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Hanna Nydahl

ARCHAEOLOGY AND WATER MANAGMENT IN JORDAN

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Abstract

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The aim of this paper is to show how archaeology can be used to find solutions to water management problems and water deficiency in dry areas. This paper deals with the projects and studies with focus on water management that have been implemented in the Hashemite Kingdom of Jordan. By looking at how water resources have been managed in the past it has been possible to come up with new ideas of how to improve the current water situation in Jordan.

Keywords: cisterns, desert, evaporation, Hashemite Kingdom of Jordan, Nabateans, precipitation, rainfall, sustainable development, Project Rainkeep, water, water harvesting

Hanna Nydahl, Department of Archaeology and Ancient history, Uppsala University, S:t Eriks torg 5, SE-75310 Uppsala, Sweden

Content

1. Introduction

The purpose of this paper is to present an example of how archaeology can be used to search for (and maybe find) a partial solution to the problem of water management in the dry areas of the world. I have chosen the Hashemite Kingdom of Jordan to illustrate how this might be possible, as Jordan is a country that is short on water and rich in archaeology.

I will first explain the current water situation in Jordan, and then present some examples of Nabatean water management systems from Humeima and Nakhl along with a description of the Nabatean civilization.

I will also present the research done on the reintroduction of cistern use, the results and the direction in which a possible continuation of research could be taken. This is closely connected with the Project Rainkeep, currently in progress.

The appendix contains background information on Jordan; its geography, population, climate and history, a chronology for Jordan's prehistory and some notes on spelling and the Arabic words used in the text.

1.1 Theory, Method & Aim

My theory is quite straightforward and one that I hope many people will agree with. It is that archaeology can be a useful tool to change conditions in the present. Archaeology can and should “be used to view the physical remains of the ancient world as a key to understand more about the reciprocal relationship between people and their environment as well as to reconstruct historical events of the past." (Pace 1996, p.369).

Specifically I would like to show how old water management techniques could be used and combined with modern technology to create a sustainable development in dry areas on the Earth. I think that it is fair to say that the introduction of western technologies is not always an improvement in dry areas with non-renewable water resources. By looking at how water has been collected and stored in the past we can gain new insight in how to solve the present problems of ever decreasing fresh water resources.

Sustaining the freshwater resources of the Middle East presents a great challenge. This challenge has been heightened as problems with freshwater quality and availability have multiplied and changed in response to a growing population, urbanization and economic activity over the past several decades. The present generation's water-related concerns in this area primarily focus on the distribution within society and the preservation and protection of water quality. Future generations must also work to ensure adequate water supplies, preserve the quality of the environment and achieve greater equality in the distribution of water. (White et al. 1999, p.1)

To meet future regional demands by simply increasing withdrawals of ground and surface water will result in an unsustainable development characterised by widespread environmental degradation and depletion of freshwater resources. For these threatened areas, it is vital to work for a sustainable development; this has been defined by the UN World Commission on Environment and Development, 1987, as the development that meet the needs of the present without compromising the ability of future generations to meet their own needs. (White et al. p.17)

I have chosen the Hashemite Kingdom of Jordan as my study area as said area has a long history of water management in arid conditions. I have taken an interest in and focused on the Nabatean period as they were a highly developed civilization and made use of many different hydrological techniques in a desert-like environment. I have also been looking at what has been published so far on the possibilities of using these technologies today.

My sources for the archaeological material have been excavation reports and papers on excavations whose primary focus has been the Nabatean period and their water management systems in Jordan. I have been trying to get a picture of the different techniques that was used during this period and also from were the Nabateans learned these techniques. I will present these techniques in a general way and also give some examples from the archaeological material that I feel is representative for the Nabateans.

I do not propose to put before you a readymade solution to the huge problem of water scarcity but will attempt to show what has been done in the area so far by people working with archaeological material, how much that remains do be done and perhaps in which direction further archaeological research could be taken to improve the situation.

As always, one should be careful when reading material that one has no possibility to verify. The author always writes with an intention and that intention is not always explicitly stated.

2.Criticism of the Sources

I have two historical sources, Strabo and Diodorus of Sicily. I have chosen not to look at their original writings, due to limited time. The quotes and information about them are taken from later writers who have selected parts of their texts for specific reasons, which might have affected my conclusions.

As for the archaeological material, I have not had any access to this on a first hand basis. All my facts come from excavation reports, sometimes preliminary, and other writings. Since much of the archaeological material has disappeared and still is disappearing due to development etc., it is difficult to verify some facts and measurements.

There is also the question of fresh facts; some of the figures and measurements are quite old and vary somewhat in different books. I have tried to find the most recent, but as always there is the problem of late publication. Much recent research has not been published in full or, indeed at all.

When writing about the Middle Eas,t you sooner or later run into politics, and in that area I found it difficult to find facts on the present division of available water that are not muddled with opinions.

3. Research History

In 1812 Petra, the capital of the Nabateans, was rediscovered by Johann Ludweig Burckhardt, a Swiss explorer. During the following century about 200 more or less serious researchers and adventurers travelled to Petra to learn about the beautiful city that had been lost to the western world since the crusades.

In the beginning, researchers were mostly interested in documenting the numerous monumental tombs and buildings that the Nabateans had created in the area around Petra.

George and Agnes Horsefield started excavating in Petra in 1929 and were the first to document and describe the characteristics of the Nabatean ceramics. Nelson Glueck later used these classifications for Nabatean sherds to identify over 500 settlements in Jordan and several dozen more in the Negev during the early 1930’s and 1950’s. (Lawlor 1974, p.16, 85, McKenzie 1990 p.1-2) Glueck published extensively and commented on the Nabateans use of water collection techniques. (Glueck 1959, 1965)

One of the first to study the role of water management systems in Israel was Lawrence Stager, who worked in the Judean desert. In the 1950s Evenandi, Shanan & Tadmor carried out experimental research in the Negev that has become a model for how to integrate the study of water usage with the life systems of the people of a particular area. They stimulated ancient runoff agriculture and were able to observe waterflow and the amounts of water produced for irrigation. (Pace 1996, p.369)

In Jordan the archaeological interest in hydrological systems grew and several reports and projects published from the 1980's and forward focus on, or at least mention, this important area of everyday life.

Helms describes the water supply system used at the city of Jawa. This town was founded in about 3000 BC and is one of the oldest found in Jordan. (Helms, 1981)

Weber has published on Gadora / Umm Qays (Weber 1991) and Mare on Abila; during the Roman-Byzantine period. (Mare 1995) Abujaber has written on water collection in dry farming societies. (Abujaber 1995)

The long running Madaba Plains Project (since 1968) has a fairly new sub-project titled 'Project Rainkeep' which focuses on water retention strategies in the Madaba area today. (LaBianca 1995, Project Rainkeep, URL)

John Peter Olesson has published several excavation reports and papers on the Humayma Hydraulic Survey (Olesson 1986, 1988, 1990, 1991, 1992, 1995) that deals specifically with the water supply techniques used by the Nabateans at the settlement of Humeima / Auara.

There is also the al-Karak Resource Project (Mattingly 1996) which does research on the utilization of natural resources in the Karak region and has published some reports on water catchments systems in the area, for example Nakhl (Mattingly et al. 1998).

Lars Wåhlin has studied household water collection in the northern al-Balqa' in Jordan, and has put forth propositions on how to reintroduce cisterns in that area. (Wåhlin 1995a, 1995b, 1998)

4. Water in Jordan

Water covers nearly three-quarters of our planet's surface. However, less than 1 % of that water is “fresh” water and it is unevenly distributed. Humid regions are endowed with an abundance of it so that most often the problem is how to dispose of excess water. Arid and semiarid regions, on the other hand, are plagued with a chronic shortage of water. (Hillel 1994, p.20)

As one of the world’s most water deficient countries, Jordan, faces great problems. It has been estimated that the country only has approximately 250 cubic meters per capita per year compared to the 1000 cubic meters per capita per year of replenishable water supply

Fig 1.
Water train in southern Jordan
Photo by the author

needed to support the average needs of a country's population and civilization. (Project Rainkeep, URL)

The water that is used by most Jordanians today comes mainly from deep-drilling, reaching citizens through waterpipes, trucks and trains. (Fig.1)

In the 1940s modern deep-well drilling and piping was introduced to the wealthier Jordan families. The national water system was later extended to many of the smaller towns and villages. The result was an intensification of land and settlement. People became used to easier and more modern ways of getting water, and the old methods became more and more ignored. (Project Rainkeep, URL). Thus water usage increased, while the traditional personal responsibility for maintaining your own water supply decreased.

4.1 “Running out of water”?

Water is a vital resource, all over the Middle East and North Africa. This region (as a whole) entered a phase of water deficit in about 1970. Some countries, the Gulf State, Jordan, Israel, Palestine and Libya, had run out of water in the 1950s or 1960s.

