# AN ARCHAEOLOGICAL RECONNAISSANCE OF WATER HARVESTING STRUCTURES AND WADI WALLS IN THE JORDANIAN DESERT, NORTH OF AZRAQ OASIS

by
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## Introduction

The Azraq Oasis lies in the north-east desert of Jordan, some 85 km., east, south-east of Amman (Fig. 1). The oasis comprises a series of mudflats, pools and marshes, usually fed by groundwater, which offer some of the few permanent, natural water supplies in a region characterised by extreme heat and aridity.

Field reconnaissance in July, 1982, revealed the apparently successful production of barley by sedentary bedouin on the floor of the Wadi al-Beida (east arm, Fig. 2) to the east of Azraq Castle. The cereals had been grown using simple terrace and wall irrigation systems fed by pumped groundwater. However, at this site, a substantial wall or barrage was found on the valley floor. The barrage was 35.00 m. in length, 1.50-2.00 m. thick and orientated obliquely across the floodplain. Although its antiquity could not be determined, its function appeared to aid farming by controlling and diverting floodwaters for farming. This and other structures subsequently noted in the *awdiyah* to the north and north-east of Azraq Druze were observed to resemble closely the "early" floodwater control and harvesting structures reported from Jawa,[1] parts of the north east Jordan,[2] in southern Jordan,[3] in the Negev.[4] the Libyan pre-desert,[5] and Algeria.[6] The known dates of construction and usage of such features vary widely: the Jawa water control structures date to the latter part of the fourth millenium; the Negev structures are Nabataean, whereas those in the Libyan pre-desert date to the Roman period, the Islamic period, and probably up to and including the twentieth century. In the present study area, the absence of excavation, and the absence of dateable pottery, necessitates concentration on the identification of such features, and discussion of their location, relative abundance and environmental relationships. In only a few instances have we been able to assess the relationships of the water control structures to dateable structures.

## Physical Background

Important accounts of the environment of the area are given in Bender (1974), Hemsley and George (1966), Nelson (1973) and Poore and Robertson (1964). In brief, the oasis occupies a shallow depression between the Jebel Druze to the north-west, and the Jebel Ashakif and the Jebel Jathum to the north-east. These northern uplands mainly comprise a series of undulating plains developed on weathered, vesicular olivine-augite basalts of Cenozoic age. The sandy or loamy regolith upon these is often in excess of 1.50 m. thick. A perched water table is often to be found at its base at the

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1 S. W. Helms, *Jawa — Lost City of the Black Desert,* London, 1981, Chapter V.

