



Watershed Management: A Tool For Flood Mitigation In The Petra Area

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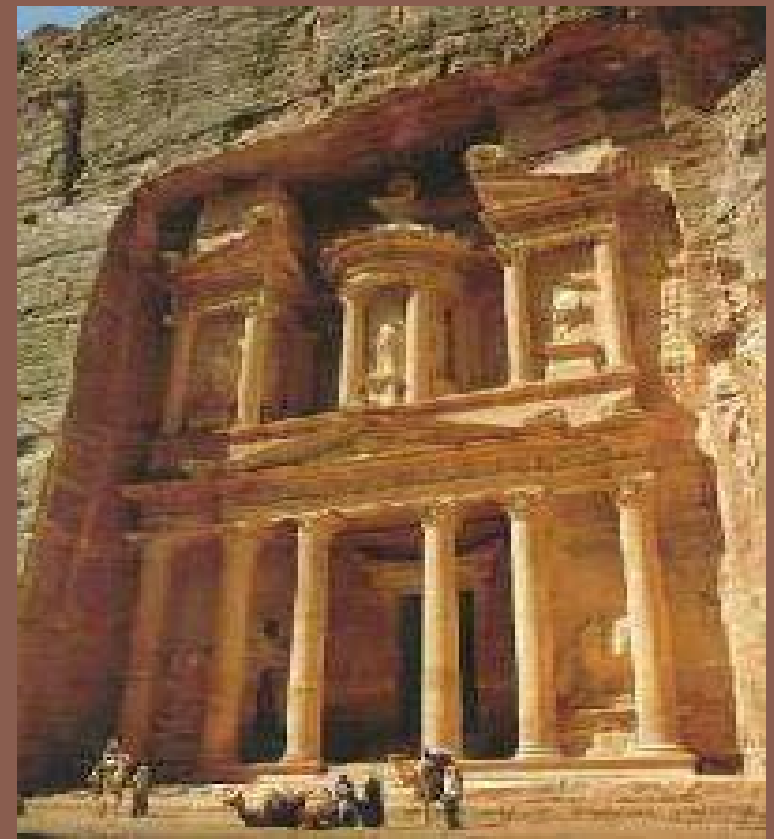
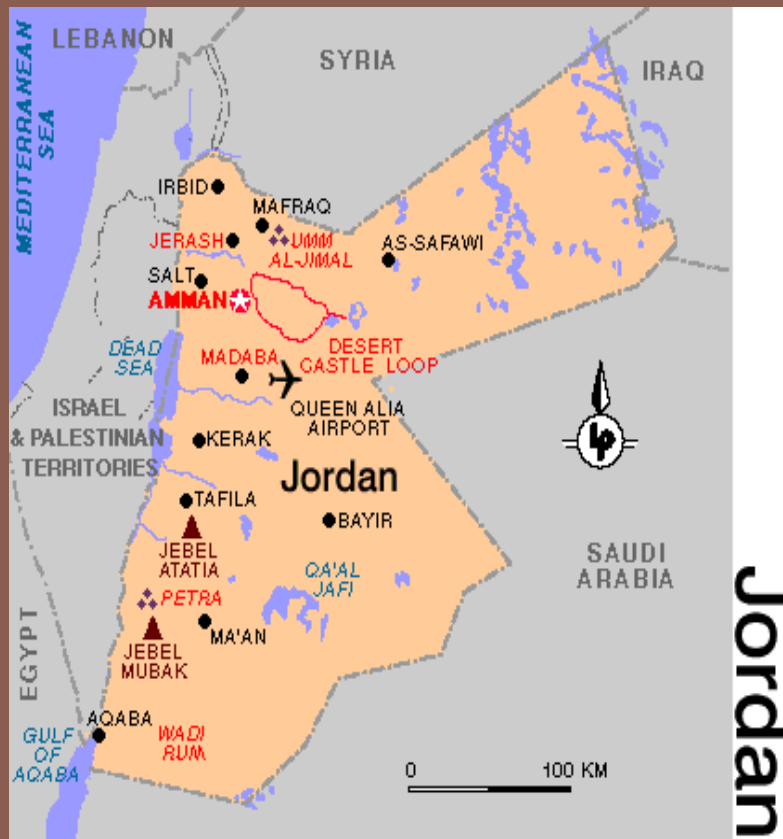
OUTLINE

