WATER ENGINEERING AND IRRIGATION SYSTEM OF THE NABATAEANS: A REGIONAL VISION

Zeidoun AL-Muheisen

"...and we made from water every living thing. Will they not then believe?" (The Holy Qur'an, Sura XXI 'The Prophets': Verse 30). Water is the source of life and every living thing is dependent on it for survival. Since his earliest existence on Earth, man has inhabited the vicinity of springs and learned to manage the storage and distribution of this vital resource. Methods of water preservation coincided with or were followed by the development of techniques of hydraulic engineering such as the channeling of water to agricultural areas, industrial sites, residential areas, public buildings and amenities. In this respect it is imperative to briefly highlight the geology and climate of Jordan, as they related to the skills and expertise in hydraulic engineering developed and acquired by the Nabataeans and other ancient peoples who lived in this land. By virtue of a succession of geological and climatic ages that greatly influenced its topography, Jordan's terrain exhibits significantly distinctive features (Bender 1974: 6-10).

Although still in its infancy, most geological studies of Jordanian regions have focused on water geology or geomorphology. In this respect, it is relevant to refer to the recent studies of Boom and Suwwan that detailed the geology of Jordan, with particular emphasis on the northeastern region. These researchers discovered six successive basalt stages in the form of volcanoes in the period between the Oligocene, Miocene and Holocene ages. Considered the oldest geologically, evidence of these was discovered while investigating the ground water in Wādī aḍ-Ḍulayl, northeast of 'Ammān, while subsequent stages were shown to have been formed in later periods; some appearing on the surface in the area of the Yarmouk River between al-Mukhayba and the river estuary, others in the eastern area of al-Mafraq (Boom and Suwwan 1966: 1-42).

Climatic research in Jordan in general, and the third and fourth geological ages in particular, needs be furthered by precise and thorough studies. The actual need for these studies is emphasized by the fact that continental and semi-continental climates dominated through most geological ages and continued through the Pre-Cambrian until the middle of the Cretaceous. This epoch was recognizable by the presence of Nubian sandstone sediments (Burdon 1959: 15). When large areas of Jordan were inundated with seawater through the third geological age, during which continental and semi-continental climates prevailed, there were few pluvial periods (Orni and Efrat 1976: 8-14). However, recent environmental research has revealed that significant climatic variations had taken place in the northern areas furthest from the Equator (Shehadeh 1985: 25-39). Two main climates then existed in Bilād ash-Shām: an extremely cold icy period with scanty rain, and a moist warm pluvial period. Each of these two periods had many subdivisions, beyond the scope of the current issue (Burdon 1959: 17). Related to the preceding information are the climatic and topographic formations that appeared in Jordan in the Pleistocene age, when fresh-water lakes formed in the Jordan Valley along with deposits in the Jordan Valley arm. The present shape and features of the Jordan River and the Dead Sea were formed at a later stage (Butzer 1961: 35).

The existence of Khirbat as-Samra (Al-Khirba as-Samra) Lake and fertile red soil sediment favored the emergence of dense vegetation in the area, which was enhanced by high humidity and heavy rainfall. However, some arid periods prevailed throughout the Pleistocene particularly in desert areas, which compared to present conditions, were probably warmer and drier. This inference is supported by a study of the mollusca fossils belonging to that period (Butzer 1963: 215-216). While further evidence of arid periods can be seen in the formation of the Dead Sea and al-Jafr. The aridity and high temperatures in the southern area contrasting with the temperate conditions and pluvial nature of the northern region, presents similarities between the present climate of Jordan and the prevailing climate during the Pleistocene, when the Dead Sea area was arid and had little rain (Abed 1985: 90). Some scholars and researchers have pointed out that 15,000 years ago an arid climate prevailed and changes in weather patterns were benign and approached stability (Butzer1961: 43). Although others adopted the theory of on-going tangible climatic variations in the area throughout the past 4,000 years, a theory based on the observation of decreasing rainfall, increasing temperature and aridity (Ionides 1939: 41-42). Contrarily however, a group of agronomists states that there has probably been no change in rainfall in the past 5,000 years (Nahal 1991: 271-278). Based on the author's hydraulic and irrigation engineering studies, it can be stated that there has not been any climatic change in the past 2,000 years, and that the present problem is a consequence of human intervention and interference, two main examples being the encroachment of urban expansion on arable land and extensive areas being denuded of vegetation as a result of tree felling for lumber, domestic heating and cooking purposes. Unfortunately, reforestation has not kept pace with felling and the problem has been further aggravated by extensive animal husbandry, particularly of goats, notorious for inflicting devastating damage on vegetation.

The scarcity of rain in Jordan generally and in the southern area in particular is the result of a variety of natural factors. The terrain in the southern area is flat and far from the Mediterranean, resulting in continual fluctuations in local rainfall as well as seasonal and annual oscillations which are likely to have caused either heavy or niggardly precipitation. In some instances, rain could have fallen on one area while others remained dry.

The River Jordan, from which a certain quantity of water is currently exploited, is the sole surface-water resource and the country is consequently dependent on rainfall, a vital source of water that should be vigorously preserved, carefully used, and stringently controlled.

The efficient usage of water has been of the utmost concern since early man first settled in the proximity of springs such as al-Fujayj ('Ayn al-Fujayj), northeast of ash-Shawbak Castle in the southern area of Jordan, al-Asa'd spring ('Ayn al-Asa'd), south of al-Azraq and Wādī al-Ḥimma, in the northern Jordan Valley.... etc. The progressive population growth in Jordan in the past, and to an even greater extent the rapid increase witnessed at present, has necessitated the development of water-harvesting techniques and much evidence has been found of ancient methods such as those found at Jāwā in the eastern desert, which date back to the fourth millennium BC (Helms 1973: 126-128, 1981: 234-237). Rain, the main source of water at that site, was harvested by canals constructed to take flood water from Wādī Rājil through a main canal that subsequently divided into a network of sub-canals assigned for specific purposes: drinking, irrigation, and supplying water to cattle compounds (Helms 1976: 14-19, 1981: 157-183, 1982: 97-13).