The meaning of the term running out of water can be explained as follows:
About 10 % of an individual’s water consumption is used for drinking, domestic, municipal and industrial uses. This, together, amounts to 20 to 100 cubic meters per person per year depending on whether one lives in an industrialized or non-industrialized economy. To provide this water is not generally a difficult challenge. The water used to grow the food consumed by an individual is of a much greater volume, estimated at about 1000 cubic meters per person per year. This means that water for food production represents about 90 % of an individual’s water needs.

Up until the 1970s the Middle East and North Africa region mobilized almost all its irrigational potential from surface and groundwater sources to meet the needs of the growing population. The opportunities to mobilize new inexpensive water closed for most economies in the early 1970s. It is true that it is possible to expand desalination projects and various water transport options, but that water would only be affordable for domestic, industrial and service sectors.

The production of staple foods requires inexpensive water. To cope with the serious water deficiency that have been evident in the three decades since the early 1970s the region has been forced to import water embedded in staple cereals. It takes 1000 tons (cubic meters) of water to raise a ton of wheat. To import a ton of wheat is much easier than to import 1000 tons of water. One must also keep in mind that since grain on the world market has been heavily subsidized, the water deficient countries importing it benefits. The price of grain has been falling on the world market scene for the past hundred years. (Allan 2000, p. 13-14)

In 1991 about 97% of the households in Jordan were supplied with public water. The supply of household water was 179 mcm (million cubic meters), a shortage of some 30% compared with a requirement of 90 litres per capita per day. Industrial requirement of 42 mcm were generally covered, while the irrigation sector received only around 615 of the 860 mcm it would need, again a shortfall of some 30%. (Wåhlin 1998, p.2)

In 1992, it was stated in Jordan Times that available facts pointed towards the conclusion that Jordan’s water supply, at the time already critically short, would worsen significantly over the next two decades. (Wåhlin 1995b, p.2)

The used total in 1997 was 882 mcm. In 1996, the per capita share was less than 175 mcm. Around 225 mcm of the 1997 total of 882 million cubic metres came from groundwater over and above the level of sustainable yield. 70 mcm came from non-renewable fossil water drilled in the southeast. Estimations seem to show that by 2025 the per capita amount will have fallen from the current 200 m^2 per person (1998) to 91 m^2 per person.

The 1994 peace treaty between the states and neighbours Jordan and Israel gives Jordan right to 215 mcm per year, through new dams, diversion structures et cetera. Jordan is already getting 55-60 mcm through a pipeline from Israel. Of course the water added from the treaty is significant but it is barely enough to maintain status quo. (Jordan's Water Shortage, URL)

4.2 Cost of Water

Modern rural Jordanian water consumption (researched by Project Rainkeep) shows large variations. It ranges from a minimum of less than 6 cubic meters per month per household, or approximately 33 litres per person per day to 22-33 cubic meters per month.

Modern urban water usage has been estimated to be as little as 100 litres per capita per day. Purchased truck water, which often is the only possibility way to acquire pure water in outlying areas, typically costs JD 15-35 per month for 10-25 cubic metres. This can be compared with daily wages as low as JD 4-5 for unskilled labourers.

4.3 Water Quality and Accessibility

In many of the rural areas where municipal water exist, water only runs for one or two days per week, sometimes only for a few hours a day. Since water pipes lie empty beneath the hot sun for many days in some areas, high levels of chemical additives must be mixed with municipal water sources to dispose of algae or bacteria in the pipes.

4.4 How Jordanians today look on water

The Pilot Phase of Project Rainkeep showed that (in the area where the experiment took place) "rural Jordanians place high value on water conservation." Water is thought of as a treasure and is kept under lock and key when purchased.

Interviews also revealed "a strong tradition of sharing rainwater harvested in cisterns with the poor and/or passing flocks".

The interviews also showed that cistern water often was preferred and saved for drinking compared with the municipal water. "We use the tap water for sheep and washing clothes but we save the cistern water for ourselves." –quote from a family in the village of Libb. (Project Rainkeep, URL)

Wåhlin states that in most cases springs and groundwater wells are publicly or communally owned, while cisterns for the collection of rainwater are private property. The water that is collected in cisterns is rarely, if ever, used for irrigation.

In the al-Balqa' area, there are also rather strict traditions and opinions on the use of water. Spring or stream water is mainly used for irrigation. Water from dug wells or cisterns is used for household chores and for watering livestock. Here, municipal water was introduced in the 1980s, which has caused the population to rely more on the authorities for their water supply (Wåhlin1995b & 1998, p.1).

5. The Archaeological Material

I have been looking at excavation reports and papers on several excavations in Jordan and have chosen some examples of Nabatean constructions that I feel show some different aspects of Nabatean water management systems. The reports are from the Humayma Hydraulic Survey carried out in 1986, 1987 and 1989 and the pilot of the al-Karak Resources Project (Nakhl) carried out in 1995.

5.1 Humeima / Auara

Humeima, site of ancient Auara, was the major Nabatean central in the Hisma, Jordan's southern desert. According to Ouranios's Arabica Auara was founded by Aretas III. (Oleson 1992, p.269) The site flourished during the Nabatean, Roman, Byzantine and Umayyad periods.

The site of Humeima is a good example of a Nabatean settlement since it has a relatively well preserved archaeological material, a well marked proto-urban focus, a clear definition of catchments areas and since a wide array of water-harvesting techniques was used. The purpose of the surveys was to be able to build a case study of the interrelationships between water supply and settlement design at a Nabatean desert site. The average rainfall in the area is about 80 mm per year. (Oleson 1991, p.46; 1992, p. 269)

5.1.1 Outside the Settlement

The survey of 1986 focused of the settlement's catchments areas: about 240 km^2. 61 sites were recorded outside the settlement centre and divided into the following groups:

51 cisterns
4 springs
1 aqueduct
1 dam
2 sets of wadi barriers
6 sets of terraces or stone piles.

One can see cisterns are clearly dominating among the recorded sites. However, 19 of these cisterns (all except one cut in bedrock) are of possible ancient origin. Oleson means that the remaining 32 examples undoubtedly are ancient due to design or present condition, even if the precise chronology is not possible to determine as yet. Of the 32 ancient cisterns from outside the settlement only two are built mostly of blocks rather than cut in the bedrock. Of the remaining rock-cut cisterns, 16 were unroofed, roofed with stone slabs, or roofed with an undisturbed stratum of bedrock. The remaining 14 were roofed in the typically Nabatean fashion using transverse arches. (Oleson, 1991, p. 46-48; 1992, p.270)

5.1.2 The Aqueduct

The aqueduct at Humeima is a great example of Nabatean hydraulic skill and determination. Oleson claim is to be "one of the most remarkable surviving examples of Nabatean hydraulic technology so far reported anywhere". It consists of a main line 18.901 km long from the 'Ain al-Qanah (a spring at an elevation of 1425 m) to the Nabatean reservoir in the settlement centre (at 995 m). The branch line of 7.625 km connects 'Ain ash-Sharah and 'Ain aj-Jamam, with the main line, joining it 6.557

km downstream from 'Ain al-Qanah. It follows the ground level and occasionally makes use of low bridges and viaducts. Average slope is 2.45 percent from the springs to the city. The level of the slope varies from less than 1 percent to 10 and 20 percent and at the ash-Sharah escarpment 45 percent.

Fig 2.
Probe at the Humeima aqueduct.
(Oleson, 1991, plate 4a)

The aqueduct consists of a heavy rubble foundation wall that supports long stone conduit blocks framed by rubble packing set in mortar. The conduit blocks are made of yellow marl or white sandstone depending on the region; the material was quarried locally. On the upper edges of the conduit blocks fist size rubble was set in a hard mortar and smoothed over with stucco/plaster on the interior. The whole structure was topped with flat slabs of limestone.(Fig. 2) (Oleson 1988, p158-159; 1992, p.270-271) This is a typical Nabatean technique, with parallel cases found on almost all Nabatean sites, although the ‘Ain al-Quanah is the longest aqueduct by far.

5.1.3 The Settlement

The focus of the 1987 survey was on the water supply system inside the settlement. 16 new structures were documented. They consisted of :

11 cisterns
2 reservoirs
2 sets of conduits or drains
1 bath building

In addition 43 probes were executed at 10 other distinct sites.

