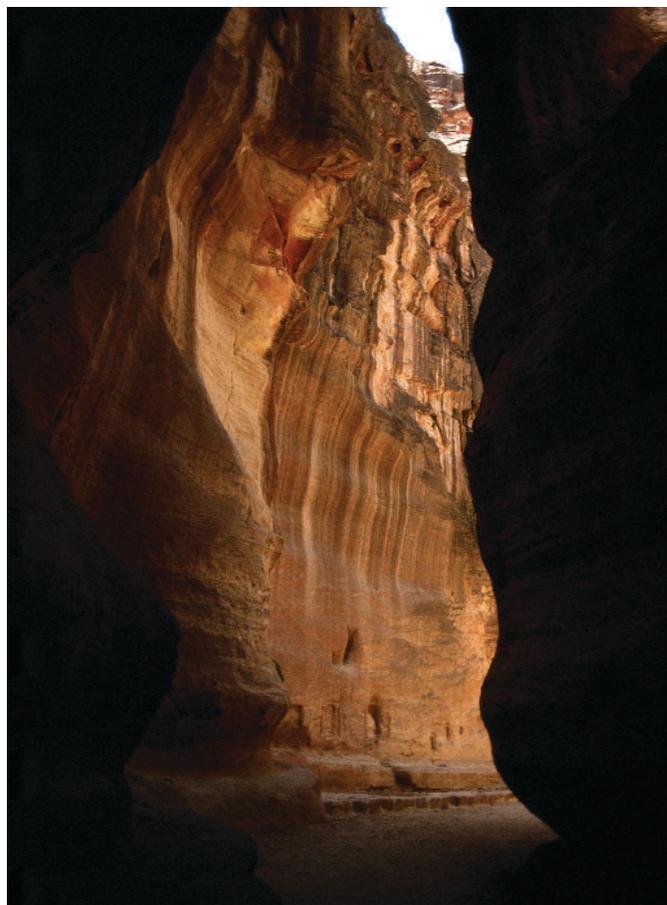


Ancient and Modern Watershed Management in Petra

By Talal S. Akasheh

The Nabataeans are recognized for their ingenuity in water management and conservation.¹ Their complex system of cisterns, dams, channels, *wadi* (an Arabic word for river valleys) barriers and terraced agriculture have attracted the attention of archaeologists. These innovations may have occurred in part as a response to the frequent, sudden and heavy rains that still today send massive water flows into the narrow gorges and *wadis*—even when the rainfalls are as brief as fifteen minutes. In the early sixties, during one of the seasonal flashfloods, a group of French tourists lost their lives in the Siq. After this tragic incident, the Government of Jordan reopened an ancient Nabataean tunnel in the side *wadi* of the Wadi Al-Mudhlim, thus diverting water flows away from the Siq, a gorge that forms the main entrance to Petra.

Since then the problem in the Siq during the rainy season has been reduced to only occasional floodwaters that rise to a maximum of twenty centimeters. Despite the extremely beneficial outcome of the relatively simple measures taken by



The nature of the geography around Petra, with its narrow gorges and *wadis*, creates a unique watershed that has tremendous destructive potential. The Siq, a narrow, 1.2 kilometer-long gorge hemmed in by one-hundred-meter-high cliffs, leads into the inner city of Petra. Photo © Erich Lessing.

Rock-carved Nabataean niches in the Wadi Al-Mudhlim. Flash floods threaten these historically important carvings.



the Jordanian Government, and while the lives of tourists have generally been safeguarded in the Siq itself, recent flash floods in 1994 and 1996 of unprecedented intensity indicate that the threat to lives and property still exists in the Wadi Musa village. In the village, the main watershed pours its rainfall into the streambed leading to the Siq just before it forks off to the Wadi Al-Mudhlim.

The level of water in the Wadi Al-Mudhlim, an even narrower gorge than the Siq, can rise to twelve meters during heavy flashfloods. Not only does this present a threat to visitors, it is also an obvious hazard to the sidewalls of the Wadi Al-Mudhlim, which contain some extraordinary rock-carved Nabataean niches. This problem did not exist in Nabataean times because the ancient inhabitants had constructed dams just before the entrance to the Siq and in the Wadi Al-Mudhlim that succeeded in slowing down the flow and reducing the flood level. Thus the gorges themselves were not at risk.

