions are the two tunnel aqueducts at Bāb Ammān . There is photographic and field evidence of an aqueduct network, which supplied irrigation water from perennial wādi flow and springs in the Jarash Valley between the village of Muqibleh and the confluence of Wādī Jarash with the R. Zarqā, as well as the Tannūr Valley below ar-Riyashi spring, although chronology for construction and use of this irrigation system remains to be established.

It is apparent that the north-west aqueduct provided an important water supply function to the west side of the city. Indeed, knowledge of the aqueduct's sources and potential alignment, the positioning of its entry into the city at the highest topographical point on the west side, and the ability to place water storage and distribution installations on the hilltop above the Artemis complex, are factors which may have formed part of the grand city plan for the west side of the city in the early Roman period. The chronology of construction, use and repair of this aqueduct is not currently known, but it is anticipated that C^{14} dating of the plaster will provide absolute dates and stable isotope analysis



18. Aqueduct plan: Gerasa Area (Don Boyer)

of carbonate sediment deposits preserved in its *specus* at various locations. Site JWP-128 in particular should yield paleoclimate proxy data spanning the period the aqueduct was in use. These results, when combined with results from important ongoing studies of the water installations in the city's north-west quarter by the Danish–German Jerash Northwest Quarter team, will provide a better understanding of the overall water management system in the city's north-west quarter. However, the part played by aqueducts approaching the west side of the city from the valley to the north remains unclear. It is hoped that it will be possible to obtain absolute dates of construction and/or use of two key elements in this northern network (the masonry aqueduct DW01 and Birkatayn reservoir) from C^{14} dating of plaster and mortar materials. The dating of materials from what may be the oldest water mill at the large water mill complex at the city's south watergate will hopefully shed some light on the timing of the introduction of water mill technology in the Jarash Valley.

The existence of higher elevation sources at Qayrawān Cave and high on the eastern hillside, together with a possible reservoir close to the highest point on the eastern side of the city, raises the possibility that this side of the city may also have enjoyed a similar (but separate) reticulated water supply to that which existed on the city's west side. A re-evaluation of the importance and use of the eastern part of the city is warranted in light of these discoveries.

Acknowledgements

The support of the Director-General of the

Department of Antiquities (DoA), Dr Munther Jamhawi, in granting a permit for the 2014 fieldwork is gratefully acknowledged. Thanks also go to the staff of the Amman and Jarash offices of the DoA for their assistance during the season, with once again particular thanks for Adnan Mjalli, the DoA Representative, for his cooperation, contributions and assistance during the survey. The author is also grateful to the support and supervision provided by Winthrop Professor David Kennedy. The season was sponsored by the University of Western Australia, and part-funded by a Rodney R.J. Prider Travel Scholarship.

David (Don) Boyer
Classics and Ancient History
University of Western Australia
M204, 35 Stirling Highway
Crawley WA 6009
Australia
don.boyer@uwa.edu.au

Abbreviations:

APAAME	: Aerial Photographic Archive for Archaeology in the Middle East www.apaame.org
Kh.	: Khirbat
M	: metre
Mm	: millimetre
My	: million years
PPNB	: Pre-pottery Neolithic B