- ◆ OVERVIEW AND INTRODUCTION
- ◆ PAST FLOODING PROBLEM
- ◆ RAINFALL IN PETRA
- ◆ DESCRIPTION OF CATCHMENTS
- ◆ FLOOD ANALYSIS AND PREDICTION



- ◆ WATERSHED MANAGEMENT SCENARIOS
 - * AFFORESTATION
 - * TERRACING
 - * CHECK DAMS
 - * STORAGE DAMS
- ◆ DISCUSSION
- ◆ CONCLUDING REMARKS

OVERVIEW 1



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OVERVIEW 2



INTRODUCTION

- ◆ **Petra is located about 260 km south of Amman, between the Dead Sea and Aqaba**
- ◆ **Petra was carved in sandstone canyons by the Nabatean Arabs over 2,400 years ago and is sometimes called the rosy rock city**
- ◆ **A major tourist attraction -- the jewels of Jordan**
- ◆ **Floods pose a serious threat to the tourism activities in Petra as well as to Petra monuments themselves**
- ◆ **To alleviate the impact of floods on tourist activities in Petra, flood mitigation measures are investigated including afforestation, terracing, construction of check and storage dams**
- ◆ **Most of these measures were widely used by the Nabatean of Petra about 2400 years ago**
- ◆ **A flood simulation model depicts up to 70 percent less in flood peakflows and volumes due to these measures**

FLOODING IN PETRA .../1

- ◆ In 1963 flood, the dam at the entrance of the Siq was filled up with sediment and consequently flood water overtopped the dam and entered the Siq instead of being diverted through the tunnel of Wadi Al-Mudhlim.
- ◆ Eye witnesses stated that the flood water depth was about 10 m in some areas of the Siq passage.
- ◆ Despite the great emergency efforts by different authorities in Jordan, it was not possible to rescue all the tourists trapped in the Siq, twenty lost their lives due to that flood event.