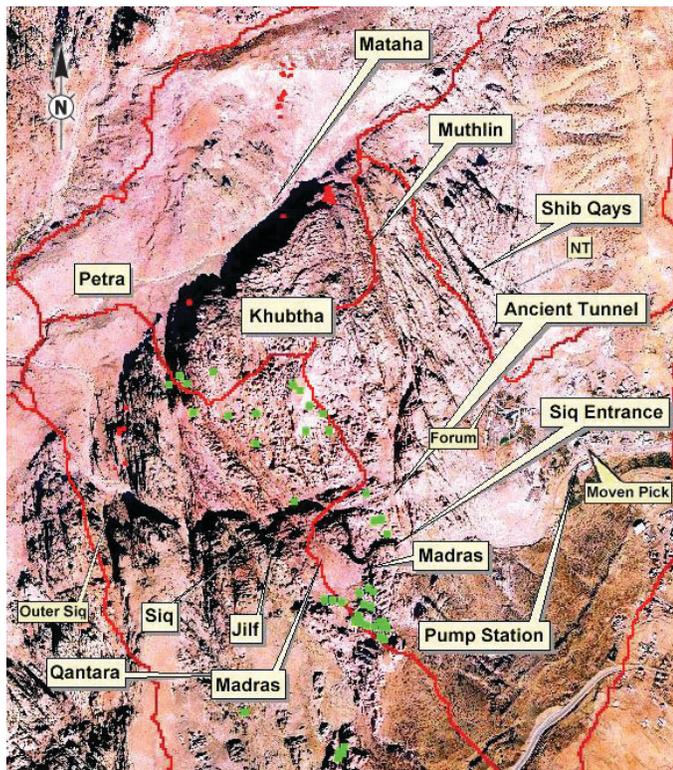
But today these dams have not been restored and the Wadi Al-Mudhlim's cultural heritage lies unprotected. With the rapid expansion of tourism facilities and its infrastructure in the modern village of Wadi Musa, a serious imbalance in the Wadi Musa watershed has been created. With the construction of roadways, hotels and homes, the precious soil cover, necessary for the drainage of rainwater, has been lost. Unfortunately, even the Nabataean approach to these problems would no longer be adequate to face these pressures.

In 1996, The Petra National Trust (PNT), an organization dedicated to the protection of Petra and its cultural heritage, conducted a study of the Siq area under my supervision. The study succeeded in patterning the ancient Nabataean

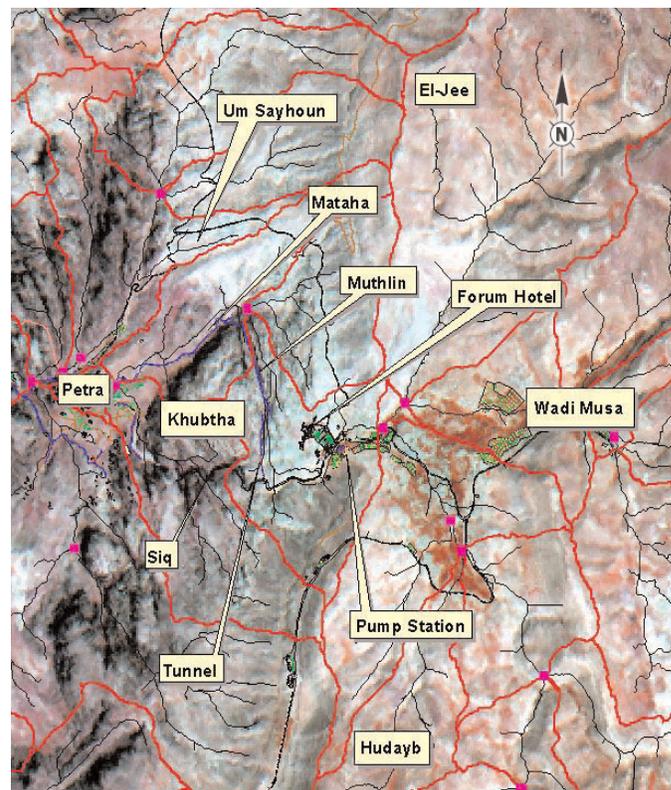
installations (dams, cisterns, channels, *wadi* barriers and terraces) to a computer-based modeling of the area. As an extension of this study the Hashemite University surveyed the study area to obtain a comprehensive understanding of the Nabataean water management systems affecting the Siq.