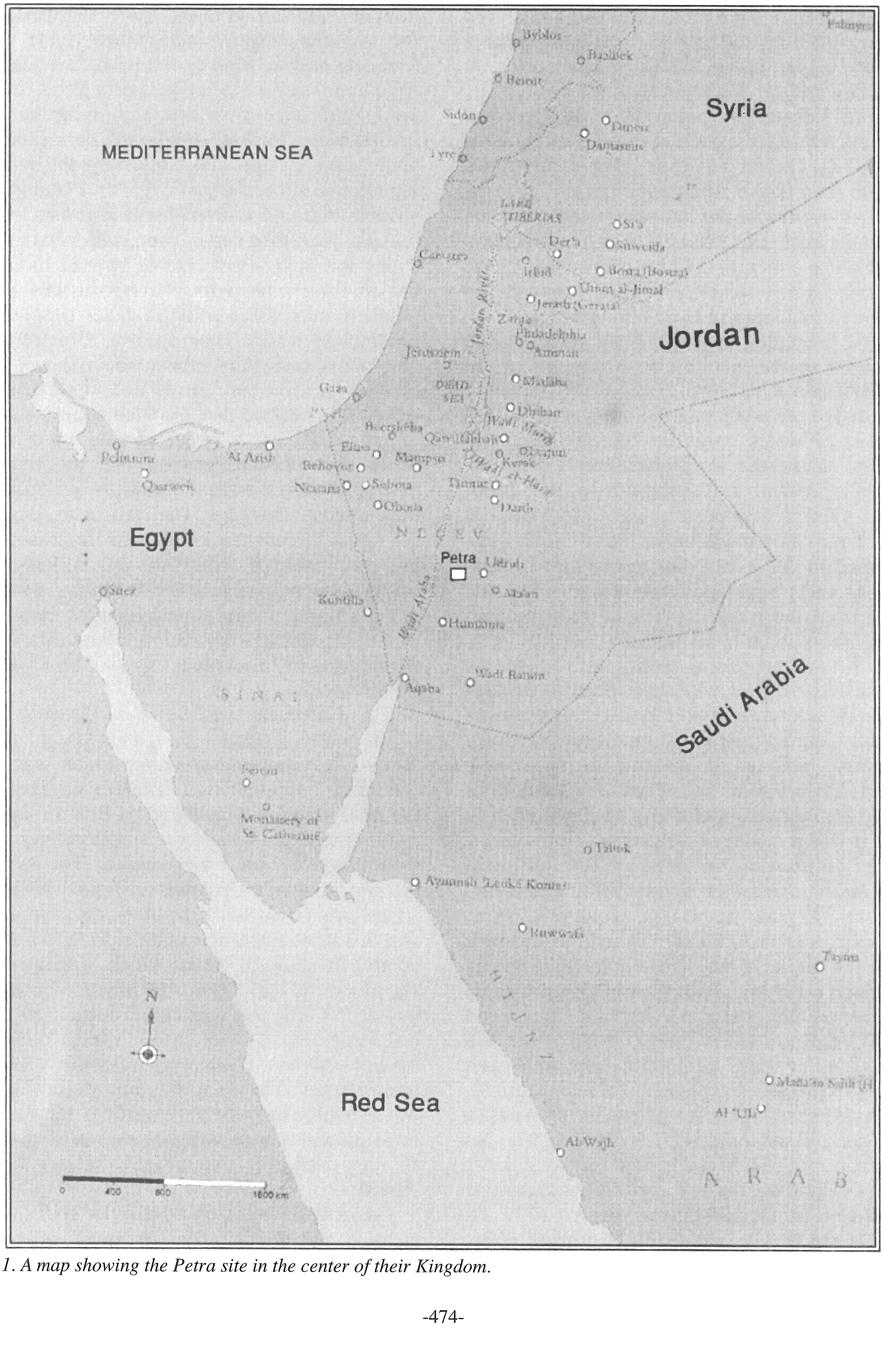
During later periods, agriculture and advanced water-harvesting methods were developed by the Nabataean Arabs who acquired skill and proficiency in the creation and development of hydraulic engineering techniques and the construction of dams, canals, cisterns, ponds and wells (Al-Muheisen 1980: 41-42). They also improved irrigation and agricultural techniques (Lawlor 1974: 18). The Nabataeans' interests and innovations were not limited to their achievements in agriculture, trade, rock carving and dam building etc. but they also played a major role as guardians of the caravan routes. Despite the facts indicating a thriving culture and civilization, they were unfairly described merely as Bedouins and overlords. Unfortunately, their important achievements and role in the development of architecture and sculpture were not only overlooked but also unjustly attributed to other ancient peoples and / or contemporaries of the Nabateans. In spite of this misrepresentation however, the facts speak for themselves and their achievements display Nabatean origin and feature Arab roots. Although influenced by architectural and artistic techniques of other peoples in the region, the Nabataean mastery of building and carving in rock cannot be denied.

The Nabataeans occupied a distinguished position among the ancient peoples of the Near East (**Fig. 1**). The prosperity they enjoyed was due to their active participation in the trade, as well as security of the caravans plying the route from the East. The diffusion of their civilization throughout the ages and its persistence to the present day provides undeniably strong evidence of their proficiency in hydraulic techniques.

The preceding synopsis is an objective description of the manifest achievements of the Nabataeans. In a harsh environment featuring generally scarce seasonal rainfall and arid land, neither of which could be considered conducive to agriculture, the Nabataeans inspired the world with innovative solutions to these problems. Their agriculture and cultivation methods may have had a modest start, but were later developed to the extent that agriculture became one of their most important occupations, not only from the point of view of food production, but also as a livelihood (Lawlor 1974: 81). With an expanding population to feed, the Nabataeans did not limit themselves to exploiting only easily-accessible land but enthusiastically expanded their agriculture, planting every available piece of arable land no matter how small. Their capital city, Petra, represented far more than a caravanserai and trading center. In fact it was a center of agriculture employing a wide spectrum of advanced agricultural methods that attained their zenith between the first century BC and the second century AD. The Nabataean control, utilization and management of water and arid land created an environment conducive to the establishment of permanent residences and settlements in Wādī ʻAraba and Hawran; expansion in the Negev followed at a later stage. Clearly, the Nabataeans developed skills and acquired expertise in efficient agriculture and successful water-management in desert and semi-desert land (Glueck 1959: 197). No other ancient people can be said to have done as much. Terracing, the first agricultural technique employed by the Nabataeans, proved to be efficient and highly successful. Hammond refers to terracing as a technique that slows down the flow of rainwater so that it can be absorbed by the soil, thus making agriculture viable. The terracing still existing at Wādī Mūsā (al-Jayy), Brāq and Amoun (Aylamoun) near Petra, slows the flow of water over and through terraces allowing water to flow slowly and permeate the soil of each terrace, thus conserving the enriching alluvial silt and organic matter. Planting the terraces not only utilized the land productively but also prevented soil erosion, which led to the expansion of available arable land in the desert. In these endeavors, the Nabataeans were uniquely successful amongst other peoples of the ancient world. Their records revealed that they had successfully grown wheat, barley and other grains, balsam, olives and vines. It may safely be deduced that the Nabataean success in agriculture was an expected outcome of their skills in water-management and the utilization of all of the natural resources available to their utmost advantage. The Nabateans, despite the harsh circumstances of their environment, proved capable of controlling and utilizing the scarce seasonal rainfall for maximum benefit, demonstrating a shrewd awareness of the value of small quantities of water and understanding the benefits of benevolent exploitation of natural resources.

The Nabataean reservoirs and basins still in use today represent solid evidence of their success in water preservation, which was accomplished through two different systems. In the first, water was gathered to flow in canals to the intended site and the surplus water was then stored for use when needed. The second system, known as Tulaylāt al-ʻInab "Hills of Vines", consisted of cairns of stones positioned like dry stone walls across hillsides and helped control the flow of water, which facilitated an expansion of agriculture. In addition, a large number of hills throughout Nabataean territory had a network of stone canals, which followed the hill contours, channeling water down to the basins below. Thanks to this innovation, water was available in sufficient quantities for trading caravans and travelers all the year round, and no shortage was ever encountered (Lawlor 1974: 79-83).

Our focus here is on Nabataean skill in the creation and development of novel, effective water-management and agriculture techniques,



1. A map showing the Petra site in the center of their Kingdom.

especially those aimed at water-harvest engineering to suit the arid and desert areas which were spreading throughout their domain. These techniques became imperative as the realm flourished and expanded between the 1st century BC and the 1st century AD **(Fig. 2)**. This was a period of high population growth, expansion in the size of cities and villages and an increase in the number of caravans and travelers. Such changes necessitated and prompted the preservation of water in dams, cisterns and wells.