5.1.4 The Reservoirs

There are two reservoirs at Humeima. One is Nabatean and one of Roman origin. The Nabatean reservoir was placed on a ridge 6 m above and 350 m northeast of the settlement centre and has a length of 27.6 m, width of 17 m and depth of 1.75 m. It was filled with water from the 'Ain al-Qanah aqueduct and had a simple overflow that fed another conduit. (Oleson 1992, p.271)

5.1.5 Cisterns nos. 67 & 68

These two cisterns are situated in the centre of the settlement ruins. They are almost large enough to be called reservoirs with a capacity of 445 and 486 m^3 respectively. The cisterns are very similar in size and design, which suggest that they were built simultaneously. Both are rectangular, narrow and roofed with stone slabs carried by sixteen transverse arches. (Fig. 3)

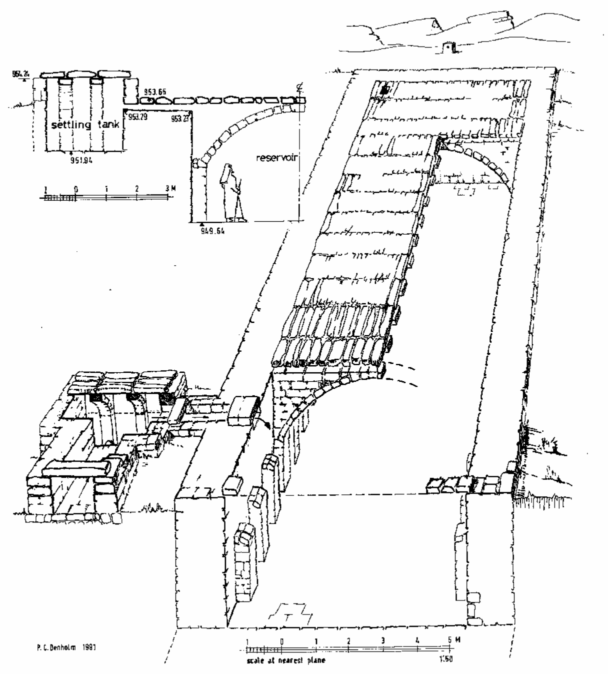

Fig 3.
Cistern no. 68 at Humeima.
Reconstructed perspective view.
(Oleson 1995, p. 712 SHAJ V)

They were built to harvest water from a large run-off field that covers approximately 100 ha north of the settlement. The area was clearly protected from habitation throughout the history of the settlement. Even today the area is nearly empty of structural remains or shards.

Cistern no 67 has a 25 m long intake channel that was completely rebuilt in the 1960's when the whole cistern was cleared out and renovated. It is still (in 1990) used as the major public water source for the region. No 68's original construction is better preserved. The original intake channel (width 0.64 m, depth 0.35 m) was built of large, heavy slabs of stone and the deep settling tank with a length of 3.18 m, width of 2.58 m and depth of 1.6 m was roofed with slabs carried by two transverse arches. Major parts of the roof are still supported by the fourteen remaining arches. The stones were carefully cut and placed and were waterproofed with a hard sandy plaster containing pebbles. (Oleson 1988, p. 164-166, 1991, p. 288) (Fig. 3)

Since these two cisterns size, interrelationship, quality and location in the centre of Auara are rather noticeably, Oleson suggests that a municipal authority built them, perhaps even under the patronage of the founder of the settlement, Aretas III. Undoubtedly they were built for public use.

5.1.6 Cistern no 54

The other nine cisterns found in the settlement centre are all built of blocks. As the settlement is located on the edge of fertile loessal plains the bedrock is out of reach. All but one of the nine cisterns are circular in shape and of a much smaller size, they all have capacities of less than 200 cubic metres. The lower capacities and the fact that they are usually partially buried in structural remains seem to imply that they were for private use and built by individual families, concludes Oleson. (Oleson 1988, p. 165) (Fig. 4)

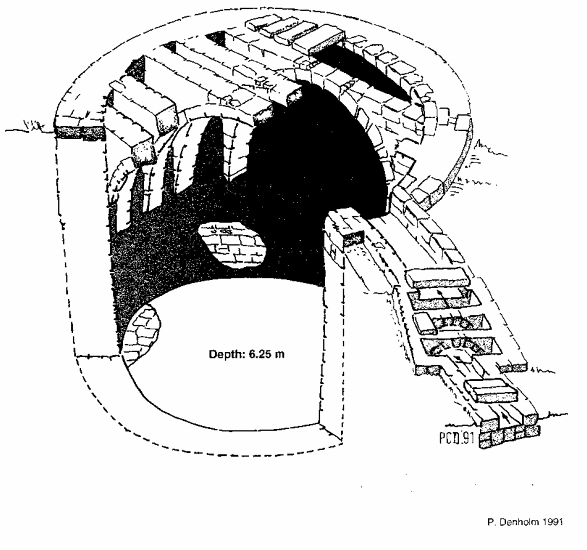

Fig 4.
Cistern No 54 at Humeima.
Reconstructed perspective view.
(Oleson 1995, p. 712 SHAJ V)

5.2 Nakhl

Nakhl is one of the larger antiquities sites on the al-Karak Plateau. This settlement required a considerate amount of rainfall for its population, with intensively cultivated crops and domesticated animals. The site is situated at the head of three wadis and the annual rainfall is much heavier than at Humeima: about 300 mm per year, falling in the winter months.

The Nabateans (and later Roman and Byzantine populations) at Nakhl used the headwaters of Wadi Nakhl and built low-placed dams to store water, usually filling the highest dam first, and then allowing overflow to fill the next lower dam downstream. They used cisterns to store water from the surface runoff of streets and buildings. Wells were constructed to allow inflow as well as overland flow for replenishment.

In the catchments area, there are preserved lateral walls that were constructed to retain moisture for crops or animals use. (Fig. 5)

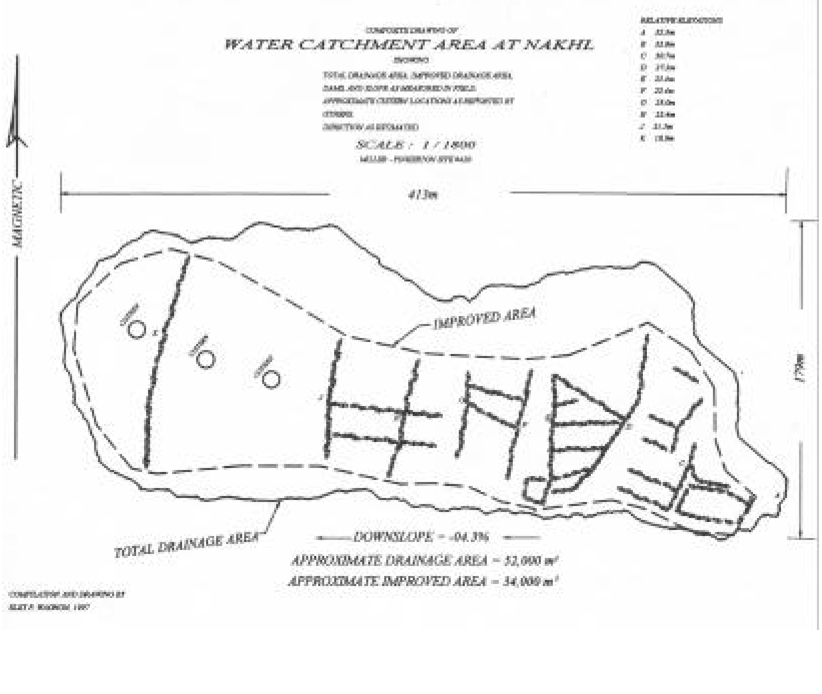

Fig 5.
The Water Catchment Area at Nakhl.
(Mattingly et al. 1998, p. 333
ADAJ XLII)

5.2.1 The Catchment Area

The total catchment area is 52.000 m^2 while the constructed walls span an area of 34.000 m^2. Walls were built of unquarried stones lying in the area. Furthermore there are low walls dividing the areas between the walls into smaller spaces that might have been pools or reservoirs. It is also possible that the walls may have retained soil which would have been used for agriculture, however, no remains exist today. (Mattingly et al. 1998, p. 332-335)

6. The Nabateans

There have been many debates on the precise origin of the Nabateans. What most writers seem to agree on is that the people were Arabic in origin and one of the many nomadic tribes that lived on the Arabian Peninsula.

Some believe that they came from the southwest of the Arabian Peninsula, from today's Yemen, but their language, script and their gods have nothing in common with those of southern Arabia. Another theory is that they originated from the east coast of the peninsula, opposite Bahrain, where it is known that they maintained trade links.

One of the more feasible theories is the one that place their home in the north, northwest (in today's Hejaz region) of Saudi Arabia. This is supported by the fact that they shared several deities with the ancient people there and that the root consonants of their tribal name – nbtw - are found in early Semitic languages from this region. (Healey 2001, p.25, Taylor 2001, p.14)

The movement of people and tribes were not uncommon during the appearance of the Nabateans in the Jordan area, so similarities in dialects and/or gods would, I think, not have been uncommon as different tribes shared contacts and ideas.