Bibliography

Abdelhamid, G.
1995 *The Geology of Jarash Area, Map Sheet No. 3154-I*. Bulletin 30. Amman: Natural Resources Authority.
Al-Bashaireh, K.
2013 Plaster and Mortar Radiocarbon Dating of Nabataea and Islamic Structures, South Jordan. *Archaeometry* 55: 329-354.
Al-Nahar, M.
2013 Tell Abu Suwwan, a Neolithic Site in Jordan: Preliminary Report on the 2005 and 2006 Field Seasons. *BASOR* 357: 1-18.
Baker, F.M.C. and Kennedy, D.L.
2010 Report on the Jarash Hinterland Survey 2005 and 2008. *AJA* 114: 519-521.
2011 Jarash Hinterland Survey 2010: An Overview of Results. *ADAJ* 55: 451-466.
Boyer, D.D.
2016 Aqueducts and Birkets: New Evidence of the Water Management System Servicing Gerasa (Jarash), Jordan. Pp. 1579-1593 in R. A. Stucky, O. Kaelin and H-P. Mathys (eds.), *Proceedings of the 9th ICAANE Conference,* vol. 3, *Berlin 2014*. Wiesbaden: Harrassowitz.
2017 Jarash Water Project: Report on the 2013 Field Season. *ADAJ* 58: 374-411.
Braemer, F.
1987 Two Campaigns of Excavation on the Ancient Tall of Jerash. *ADAJ* 41: 525-530.
1989 History of Exploration at Jerash. Pp. 316-319 in, I.D. Homès-Fredericq and. J.B Hennessy (eds.), *Archaeology of Jordan II. vol.1: Field Reports, Surveys and Sites (A-K).* Leuven: Peeters.
1992 Occupation du Sol Dans la Région de Jérash aux Périodes du Bronzes Récent *et du*. fer. *SHAJ* 4: 191-198.
Chen, X.Y., Lintern, M.J. and Roach, I.C.
2002 *Calcrete: Characteristics*, *Distribution and Use in Mineral Exploration*. Belconen ACT: CRC LEME.
Costa, J.E.
1984 Physical Geomorphology of Debris Flows. Pp. 268-312 in J.E Costa and P.J. Fleisher (eds.) *Developments and Applications of Geomorphology*. Berlin: Springer-Verlag.
Darabseh, F.M.Q.
2010 *A Strategy for the Development of the Tourist Trail of the Decapolis Sites in Northern Jordan*. PhD Thesis, University of Birmingham.
Döring, M.
2004 Wasser für die Dekapolis Römisches Wasserversorgungssystem im Norden Jordaniens. *Schriften der Dt. Wasserhist. Ges*. Bd. 5: 183-212.
2005 Römische Wasserversorgungstunnel im Nordjordaniens. *ZDPV* 121: 130-139.
Finlayson, B., Lovell, J., Smith, S. and Mithen, S.
2011 The Archaeology of Water Management in the Jordan Valley from the Epipaleolithic to the Nabataean, 21,000 BP (19,000 BC) to AD 106. Pp. 191-217 in S. Mithen and E. Black (eds.), Water, *Life and Civilisation: Climate, Environment and Society in the Jordan Valley.* Cambridge: Cambridge University Press.
Ford, T. D., and Pedley, H.M.
1996 A Review of Tufa and Travertine Deposits of the World. *Earth-Science Reviews* 41: 117-175.
Fuller, J.
1830 *Narrative of a Tour Through Some Parts of the Turkish Empire*. London: Murray.
Glueck, N.
1951 Explorations in Eastern Palestine IV. *ASOR XXV-XXVIII* (1945-49). New Haven: ASOR.
Hawamdeh, A., Jaradat, R. and Alsaad, Z.
2015 Integrated Application of Geophysical Methods for Investigation of the al-Berktain Archaeological Site in the City of Jerash, Jordan. *Environmental Earth Sciences* 73: 3665-3674.
Hammouri, N. and El-Naqa, A.
2008 GIS Based Hydrogeological Vulnerability Mapping of Groundwater Resources in Jerash Area-Jordan. *Geofisica Internacional* 47: 85-97.
Hanbury-Tenison, J.W.
1987 Jarash Region Survey 1984. *ADAJ* 31: 129-157; 555-556.

Hütteroth, W. and Abdulfattah, K.

1977 *Historical Geography of Palestine*, *Transjordan and Southern Syria in the Late 16th Century*. Nürnberg: Erlangen.

Itkin, D.,Geva-Kleinberger, A., Yaalon, D., Shaanan, U. and Goldfus, H.

2012 Nāri in the Levant: Historical and Etymological Aspects of a Specific Calcrete Formation. *Earth Sciences History* 31: 210-228.

Keenan-Jones, D., Motta, D., Foubert, A., Fried, G., Sivaguru, M., Perillo, M., Waldsmith, J., Wang, H., Garcia, M. H., and Fouke, B.W.

2014 Hierarchical Stratigraphy of Travertine Deposition in Ancient Roman Aqueducts. Pp. 293-295 in E. Calandra, *et al. (eds.) Lazio e Sabina 10* (Atti Del Convegno "Decimo Incontro Di Studi Sul Lazio E La Sabina", Roma, 4-6 Giugno 2013). Roma: Soprintendenza per i Beni Archeologici Del Lazio 10.

Keenan-Jones, D., Motta, D., Garcia, M. H.; and Fouke, B. W.

2015 Travertine-Bsed Estimates of the Amount of Water Supplied by Ancient Rome's Anio Novus Aqueduct. *Journal of Archaeological Science: Reports* 3: 1-10.

Kehrberg, I and Manley, J.

2002 The 2001 Season of the Jarash City Walls Project: Preliminary Report. *ADAJ* 46: 197-203.

Kennedy, D.L.

1995 Water Supply and Use in the Southern Hauran, Jordan. *Journal of Field Archaeology* 22: 75-90.

Kennedy, D.L and Baker, F.M.C.

2009 Jarash Hinterl and Survey 2005 and 2008. *CBRL Bulletin* 4: 19-26.

Kennedy, D. L. and Bewley, R.

2004 *Ancient Jordan from the Air*. London: CBRL.

Kerner, S.

2004 Water-Systems in Gadara and other Decapolis Cities in Northern Jordan. Pp. 187-202 in H-D Bienert and J Häser (eds.), *Men of Dikes and Canals. The Archaeology of Water in the Middle East*. Rahden: Verlag Marie Leidorf.