2 D. L. Kennedy, *Archaeological Explorations on the Roman Frontier in North East Jordan,* Oxford, 1982, p. 31-36.

3 Helms, *op. cit.*

4 M. Evenari, L. Shanan and N. Tadmor, *The Negev,* Cambridge, MA, 1971, p. 95.

5 G. W. W. Barker and G. D. B. Jones, *UNESCO Libyan Valleys Survey, Summary, 1979-1981,* London, 1982, p. 29.

6 J. Bardez, *Fossatum Africae,* Paris, 1949, p. 165-212.

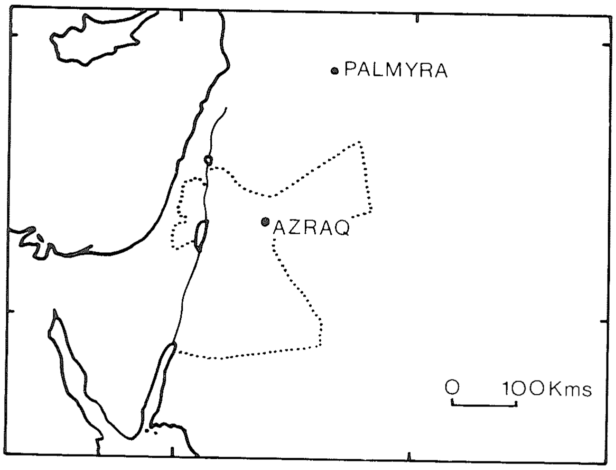


Fig. 1

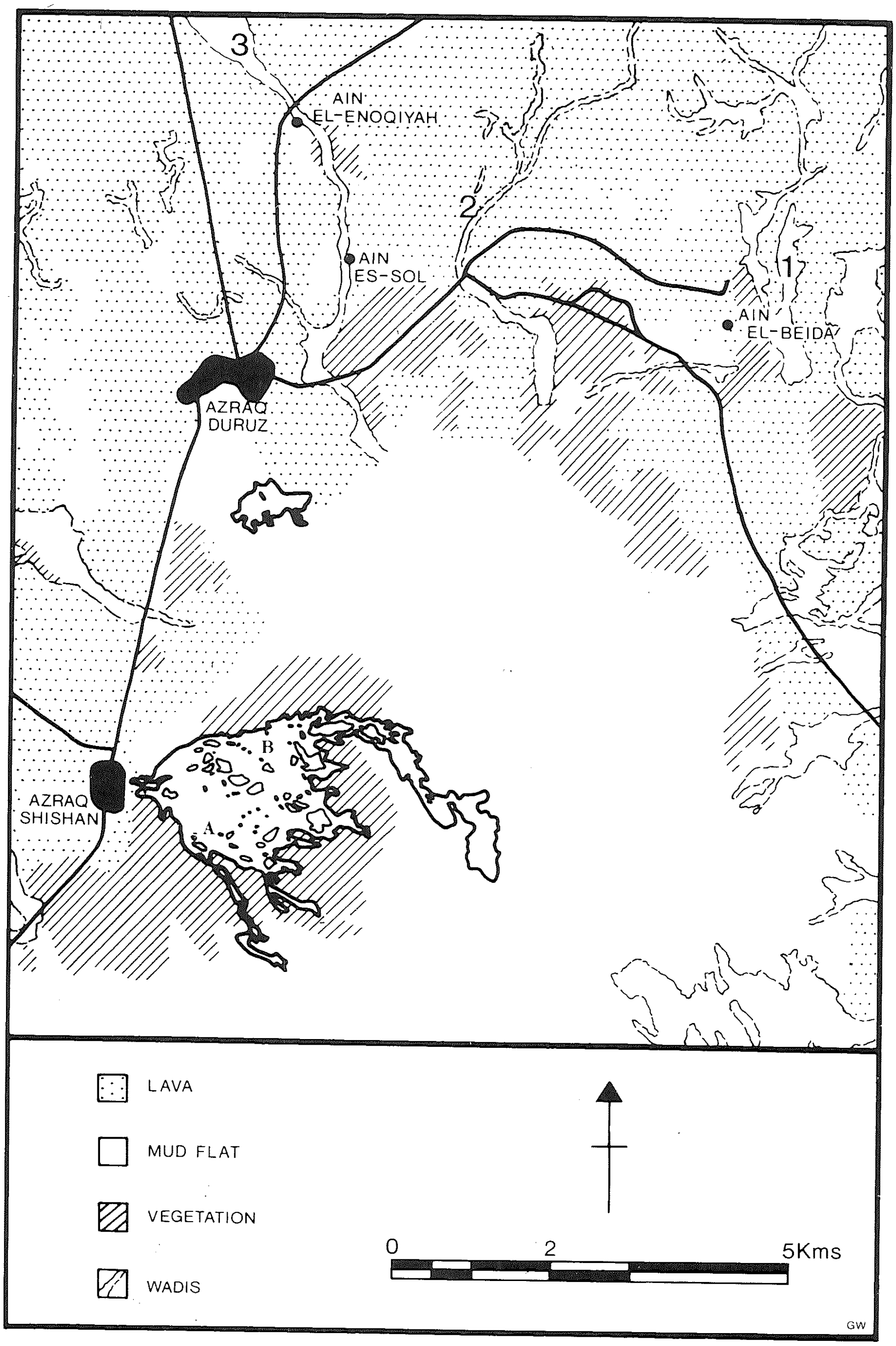


Fig. 2: 1. Wadi El Beida
2. Wadi Shu'ayib- Huwaynit El-Qaryatein
3. Wadi El-Enoqiyah.

contact with the underlying basalt. This is in contrast to the rocky hamada and/or shallow soils reported on the basalt at Jawa.[7] Three *wadi* systems are eroded into these basalt surfaces to the north of the Azraq depression. These are the Wadi el-Enoqiyah, the Wadi Shu'ayb-Huwaynit al Qaryatein and the area around the entrance to Wadi al-Beida, which are located in Figure 2. These *awdiyah* have rather narrow, rock-floored and boulder strewn upper reaches, middle sections with occasional large alluvial basins, and lower tracts with narrow, basalt-walled valleys.

The character and stratigraphic relationships of their infill Quaternary deposits are poorly known. At 'Ain el-Enoqiyah (Fig. 3) the *wadi* sides are 3.00-5.00 m. high erosional scarps eroded into the Cenozoic basalts. A complex of low-angle fans, colluvial debris and fluvial deposits give rise to a low terrace 0.80-1.00 m. above the floodplain (the 1.00 m. terrace, Fig. 3) at the scarp foot. Several springs emerge at this level from beneath the basalts (Fig. 3) and are associated with finer grade silts and loams. Temporary exposures in the active channels eroding into the *wadi* floor sediments reveal 0.50-1.00 m. of a lower stratum of red/brown fluvial sands and loams containing well-preserved Levalloisian implements. A rubified textural B horizon of a palaeosol may be developed at this level. This feature is overlain by 0.50-1.00 m. of unconsolidated fluvial sands, gravels and cobble deposits which form the modern, aggrading *wadi* floor surface. Coarser, gravelly, fluvial facies between 1.50 and 5.00 m. down yield water to shallow bedouin wells and pits.

The climate of the region offers very few opportunities for growing cereals by conventional agricultural practices. The climate has been classified by Poore and Robertson (1964) as a Saharan Mediterranean of the very warm variety. Daily temperatures average 35°-37°C in summer. On average, less than 100 mm. of precipitation is recorded each year. This scanty precipitation does not fall evenly throughout the year. The precipitation regime is characterized by very heavy falls, in brief periods, in the months from November to April. The effect is so extreme that the percentage of annual precipitation falling in a single day averages 50%. Potential evapotranspiration is calculated as between 1150 and 2100 mm. per annum.