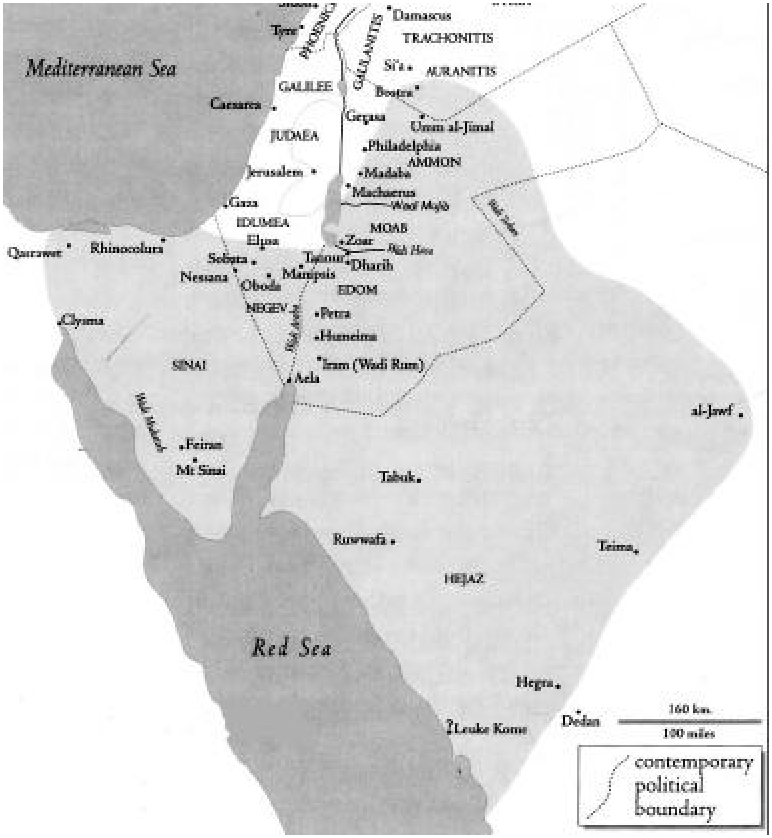

Fig 6.
Approximate maximum extent of the Nabatean Kingdom (Taylor 2001, p .7)

6.1 When?

There have been some discussions on whether the Nabateans drove off the Edomites that occupied the area before or if it was already deserted when the Nabateans arrived. (see: Hammond 1973, p.13) There have even been suggestions that the Nabateans in fact were a latter transformation of the earlier people (Healey 2001, p.25). Nelson Glueck, who has done extensive surveys in the area, does point out that there are similarities between Nabatean and Edomite ceramics (Hammond 1973, p.13) and a common god, (Taylor 2001, p.37) which would indicate, if not common roots, then at least a longer period of existence side by side.

According to Lawlor, the immigration of the Nabateans in to the Jordan-Palestinian area took place during a period of 200-300 years. (Lawlor 1974, p. 27-30) Since the Nabateans were nomads it would be difficult to make a more precise estimate. The need for water surely prompted movements within the area.

6.2 Rise of a Civilization

Diodorus of Sicily wrote during the 1st century B.C. and used as a source Hieronymus of Cardia, who in turn wrote in the 3rd century B.C.

Diodorus, using Hieronymus, describes the Nabateans as a nomad people whose well known wealth came from pillage and trade, using the desert as a shelter, and digging hidden wells and cisterns. (Healey 2001, p.26-27 (quotes from Diodorus: II, 48.1-2, 48.6 :trans. Oldfather 1935, XIX, 94.2-6:trans: Greer 1954)) About 310 B.C. Petra, the “capital” of the Nabateans, was twice attacked by the generals of Alexander the Great. Their goal was to take over the, by then well established, caravan trade and take control of the trade routes and taxes. They failed their task, but these incidents show that Petra already was seen as profitable to plunder. (Fiema & Jansson 2002, p.13)

By the 1st century B.C. the descriptions of the Nabateans have changed considerably. Strabo, a contemporary writer, depicts them as a settled people, with laws and kings., although they still honoured equality and the nomad way of living (Hammond 1973, p.11-12) These two writers, Diodorus of Sicily and Strabo, are often used to exemplify the transition from nomadic to a more agricultural, settled life that the Nabateans made.

Nelson Glueck also noted this formative shift (from about the 1st century and forward) during his archaeological surveys of Nabatean settlements in the Negev and Jordan. Hammond associates this rapid transition with the increasing need for depots, shipping centres etc. that came with intensified trade. (Hammond 1973, p.14) There is however no doubt that a lot of people still lived nomadic or semi nomadic lives, making use of tents. (Healey 2001, p.27)

Up until the 2nd century A.D. the Nabateans traded on the peninsula's southern routes from the rest of the Middle East, Asia and Africa to Egypt, the Mediterranean and the expanding Rome. They were positioned to take maximum advantage of the existing trade routes and took taxes on passing caravans. Working as middlemen they traded with all valuable things. Balm, bitumen, spices, myrrh, incense, perfumes, ivory, rice and drugs are just naming a few. (Bowersock 1983, p.15, Charlesworth 1926, p. 62, 64ff, Schmid 2002, p.29) They probably also traded with more common items such as ceramics (Hammond 1973, 67-68) and provisions and equipment for passing caravans. (Fig. 7)

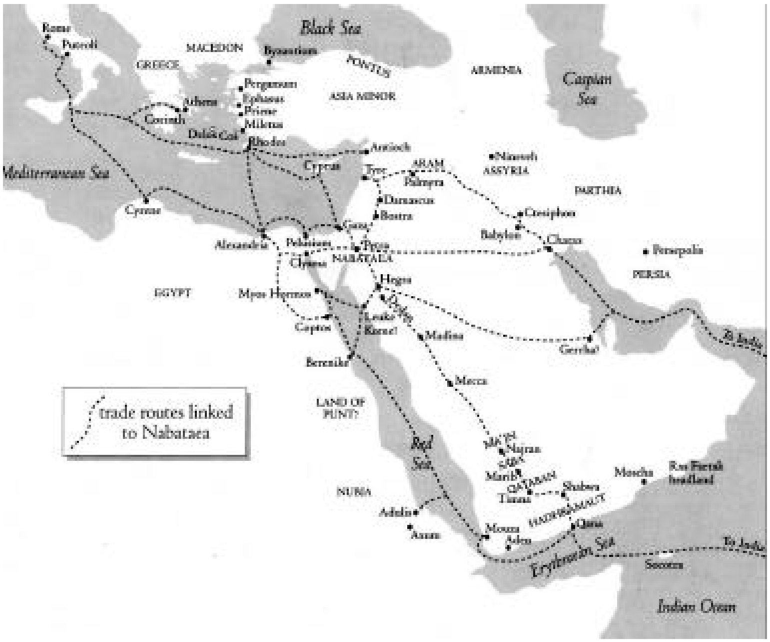

Fig 7.
Nabatean Trade Links in the Ancient World
(Taylor 2001, p. 7)

After several periods of political unrest in the countries around the Mediterranean and the unavoidable involvement of the Nabateans, the independency of the Nabateans and their kings came to an end in A.D. 106 when an expanding Rome finally annexed the area, creating Provincial Arabia with Petra as capital. The people of the kingdom carried on much as before, only upper strata were replaced. Roman legions were positioned throughout the area but it seems that there were little fighting done, and they concentrated mostly on building forts and developing existing roads.(Taylor 2001, p.74, 76)

6.3 Development of Nabatean Hydraulics

As the Nabateans gained more wealth and prospered, their increased standards of living and settlements needed more water. To meet the needs they increased the use of the traditional water harvesting techniques of the area. They also started using new techniques learned from their contacts, noticeably the Hellenistic world. (Oleson 1995, p. 708)

John Oleson has written quite extensively about the Nabateans water supply systems and how they evolved.

Of the traditional water harvesting techniques, the terracing of hillsides is perhaps the most noticeable. Heavy stonewalls were built across the slope of a hill to capture rainwater and the soil that the water carried with it. Crops were planted on the resulting flat surfaces and benefited from the accumulated moisture. (Mattingly et al. 1998, p.335, Oleson 1995, p. 709)

A variant of this technique was to build barriers across wadis and streambeds. These were more vulnerable since they could get damaged by flash floods that carry the concentrated runoff from a whole catchment area, but on the other hand was more water collected when the barriers held. There is a difference between these smaller barriers and those that are called containment dams.

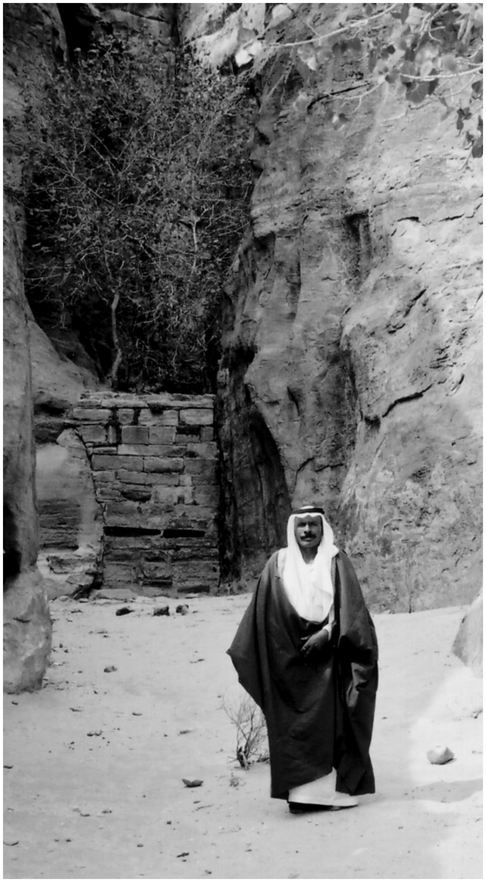

Fig 8.
Wall in a small wadi in Wadi Rum, Jordan.
Photo by the author

Containment dams are large barriers that are designed to trap and hold a large body of water, creating a pool. They have to be constructed with utmost care since they have to resist the sudden income of water, also the erosion that takes place when the water flows over the spillway and percolation. There is also the problem of high precipitation and the low water quality caused by organic material falling into the open pool.