TREASURE

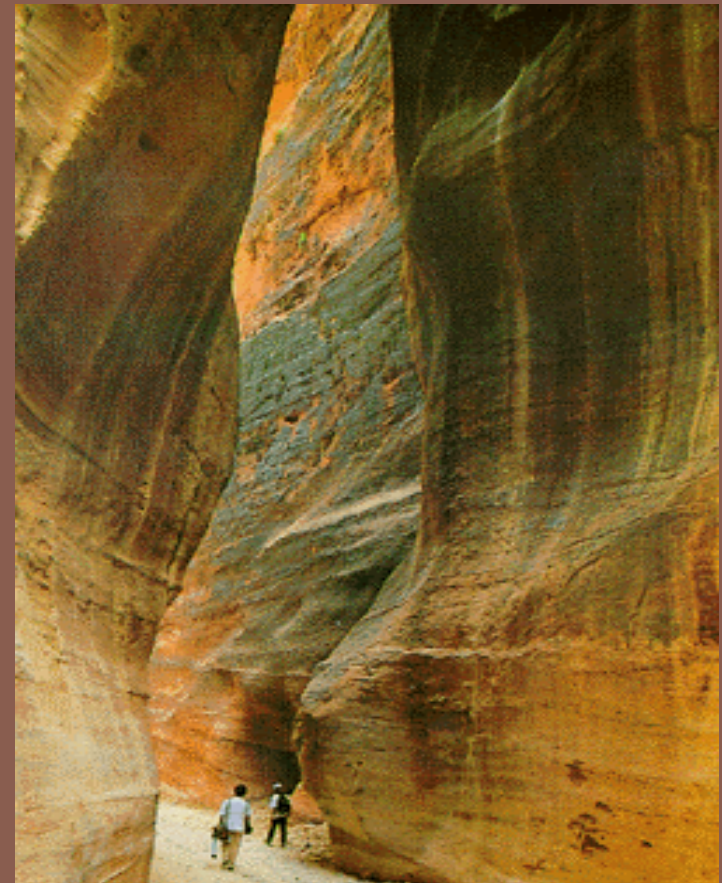
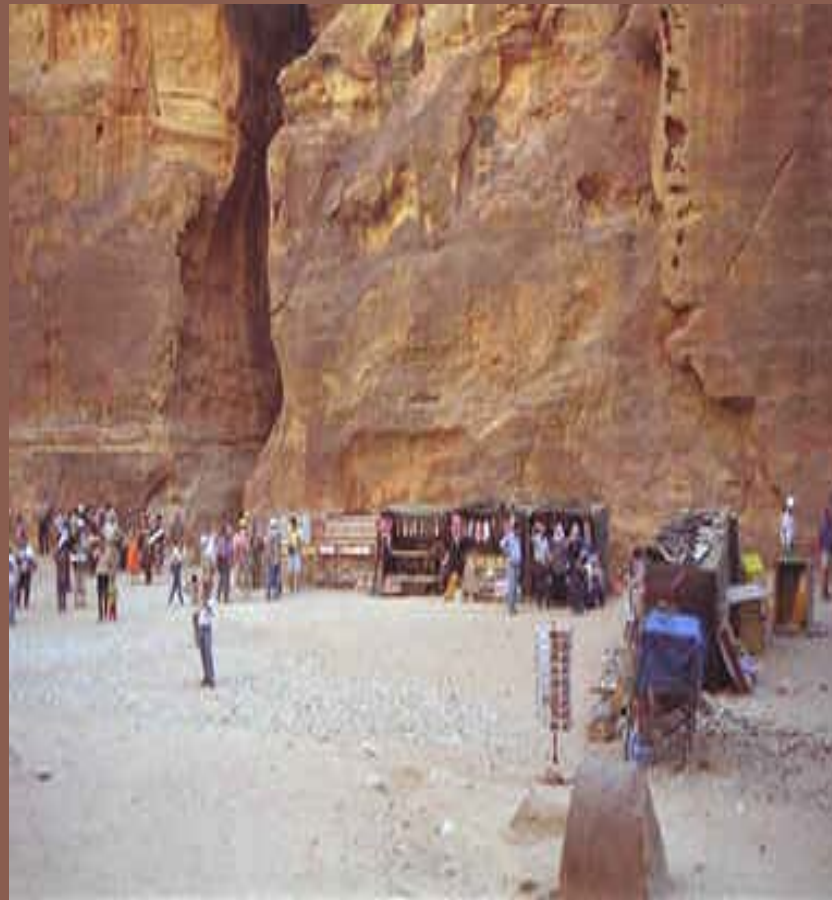


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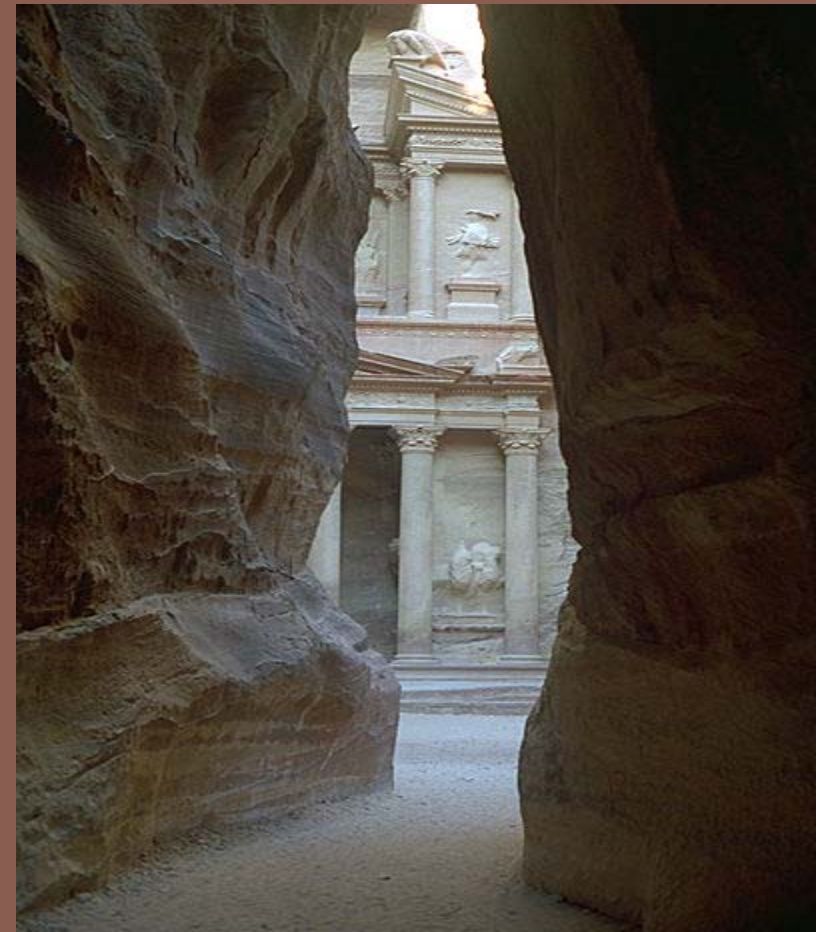
FLOODING IN PETRA .../2