### Wadi Al Beida (eastern arm)

As noted above, a possible floodwater control structure was found near the mouth of the east arm of the Wadi al-Beida close to its western margin. The structure consisted of a wall, 1.50 m. to 2.00 m. wide, double-faced and rubble-filled, standing 1.00 m. high. It was 35.00 m. long and orientated obliquely across the long axis of the *wadi* floor. Smaller, linear, earthen dams had been built onto this feature on its south-east side, running south-west from its "upstream" end, to produce a *V* in plan with its point upstream. Those bedouin now settled in the vicinity have placed their daytime tent shelters in its lee and are growing crops in that area to which floodwater would be deflected by the barrage during the rains. Since the original wall and its later additions are not readily explicable in terms of stock enclosures, territorial or other boundaries, the feature is interpreted here as a water harvesting structure. To some extent both may have been superseded by the pumping of groundwater from a spring on the eastern margin of the *wadi*.

In a brief survey of the *wadi* floor and its basalt margins both up- and downstream of the structure, no other features were found which could be interpreted solely in terms of water control. Corrals, huts and other walls were common, but in each case, these appeared to be principally concerned with stock control or habitation.

### Wadi Shu'ayb-Huwaynit Al-Qaryatein

The area covered by the ground survey is illustrated in Figure 2. The *wadi* is

[7] Helms, *op. cit.*

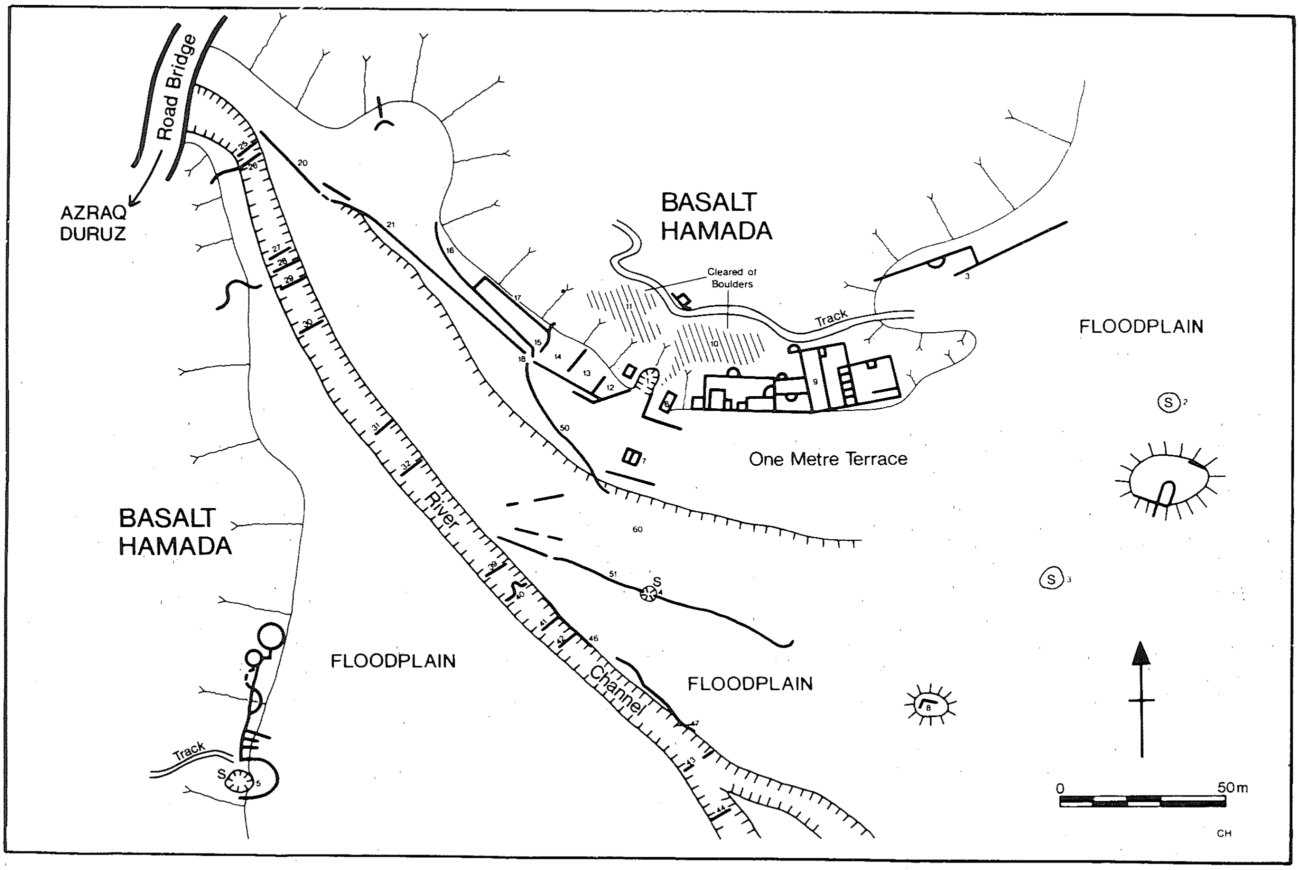


Fig. 3: 'Ain El-Enoqiyah, Azraq.