Natural pools easily form in soft stone and have been used from antiquity to the present. (Oleson 1995, p.709)

6.3.1 Cisterns

Cisterns are good for storing water as the entry of the water can be controlled; the water is also easy to keep clean and there is virtually no evaporation.

Cisterns in different forms have been in use since the early Bronze Age. By the Iron Age, the Edomites used a cistern type that was rock-cut and shaped like a bottle. They were usually made small with a narrow neck and a width of 3-4 m as the greatest diameter. This type of cistern was later taken over by the Nabateans as they moved into the area. Diodorus of Sicily claims that the Nabateans made them much larger, "one plethron [27 m. (Oleson)] wide". (Oleson 1995, p. 709)

The Edomite cistern was usually cut in the bedrock. It was placed close to a focus of a natural catchment and had feeder channels that led water into the draw-hole or a special intake.

6.3.2 Flowing Water

Since springs and seepages are not common in the desert like environment of Jordan those that exist have been a focus of human activity throughout history. Many of these sites have been in use from the Paleolithic to the present, and it is therefore nearly impossible to document their original appearance and the earliest methods of enhancing and capturing their flow.

6.3.3 New Ideas

The techniques mentioned above were the ones that were available to the early Nabateans, around the 5^{th} century B.C. During the 1^{st} and 2^{nd} century B.C. new techniques appeared. These were probably due to a growing population and more frequent transits through the desert and later a shift to a settled, agricultural economy, as already mentioned. These new technologies remained in use through the Byzantine period in the areas were the Nabatean lived. That is roughly: from Hawran on the north to the Hijaz on the south and west across the Negev desert to the Mediterranean. It is therefore very difficult to document the exact time and place for their introduction. Oleson's excavations at Humayma/Auara suggest that the 1^{st} century B.C. "was a period of particularly rapid innovation". (Oleson 1995, p. 710)

Oleson divides these new water management techniques into three groups; collection, transport and storage. I will use these groups as well since it is a quite rational way as it follows the route the water took.

6.3.4 Collection

The collection of water was obviously the first and most important step. Even though the underlying principles were quite simple they demanded careful consideration.

A desert landscape does not hold a heavy ground cover of plants and humus. Usually, the rain runs off the surface unimpeded, gains speed and transforms into fast torrents that follows the wadis "until they empty out in mud flats or cross absorbent geological deposits". In the sandstone mountains of the Petra region, runoff is even more impressive (Oleson 1995, p.710) and has been known to cause disasters even in our days. (In 1963 a group of French tourists was caught in a flash flood in the Siq leading to Petra and 23 people died.)

The problem of heavy flash floods in the Siq of Petra was partially solved by the Nabateans by the construction of a tunnel and dam system that caused incoming flood water to be directed along a subsidiary water course, they also built dams across side-wadis to reduce the speed of the water. (Taylor 2001, p. 85, 86-87)

The Nabateans walked a fine line. A catchment area too large and you have a torrent very difficult to control, too small and you might end up with no water at all due to the fact that rainstorms in the desert often are small and localised. Obviously the risk of excess flow became even more important if the water was supposed to end up in cisterns inside or close to settlements, especially if the cisterns were built of blocks rather than cut into the bedrock.

By building containment walls and/or cutting channels at the edges of a slope to salvage water or to divert it towards a small cistern the Nabateans were able to adapt catchments areas. These two types of alteration were relatively easy to arrange on bedrock slopes and many still function today.

To enhance the runoff on earth slopes it takes a little more effort, planning and maintenance and there are few of these sites that have survived. In slopes filled with gravel the stones have been piled in regular heaps or lines. (Oleson 1995, p. 710-712)

Their exact use has been debated on but Oleson writes that the piles probably had two purposes. By removing the surface stones the soil crusted over almost immediately after a rain. This crust led to a greater runoff thus increasing the yield of water. There was also a transportation of soil particles to terraced field on the slopes or the wadis below. It has not been possible to date the stone pile technology precisely but they first occurred around the 1st century B.C. or A.D. and remained in use through the Byzantine period. These catchments field are very rare in southern Jordan, probably because of differences in local geology and topography; the large areas of exposed bedrock in the south of Jordan form natural runoff areas.

Common in Nabatean settlements was to use wadi barriers “to direct excess water flow into channels that carried it to fields above the wadi bed proper”. This was useful since it expanded the area of watered field and avoided the loss of soil and moisture that was the result when a heavy runoff breached a wadi wall. This technique might have been copied from the Nile Valley, were it was used to irrigate fields above the level of the Nile flood, and by the time of the Nabateans already had been in use for millennia.

Small containment dams were quite common among the Nabateans in Petra and southern Jordan. They were built across steep-walled gullies, and were in effect a type of cistern. These small dams do not have the construction problems that larger ones have. Some of the problems with large, open, standing bodies of water have already been mentioned. Both these and the smaller ones would have needed constant maintenance to keep them from filling up with sand and silt. (Oleson 1995, p.713)

6.3.5 Transport

Transport of the collected water to places of storage or use was often needed.

Among the Nabateans small channels for directing water were in use everywhere, either cut in the bedrock to lead small amounts of runoff to cisterns or cut in sandstone blocks (conduit blocks) to lead water from roofs or pavements into cisterns. These conduit blocks were usually a cut channel in a block of the local sandstone, marl or limestone 60 to 90 cm long. They were the most common water channels used in the Nabatean area from at least the 1st century B.C. through the Byzantine period.

These types of conduits were typically associated with spring water and common throughout the area of the Nabateans. They vary from a length of a few metres to the 27 kilometres of the aqueduct at Humeima. The one carrying water from 'Ain Musa to Petra was approximately 6 kilometres long.

Aqueducts need constant maintenance and are expensive and difficult to build. Olesen therefore believes that the Nabateans rather depended on the harvesting of desert precipitation than long, spring-fed conduits. The Nabatean conduits differ from the typical Hellenistic and Roman in the way that the size and design flow of the channels are lower, which reflects the amount of water available. They were also often built on a ground level course while Roman aqueducts made use of arches to maintain maximum flow and speed.

The smaller format of the Nabatean conduits allowed for greater flexibility during the construction of water management systems. The flexibility was necessary due to the ground level course. The landscape of the Nabatean is craggy, which gave the Nabatean engineers a series of different problems to overcome. Some of the techniques they used were heavy support walls, low viaduct bridges, channels cut in faces of cliffs and slab bridges over small gullies. Terracotta pipelines were used on some occasions, the Siq at Petra is one, but Oleson says that there are no records of pressurised systems being in use. However, pressurised systems existed at the time, and can be found in many Hellenistic and Roman cities, the closest sites being in Jerusalem and the Jordan Valley.

The smaller size of the conduits also made it possible to make sharp turns and variations in inclination without putting too much stress on the system. Hellenistic and Roman channels have very small changes in slope. Vitruvius said that a slope of 0.5 is most appropriate and surviving aqueducts generally vary between an inclination of 2.0 and 0.03 %. (Oleson 1995, p. 714-715)

The Nabateans felt no such restraints; the average slope at the Humeima aqueduct is 2.45% and where it passes the ash-Sharah escarpment the inclination varies from 10 to an impressive 45 %. (Oleson 1992, p. 271)

6.3.6 Storage

The water that was collected from springs was commonly fed into public reservoirs. The access to this water was governed by tribal costumes and perhaps sanctioned by religion. The Nabateans didn’t have the ability to roof these larger cisterns in the beginning. In cases were the water was constantly renewed this would not have been such a large problem but in the cases were the open reservoir was a dead end water quality would have decreased rapidly. Oleson proposes that this type of cistern only was used to water animals or that the water was carried away manually to fill domestic tanks and cisterns. (Oleson 1995, p. 715-716)

The bottle shaped cistern that the early Nabateans used was part of their success in taming the desert. Its main drawback is that it must be placed on suitable bedrock with a close adjacent runoff field, which limited the places suitable for settlement.

As the Nabateans gained significant skills in stonemasonry it is reasonable that cisterns built out of cut stone were in use among the Nabateans from at least the 2nd century B.C. The built cisterns were waterproofed with the same plaster types used for rock cut cisterns. The problem of roofing still remained since there was not nearly enough wood around and the soft sandstone could not bridge large spans.

There is no definite date for the introduction of the arch and vault in the Nabatean society but they probably learned the technique from adjacent states influenced by the Greek. Both Nabatean officials and merchants travelled to the Hellenistic capitals around the Mediterranean and traded on the Red Sea by at least the 1st century B.C. and there is a great similarity in the design between Hellenistic and Nabatean cisterns.

Thus the Nabateans started to use transverse arches spanning the cisterns. The squinches of these were then levelled of with filler blocks to support roofing slabs. These new techniques made it possible to construct cisterns were the water was needed. The Nabateans were no longer dependable on bedrock to make roofed cisterns, which probably helped to increase the settlement and sedentarization process. The arch and vault became typical in virtually all Nabatean sites and the same method was used on houses until the early Islamic period. It seems that they worked out the maximum span to 6 to 7 metres for it to be safely roofed. The same goes for the maximum depth of 5 to 6 metres; deeper would have been inconvenient and structurally difficult.