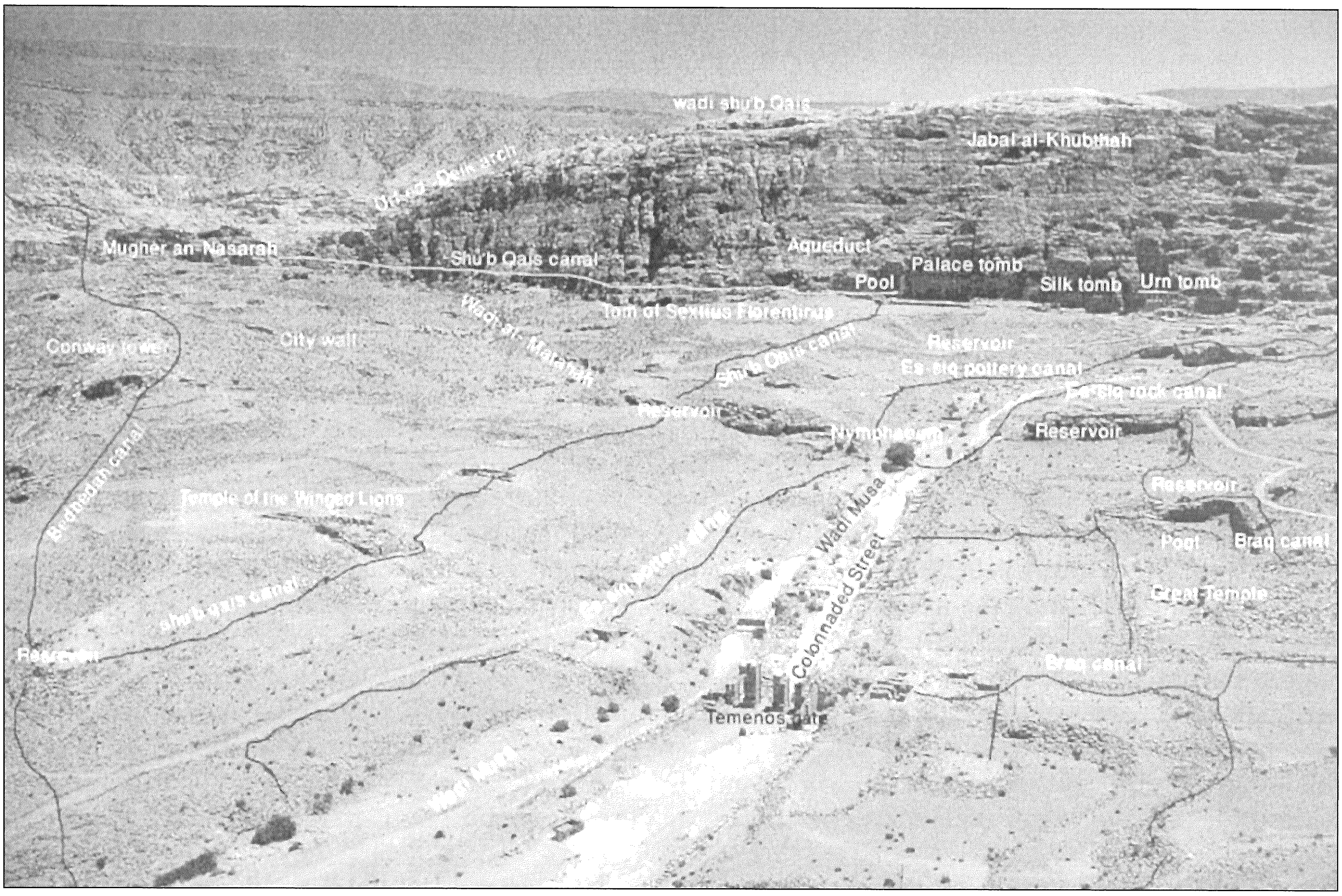
The geographical nature of their domain motivated the Nabateans to explore and develop innovative techniques for harvesting rainwater, their only source of water, in notoriously arid areas such as Petra, Wādī Rum, the Negev, Umm al-Jimāl, the north-eastern area of Jordan and the south-eastern area of Syria.

Water and agricultural affairs were sponsored, controlled and managed by a central authority responsible for the preservation and allocation of water as well as the allocation and irrigation of arable land (Starcky 1957: 215-217; Al- Muheisen and Villeneuve 2005: 489-499). This indicates that the Nabataeans were efficient administrators in addition to being skilled builders, engineers and soil conservationists.

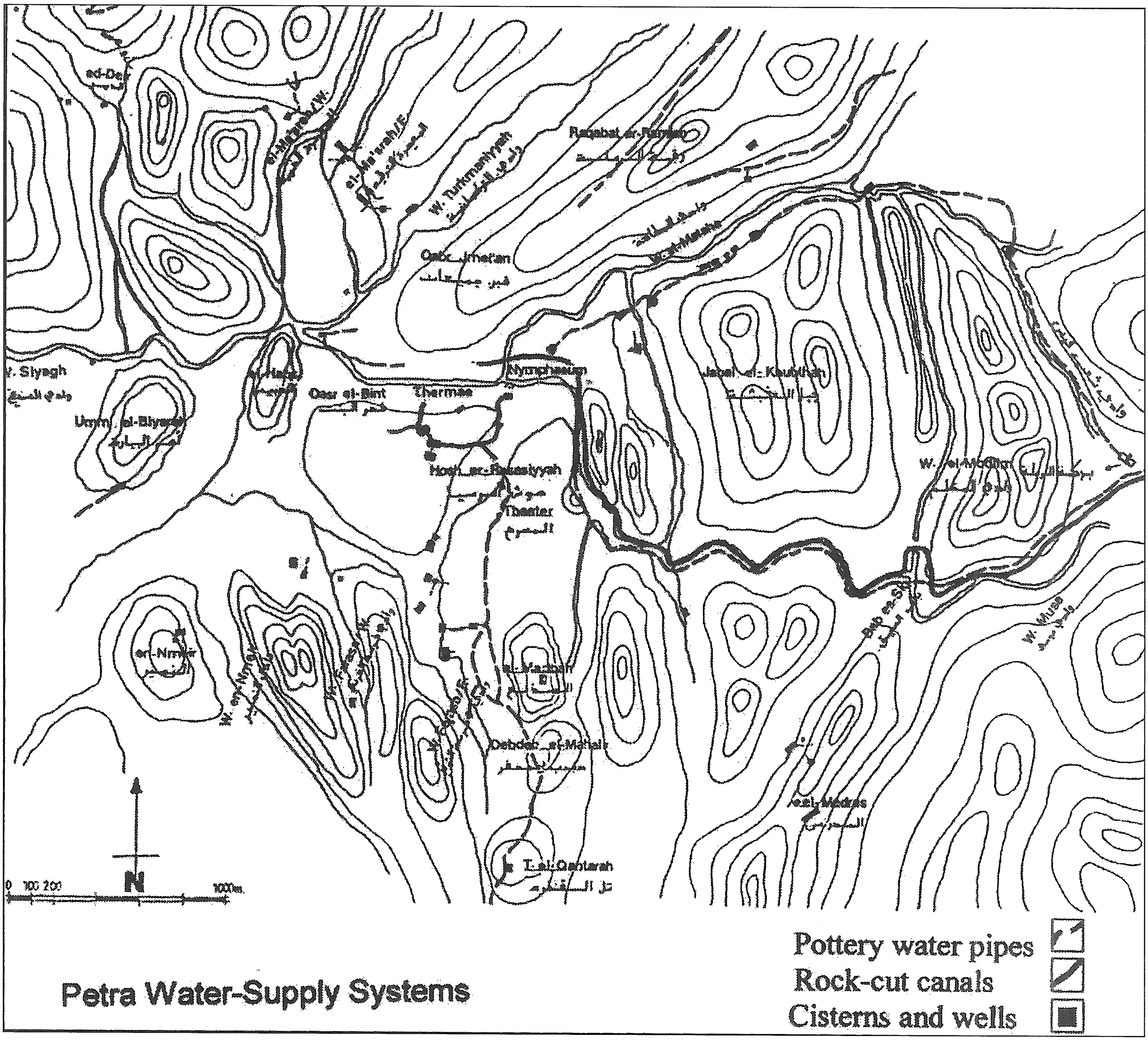
It is worth mentioning that many of the Nabataean water systems studied since 1978 could be re-vitalized, **(Fig. 3)** (Al-Muheisen 1983, 1986). Thus providing a low-cost solution for our present serious water problem.

The Nabataeans' own description of their land as "The abandoned land deprived of rivers and springs" was cited in Diodore of Sicily's account of the Nabataeans (Diodore XIX 94: 3-4). Interpreted cautiously, this description is to a certain extent applicable nowadays to certain sites in southern Jordan. A similar view is expressed in Layard's conclusions regarding his adventure in Petra, full of astonishment that the Nabataeans had carved with great difficulty, temples, theatres, private and public buildings and burial sites, establishing a city at the edge of the desert in an arid, unattractive land short of life's necessities (Layard 1840; Murray 1887). Many visitors expressed a similar opinion.