often rock-floored and boulder strewn. Corrals and broadly similar features are common on the basalt above the wadi sides. No water control structures were found on the *wadi* floor, or at its margins. These were seen to be the site of active and rapid boulder transport by floods. The trimline evidence indicated that floods reach at least 2.00 m. above the *wadi* floor. Minor terraces of finer-grained sediments occur in the *wadi*. Many of these are likely to be ephemeral features. depending for their existence on the characteristics of late-stage erosion and deposition in major floods. Therefore the floors of such *awdiyah* are unlikely to have been developed and used by floodwater farmers.

## Wadi El-Enoqiyah

The areas surveyed in this third *wadi* draining into the Azraq depression are shown in Figures 3 and 4. The *wadi* has four distinct geomorphic units. The upper tracts comprise steeper, rock-floored, boulder-strewn river beds similar to those in the upper reaches of the Wadi Shu'ayb-Huwaynit al-Qaryatein. These enter a large alluvial embayment of approximately 1.5 km. radius. The *wadi* then continues as a 150.00-250.00 m. broad valley with a well developed alluvial terrace towards the south-east, which ends near the springs and former settlement of 'Ain el-Enoqiyah. Here the *wadi* enters another large alluvial embayment, before turning south at the springs and settlement of 'Ain es-Sol, where it again becomes a 100.00-200.00 m. wide valley. This runs between 3.00-5.00 m. high basalt scarps, with a low terrace described previously.

Although corrals, kites, huts and similar features are abundant on both the margins of the *wadi* and the basalt hamada above them, with the exception of two sites at 'Ain es-Sol and 'Ain el-Enoqiyah, ground survey of the *wadi* failed to reveal any certain features which might be directly related to early floodwater farming. This may reflect a genuine absence in the area, although differential survival is no doubt important. Few structures may be expected to endure on the upper, steeper tracts, whereas the large embayments are efficient sediment traps, and older features may be buried within them.