- ◆ **Recent floods occurred in 1991, 1995, and 1996. Although the flood water did not enter the Siq during these events, traces of high water within Wadi Al-Matahah (to which the diversion tunnel of Wadi Al-Mudhlim discharges) indicated that the water level reached an elevation of more than 12 m above the wadi bed.**
- ◆ **During these recent events, the Siq entrance area was flooded and tourists had to be rescued.**
- ◆ **Flooding is considered a major issue in planning any development in Petra.**

THE SIQ (GORGE)



THE SIQ (GORGE)



RAINFALL IN PETRA

- ◆ **Petra region belongs to the Mediterranean climatic zone.**
- ◆ **The average annual precipitation is around 200 mm. Most rainfall is concentrated between October and April and is mainly of orographic origin.**
- ◆ **There are three rainfall gauging stations in the Wadi Musa watershed. These stations, designated DG1, DG2, and DG3, are operated by the Water Authority of Jordan (WAJ).**
- ◆ **Annual total rainfall records are available for these stations since 1937, and daily total rainfall records are available since 1980**



DESCRIPTION OF CATCHMENT

- ◆ **The overall Petra catchment has an area of about 50 square kilometers.**
- ◆ **This catchment can be divided into nine sub-catchments as shown in Figure 1.**
- ◆ **The hydrologic characteristics of each of the nine sub-catchments in the Petra catchment are described in Table 1 below.**



Model Used: WMS (Watershed Modeling System)

- ∩ It has been developed by the Engineering Computer Graphics Laboratory of Brigham Young University in cooperation with the U.S. Army Corps of Engineers Waterways Experiment Station.
- ∩ WMS can be used to create geospatial terrain models from Triangulated Irregular Networks (TINs). The TIN can then be used to automatically delineate watersheds, streams and subbasins and calculate their hydraulic parameters.
- ∩ WMS is a powerful comprehensive environment for hydrologic analysis.
- ∩ It can use several methods for abstraction and available models like HEC-1, Rational Method, etc.)

Watershed map



- LEGEND:
- CATCHMENT BOUNDARIES
 - STREAM LINE
 - FLOOD GAUGING STATION
 - RAINFALL GAUGING STATION

CATCHMENTS NAMES AS KNOWN LOCALY

FIG. 2. Petra Catchments and Gauging Stations

DESCRIPTION OF CATCHMENT 2

TABLE 1. DESCRIPTION OF CATCHMENTS

Catchment Name	Area (km²)	Average Slope (%)	Weighted CN	Lag Time (hrs)
Kafr Isham	4.30	5.7	80	0.76
Qurnat Bin Sa'd	21.11	6.2	81	1.50
Al Hai	10.75	9.0	81	1.00
Jebel Zubaira	13.90	5.3	75	1.19
Al Madras	3.90	6.7	91	0.66
Al Mataha	4.20	8.7	91	0.60
Wadi Kharubit	6.90	10.0	91	0.96
Wadi Al Ulyqa	7.05	9.1	91	1.02
Wadi Siagh	7.90	11.8	91	0.67