The Study Area

Flanking the Petra Siq from the north is the Al-Khubtha rock outcrop. It is here the problem of flashfloods in Petra is centered. The Siq lies to the city-side with an open area where the famous Al-Khazna (Treasury) faces it.² To the east of the Al-Khubtha outcrop, there are a series of narrow gorges—one of these is the Wadi Al-Mudhlim, which is adjacent to the plateau. Wadi Al-Mataha lies to the north and the Outer Siq to the west, leading to the main streambed in Petra, the Wadi Musa, which originates in the Wadi Musa village and flows through both the Siq and the Outer Siq. Most of the flow in the Siq originates from three *wadis*, Wadi Musa, Wadi El-Jee and Wadi Al-Hudayb. The Nabataeans managed to divert this flow through a rock-carved tunnel (cleared again in modern times) through Wadi Al-Mudhlim into Wadi Al-Mataha, which in turn flows into the Wadi Musa on the west side of



Spot Image scene taken in 1992, showing the Wadi Musa, Petra and part of the watershed system under study. The Siq lies to the city-side with an open area where the famous Al-Khazna (Treasury) faces it. Pink squares mark the nine ancient dams surveyed by the Hashemite University.



An ortho-photo of the Al-Khubtha area showing the Siq and Al-Mudhlim flows. The dams and cisterns surveyed by the Petra National Trust are shown as green points. Red demarcates the watersheds or basins. The proposed tunnel is marked as NT. (The term ortho-photo refers to a photograph that has been corrected for the distortions that result from the angle of the camera. It corrects the image so that it stretches out to fit the coordinates of a map.)

Petra. Less serious, at least as far as the Siq is concerned, is the flow from the rocky outcrops of Al-Khubtha to the north of the Siq and Al-Madras, Qantara and Jilf to its south. The wide streambed between the Siq Entrance and the Sewage Pump Station also receives water from the Crowne Plaza (Forum) Hotel, and from the southern flanks that lie east of Al-Madras and the Siq entrance.³

Nabataean Water Management in the Siq and the Wadi Al-Mataha

For safety and protection from erosion, the Nabataeans undertook measures to ensure the safety of the Siq passage: They constructed dams, cisterns, channels, *wadi* barriers and terraces in the plateaus flanking it thereby securing the passage against flashfloods and erosion. These were all designed to soak up as much rainfall as possible and, if not reduce the water flow, then to slow it down. The measures kept the main entrance to Petra free from erosive debris, protected the paved Siq bed and guaranteed pedestrian safety.

The study conducted by the Petra National Trust concentrated on the Nabataean hydrological systems around the Siq, namely the Al-Madras, Jilf, Qantara and Al-Khubtha outcrops. The field survey documented some thirty-six dams and cisterns, many channels and more than four hundred *wadi* barriers and terraces. The terraces and the water collection system turned the Qantara and Jilf localities into thriving agricultural areas, and on the rocky Al-Madras and Al-Khubtha tracts water was collected and erosion prevented. We estimate the total capacity of the dams and cisterns to have been eleven thousand cubic meters of water. For every one millimeter of rainfall, the area (0.89 square kilometers) receives 890 cubic meters of rain. In a rainstorm of fifty-millimeters intensity, the total is 44,500 cubic meters. The hydrological study indicates not only that the Nabataeans protected the Siq, but that these measures adequately served for rainstorms of this intensity or less. There are also



One of the Khubtha dams surveyed by the Hashemite University.

indications that the Nabataeans constructed special outlet drains for their dams, thus allowing for sufficient drainage should the need arise.

More recently we surveyed the Al-Khubtha and Wadi Al-Mataha areas for dams and cisterns. Not covered by the Petra National Trust study, we were able to record a total of nine previously undiscovered dams.