The public cisterns, which needed to have a large capacity, were thus rectangular in shape, with a width of about 7 metres and a length depending on need. The private cisterns, with a smaller capacity, were usually round with a maximum diameter of 5 to 6 metres and a depth of 6 metres. It is possible that the circular shape originated in the bottle-shape of the Edomitic cisterns but the circular shape is also more economical of material, easier to build and plaster and more resistant to the compression effect of the surrounding soil than a square one.

The round cistern usually had long intake channels with a rectangular settling tank, usually with an arch-supported roof. The settling tank allowed some of the debris carried by rapid runoff to settle before the water spilled over into the main tank. (Oleson 1995, p. 717-718)

7. Project Rainkeep

Project Rainkeep "was conceived as a possibility to increase personal responsibility of rural Jordanians citizens for their water needs". The aim is also to improve health and financial status for the participating families.

Workers on the Madaba Plains Project gathered information about the design and uses of cisterns in the research area during the late 1980s and early 1990s. The site was chosen for the MPP's archaeological expertise and for its close proximity to the urban centre of Amman, which allowed for greater knowledge and information distribution about the project.

The Pilot Project Phase of Project Rainkeep was completed in 1995. 28 cisterns were restored for families in 11 villages in the Amman/Madaba area. Beginning in the summer of 1996 and continuing during the summer of 1997, an evaluation process took place. Guidelines for how to restore cisterns were developed.

Calculations by Project Rainkeep show that if restoration were to take place in the context of a large-scale project, an average cost of JD 600 has been considered reasonable.

"This cost is off set by estimated savings of JD 150 per household for a cistern holding 90 m^3 (given the cost of trucked water; costs are lower if piped water is available). The resulting capital/output ratio reaches 4.0: "...given otherwise unused (and often unusable) land and allowing JD 10 for the value of labour to clean the catchment and annual silt, an investment of JD 600 produces average annual savings of JD 140 indefinitely" (Russell 1996). Project Rainkeep evaluations of smaller rooftop catchment systems also yield savings averaging JD 65 annually, or a 10% post-tax return" (Project Rainkeep, URL)

8. Discussion

Jordan is a country that has been accepting new technology and new ideas at a rapid pace and has been very intent on modernization. This has led to an abandonment of traditional water harvesting techniques, noticeably the habit of using cisterns for the collection of water for personal use.

The studies made in connection with Project Rainkeep and the studies done by Wåhlin in the al-Balqa area have focused on the possibilities of restoration and reintroducing the habit of cistern usage. Project Rainkeep is still in its initial stages; the pilot project seems promising, but the long time effects and results are not known.

White et al. has put forward several criteria that should be considered when looking at water collection options. The effectiveness, impact on the available water supply, technological and economical feasibility, environmental impact and opportunity for sustainable development are all important factors. (White et al. 1999, p. 5-6)

The use of cisterns (water harvesting) is, I believe, something that is clearly a possibility when looking at these criteria. The effectiveness has been well established by the archaeological record and they augment the existing supply by preventing water evaporation.

Eventual environmental impact is dependant on where the cistern is placed and the type of runoff area it takes its water from. This and the sustainable development aspect are a bit complicated, since the cisterns collect rainwater that mostly would have evaporated anyway. On the other hand is it difficult to assess the implications of this approach for future generations, since you would need specific details on the area involved. Water that goes into cisterns may in normal cases recharge the groundwater.

In 1997 and 1998 a study concerning water quality in old cisterns took place. It was carried out by the UJ Institute of Geology and led by Elias Salameh. In the Madaba, Hallabat, Husn, Hisban and Tafileh study areas the water was said to be of high quality with low concentrates of salinity, nitrate and faecal coli forms. (Charkasi 1999, Jordan Times)

The technologically of cistern construction is not difficult and different variants can be found in the archaeological material. It is possible to improve cisterns with modern pumps and filters. Project Rainkeep calculations also seem to show that restoration is economically feasible in the project area. (Project Rainkeep, URL). The water is practically free if the initial cost of construction is not considered.

In 1999, collected rainwater accounted for only two million cubic metres of the total amount of 240 million cubic metres of municipality water used in the Kingdom each year.

In an interview in Jordan Times, Adnan Zou'by, who is director of public awareness and information at the Ministry of Water and Irrigation, said that “The collection of rainwater from roofs will be highly useful...any drop that we can collect is valuable” He also stated that there existed an aim which was to double the amount of rainwater collected by the end of the year 2000. (Charkasi 1999, Jordan Times)

So far the focus in Jordan has been on cistern use but much research remains to be done in the area. The people on the Project Rainkeep think that ancient water conserving agriculture systems may be an area worth exploring further (Project Rainkeep, URL)

Using water conserving agriculture systems they way the Nabateans did may not longer be considered an economically sound way of growing food; in Jordan there is no shortage of food as such. But water retention systems (catchments areas) such as those at Nakhl and Humeima, may promote added natural growth and reforestation. More moisture would also be contained and could add to aquifers and groundwater levels.

Since the overdraft of groundwater is an urgent problem everything that decreases the stress on the groundwater must be considered positive.

Awareness of the different water controlling techniques used in the past has been increased by the archaeological excavations and the multidisciplinary studies carried out in Jordan has shown that at least some of these ideas still are worth a second look. They may not give a full solution to the problem of water scarcity but certainly they can give partial relief.

Cisterns have been in use in many of the dry areas of the world. I think looking into the ancient techniques used both in other countries in the Middle East as well as elsewhere would prove fruitful and give insight into how to create a sustainable development, blending old ideas with new technology.

9. Summary

The aim of this paper is to present an example of how archaeology can be used to find solutions to water management problems and deficiency in dry areas. I have taken the Hashemite Kingdom of Jordan as my example as some research projects have already been implemented in the area.

Jordan has a deficiency of water that is predicted to increase. This trend was started in the 1940s when modern deep-well drilling and water transportation by trucks were introduced in the country. The water usage habits changed dramatically as Jordan intensified land and settlement without the coinciding development of surface water facilities. This led to a continuous overdraft of ground and fossil water, when at the same time traditional personal responsibility of maintaining your own water supply decreased. It has been estimated that the country only has approximately 250 cubic meters per capita per year compared to the 1000 cubic meters per capita per year of replenishable water supply needed to support the average needs of a country's population and civilization. If the trend continues, the per capita amount of water will have fallen from the current 200 cubic metres per person (1998) to 91 cubic metres per person by 2025.

The interest of water management among archaeologists increased in the 1980's. By the 1990's, several field studies, such as the Humeima Hydraulic Survey and projects, among them Project Rainkeep, had started in the Jordan area. The aim of these studies was to gain greater knowledge about how the past inhabitants of the Jordan area had managed their water resources.

I have focused on the Nabatean period, as they were a highly developed civilization with water management systems well adapted to the desert like environment they lived in. The Nabateans were in the beginning Arabic nomads that settled in the Edom. Their precise origin and time of appearance has been difficult to place, but in the 3rd century B.C., they are mentioned in written sources and seem to be well established in the area. They lived off trade, taking shelter in the desert and digging hidden wells and cisterns to create semi-permanent water resources.

The Nabateans used a variety of water collecting techniques, many of them long established in the area, such as the use of cisterns to collect rainwater from runoff areas. When the Nabatean realm grew and they became more settled they adapted new ideas (noticeably from the Hellenistic world which they traded and had other contacts with), to support growing populations and the change in lifestyle. By the 1st century, they had laws, kings and were in control of virtually all trade on the peninsula's southern routes from the rest of the Middle East, Asia and Africa to Egypt, the Mediterranean and the expanding Rome. They were positioned to take maximum advantage of the existing trade routes and took taxes on passing caravans, trading with everything of value. In A.D. 106, Rome annexed the kingdom, creating Provincial Arabia, with the Nabatean capital Petra as the new capital.

I have studied excavation reports from the Nabatean settlements at Nakhl and Humeima and selected examples that show the variety of the techniques that were at the disposal of the Nabateans. Nakhl has a very well preserved catchment area with walls that was supposed to slow the water down, capture moisture in the soil and direct water to cisterns and wells. Nakhl has had a much higher rainfall than Humeima (300 mm/year compared to 100mm), so they were able to cultivate a considerable amount of crops and support a larger population.

At Humeima the majority of remaining structures are those of cisterns, either cut into bedrock or built. The cistern was of central importance since the inflow can be controlled and the water is kept clean, which is not the case with larger open containment dams. At Humeima there two large rectangular cisterns (nos. 67 & 68) that probably were for public use, and perhaps built by some municipal authority. The other cisterns in the area are smaller, were very likely private, and built by individuals. Cisterns were fed with water from natural catchment areas that have been kept clear of constructions or runoff from roofs in the settlement centre. Other structures at Humeima include the longest known Nabatean aqueduct, 27 km long, and several wadi barriers, conduits and remains of terracing.