WATERSHED VIEWS



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WATERSHED VIEWS



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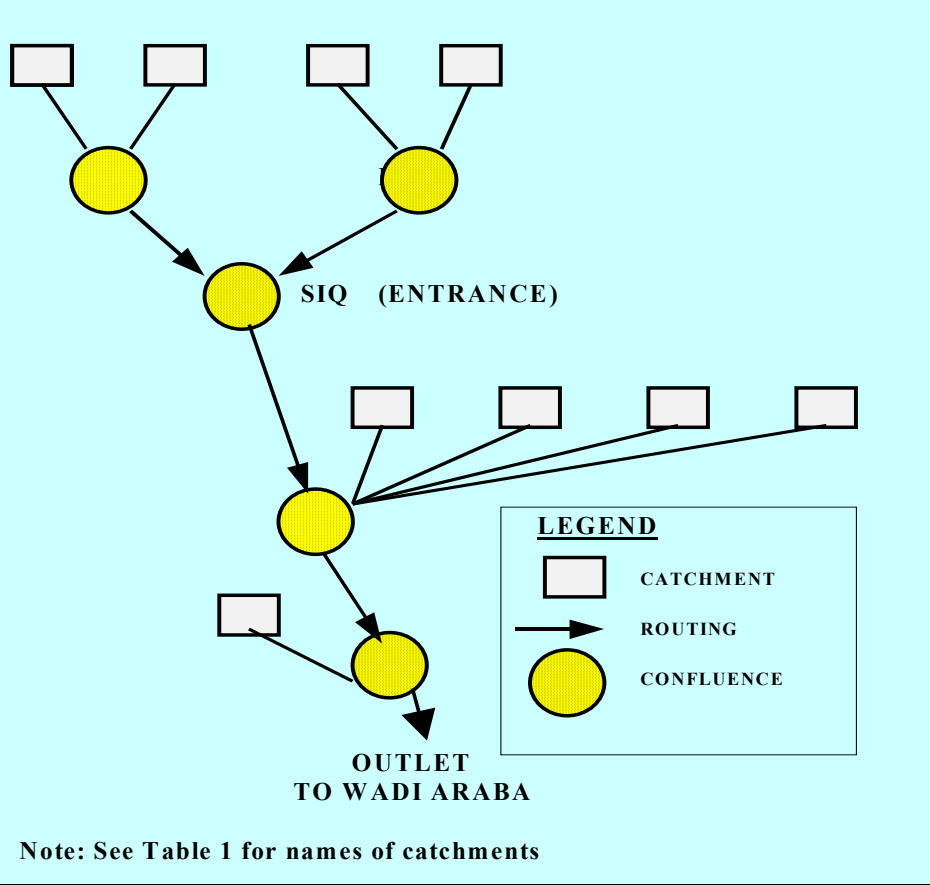
MAP OF CATCHMENT



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FLOOD ANALYSIS AND PREDICTION

- ◆ The Watershed Modeling System (WMS) developed by the Brigham Young University (WMS, 1996) was used for hydrologic analysis.
- ◆ This model was calibrated and then used to estimate the peak flow and flood volume, for return periods ranging from 10 and 100-year at the Siq entrance.
- ◆ The Intensity-Duration-Frequency (IDF) curves developed for Wadi Musa meteorological station by the WAJ (WAJ open files) were used to estimate the 24-hour design storm for these return periods.





WATERSHED MANAGEMENT SCHEMES

- **Four possible watershed management scenarios or measures were hydrologically analyzed to estimate their effectiveness in reducing floods in critical sites in Petra like the Siq entrance.**
- **The four scenarios are:**
 - * **I: Afforestation of selected parts of the watershed;**
 - * **II: Construction of storage/detention dams;**
 - * **III: Combination of storage/detention dams and afforestation; and**
 - * **IV: Contour terracing and construction of check dams with afforestation.**



WATERSHED MANAGEMENT SCHEMES

- * Most of these measures were originally used by the ancient Nabateans of Petra.
- * The Petra hydraulic system was unique, well-maintained and integrated in their life style and agricultural practices.
- * Most of these measure are dual purpose practices, they can be used for water harvesting and flood mitigation.
- * Our approach was careful in avoiding any intrusion on the aesthetics of the historical setting of Petra.