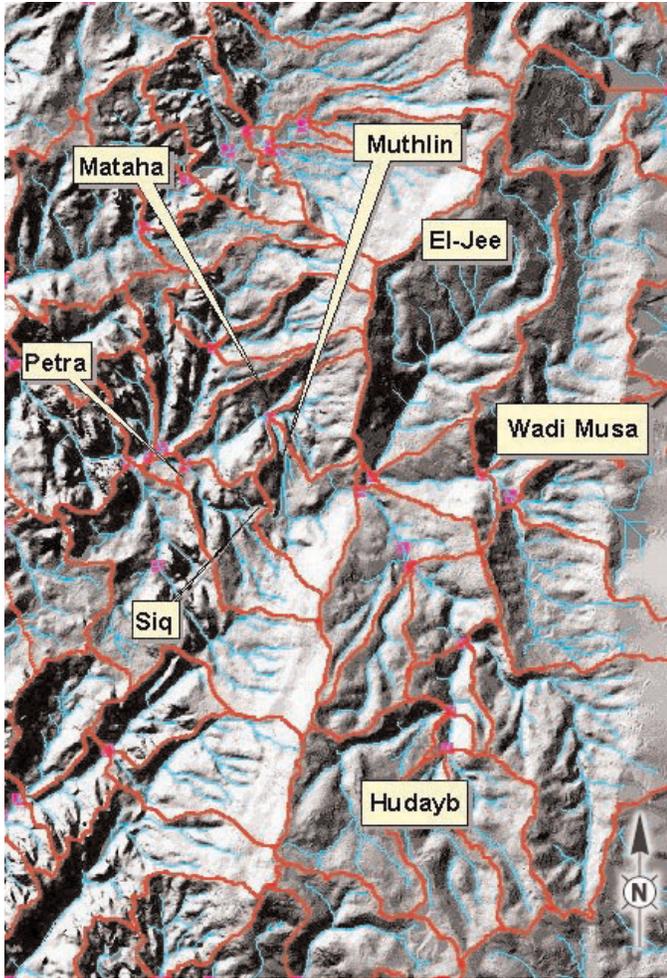
Watershed Modeling

The three most important watersheds are El-Jee (Basin 17), Wadi Musa Village (Basins 16, 34, 35, 37) and Wadi Al-Hudayb (Basins 41,42, 48 and 49). This represents more than ninety-five percent of the total Siq-related flows. Independent of these three main watersheds, the Siq streambed also receives some of the flow from Basin 28.⁴ In addition to Basins 30 and 31, and even with the tunnel completely closed, Wadi Al-Mudhlim receives most of its drainage from its flanks. Under these conditions, the flow from Basins 30 and 31 feeds into the Siq through Basin 32. Watershed 28 empties into the Siq along with the Al-Khazna's open space and the Outer Siq, in the ratio of 0.89 square kilometers to 1.76 square kilometers respectively; the total area contributing to the Siq flow is 54.75 square kilometers. When the tunnel is fully open, Basin 32 drains mostly into Wadi Al-Mudhlim and eventually to Wadi Al-Mataha's Basin 24. The Siq is then subjected to flows from only its rocky sides (Al-Khubtha, Al-Madras, Jilf and Qantara) an area of 0.89 square kilometers. These simple calculations do not account for the variation of soil permeability from basin to basin, and serve only to indicate the extent of protection afforded to pedestrians in the Siq. It is not surprising that the Nabataeans found the tunnel to be a very opportune solution.