Since the first people settled in Petra, Bed-



2. Aerial view of the center of Petra (1980) showing the water distribution system.



3. A plan showing the water distribution system in Petra.

ouins have been living in that area in similarly harsh conditions as those mentioned earlier. In such circumstances the water issue was, and still is, a major concern to which a great deal of each family's time and effort is dedicated.

Strabon's view of Petra as a city that had many springs assigned for domestic use and irrigation purposes (Strabon: XVI, 4, 21). Is really surprising. On the contrary, the many cisterns, canals and reservoirs still standing today are evidence of a well-developed network, comprising various systems of water collection constructed to meet the needs of a growing city.

Reservoirs for rainfall at Umm al-Biyāra Mountain were hewn out of the rock in the first millennium BC and provided sufficient water for a small urban population. In addition, various water management systems were established by the Nabataeans not only in Petra but also in most sites influenced in varying degrees by their civilization. Generally speaking, ancient accounts of the issue are scarce[1]. The above- mentioned views of Diodore of Sicily and Strabon show gross contradictions that could be interpreted in

1. Reference is made here to an exception that involves documents on Antioch city, its water and population (Downey, G., The Water Supply of Antioch on the Orontes, An. Ar. Syr. 1,2).

terms of time reference, with the former referring to the early stage of Nabataean settlement in the area in the fourth and third centuries BC, while the latter was concerned with the period in which their civilization was flourishing, in the first century BC. Due to the absence in later periods of other testimonies or records, particularly of the Byzantine era, Diodore and Strabon's views remain the only available records that tackled the Nabateans' proficiency and expertise in the domain of hydraulic engineering techniques[2].

Water networks, a major component in these techniques, consisted of a system of inter-connected pottery pipes. However, natural forces such as erosion and earthquakes in particular have devastated many of the dams and clay-pipe networks leaving researchers with only a fragmented picture, which can nevertheless be pieced together by well-designed excavations and shrewd observation. This last point needs to be considered seriously if future research is to avoid the shortcomings and pitfalls evident in the past, which led to limited and incomplete results. An example of this can be seen in the work of Dalman and Musil, who tracked the course of the Brāq canal beyond the so-called al-Qanṭara sector. They assumed that the canal ran towards al-Khazna; an assumption that was later disproved (Dalman 1912: 42). To accomplish this study, research was conducted on the various hydraulic installations in Petra itself and in other sites in southern Jordan. In this context Khirbat adh-Dharīḥ, where many meticulous archaeological excavations have been carried out since 1984, is of special interest. Equally interesting is Finān, another site famed for its significant installations that are still standing and in good condition[3].

The groundwork of the French Geographical Center (IGN)[4] enabled the author, in his capacity as a researcher, to identify some reservoirs and canals in Petra utilizing the aerial survey charts and illustrations of Petra provided by IGN, without which it would have been quite difficult to identify the said installations due to the complex topography of the site[5].

This work completed the author's preliminary research in Petra that was begun in 1978. Fortunately for researchers, the Nabataeans favored installations carved in the rock rather than erected constructions, probably because of the vulnerability of the latter to damage and destruction by time and the elements.

This preliminary research also included certain examples of Nabataean designs, both interior and exterior, found in a variety of comparative installations. Eventually, through eliciting as much information as possible regarding the developed management systems of Petra, deductions could reasonably be made in defining certain technical and social aspects of Nabataean life.

The sites under discussion are related to one geographical unit, namely Southern Jordan, yet there are gross dissimilarities between these sites in terms of topography and climate.

Petra, the Nabatean capital, is the most important site in the area. It lies between mountain rifts to the north of the Gulf of ʻAqaba, 100km to the south of the Dead Sea and 30km south of Maʻān. A bird's-eye view of the site shows a collection of red and white sandstone masses split by grooves of variable depths eroded by rainwater torrents. The 900m high interior basin of the site is surrounded by heights 1,200m above sea level. To protect the city center, the surrounding valleys were enclosed with walls and dams. These exceptional topographic characteristics constitute the main issue of the study and will be detailed later in this book.

The climate of Petra is a combination of the East Mediterranean and Desert Rim climates, a fact that explains the noticeably wide climatic variations in the area; mild winters but very hot summers with temperatures soaring to 35-40° C. The annual precipitation is about 200-300mm (Bender 1968: 11) yet extreme annual fluctuations have been recorded in certain years, a finding that is relevant to the study area. However, the generally held view that Petra has a desert climate is absolutely untrue (AL-Muheisen 1990: 29). The northern area, where adh-Dharīḥ and as-Silaʻ are located, is moun-

2. An indirect, though sufficient testimony that gives an idea of the harvest of rainfall in Petra in the Syrian Barsauma age. See page 25.
3. Reported in ʻAqaba-Maʻān Survey, January – March, 1985.
4. Comprehensive aerial survey of the areas of Petra.
5. The paragraph particularly applies to Brāq canal.

tainous and comprises deep valleys stretching east to west to form geographical boundaries. Wādī al-Mūjib and Wādī al-Ḥasā are the main valleys, one of the branches of the latter running alongside Khirbat adh-Dharīḥ site. With an annual precipitation of 300-600mm, the slopes in the area provide a good environment for agriculture. However, regional variations in the annual rainfall are significant; for example 600mm in al-Karak contrasts sharply with that of al-Ḥasā region where the annual precipitation is in the range of 215mm (Abel 1933-1938: 66).

The third area in this study is Wādī 'Araba (al-Ghawr al-Janubī) or the South Jordan Valley, low-lying land extending over 180km between the Gulf of 'Aqaba and the southern coast of the Dead Sea. The area features heights of 200m above sea level but dips 100 meters below sea level in its northern part. Other characteristics are mild winters with a temperature of no less than 8° C, and very hot summers. The soil there can be cultivated to produce three crops per year despite an annual precipitation of no more than 100mm, except for Finān where the annual precipitation is probably less than 50mm (Bender 1974: 11). The area is known to have many springs supplied by the ponds of ash-Shawbak area, which run westwards.

The last and driest area of all is Wādī Rum and Negev, a fossiliferous area, which is geologically unique in terms of the strata dating back to the Ordovician, 500 million years ago. It has a desert climate with an annual precipitation of less than 50mm and in certain years there has been no rain at all.

The problems pertaining to irregular rainfall in the area have become increasingly important over recent years, although the dispute over the probability of climatic variations and their influence on the areas of the Arabian Desert Belt is a long-standing one (Drayton 1974: 45-46). Among researchers interested in this field who have adopted the notion of change is the director of the AL-Faw (al Fau) Archaeological Research, Abdul-Rahman Al-Ansari.

The problem inherent in this context is that the records of annual rainfall that are available provide information on only a few decades, yet this information is sufficient to study the annual variations. For example, the average annual variation of 1-50mm in Ma'ān could be calculated from the records of 1956 and 1958 showing zero rainfall, whilst 50mm was recorded in 1954 and 1959 (Bender 1974: 13). Another example is found in the recent record of rainfall in Petra that also reveals wide variations. A heavy rainfall that filled up two thirds of the capacity of a large basin in Bayḍa in the winter of 1983/84, contrasted with a modest precipitation in the spring of 1985. In May 1985 that basin was empty. With respect to the oldest period in the documented history of the region, we have the valuable testimony of Barsauma the Syrian. Although the context is religious rather than historical, it details an amazing incident of heavy rain in Petra during Barsauma's visit to the city. The said "miraculous" rain was preceded by an arid period, which had lasted four years (Milik XXXVI: 161). It can be inferred from such testimony that the climate of Petra was no wetter in the fifth century AD than it is at present.