EXISTING PRACTICES



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TERRACING AND GABIONS



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CHECK DAMS

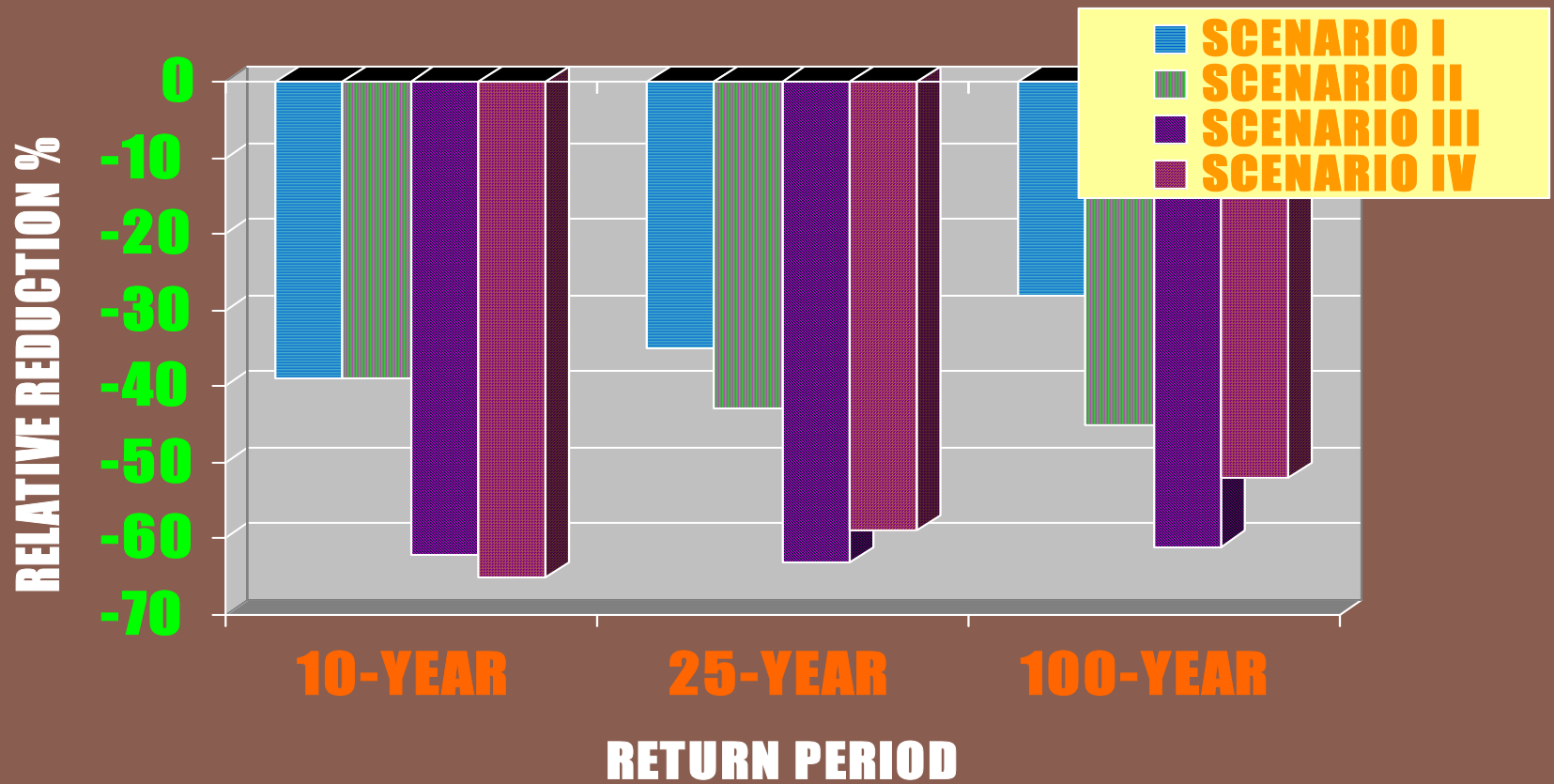


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COMPARISION OF RESULTS

- ✉ The analysis of the above results focused on evaluating the relative percentage change in the peakflow, time to peak, and flood volumes for storm events of return periods of 10 and 100 years.
- ✉ Improvements are referenced to existing conditions (do-nothing option). The station at the entrance of the Siq was selected because it is a very critical point for tourism activities.
- ✉ Figure 2 shows the relative impact on peakflow. From this figure, it can be seen that afforestation and terracing as well as afforestation and dam storage are the most effective measures for all return periods.