The Problem of Wadi Al-Mudhlim

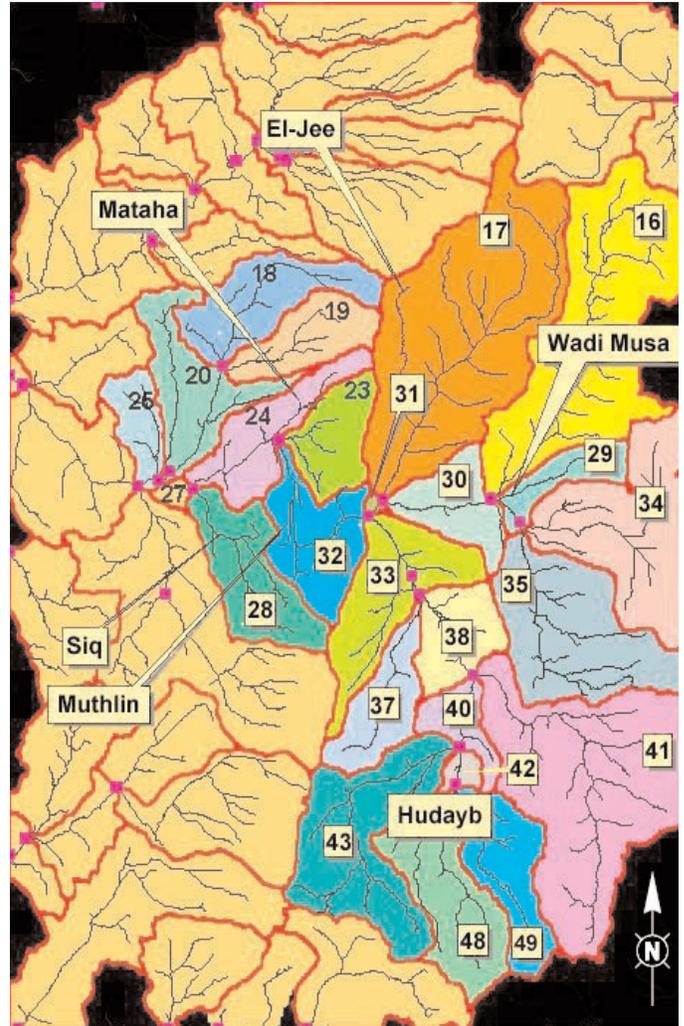
Under current conditions the total flow in the Wadi Al-Mudhlim is due to a total area of about 54 square kilometers, yielding 54,000 cubic meters per one millimeter of rainfall. Less than 2,476 cubic meters per millimeter is from the immediate vicinity of the *wadi* (Basin 32). It also receives some flow (1,500 cubic meters) from Basin 23 (not relevant to the Siq). The remainder is from all the other basins that collect into Basin 32. In an intense rainstorm of twenty-five millimeters, this leads to accumulation of about 1.40 million cubic meters. This large flow, although rare, can endanger people in the village of Wadi Musa on the streets immediately leading to the Siq near the Mövenpick Hotel. It also places at risk the important archaeological inscriptions and the Wadi Al-Mudhlim itself.

As a result of the Middle East Peace Process, the town of Wadi Musa has received a considerable amount of attention from tourism investors and developers. The past ten years have witnessed an increase in available hotel rooms from fewer than two hundred to more than twenty-five hundred. Obviously the environmental pressures have been enormous with the increase of water consumption and sewage. The rapid growth of concrete and asphalt ground cover in Wadi Musa also



Computer terrain modeling of the region being studied. Superimposed in light blue are the streambeds on a hillshade view, derived from a Digital Elevation Model (DEM), kindly provided by the Royal Jordanian Geographic Center. A Digital Elevation Model (DEM) is a diagram that shows the elevations of any terrain as pixels that have different shades of gray (depending on the elevation). Elevations can also be shown in colors derived from the gray shades or levels, thus indicating the contour of the region. After a 3D surface is created from the DEM, contours and hillshade views are easily obtained using any of the common Geographic Information Systems (GIS) software. An analysis of the surface created also affords a description of the watersheds that contribute to various flows in the streambeds. Hillshade is a GIS geographic term referring to the shaded diagram of a hilly region. It is usually based on the topographic data from surveying and allows the programmer to look at the area in 3D. Different sun angles can be changed or simulated so the sun's rays illuminate the hillsides from any direction.

requires an adequate underground urban rainwater drainage system. Because the village and the hotels formerly relied on conventional septic tanks (a threat to archaeological monuments), a proper sewage system has been established. Currently, the sewage network is pumped from the Pump Station, across the street from the Mövenpick Hotel in Wadi Musa, to a remote area in the north where a wastewater



Complete system of watersheds in the Petra area. About fifty-three watersheds (outlined in red) were derived from this analysis. Only basins of relevance to Petra are labeled here. The streams are shown in black and their pour points (where rainfall pours into a point) are shown in pink. The watersheds (basins) that contribute to flow into the Wadi Musa, to the west of Petra, total seven (numbers 18, 19, 20, 23, 24, 26 and 27). Eighteen more, marked by boxed numbers, play a role in the Siq and/or Wadi Al-Mudhlim flow.

treatment plant has been constructed. Although limited, rainwater drainage channels were also built as part of the sewage network.