The aim of Project Rainkeep is to restore the personal responsibility of the rural Jordanians in providing their own water. The pilot project, which was competed in 1995, showed that restoring and building cisterns on a larger scale might be possible. Guidelines for cistern restoration were developed as well as economical calculations.

White et al. have put forward several criteria that should be considered when looking at water collection options. The effectiveness, impact on the available water supply, technological and economical feasibility, environmental impact and opportunity for sustainable development are all important factors. The effectiveness of cisterns has been well established by the archaeological record and they have a positive effect on the existing water supply by preserving rainwater which otherwise would have evaporated.

Results from Project Rainkeep have shown that restoration is economically and technically feasible. Environmental impact is dependant on the site of the cistern, there is no data on long-term effects of large-scale cistern use. A possible negative effect is the possibility that water that goes into cisterns would otherwise had gone into underground aquifers and helped restore groundwater levels.

There exists today government plans on increasing rainwater harvesting. So far, focus has been on the possibilities of cistern use, much research on other techniques remains to be done. The researchers in the Project Rainkeep think that ancient water conserving agriculture systems may be an area worth exploring further.

Awareness of the different water controlling techniques used in the past has been increased by the archaeological excavations and the multidisciplinary studies carried out in Jordan has shown that at least some of these ideas still are worth a second look. They may not give a full solution to the problem of water scarcity but certainly they can give partial relief. Cisterns have been in use in many of the dry areas of the world. I think looking into the ancient techniques used both in other countries in the Middle East as well as elsewhere would prove fruitful and give insight into how to create a sustainable development, blending old ideas with new technology.

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Figures:

Fig 1: **Author** (photo)

Fig 2: **Oleson, J. P.** 1991. plate 4a. Aqueducts, cisterns and the Strategy of Water Supply at Nabatean and Roman Aura (Jordan). In: (ed.) Hodge, A. Trevor. *Future Currents in Aqueduct Studies.* Leeds.

Fig 3: **Oleson, J. P.** 1995. *The Origins and Design of Nabatean Water-Supply Systems.* SHAJ V. Amman.

Fig 4: **Oleson, J. P.** 1995. *The Origins and Design of Nabatean Water-Supply Systems.* SHAJ V. Amman.

Fig 5: **Mattingly et al.** 1998. *The Water Catchment System of Nakhl, Jordan.* ADAJ XLII . Amman

Fig 6: **Taylor, J.** 2001. *Petra and the Lost Kingdom of the Nabateans.* London

Fig 7: **Taylor, J.** 2001. *Petra and the Lost Kingdom of the Nabateans.* London

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Fig 9:**Bowersock, G.W.** 1983. *Roman Arabia.* Cambridge, Massachusetts.

Fig 10: **White, G. et al.** 1999. Commitee on Sustainable Water Supplies for the Middle East. *Water for the Future.The West Bank and Gaza Strip, Israel and Jordan.* 1999. Wahington, DC.

Appendix

A. The Hashemite Kingdom of Jordan

Geography

The total area of Jordan is 89 210 km^2.

Jordan is situated the Middle East. (Fig. 9) It is bordered in the north by Syria, in the north-east by Iraq, in the south-east and south by Saudi Arabia, in the far south-west by the Gulf of Aqaba (northern shores of the Red Sea) and in the west by Israel. (Aquastat, URL) The country lies east of the Jordan river and is divided into 12 governorates; Ajlun, Al 'Aqabah, Al Balqa', Al Karak, Al Mafraq, 'Amman, At Tafilah, Az Zarqa', Irbid, Jarash, Ma'an and Madaba. The capital is called Amman. (CIA-World factbook,URL).

“The country can be divided into four regions:
-The Ghors (lowlands) in the western part of the country, which consist of three zones: the Jordan valley which starts at Lake Tiberias in the north (220 m below sea level), the lowlands along the Dead Sea (405 m below sea level) and the Wadi Araba which extends in a southerly direction to the northern shores of the Red Sea.
-The highlands, which run from north to south at an altitude of between 600 and 1 600 m above sea level.
-The plains, which extend from north to south along the western borders of the desert (Badiah)

-The desert region (Badiah) in the east, which is an extension of the Arabian desert“ (Aquastat, URL)

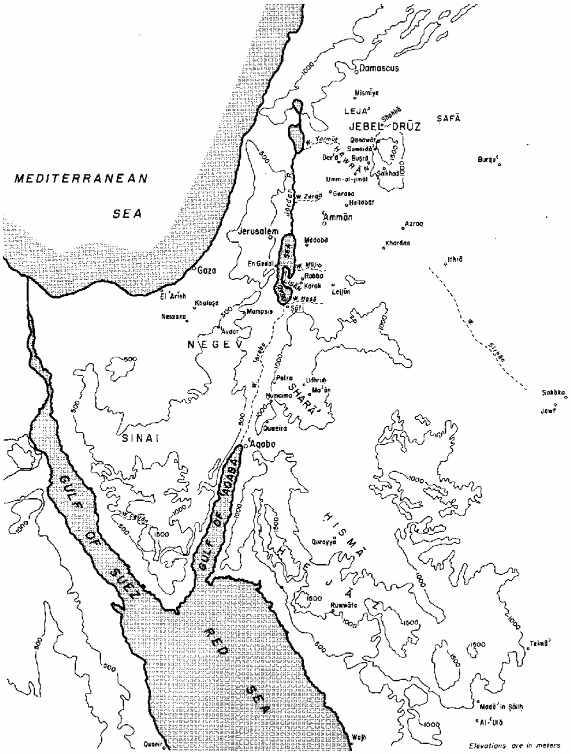

Fig 9.
Topography of the Jordan area.
(Bowersock, 1883)

Jordan is situated on one of the world’s most important landbridges – the one that connects North Africa with Europe, Asia Minor, Mesopotamia and much of the Far East. Together with the costal plain of western Israel, the western highland plateau of Jordan have for centuries and millennia provided armies, caravans and people groups with a corridor along which to pass in order to avoid having to traverse the desert.

Climate

For the people that have been living in the Jordan area, water has probably always been a major concern. The participation patterns over the Middle East have been about the same for the last 7000 years. The rains (which occasionally comes down as snow in the higher areas) generally fall from September-October to Mars-April. The summers are hot and dry.

Average annual rainfall over Jordan varies from over 600 mm in some restricted highland regions to less than 50 mm in the southeastern desert. (Fig. 10) Annual variation in rainfall is inversely proportional to the total, varying from 20-25 % in the northwest to over 70 % in the southwest. Only some 3 % of Jordan's area receives an average rainfall of over 300 mm, the amount considered sufficient (some say 250 mm) for successful rainfed agriculture (Wåhlin 1998, p.2).

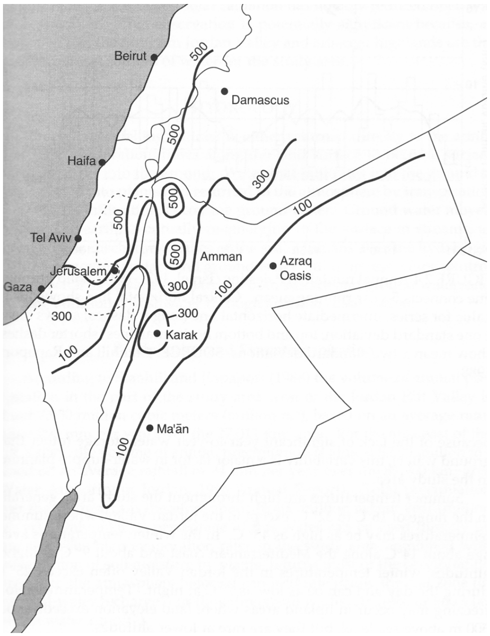

Fig 10.
Rainfall over Jodan in mm.
(White et al. 1999, p.31)

It is possible to divide the climate of Jordan into three zones. The zone to the west is the Jordan Valley depression with very hot summers and with little rainfall. The middle zone is the ash-Shafa or Plateau, broken up by streambeds that empty out in the Jordan River. It has a Mediterranean climate and can, if the winter is cool and wet, receive an annual rainfall varying between 200 and 700 mm. The easternmost zone is the steppe, east of the Hijaz railway, with hot summers and cold winters with very little precipitation. (Abujaber 1995, p. 737)

It can take one or two thousand years for rainwater to trickle down and refill the aquifiers that are used for deep-drilling water sources.

It has been estimated thar 85 % of Jordan’s rainfall evaporates. (Project Rainkeep, URL) Wåhlin says it is as high as 92 %. (Wåhlin 1995b)

Population

Jordan’s population is close to 5.5 million (2002). In 1995 29% of these were living in rural areas. The growth of the population is estimated at 3.4 %, which can change because of international political events, such as refugees. (Aquastat, URL)

History

As one of many other countries, Jordan escaped a long period of Turkish rule after the collapse of the Ottoman Empire in the wake of WWI. Britain was given a mandate over Palestine and created Transjordan with King Abdulla as ruler in 1921.The remains of Palestine corresponded more or less to the present state of Israel and the Occupied Territories.