Researchers studying wells in the Negev reached a similar conclusion[6]. Woolly reported that the water-level in ancient wells had not changed remarkably. In Elusa, Negev, the water level in ground ponds has remained at 18m (Woolley 1935: 53). An observation in conformity with and emphasized by records of other sites (Evenari 1974: 16). Based on the above-mentioned observations it can be assumed that the present difficulties of insufficient rainfall, gross dissimilarity in distribution and substantial variation in annual precipitation are similar to those of the past. Furthermore, the rain torrents formed lead to wastage of water and continuous soil erosion (Abel 1933-1938: 124).

The Nabataeans devised ingenious solutions, which contributed to the preservation of structural installations and civilian monuments in Petra. Such valuable assets could neither have been established, nor would have survived thousands of years without efficient hydraulic techniques (Al-Muheisen 1995: 721-725). Water resources in Petra can be classified into two groups: first, springs in Petra itself that are supplied by one or several subterranean ponds, and second, springs

6. The annual rainfall in this area may drop from 285mm to 25mm, but the average range is between 80-100mm. See: Evenari, M. Faire reviver le desert, P: 9.

in the surrounding area flowing down from a height of approx. 1,440 meters above sea level, With the exception of one, all other springs in Petra are weak flux. Canaan's estimate of six springs on the site that fall under this heading (Canaan 1929: 168) sounds rather an overestimation.

Examples of Petra Water Supply Network

1- The Southern Water-Supply Network Emerging from Brāq *Spring*

Musil and Dalman referred to a canal connecting the Brāq spring to Petra (Dalman 1908: 40), yet their assumption that the canal must have reached the defile near al-Khazna (al-Jarrah) indicates that they had not recognized the correct course of the canal. As a result, the role of the canal or network of canals cannot be precisely ascertained since the Lions Fountain and the Nymphaeum are both famous installations that have their own water distribution network.

The Brāq canal passes over the Lion Fountain. Northward, it intersects branch A at a distance of 80 meters. Some tens of meters further on, branch B passes near a religious complex, including a niche 0.7m long, 0.13m high and 0.4m deep. The niche encompasses three stelae, the central one being slightly larger than the other two. Another niche, 0.11m long, 0.22m high and 0.8m deep is located below, with a statue depicting a man with his right hand resting on a small altar.

The Brāq canal courses north toward the center of the city, passing over the western rocks at the theatre to approach the sector known as al-Katuteh. As the rocks end at this site the canal could not be traced any further here, but carries on in the south-eastern sector of the city center. At a distance of a hundred meters north of the rocks it reappears for a few meters to reach the main distribution center, which comprises two rounded stone basins. The first, 0.4m in diameter and 0.1m in depth, is connected to the second basin, 0.27m in depth and 0.6m in diameter, through a 0.5m long canal.

Despite the modest style of this installation, the emphasis here is on the distribution center from which a network of canals emerges to supply the southern part of the city center **(Fig. 4)**.

4. The main reservoir for water distribution south of the center of the City, which was supplied by Brāq canal branch B.

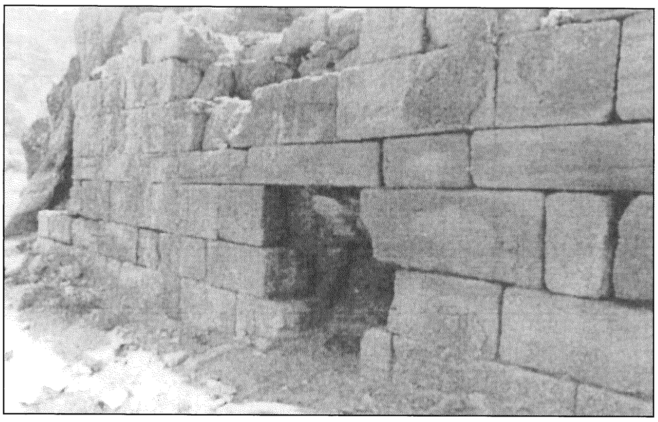
Two pottery canals of 0.22m length and 0.1m diameter emerge at this site: the first one runs east then north, while the second runs west.

They were made of red or reddish clay[7], joined together with white plaster and protected under a cover of stone slabs.

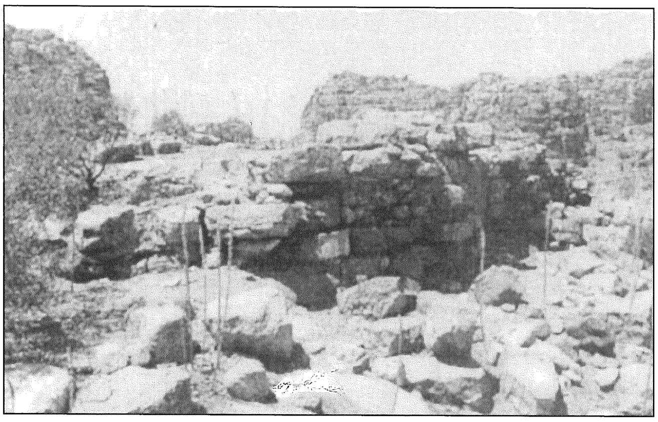
Branch B of Brāq Canal in the Center of the City (The northern canal)

This canal had been devastated to such an extent that it cannot be recognized at present. However, it ran 100 meters to reach a now destroyed oval reservoir, 11m in length, 2.5m in width with walls 1m thick **(Fig. 5)**. The canal leaves the reservoir and continues northward to reach an oblong reservoir **(Fig. 6)** 9.5m long, 4m wide and 3.5m high, dominating the colonnaded street on the southern side. At the lower level of the northern wall of this reservoir is an outlet to supply the adjacent areas with water. However, the earthquakes that almost completely destroyed the center of the city caused complete destruction of the reservoir, which now

7. They differ from those used in the pottery canal of as-Sīq canal.



5. Reservoir No. 1 in the center of Petra was supplied by the northern branch of the main distribution basin, Brāq Canal - branch B.



6. Reservoir no. 2, north of the first one was also supplied by the Brāq canal. Notice the outlet in the northern wall of this reservoir, which supplied the Nymphaum on the opposite side.

lies shattered under fallen boulders.

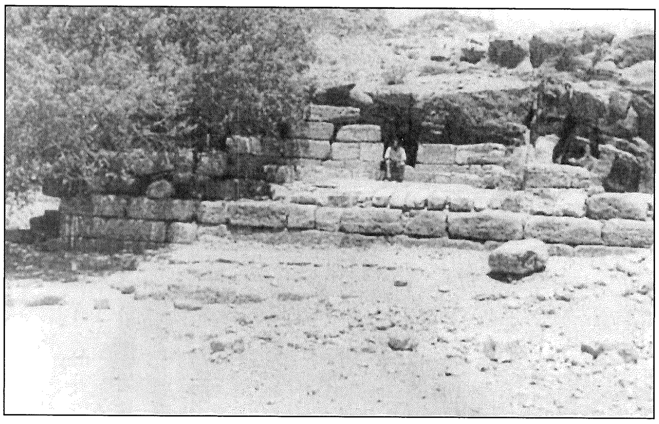
Halfway up the western side of the reservoir is a particular formation designed to supply a westward-running network of canals, which have now vanished completely. Despite focusing on the northern offshoot, now untraceable except in a few locations, the western branch was very important because it supplied the eastern area of the Great Temple **(Fig. 7)** [8]. The latter branch provided the water supply to a now destroyed semi-circular fountain; located to the left of the Cardu, toward the Triumphal Arch (Temenos gate no 406). The Nymphaeum was likely to have been supplied by the northern canal, since the characteristics of the reservoir lead to an assumption that it was the source of sufficient water to supply the Nymphaeum. In support of this assumption are the remains of a canal running

7. An oval reservoir no.3 in the southern central sector of the City supplied the eastern area of the large Temple and was supplied by the northern branch of Brāq canal, the main distribution basin.