Modern Solutions to an Ancient Problem

A report to the World Bank, prepared by the Dar Al-Handassah engineering firm, suggested the construction of several small dams in the upper watersheds of El-Jee, Wadi Musa and Al-Hudayb as well as increased terracing and reforestation. These measures would be of little value if future urbanization continues to reduce the soil cover. The French Electricity Company (EDF) also prepared a study to counteract the erosive weathering of the rock-carved monuments on the

western cliffs of the Al-Khubtha Plateau, the evacuation of sewage as well as flashfloods in the Wadi Al-Mataha and the Wadi Al-Mudhlim. The proposal suggested the construction of a network of tunnels under the Al-Khubtha outcrop in the Wadi Al-Mudhlim, which would house sewage disposal and would lead to a wastewater treatment plant west of Petra. Such tunnels also would serve for the drainage of groundwater under the Al-Khubtha outcrop and would protect the archaeological monuments from weathering. Some of the tunnels would also serve for water collection, and would feed the large dams dug under the flanks of Al-Khubtha in the Wadi Al-Mudhlim. Since water is the main source of weathering in Petra, this is not a very attractive solution. In any event, this proposal was not undertaken due to its anticipated costs and because the construction of the present wastewater system was already underway. Experts were also skeptical about the location of underground tunnels and sewage networks in proximity to the monuments and archaeological remains on the western outskirts of Petra. Others were skeptical about the lowering of the water table under Al-Khubtha, because now there exists a natural equilibrium in the plateau and its imbalance might lead to an unpredictable outcome. It is well known that electro-osmosis techniques utilized to lower the water table under stone monuments have done more harm than good, precisely because of the disturbance of the equilibrium between the stone and its surroundings.⁵ Additionally, the open dams suggested by the Dar Al-Handassah study may cause serious water pollution in the area.

Our own proposal, stemming from this study, calls for urban rainwater drainage system (underground if necessary) and the construction of a tunnel to divert the flow from near the Pump Station to the Wadi Shi'b Qays, a gorge that eventually leads to the Wadi Al-Mataha. The proposed tunnel, labeled NT, would be less than 650 meters in length and would reduce the water flow in the broad valley south of the Crowne Plaza (Forum) Hotel and Wadi Al-Mudhlim by about 52,000 cubic meters per millimeter of rain. An underground drainage system in the upper area of Wadi Musa town would free the streets, houses and hotels from any danger, and would provide access to the tunnel. Rainfall in the Wadi Musa/Petra area averages some one hundred millimeters each year (recent years have not been as bountiful). This implies a total flow of 5.6 million cubic meters each year into the proposed tunnel. The possibility of constructing one or more dams to collect the tunnel's flow should also be considered seriously.

Thus various suggestions have been put forward to protect the Siq from flashfloods and the Jordanian Government continues to consider these proposals. Only time will tell if any of these measures will be successful.

Notes

1. This study received financial support from the Japanese Junior Overseas Cooperation Volunteers (JOCV) program, and the Higher Council For Science and Technology (HCST) in Jordan. This assistance is gratefully acknowledged. I am also grateful to the Royal Jordanian Geographic Center. Fawwaz Isshaqat from the Hashemite University and

Massaki Tokoaka and Tomoya Hayashi from JOCV implemented this fieldwork.

2. All images and maps are in an UTM WGS 84 coordinate system. Superimposed on the ortho-rectified (the process of correcting the distortions that result from the angle of the camera) satellite image, is a map that the Hashemite University has produced in collaboration with the American Center of Oriental Research (ACOR).

3. The recently constructed Pump Station pumps sewage to a wastewater treatment plant north of Petra and Umm Sayhun village, which lies beyond the maps shown here.

4. The Al-Hudayb Basins empty into Basins 38, 40, and 43 and Basin 40 receives its flow from Basin 43, and in turn pours into Basin 38. The Wadi Musa watersheds pour into Basins 29, 30 and 33, and Basin 33 also receives its flow from Basin 38, followed by Basin 33. Basin 29 empties into Basin 30, while Basin 33 flows into Basin 32. Basin 30 flows into Basin 31, and, from there, to Basin 32, which is the Wadi Al-Mudhlim watershed. A more detailed basin analysis shows that the stream of the Basin 32 watershed is divided. One section (0.65 square kilometers) flows into the Siq, while the other (1.83 square kilometers) flows into Wadi Al-Mudhlim from the Al-Khubtha plateau (Basin 23 and part of Basin 24).

5. A current proposal with less negative environmental and cultural-heritage impact would implement one or two dams, dug underground in the Wadi Shi'b Qays, in an area that does not have ancient archaeological monuments. This proposal is also relatively inexpensive. A thorough engineering study with a complete Environmental Impact Assessment and Cultural Heritage Impact Assessment is underway.

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