In 1946 Transjordan gained independence and its name was changed to the Hashemite Kingdom of Jordan. Due to increasing conflicts in Palestine Britain decided to end the mandate in 1948. The matter was handed over to the UN in 1947, which voted in favour of a partition of Palestine into Arab and Jewish states, but no agreement was made. The independent state of Israel was proclaimed in 1948 and the ensuing conflict ended with an Israeli occupation of the zones allocated to them under the UN plan and virtually all those assigned to the Palestinian Arabs.

From 1950 until the Six Day War with Israel in 1967 Jordan had control of the West Bank. With the loss of the West Bank Jordan lost 70% of its agricultural land and 50% of its industrial establishment and virtually all tourism. From 1967 Jordan worked for the return of Arab land lost in the war. PLO and other Palestinian groups operated from Jordanian territory and eventually came to contest power in the Kingdom. This ended in 1970-71 when most of the groups were evicted from Jordan. The responsibility of negotiating for the return of occupied Palestine was transferred from Jordan to PLO in 1974 and in 1988 Jordan gave up all claims on the West Bank.

As a result of the Gulf War Jordan ended up hosting 1 million refugees, which put hard strains on the available water supplies and infrastructure. Since King Hussein feared unrest among Jordan's pro-Saddam population, he refused to side against Iraq during the Gulf War. By playing a peace-broker role and adhering to, officially at least, the UN embargo on trade with Iraq, the country managed to avoid total isolation.

In June 1994 Jordan and Israel signed the Washington Declaration ending 46 years of state of war. On October 26th 1994 the Jordan – Israel Peace Treaty was signed, guaranteeing equitable share of water from the Yaermouk and Jordan rivers.

King Hussein died in February 1999 and was succeeded by his son Abdullah. (Jordan History, URL , Simonis 1997, p.401,403)

B. Chronology

Mesolithic period 14000-8000 BC

First primitive agriculture and animal breeding.

Neolithic Period 8000-4500 BC
Still few people / Starting to live together at fixed sites

Chalcolithic Period 4500-3000 BC
Prosperous villages / Still plenty of forest around to prevent erosion

End of 4th century BC
Jawa is built in northern Jordan. A settlement with an elaborate hydraulic system.

Early Bronze Age 3000-2100 BC
Continuation of the progress taking place during the Calcholithic. / Copper implements used on larger scale. / Permanent streams become seasonal wadis as forests disappear and erosion increases.

c.2300 BC
Invasion of nomads. Every town in Palestine and Jordan destroyed and abandoned for centuries, probably due to destruction of the balance between people and resources

Iron Age 1200-550 BC
Jordanian kingdoms of Edom, Moab and Ammon. Wars with Israelites.

c.890 BC
Mesha, King of Moabs put out a decree that states, “make for yourselves every man a cistern in his house”.

Construction of wells and cisterns increase and continues through the following Hellenistic Roman and Byzantine Periods.
(Abujaber 1995, p. 737-739)

The Nabateans:

The Nabatean Kings:

c.168 BC	Aretas I
? late 2nd C BC	Rabbel I
c.103-96 BC	Aretas II
c.96-86 BC	Obodas I
86-62 BC	Aretas III
62-59 BC	Obodas II
59-30 BC	Malichus I
30-9 BC	Obodas III
9 BC-AD 40	Aretas IV
AD 40-70	Malichus II
AD 70-106	Rabbel II

Before the Kingdom:

332 BC	Alexander the Great captures Gaza
323 BC	Death of Alexander the Great
c.312 BC	Army of Antigonius attacks Nabatean stronghold (at Petra?)
259 BC	Envoys of Ptolemy II meet Nabateans in southern Syria
late 3rd C BC	Ptolemaic fleet punishes Nabatean 'pirates' in Red Sea

Aretas I c. 168 BC

1st half 2nd C B	Inscription in Elusa, Negev, mentions 'Aretas king of the Nabateans'
Rabbel I Late second century BC	
Late 2nd C BC ?	First Nabatean coins minted
129 BC	Moshion of Priene visits Petra on diplomatic tour of eastern Mediterranian
Aretas II c. 103-96 BC	
100 BC	Birth of Julius Caesar
c.100 BC	Gaza asks Aretas II for help against attck by Alexander Jannaeus of Judea
Obodas I c.96-89 BC	
c.93 BC	Obodas I defeats the Judaeans under Alexander Jannaeus
87 BC	Obodas I defeats Seleucids of Syria under Antiochus XII
Aretas III 86-62 BC	
? c.85 BC	al-Khazneh (Treasury) carved in Petra by Alexandrian craftsmen
85-71 BC	Aretas III addds the city Damascus to Nabatean kingdom
82 BC	Aretas III Defeats Alexander Jannaeus inside Judaea
65 BC	Pompey annexes Seleucid kingdom and creates Roman province of Syria.
64 BC	Pompey's expidition against Petra aborted
Obodas II 62-59 BC	
60 BC	Julius Caesar elected consul in Rome

Malichus I 59-30 BC	
55 BC	Gabinius, Roman governor of Syria, defeats Nabateans
49-31 BC	Roman civil wars (first between Pompey and Julius Caesar)
47 BC	Nabateans send forces to Julius Caesar; Cleopatra Queen of Egypt
44 BC	Julius Caesar murdered by conspirators led by Brutus and Cassius
42 BC	Mark Anthony and Octavian defeat Brutus and Cassius at Philippi
40 BC	Roman general Labienus and Parthian allies capture Jerusalem / Herod seeks help from Malichus I in Petra: then goes to Rome
37 BC	Romans appoint Herod King of Judaea / Parthians driven from Jerusalem / Cleopatra asks Anthony for Judaea and Nabatea – request refused
31 BC	Herod and Malichus I go to war (Nabateans defeated) / Octavian defeats Mark Anthony at Battle of Acitum
30 BC	Malichus I burns Cleopatra’s fleet / suicide of Cleopatra / Octavian annexes Egypt
Obodas III 30-9 BC	
27 BC	Octavian named Caesar Augustus by Senate
26-25 BC	Augustus sends Roman army, including 1000 Nabateans, to Arabia
c.12 BC	Syllaeus, Nabatean chief minister, proposes marriage to Herod’s sister.
9 BC	Syllaeus goes to Rome to complain about Herod / death of Obodas III

Aretas IV 9 BC – AD 40	
9 BC	Syllaeus seeks Augustus' support for own accession to Nabatean throne/ Aretas IV accuses Syllaeus of poisoning Obodas III
6 BC	Syllaeus, back in east, plots to murder Herod/flees to Rome/executed
4 BC	Death of Herod the Great; kingdom divided between three sons/Aretas IV helps Romans put down popular Jewish revolt
c.0 AD	Birth of Jesus of Nazareth
AD 27	Herod Antipas, tetrarch of Galilee and Peraea, divorces Nabatean wife
Malichus II AD 40-70	
AD 66-74	First Jewish Revolt against Romans
AD 70	Roman destruction of Jerusalem and its temple, with help from Malichus II
Rabbel II AD 70-106	
Ad 106	Roman emperor Trajan annexes Nabatea and creates province of Arabia
After the Kingdom:	
AD 111-114	Trajan's new road (Via Nova Traiana) built: Bostra-Petra-Aela (Aqaba)
AD 113/4	Earthquake causes damage in Petra
AD 132-135	Second Jewish Revolt against Roman rule
AD 284-305	Emperor Diocletian; persecution of Christians (including at Petra)

AD 306-337	Emperor Constantine the Great; Christianity legalised
AD 363	Earthquake causes much damage at Petra
Late 4th / early5th C AD	Ridge church built at Petra
AD 570	Birth of Prophet Mohammed
AD 630	Beginning of Muslim conquest of eastern Byzantine Empire
AD 661-750	Umayyad Caliphate, first dynasty of Islam
AD 1099	Crusaders capture Jerusalem
AD 1100	Crusaders first visit to Petra

(Taylor 2001, p. 219-220)

The location of Petra is later forgotten in the west.

AD 1812	Swiss explorer J.L.Burckhardt rediscover Petra. Beduins still lives in the area.

C Spelling and Arabic words used in the text

As far as I have gathered there has not existed one set way of Arabic transliteration. Instead there, seems to be quite a lot of them around. This certainly shows in the archaeological texts that I have been reading. Spelling, at least in the past, seems to have been practised as ‘you write down what you hear’. This is somewhat confusing since names on maps and text can differ and change over time. The example of Humayma / Humeima is fairly easy to figure out. So is the changes between Auara / Avara. The name of the spring:Qana / Ghana / Qanah was a bit more difficult.

The original transliteration of the modern Arabic name of Humayma was chosen in 1981 when the fieldwork started in the region. The transliteration was changed in the 1989 report to Humeima, which apparently is more correct.

I have tried to be consistent in my spelling. Since I don’t speak or read Arabic I have been forced to rely on the use of the most recent transliteration, even so I probably have missed a few places.

Two Arabic words that I have used in this paper are 'Ain: spring and Wadi: streambed.