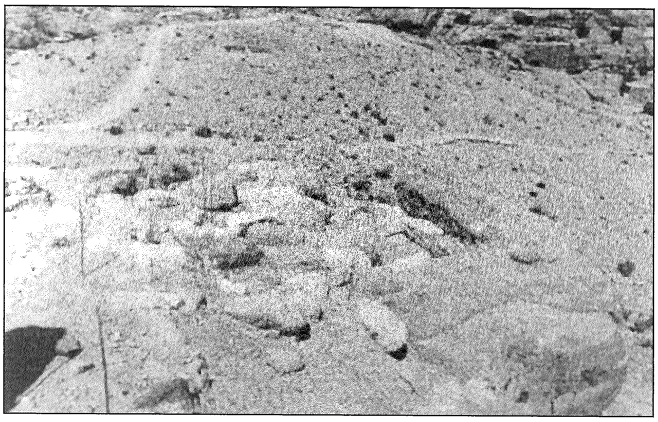
along the Nymphaeum in a north-south direction. Seemingly, the said canal emerged in the sector north of the Cardu and headed west, to supply the Nymphaeum at the mid-point of its internal wall **(Fig. 8)**.

Continuing westward, the canal supplied a now ruined reservoir, which had 0.7m long sides **(Fig. 9)**. The network of canals in the area was supplied with water flowing from the main distribution center, namely Brāq spring, which played a most important role in the distribution of water to various areas of the southern part of the city center. Southward is a 50 meter long canal that extends towards another canal 2.5 meters long, which supplied the al-Katuteh area; whereas northward there is a 60 meter long rock-cut canal with pottery pipes, similar to those described above, laid inside. This canal meets a square reservoir with sides 3.5 meters in length.

8. It seems likely that this branch supplied an ovoid reservoir, 10m long, 4m wide and at least 1.2m high. The reservoir was located on the left side.



8. *Nymphaeum district beside the paved street was supplied by the* Brāq *canal and as-Sīq rock canal.*



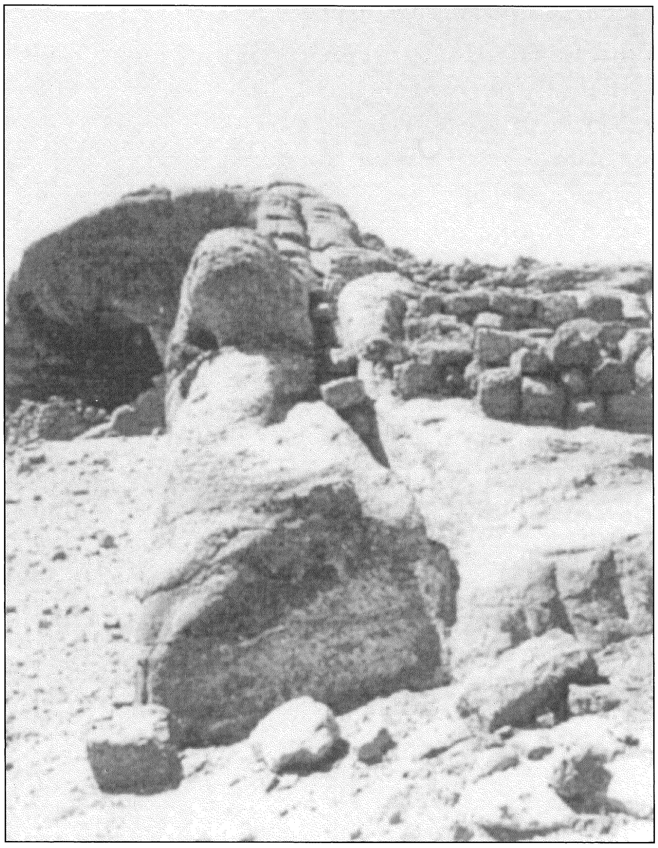
9. *Reservoir No. 4 in the southern central sector of Petra was supplied by the western branch of the main distribution basin of the Brāq canal.*

10. *A canal emerging from reservoir no. 4 toward the great Temple and* Qaṣr *al-Bint.*

Its walls, now 0.6 meters high, were rock-cut. In the north-western corner was a square, rock-cut basin, deeper than the reservoir level, from where a canal emerged and headed north then west for a few meters before it split into two branches **(Fig. 10)**. The first branch turned north **(Fig. 11)** to reach the Great Temple area and the baths south of the Cardu. The point of entry of the canal into the building is still clearly recognizable.

The second branch, of which a few sections formed of pottery pipes can still be seen, seemingly ran west toward the Great Temple and Qaṣr al-Bint Temple. The preceding data may explain the legend recounted by Dalman and Cana'an, (With a few dissimilarities in details) (Dalman 1912: 16 and Canaan 1929: 145) [9]. The legend is that Pharaoh's daughter, who lived in the palace, enthusiastically encouraged the canal project and gave it her personal interest and support, and even drank water from Brāq spring. It was probably easier to trace the remains of this canal in times past than it is at present[10], since its course was quite well-known by the Bedouin. At any rate, the author's studies of 1978 showed that what had been meant by the word "palace" was in fact the Great Temple rather than Qaṣr al-Bint, an inference based on the many water networks supplying the Great Temple. The interlinked collection of reservoirs in the city center is similar to that of Elusa (al-Khalsa) in the Negev despite the dissimilarity in the method of water supply, which in Petra is derived from springs. In Elusa, the water supply is derived from wells and a network of reservoirs connected in a north-south direction, at a right-angle to

9. Canaan precisely recounted that Pharaoh's daughter, who was living in the palace, decided to marry whoever would conduct water from any spring to her palace. Two young men succeeded in doing so on the same day: the first delivered Brāq spring water; the second from Abū-Hārūn spring. The second man showed poor faith in divine help, so he was disqualified.
10. The canal course is used daily by Bedouins because it is the easiest path between the city center and Brāq sector.



11. Part of another canal emerging from reservoir no. 4 which supplied the baths northward.

the main streets. Water distribution was through clay pipes 0.1m in diameter that are, to a great extent, similar to those used in Petra. According to A. Negev (Negev 1974: 12), those pipes supplied water directly to Elusa houses by a system, which is not evidenced in Petra, except in the baths.

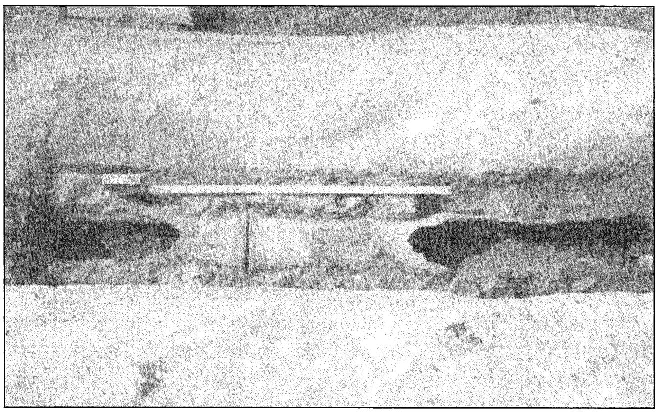
Compared to the opposite part of the city, this sector under discussion encompasses a larger group of religious and civil structures, reservoirs and canals and is hence of greater significance.