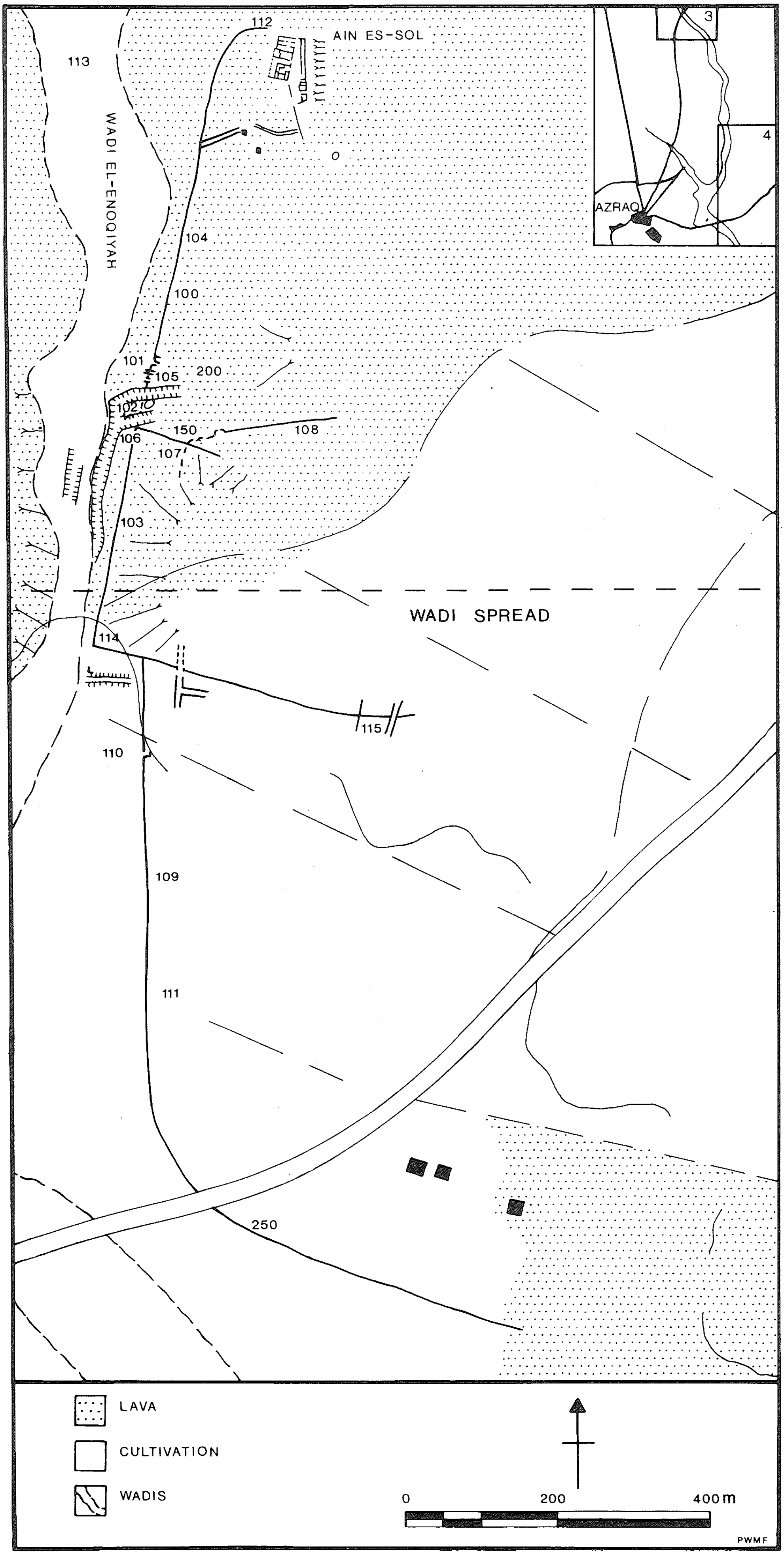


Fig. 4: 'Ain es-Sol and Vicinity, and Key map. Below the dashed line the fearures were plotted from an ariel photograph.

### ʻAin El-Enoqiyah

The locations of important archaeological sites and geomorphic features are given as numbers in Figure 3 and are described below. The superficial geology was described previously. Several types of structure may be related directly or indirectly to water management at this small, but complex settlement.

Springs

The main spring (1) is a boulder-lined hollow, 4.00-8.00 m. in diameter. It has been enlarged by natural spring sapping and no doubt excavation at the base of the 4.00-5.00 m. high basalt scarp. Further springs (2-4) on the floodplain are marked by tall colonies of *Phragmites.* A fifth spring (5) probably occurred on the south bank in an area currently being cleared and quarried by well diggers.

Huts and Corrals

Small huts or houses occur by the main spring at (6), possibly at (7), and on the small inlier of basalt exposed at (8) on the *wadi* floor. Walled enclosures and corrals (9) are common to the east of the spring (1). Many of these contain further subdivisions and possibly the remains of smaller pens or huts. Enclosures (10-11) occur beside a cleared track of unknown antiquity. A further set of oblong enclosures occur on an alluvial terrace immediately in front of the basalt scarp west of the main spring (1). Enclosures (15) is separated from the scarp by a wall (17).

It is difficult to date these structures. Worked flints were noted amongst them as were fragments of pottery. The latter was all coarse ware of red and orange buffs. Unfortunately the pottery fragments were not readily identifiable. They were almost certainly of local origin. No painted or incised wares were noted.

Even today, at this otherwise unoccupied site, bedouin graze their camels and/or goats. In the recent past it was a natural stopping point for travellers between Azraq and the Jebel Druze.[8] In the more distant past, there is every reason to believe that the spring would have proved attractive both to travellers on the Roman Road (the subsequent Pilgrim Road), as well as to would-be settlers seeking to exploit this traffic and/or the site's limited potential for agriculture. Indeed some of the enclosures might be interpreted as stock pens, others may have been used for crops or kitchen gardens.

Canals

Of greater importance are the many structures apparently intended to control surface water flow at the site. The most obvious are the two canals (20 and 21), illustrated in Plate XVII: 1. The structures are 1.00 to 1.20 m. in width, up to 1.20 m. high, enclosing water channels of rectangular cross-section between faced basalt boulders. The water channel in canal (21) measures 0.60 m. across. Its depth is impossible to determine since the channel is filled with sediment. Its joins an entrance-like feature in the field boundary of enclosure (15) with the edge of the small terrace scrap where the continuation of the canal, or a further feature, is marked by a 10.00 m. long, dense scatter of worked boulders. Curiously, the surface of this canal slopes from the basalt scarp to the terrace edge with a slope of 1°.

Canal (20) also has a channel with a rectangular cross-section exposed near the present *wadi* channel. The canal's water channel measures on average 0.35 m. across (max. 0.45 m.; min. 0.31 m.) and is approximately 0.43 m. deep. It slopes at 3° from the present *wadi* channel and intercepts the alluvial terrace just below its surface. Again, erosion has eroded this interception point, and it is unclear whether the boulder piles at this site mark its former extension, or a separate but associated structure. It is possible that canals (20) and (21) were previously linked along a line immediately in front of the present terrace scarp.

There is no evidence that canal (20) ever extended beyond the line of the present active *wadi* channel; although the

[8] Kennedy, *op. cit.*, p. 176.

passage of construction vehicles and the building of a new embankment and road bridge for the H-5 and Iraq highway have no doubt brought about the destruction of archaeological remains in this area; consequently, we cannot be absolutely certain of the source of water transported by these canals. The water may have been obtained from a spring, now lost. Alternatively water might have been supplied from floodwater dammed up in the present active channel area by the many barrages that have been mapped immediately downstream in the active channel (25-41).