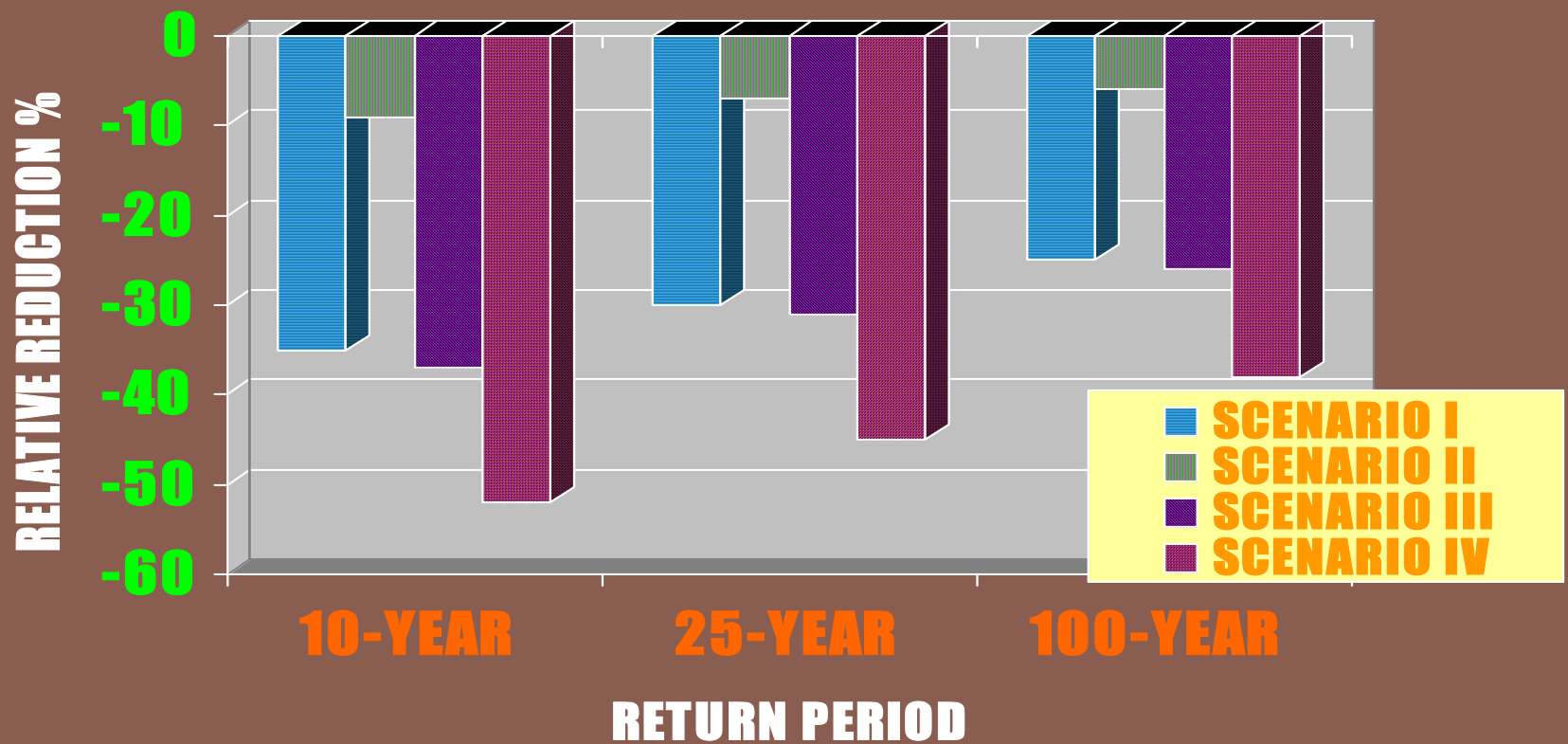
FIG. 2: REDUCTION IN PEAKFLOW



COMPARISION OF RESULTS

- ✉ **Terracing/check dams and afforestation are slightly superior to afforestation and storage action for more frequent (small) events (e.g., return period less than 10 years).**
- ✉ **The reservoir storage option starts to be slightly more effective than terracing for less frequent (larger) events.**
- ✉ **Figure 3 shows the relative impact on flood volumes for the four flood- mitigation scenarios. It can be seen that afforestation and terracing as well as afforestation and storage are the most effective volume control measures for all return periods.**

FIG. 3: REDUCTION IN FLOOD VOLUME



COMPARISION OF RESULTS

- ✉ A comprehensive evaluation of each alternative would consider economical, social, legal and environmental aspects.
- ✉ From a flood- mitigation perspective, terracing and afforestation provide more than 60 percent reduction in the flood peakflow and about 30 percent reduction in the flood volume at the Siq entrance. On the other hand, the terracing/check dams are usually necessary to provide suitable land for afforestation. Terracing/check dams can be used for water harvesting to sustain small amounts of water needed for afforestation.

COMPARISION OF RESULTS

- ✉ Terraces/check dams can be constructed by local people without any sophisticated engineering design, contrary to the storage option where skilled technicians and complete engineering designs are needed for the construction of dams.
- ✉ The dam storage option also would be more costly compared to the terracing/ check dam option. The risk involved in the construction of dams option is usually higher in case of dam break compared to the risk posed by the terracing/check dams failure.

CONCLUDING REMARKS ... /1