2- North-Eastern Water-Supply Network Emerging from Bedbedah (Dibdiba) Spring

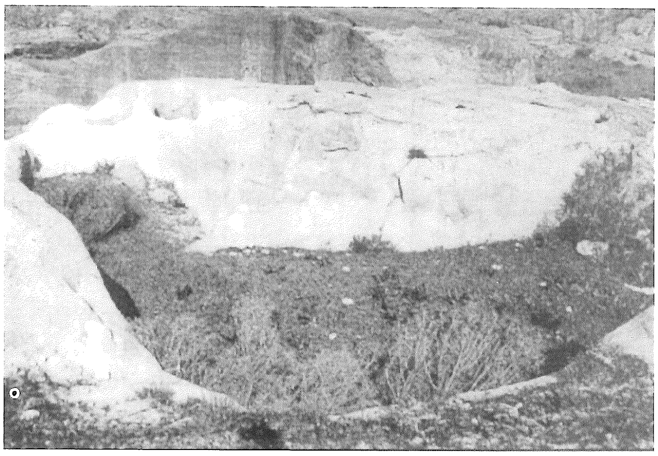
Below the spring, at a distance of 500m westward, are the remains of a small wall, which supported the canal. The canal then extends westward where it joins Wādī Umm Qusa over an arched viaduct, now vanished except for rock piers on the north-eastern side of the wadi, although on the other side some remnants are seen. The bridge, 1.6m wide, was 4m above the wadi bed. The canal extends throughout Umm Qusa and Etnub sectors. In 1980, the author carried out archaeological excavations at this very site east of Etnub. The site excavated was a few meters from the canal that comprised clay pipes laid down through the rock **(Fig. 12)**. The excavation was relatively difficult because the plaster covering the pipes was very hard.

The canal extends in the same direction, as confirmed by the many shards of pipes found in the canal course. West of the Bayḍa road, the canal reappears to carry on toward Wādī Marma al-Barqa, and continues thereafter. In this sector, a small square basin with sides 0.45m in length helped in filtering the water and regulating the flow inside the canal. Seen next to the basin is a wall, 10m long, 1m thick and between 1-1.5m high. In the wadi the canal crosses a comparatively flat sector then continues over a viaduct, 8m long and 5m high, of which the only remaining traces are the supporting arches. After crossing the bottom of the wadi and following its course on a wall over a distance of 10m, the canal extends 300m in rock in a south-west direction.

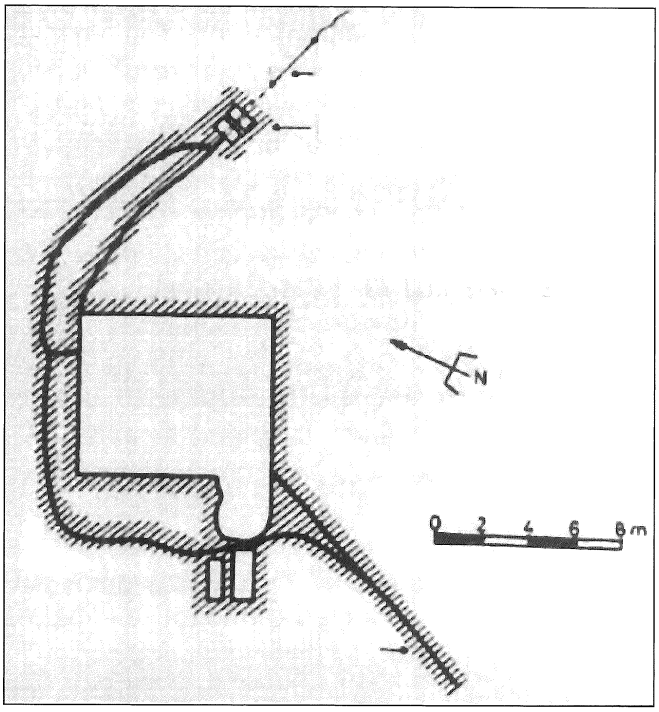
The canal is encountered again west of the present road as it reaches Thera'a Marma al-Barqa sector. At the said site, excavations were carried out aimed at discovering the rock course of the canal. However, a little further on the course was found to be executed in stone masses, 0.7-0.8m in length and 0.4m in both width and height. No pottery remnants were found there but some stone slabs 0.8-1m long were seen covering the canals. A few meters lower down, the canal reaches the top of a reservoir, 9m long and 7m wide **(Figs. 13 and 14)**. At the south-western corner, a rounded basin 3m in diameter and 1.5m in depth is located beside the reservoir. Because sand and sediment now cov-



12. The pottery canal emerging from Bedbedah spring after it had been excavated.



13. The main reservoir, which was supplied by Bedbedah spring canal in the Marma al-Barqa area - Umm Ṣayḥūn.

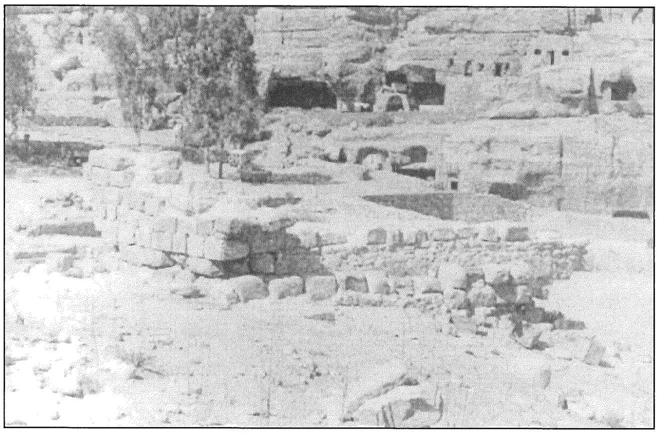


14. A plan of the main reservoir in Marma al-Barqa (Bedbedah canal).

er the floor, it can be assumed that its original depth was greater than that observed today. The special importance of the reservoir is due to it being the first installation of its kind in the extreme north of the city. In addition, it functioned as a storage site that regulated the water flow in the canal, as it ran down a steep slope at this particular site.

The canal approaching from the east supplied the reservoir with water through two sub-branches: the first, which was the more important, reaches the reservoir at its northern corner; the second reaches the reservoir where it is higher, on the north-western side. The canal continues around the north-western and south-western sides of the reservoir and continues south. A few meters lower down, a small canal emerging at the south corner of the reservoir joins the main canal. This small canal drained the surplus water from the reservoir. Thereafter, the main canal runs south-west and disappears for the next 25 meters along the slope of the reservoir where the rock has been eroded. A few tens of meters farther on the canal reappears as it extends along rocks to reach Dharat Umm Ṣayḥūn. Here it is quite easy to track as it runs alongside rock and follows a small wall built of stones, now destroyed. In Umm Ṣayḥūn sector the wall becomes hard to identify and this problem is further compounded in Raqabat ar-Ramla. In the latter site, the rock replacing the wall is completely smashed and the rock-cut canal is almost obliterated. It seems likely that a branch of this canal supplied all the neighboring areas of Mughur al-Maṭaḥa. Again, traces of a small wall are found in ʻArqūb al-Hīsha area where a small basin, of unknown function, is seen cut in basalt; this arrangement can be compared to a similar one in as-Sīq rock canal. The canal then disappears over a long distance until the center of Petra. According to Bedouin accounts the canal was seen there 50 years ago. Presently, its course cannot be traced except at the site where it connects to a large reservoir on the Wādī Mūsā site, in front of Qaṣr al-Bint. The constructed walls of this reservoir are 9m long, 6m wide and 1.2m in width **(Fig. 15)**.

Its depth cannot be accurately defined because the walls are partially destroyed. The



15. A reservoir built of stones in the center of Petra opposite the courtyard of Qaṣr *al-Bint was supplied by Bedbedah canal.*

stone masses forming these walls were chiseled, aligned with a grayish mortar and had two layers of plaster, a thick rough coat overlaid with a smooth layer. At the lower level of the reservoir a canal emerges and heads for Qaṣr al- Bint.

Rainwater Harvesting

The large number of rainwater-collection canals constructed in Petra by the Nabataeans, confirms that they were in agreement with Virtuve's statement: "No water is healthier than rainwater" (Vitruve Livre VII, Chapitre II). The Nabataeans, probably benefiting from the geological nature of the area and the fact that the sandstone rocks in Petra are relatively easy to carve, found it suitable for the construction of canals and other hydraulic installations (AL-Muheisen 1997: 73), and such techniques are encountered in other Nabatean sites, such as Sila'. In other towns and villages different innovations were found, in which loess was used as a stream bed. In this technique, the moisture disintegrates the coherence of loess elements, thus forming a solid coherent superficial layer, which is impermeable to water so the water is not absorbed. The speed at which this layer forms positively depends on the rainfall density, so 30% - 50% of rainwater can be collected. Stream water, known to be devoid of harmful salts, is highly appropriate for irrigation (Evenari 1974: 9-10).