The maximum water carrying capacity of the canals may be estimated using the Manning formula given in Chow.[9] This equation is derived from studies of open channel hydraulics:

$$Q = \frac{1.5A\ R^{2/3}\ S^{1/2}}{n}$$

where Q is discharge in cubic feet per second (1 cubic metre per second — a cumec = 35.3 cubic feet per second - cfs). A is the cross-sectional area of the channel; R is the hydraulic radius =

$$\frac{\text{cross-sectional area}}{\text{wetted perimeter}}$$

S is the slope of the channel; n is a coefficient describing the roughness of the channel bed which is related to frictional drag, turbulence, and hence affects flow velocities.

It is impossible without excavation to assess the roughness state of the channel beds. They might have been lined with clay/silt to waterproof the basalt construction. Alternatively, they may have been formed of dressed stones. Appropriate values of Manning's *n* for these possibilities are available in published tables: the most likely conditions are given below:-

| Channel type | Manning's n. |
|---|---|
| dressed stonework | 0.013-0.17 |
| earth canal, straight and uniform | 0.017-0.025 |
| rock canal, trimmed, smooth and uniform | 0.025-0.035 |

Taking the lower and upper likely values of Manning's *n* of 0.013 and 0.035, and inserting them with the channel measurements of canal (20) into the Manning equations, indicates that when full, the canal would have been capable of transporting the following discharges: 0.2 cumecs in a dressed stonework channel; and at least 0.075 cumecs in a trimmed rock channel. Excavation is needed to assess the nature of the demand placed upon this resource by humans and stock.

The second canal (21) is more difficult to interpret. The slightly larger dimensions of its channel suggest a greater capacity than canal (20). Observations of its exposed surface stones suggest it slopes away from the basalt scarp. Excavation is needed to confirm the channel floor also slopes in this direction. If it does, two possibilities need to be explored. First, that the canal conducted water from springs at the foot of the basalt scarp (or other water control structures) towards the collapsed structure at the intersection with canal (20). Second, its gradient may have been reversed by tectonic activity, in which case, its gradient and discharge capacity estimates would have to be significantly increased.

Barrages

A complex series of barrages is exposed in the modern, active *wadi* channel in the area immediately downstream of its intercept with canal (20). These features (25-45) are 0.50 m. to 1.50 m. in width, and one or two courses of boulders high. The size (*ca.* 0.30 to 0.50 m. dia.), angularity, and rectangular character of the boulders indicates they have been quarried from the nearby basalt scarps. The boulders and cobbles of the fluvial bars and dunes in the active channel are moderately to well rounded. Occasionally more complex barrages are found, with a double facing of quarried stone, and packing of cobbles obtained from the channel floor.

At points (32) and (34) there are sequences of barrages, three or four in

[9] V. T. Chow, *Handbook of Applied Hydrology,* New York, 1964.

number, the individual barrages being 2.00 to 5.00 m. apart. The size, shape and frequency of these features suggest they were principally intended to impede and dam floodwaters to produce ponds and lakes. Some of these waters may have been led away by the canal described previously, or by oblique *wadi* walls, described below.

The ponding may also have raised groundwater levels locally within the *wadi*-floor deposits, hence favouring deeper rooting, grass-pasture species. To date, no evidence has been found which would suggest these walls are part of field systems, or walls intended to confine animals. The function of barrage (40) is unclear. In plan it forms a convex-upstream hemispherical barrier. It may be a more sophisticated barrage.

Oblique Cross-Wadi Walls

Two substantial walls (50 and 51) are orientated obliquely across the *wadi* floor. Feature (51) is up to 1.00 m. across, often double faced with packing, and one to three courses of boulders high. The basalt boulders appear to have been obtained from the basalt scarp rather than the river bed. The wall commences by the barrage (39) which is exposed in the modern active channel. It then traverses a number of small springs marked by *Phragmites*. It terminates with a small recurve, close to a modest hut built on a small inlier of basalt which crops out above the *wadi* floor. This wall is not connected to further walls at either end which might have formed an enclosure. Its substantial form suggests it was intended to withstand considerable stresses, interpreted here as floodwaters. The feature is interpreted as a wall intended to divert and spread floodwater, and hence irrigate the *wadi* floor in area (60), just beyond the small settlement. Its location and orientation have similarities to the feature described at Wadi el-Beida.

The second wall (50) commences near an opening in enclosure wall (15). It forms a barrier *ca.* 0.50 to 0.60 m. wide, with one or two courses of boulders exposed. The wall curves along much of its length, the convex side facing the main channel. Consequently it encloses and partially protects the *wadi* floor in front of the main settlement. There is no sign of any further features which would suggest this sweeping wall was part of an enclosure. In a flood, this wall would serve to protect the land in front of the settlement from flooding and soil erosion. Water would tend to be diverted to the same general area (60) as achieved by wall (51). In the absence of any other evidence wall (50) is therefore regarded as a structure concerned with flood diversion and soil conservation.

**Conclusions**

'Ain el-Enoqiyah is a complex settlement originally located to take advantage of spring waters at the site, but which during as yet unknown periods, employed barrages, canals and oblique *wadi* walls to control and direct floodwaters. Stock were probably kept and it is likely cereals such as barley were grown on the flood-irrigated land around point (60).