- ✉ **Flooding poses a serious risk to lives and property in the Siq area under present conditions, immediate actions should be taken to mitigate the flood risk at these areas. Structural measures that intrude the integrity and the aesthetics of the historical setting of Petra are not encouraged. However, restoration of some watershed management practices used by the ancient Nabateans of Petra are more attractive and sound in this case.**
- ✉ **Afforestation only, of 1000 ha in both Jebel Zubaira and Qurnat Bin Sa'd subbasins, provides about 30 to 50 percent reduction in flood peakflow. However, it has a limited impact on flood volume (about 20 percent) for most storm events.**

CONCLUDING REMARKS .../2

- ☒ **Afforestation combined with terracing and check dams in the watershed upstream from the Siq entrance, produced about 50 to 80 percent reduction in the flood peakflow, and about 40 to 70 percent reduction in flood volumes for most storm events.**
- ☒ **Afforestation combined with dam storage of 214,000 m³ produced about 60 percent reduction in the flood peakflow, and about 30 to 50 percent reduction in flood volumes for most storm events. This scenario would required a chain of seven dams over major wadis in the watershed upstream of the Siq entrance**

CONCLUDING REMARKS ... /3

- ✉ Terracing with check dams measure would be more suitable and less expensive compared to dam storage and more desirable from the socio-economic, environmental and risk perspectives. However, a further detailed evaluation of these two options must consider all relevant parameters including social, economical, environmental, risk, etc.

ACKNOWLEDGMENTS

- ✉ *This research was partially done under the Petra Planning Project for the Ministry of Tourism and Antiquities (MOTA) of Jordan done by Dar Al-Handasah Consultants (Shair and Partners) in Amman and Cairo.*
- ✉ *The Speaker would like to acknowledge the contribution of his co-author Mr. Fouad Khoury of Dar Al-Handasah*
- ✉ *The full paper appeared in the ASCE J. of Water Resources Planning and Management Vol. 125, No. 2 (May/June 1999).*

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PHOTOS



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