Kirkbride, D.

1958 Notes on a Survey of Pre-Roman Archaeological Sites near Jerash. *BIALond* 1: 9-20.

Kraeling, C.H.

1938 *Gerasa: City of the Decapolis*. New Haven: ASOR.

Kriseleit, I.

1984 Ein Fußbodenmosaik aus Gerasa. Die Restaurierung der Berliner Fragmente. *Forschungen und Berichte* 24. Archäologische Beiträge: 75-97, T15-20.

Lepaon, T.

2008 Les édifices balnéaires de Gerasa de la Décapole: Premières observations. *Syria* 85: 51-70.

Le Strange, G.

1890 *Palestine Under the Moslems. A Description of Syria and the Holy Land from A.D. 650 to 1500*. London: Watt, PEF.

Lichtenberger, A.

2014 Archaeology of the Decapolis. Pp. 2066-2069 in C. Smith (ed.) *Encyclopedia of Global Archaeology*. New York: Springer Reference.

Lichtenberger, A., Lindroos, A., Raja, R. and Heinemeier, J.

2015 Radiocarbon Analysis of Mortar from Roman and Byzantine Water Management Installations in the Northwest Quarter of Jerash, Jordan. *Journal of Archaeological Science: Reports* 2: 114-127.

Lichtenberger, A and Raja, R.

2012 Preliminary Report of the First Season of the Danish-German Jerash Northwest Quarter Project 2011. *ADAJ* 56: 231-239.

2014 Jarash Northwest Quarter Project. *AJA* 118: 643.

Macumber, P.G. and Edwards, P.C.

1997 Preliminary Results from the Acheulian Site of Mashari'a 1, and a New Stratigraphic Framework for the Lower Palaeolithic of the East Jordan Valley. Pp. 23-43 in H-G. Gebel, *et al.* (eds.), *Prehistory of Jordan 2. Perspectives from 1997*. Studies in Early Near Eastern Production, Subsistence and Environment 4. Berlin: ex oriente.

McQuitty, A.

1995 Water-mills in Jordan: Technology, Typology, Dating and Development. *SHAJ* 5: 745-751.

Parenti, F., AI-Shiyab, A.H., Santucci, E., Kafafi, Z. and Palumbo, G.

1997 Early Acheulian Stone Tools and Fossil Faunas from the Dauqara Formation, Upper Zarqa Valley, Jordanian Plateau. Pp.7-22 in H-G. Gebel, *et al.* (eds.), *Prehistory of Jordan 2*. *Perspectives from 1997*. Studies in Early Near Eastern Production, Subsistence and Environment 4. Berlin: ex oriente.

Pierobon, R.

1984 Gerasa in Archaeological Historiography. *Mesopotamia* 18-19: 13-35.

Raja, R.

2012 *Urban Development and Regional Identity in the Eastern Roman Provinces*, 50 BC-AD 250. Copenhagen: Museum Tusculanum Press.

Sapin, J.

1998 A l'est de Gerasa. Aménagement Rural et Reseau de Communications. *Syria* 75: 107-136.

Schumacher, G.

1902 Dscherasch. *ZDPV* 25: 109-177.

Seigne, J.

2002 A Sixth Century Water-powered Sawmill at Jarash. *ADAJ* 46: 205-213.

2004 Remarques préliminaires à une étude sur l'eau dans la Gerasa antique. Pp. 173-185. in H-D. Bienert and J. Häser (eds.) *Men of Dikes and Canals. The Archaeology of Water in the Middle East*. International Symposium held in Petra, Wādī Musa (H. K. of Jordan) 15-20 June, 1999. Rahden: Verlag Marie Leidorf.

2008 Fontaines et Tdduction d'eau à Gerasa (Jerash, Jordanie). *Syria* 85: 33-50.

Shiyyab, A.
2013 The Cross Church: A new Archaeological Discovery in Jerash, Jordan (in Arabic). *Journal for History and Archaeology* 7: 153-172.
Sürmelihindi, G., Passchier, C.W., Spötl, C., Kessener, P., Bestmann, M., Jacob, D.E. and Baykan, O.N.
2013 Laminated Carbonate Deposits in Roman Aqueducts: Origin, Processes and Implications. *Sedimentology* 60: 961-982.
Vita-Finzi, C.
1964 Observations on the Late Quaternary of Jordan. *PEQ* 96: 19-33.
Winogradov, Z.S.
2002 The Aqueduct of Tiberias. Pp. 295-304 in D. Amit *et al.* (eds.) *The Aqueducts of Israel*. JRA Supplement 46. Portsmouth: JRA.
Yaseen, I.A.B, Al-Amoush, H., Al-Farajat, M. and Mayyas, A.
2013 Petrography and Mineralogy of Roman Mortars from Buildings of the Ancient City of Jerash, Jordan. *Construction and Building Materials* 38: 465–471.