**'Ain Es-Sol**

The locations of important archaeological and geomorphic features are shown in Figure 4. The small fort and bath house at this spring are described in Archaeological explorations on the Roman Frontier.[10] They are attributed to the Roman (and Umayyad?), periods respectively. Kennedy[11] also describes the major wall (100) which sweeps south from the north-west corner of the site (Pl. XVII: 2). This feature may have had a role in water control.

The basalt scarp to the west has a small terrace of fanglomerates and other colluvial deposits at its base. The *wadi* floor comprises sandy loams, sands, gravels, and cobbles; except where *wadi* (200) enters from the east. The entrant *wadi* floor comprises large fluvial dunes and megadunes of gravel and cobble grade materials. The eastern margin of the *wadi*

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[10] Kennedy, *op. cit.*

[11] *Ibid.*, p. 131.

floor comprises a 0.50 to 1.00 m. terrace scarp marking the edge of low fluvial terrace deposits. The main spring lies immediately to the south-east of the bath house.

Barrages

No reliable field evidence of barrages or cross-*wadi* walls was found in this area. Fragments of walls orientated across the *wadi,* possibly former barrages, are occasionally exposed in shifting minor channels on the floodplain (113).

Walls

Ground survey confirms that the north-south orientated wall (100) is a substantial and complex construction. In its northern part it is often over 1.00 m. wide and built of several courses of boulders each 0.25 to 0.50 m. high. These have been obtained from the basalt scarp to the west, rather than from the rounded cobbles of the *wadi* floor. North of (104), the wall curves across the *wadi* floor, joining the low terrace at (104) with the buildings to the north of the bath house, which are also on slightly higher ground. From point (104) to (105), the wall is built along the top of the 1.00 to 1.50 m. terrace scrap. There appears to be a deliberately constructed break or entrance at (101). The wall is aligned directly across the incoming *wadi* (200) at point (102), where it is frequently buried in coarse gravels and cobbles.

At the southern margin of the confluence of these, *awdiyah* at point (106), the structures become more complex. Wall (103) is sometimes only 1.00 m. wide as it continues south on the terrace scarp, separating the *wadi* floor from the terrace. However, in parts at least, it lies on a substantial earthen bank. Wall (107) runs eastward with similar topographic relationships along the southern border of the entrant *wadi* (200). However, the major wall (108) soon diverges from (107) and is orientated obliquely across the entrant wadi. This is a substantial wall, 1.00 m. wide, often double faced with packing stones. At point (150), at which (107) leaves (106), there were traces of some sort of structures, these and the wall being difficult to disentangle. A few sherds of coarse pottery were noted amongst these structures.

A dog-leg separates the north-south terrace margin wall from its southward continuation (109), which is also a strong, double-faced 1.00 m. wide wall. An entrance or exit appears to be present at (110). In this region the long north-south wall runs directly across another wide, entrant side *wadi*. Beyond (111) it was not possible to follow this structure with confidence into cultivated and fenced land. It was however, located again beyond this farm, where it crossed the Azraq to 'Ain el-Beida road. On the 1955 aerial photograph, which pre-dates the modern agricultural improvements, the wall can be seen to cross the area both of this farm north of the road, and again to the south of it, where it begins to curve off south-east towards Qa el-Azraq (250). Aware of its former existence south of the road, we were able to detect in the fields, occasional spreads of boulders which marked its course. In a few years it will be totally lost, and but for this aerial photograph record, would have been unknown. One can only surmise that in this region of spreading agricultural activity, that other such archaeological remains have now been irrevocably lost. Access to aerial photographs of even twenty years ago would almost certainly reveal a much more extensive system than is visible today. The dog-leg itself has an extension from (114) to (115) and eastwards across what is today farmed land.

The interpretation of these features presents more difficulties than at 'Ain el-Enoqiyah. From point (112) to (104) the curving wall may have served to protect land immediately in front of the bath house from fluvial erosion. The feature is largely buried. It may prove to have within it a series of drop structures to facilitate irrigation of the enclosed area.[12]

Further south much of the wall system appears to delineate the boundary between

[12] Evenari, *op. cit.*, fig. 70; Kennedy, *op. cit.*, p. 59, 62.

the *wadi* floor and the presently cultivated lands of the terrace. These walls would undoubtedly have served to control flooding and flood damage at high flows, but their principal functions appear to concern the further delineation of natural land boundaries. Where these features cross entrant *wadi* floors at (102) and (109), some flood-damming and irrigation may have occurred. However, the continuity of wall line with the terrace margin suggests that here also the delineation of land divisions was important. Otherwise, at the moment we have only found the single oblique cross-*wadi* wall (108) which may be related to water control with confidence.

Conclusions

One part of a major wall system at 'Ain es-Sol may have been designed with water or soil control in mind. Cross-*wadi* barrages may have once been present. Otherwise, the wall system appears to be part of a major agricultural land division which adopted natural boundaries separating more important terrace lands from flood-prone *wadi*-floors.