Each sector in Petra was capable of harvesting sufficient rainwater to meet its needs and to be self-sufficient, without resorting to the central water system. Because early annual rainfall invariably occurred in November and the later precipitation in March, rainfall-harvesting seasons were autumn and winter. And since rainfall occurred in heavy bouts over short periods of time, an efficient system had to be designed and implemented to conserve and benefit from this rainfall[11]. Even now some reservoirs continue to be supplied with water, even indirectly, through a network of collection canals that was originally constructed by the Nabataeans. Finally, a comparison should be made to show the difference existing between the rainwater collection system and spring water procurement. In certain instances the two systems co-exist, as in the case of the large reservoir of Wadi Farasa, which was partially supplied by streams of rainwater in winter.

Ultimately, Layard's assertion seems questionable. Petra has never been a barren, unbearable desert. The Nabataeans used their skills to transform their city and other sites in their domain into places with an abundant water-supply, surrounded by orchards and fields. As noted, these accomplishments were the outcome of a slow, gradual development of technical expertise that helped the Nabataeans to achieve a remarkable advancement of civilization and culture. A quick glance at the site of Petra is sufficient for us to appreciate the transformation of their society from a remote settlement of semi-nomads into a capital city on a par with other urban centers in the ancient Near East.

In tracing the stages of its development, we can recognize and appreciate the effort and dedication of the Nabataeans in building their capital in an area with such scant water resources. The few springs in and near Petra provide a modest average output, compared for example to those around Palmyra, (such as Ifqa with 5,000 m^3 average output), and were insufficient to meet their needs, particularly in regard to irrigation. These difficulties motivated the Nabataeans to utilize and improve upon indigenous techniques of water-management in gathering and storing the maximum amount of rain and flood water. In this study we surveyed the main features of some, though not all, of these techniques.

The Nabataean agricultural installations are noteworthy here; we have already mentioned that some of these installations, particularly in Wādī Fīfā and Wādī khuayzīra were later reused or modified and in this context therefore, encouraging small projects such as those being managed by the Jordan Valley Authority would be advantageous. Although dwarfed by the resources of larger projects such as the East Ghor Canal (output: 20m^3 per second) and the King Ṭalāl dam, these smaller projects are also important resources. In this regard, the adoption of other Nabataean techniques particularly in ter-

11. The phenomenon of heavy rain falling in short periods of time, impose great danger to the religious and domestic installations in the city center; the Nabateans employed a complicated and comprehensive hydraulic system to avert such danger. See: Al- Muheisen, Z., and Tarrier, D., "La Protection du Site de Petra a L'epoque Nabatèenne. *SHAJ* V: 721-725.

racing, irrigation of fields and soil-erosion prevention would be beneficial.

We hope that current research will continue by conducting excavations in sites other than Petra and Bayḍa, such as Sulaysil, Khirbat adh-Dharḥīh and the Nabataean sites in Wādī 'Araba and Wādī Rum. The proposed excavations should provide further examination and expansion on the notes expressed in this study, in particular those concerning agriculture.

In conclusion, the 152 Greek papyri found recently in the Petra church and dating to the 5th and 6th centuries AD, should contain valuable information concerning water, agriculture, land ownership and purchasing and selling of land in Petra, despite the fact that this information post-dates the Nabataean era.

Bibliography

The Holy Qur'an.

Abed, A.
1985 Plaeoclimates of the Upper Pleistocene in the Jordan Rift. *SHAJ* 11: Amman.

Abel, F.M.
1983-1983 *Géographie de la Palestine*. Paris.

Al-Muheisen, Z.
1980 *L'alimentation en eau de Petra, Thèse*, 2 Vols. Paris 1, Sorbonne.
1980 Leau'a Petra, MDB, 14. Paris.
1983 *L'alimentation en eau de Petra, Thèse*, 2 Vols. Paris I, Sorbonne.
1986 Techniques Hydrauliques dans le Sud de la Jordanie, en *Particulier à l époque Nabatéenne, Thèse*. 2 Vols. Paris I, Sorbonne.
1990 Exemples d'installations hydrauliques et de techniques d'irrigation dans le domaine nabatéen. *B.A.H.* CXXXVI, T.2. Paris, 1990.
1990 Maîtrise de l'eau et agriculture en Nabatéenne : l'exemple de Petra. *ARAM* 2. Oxford.

Al-Muheisen, Z. and Tarrier, D.
1995 La Protection du Site de Petra à l'époque Nabatéenne. *SHAJ* V : Amman.
1997 Ressources Naturelles et Occupation du site de Petra. *SHAJ* VI : Amman.

Al- Muheisen, Z. and Villeneuve, F.
2005 Archaeological Research at Khirbat edh-Dharih. *ADAJ* 49: Amman.

Bender, F.
1974 *The Geology of Jordan*. Berlin.

Boom, V. and Swwan, O.
1966 Report on the Geological and Petrological Studies of the Plateau Basalts in NE Jordan. Hanover.

Burdon, D.
1959 *Handbook of the Geology of Jorda*n.

Butzer, K.
1961 Climatic Change in Arid Regions Since the Pliocene, A History of Land Use in Arid Regions, Arid Zone Research. UNESCO.
1963 The Last Pluvial Phase of the Eurafrican Subtropics, in Changes of Climate, Proceedings of the Rome Symposium. UNESCO & WMO.

Canaan, T.,
1929 Water and the Water of Lif. *JPOS*.
1929 Studies in the Topography and Folklore of Petra. *JPOS*, vol. IX.

Dalman, G.
1908 *Petra Und Seine Felsheiligtümer*. Leipzig.
1912 *Neue Petra*. Forschungen, Leipzig. Diodorus siculus, The Library of History, XIX 94: 3-4.

Downey, G.
1951 The Water Supply Of Antioch on Orontes in Antiquity, An. Ar. Syr. 1,2.

Drayton J.
1974 The Problem of Climatic Change in the Peninsula Arabia. *PSAS* 5.

Evenari, M.
1974 Faire Revivre le Déssert. Expériences d'Agriculture en Zones Arides- édit. Française, Zurich.

Glueck, N.
1937-39 *Explorations in Eastern Palestine II*. AASOR vol. XV (1934-1935), vol. XVIII-XIX.
1959 Rivers in the Desert. New York.

Helms, S.W.
1973 Jawa, An Early Bronze Age Fortress. *Levant* 5.
1976 Jawa Excavations 1974. A Preliminary Report. *Levant* 8.
1981 *Jawa: Lost City in the Black Desert*.
1982 Paleo-Beduin and Transmigrant Urbanism. *SHAJ* 2: Amman.

Layard, A.H.
1887 *Early Adventures in Parsia, Suziana and Baylonia*, 1840, Murry.

Lawlor, J.I.
1974 *The Nabataeans in Historical Perspective*. Michigan.

Milik, J.T.
Mélangie de l'Universitié St. Joseph de Beyrouth, XXXVI.

Negev, A.
1976 *Die Nabatäer*. Antique Welt 7.
1974 Elusa, Ville nabatéenne, *BTS* 164.

Orni, E. and Efrat, A.
1976 Geography of Israel. Israel University Press.

Shehadeh, N.
1985 The Climate of Jordan in the past and Present. *SHAJ* 3: Amman.

Starcky, J.
1957 Y a-t-il un dieu Rêš aïn La'aban? *RB* 64.
Vitruve
1970 les dix livres de l'architecture. Chapitre II, VI. In K.D. White (ed.), *Roman Farming*. London.
Woolley, G.L. and Lawrence, T.E.
1935 The Wilderness of Zin, *PEF*.