Again little can be said about the antiquity of the wall systems. The system that survives today may have been constructed at the same time as the defended site of Qasr 'Ain es-Sol, itself in use, in the late Roman or Umayyad period. Some confirmation was noted between (106) and (114), where a few distinctive sherds of painted early Islamic pottery were weathered out on the east slope of the *wadi*-sidebank along which the wall lies at that point.

**Discussion**

In this survey area, our ground observations have indicated that water control structures are either rare or absent on the basalt hamada, the basalt *wadi*-side scarps, the rock-floored upper *wadi* tracts, and in the wider alluvial embayments. The three sites where water control structures were noted are all close to groundwater supplies from wells or springs. This is not the usual situation at Jawa,[13] the Libyan pre-desert, or in the Negev.[14] It suggests that in this area of the Jordanian desert, floodwater control was practised to supplement the more important, and more reliable groundwater supplies.

To date, three types of water control structures have been found in the study area: barrages to pond back water; canals to redistribute water from springs or ponded supplies; and oblique cross-*wadi* walls to redistribute floowater and possibly to protect other floodplain areas from flood damage. The most noticeable wall type *not* found in this reconnaissance is the water harvesting wall built on the hamada to gather storm run-off and lead it to the *wadi* floor. The "kite" walls observed in this study area do not have these properties.

Several inter-related explanations for the comparative local scarcity of water control structures may be suggested. A complete lack of interest in cereal growing might be advanced as an explanation. However, Betts[15] amongst others[16] has commented on the Bedouin optimistically casting seed onto alluvial embayments and mudpans in the hope of gaining a crop. This is essentially the same agricultural practice as found in the Libyan pre-desert. It is worth noting in support of this possibility that there was an abundance of meat on the basalt until comparatively recent times. Gazelle and Oryx were apparently common and figure prominently in the rock graffiti; their entrapment may have been the function of the numerous kites constructed in the area.[17] Cattle are likewise depicted in other rock art on the basalt,[18] whilst numerous species of animal and bird occurred around the Azraq marshes themselves.[19] Furthermore, the region may not have proved attractive for the degree of settled life implied by extensive water gathering systems. These

[13] Helms, *op. cit.*

[14] *Evenari, op. cit.*, p. 95.

[15] A. Betts, The Qa' Mejalla Survey, *Levant*, 14 (1982) p. 1-34.

[16] Evenari, *op. cit.*, p. 4ff.

[17] Helms, *op. cit.*, p. 39-47.

[18] *Ibid.*, p. 26ff.

[19] Kennedy, *op. cit.*, p. 69.

require secure conditions which, so close to a major oasis and not far from an important route, may not have been available except in the relatively short periods of time represented by much of the Roman and Umayyad periods. One has only to recollect the awful reputation of the Azraq region, and the resulting infrequency of travellers even in the historic period up to the early years of the twentieth century.[20]

The climate may have been too hot and dry, with the rainfall concentrated in too short a period to justify the construction of such water-control systems. The area receives approximately 30 to 40% less precipitation than Jawa to the north.

The modern environmental data suggest major hydro-meteorological problems must have been faced by potential builders of water harvesting structures in this area. The structures would have had to content with essentially rare, but sudden and violent floods in those periods when precipitation intensity sufficiently exceeded the high infiltration capacity of the locally deep and porous basalt soils to generate overland flow and so feed surface water into the *awdiyah*. Undermining of structures in the violent floods is also likely to have been common. If the structure diverted to much water into an area then major problems of scour and soil erosion might be anticipated.

In periods of less intensive precipitation, the high potential evapotranspiration rate and high infiltration capacity of the soils on the basalts are likely to promote little run-off; water loss to the lower, perched water table, or to the atmosphere, being the dominant processes.

These problems only seem to have been overcome in the floors of shallow valleys 100.00 to 200.00 m. wide. Here the water control systems appear to have been constructed to supplement the groundwater supply. Elsewhere in the Jordanian Desert, the situation may be different. Our present evidence suggests that in the Azraq type of climatic regime, better opportunities for water harvesting should be available where the hamada soils are less deep, or are developed upon a more impervious bedrock. In addition, a less concentrated precipitation regime would also be an advantage.

Finally it is worth emphasising that all these considerations derive from field observations only. In the absence of aerial photographs and excavations, both the larger scale of such systems and the socio-politico-economic factors which influenced them, must remain inadequately understood.

## Conclusions

An archaeological reconnaissance of a very hot and arid area of the Jordanian Desert, north of Azraq oasis has revealed the presence of three types of water control structures — barrages, canals, oblique cross wadi walls — around small settlements whose original location appears to be related to the availability of ground water supplies. Floodwaters may have served only to supplement these more reliable water sources. The local scarcity of water control structures, especially on the basalt hamada, may reflect the severity of the prevailing climate, but also the hydrological properties of the deep, basalt soils in the area.

The little dating evidence available, suggests that whatever their actual date of construction, the walls to the south of Qasr Ain es-Sol at least, were functioning in the late Roman/early Islamic period.

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[20] *Ibid.*, p. 71.

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