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The Potential for Stormwater Harvesting in the Eastern Surface Catchment of the West Bank

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Collaborative Approaches for Resolving Water Issues

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ACRONYMS

ARIJ	Applied Research Institute Jerusalem
ASIR	Arab Scientific Institute for Research and Transfer of Technology
du	Dunums
EAB	Eastern Aquifer Basin
ESC	Eastern Surface Catchment
km	Kilometer
L/S	Liter Per Second
m	Meter
m^2	Squared Meter
m^3	Cubic Meter
m^3/d	Cubic Meter Per Day
m^3/s	Cubic Meter Per
MCM	Million Cubic Meter
MCM/yr	Million Cubic Meter Per Year
mm/year	Millimeters Per Year
MOPIC	Ministry of Planning and International Cooperation
PWA	Palestinian Water Authority
R_c	Runoff Coefficient
USAID	The United States Agency for International Development
WBWD	West Bank Water Department

EXECUTIVE SUMMARY

A preliminary assessment of the potential for harvesting stormwater runoff in the Eastern Surface Catchment (ESC) of the West Bank was conducted. This entailed:

- A survey and screening of potentially feasible wadis;
- Identification and screening of feasible stormwater harvesting technologies; and
- Development of potentially feasible stormwater harvesting schemes for two wadis within the ESC.

The main objective of the study was to assess the potential for augmenting recharge of the Eastern Aquifer Basin (EAB), particularly in the upper reaches of the ESC, to augment available water resources for urban centers.

The catchment areas and wadis within the ESC were screened and ranked based on a set of pertinent criteria. These criteria generally represent physical, hydrological, environmental, and political characteristics of the catchment areas. Since not all screening criteria can be evaluated quantitatively, a protocol, based on a direct weighing approach, was devised to rate those criteria and to rank wadis within the ESC, with respect to runoff potential.

The initial screening indicated that the stormwater harvesting potential for augmenting recharge within the upper reaches of the ESC is limited, particularly for the Hebron-Bethlehem area. This is attributed to several factors; permeable outcrops, small sub-catchments, gentle slopes in the main regional recharge areas, unreliable rainfall, and water quality concerns. It was observed that nature is quite effective in optimizing recharge through natural terracing and existing vegetative covers. The most suitable locations for capturing stormwater in wadis are located downgradient of well fields accessible to Palestinians. The cost of conveying this captured water to upstream locations for recharge or direct use are considered prohibitive.

The analysis of rainfall data indicated that runoff potential in the ESC is limited due to the sporadic and erratic characteristics of runoff-causing rainfall occurrences. Individual occurrences are of short durations (a few days) between January and March. The average total rainfall during these occurrences was estimated to constitute approximately 30 to 40 percent of the total annual rainfall. The average total annual runoff was estimated, based on the characteristics of these occurrences and runoff threshold criteria in the ESC wadis, to vary between 0 and 10 percent of the total annual rainfall. The average total annual runoff to individual wadis was estimated to vary between less than 0.5 and 10 MCM/year.

The assessment of the runoff potential indicated that only a few wadis could actually be considered feasible for capturing runoff. These wadis include Fari'a, Qilt, Al-Ghar, and Nar. The average potential runoff for Wadi Fari'a and Qilt was estimated to range between 3 and 10 MCM/year, whereas for Wadi Nar and Al-Ghar it was estimated to range between 1 and 3 MCM/year. Wadi Nar was discarded from further assessment due to water quality concerns associated with raw sewage discharges from urban areas, whereas Wadi Al-Ghar was discarded because of the topography, severe terrain and low and erratic runoff potential. However, it was assessed that small-scale schemes could

be developed along Wadi Al-Ghar (and possibly others) for local harvesting of stormwater runoff. These schemes may include check dams and/or surface impoundments for ultimate usage of captured water by bedouin communities. A portion of this water may infiltrate into the subsurface and recharge the groundwater. However, the potential gains from such schemes could not be reasonably projected or evaluated with available

Further evaluation of Wadi Fari'a and Qilt and comparative assessment of potentially applicable stormwater harvesting schemes was carried out. Accordingly, two schemes were selected for harvesting stormwater, a detention dam at Wadi Fari'a and an infiltration system in Jericho for Wadi Qilt. Both schemes are intended for reuse in irrigated agriculture nearby or downstream of the proposed scheme locations.

The proposed infiltration system at Wadi Qilt is located approximately 2 km southeast of Jericho center, and has a 4 MCM capacity. This system could potentially be conjunctively managed along with excess winter water from Ein Sultan, and possibly from other springs in the area (most of which is currently lost) and treated wastewater from a planned nearby Jericho treatment plant. The total capital and annual O&M costs for major system components were estimated to be about US $36 and 1 million, respectively. The average unit cost of water for the proposed scheme was estimated to range from US $1.1/m^3 to US $1.5/m^3, depending on the engineering complexity of the scheme. This does not cover any water treatment costs.

The proposed detention dam at Wadi Fari'a is located approximately 1.5 km downstream of Jisr Al-Malaki and the confluence of Wadi Fari'a and Badan. The storage capacity of the dam is estimated at 10 MCM. The dam would store an estimated average annual stormwater runoff of 6 MCM, and winter spring water from Fari'a and Badan springs, estimated to average about 4 MCM. The dam is estimated to be approximately 40 to 50 m high. The lake behind the dam was estimated to extend approximately 1 to 2 km upstream of the proposed dam location. The total capital and O&M costs for major system components were estimated to average about US $75 and 2.5 million, respectively. The average unit cost of water for the proposed scheme was estimated to be about US $1.3/m^3. This does not cover any water treatment costs.

The estimated average unit cost of water for these two stormwater harvesting schemes are higher than the current average unit water cost for irrigation (and municipal) water in the Jordan Valley, which was estimated at about US $0.3/m^3 (CPF 1997). In fact, these unit water costs are higher than the current average unit cost for municipal and domestic water in the West Bank, which was estimated at about US $1/m^3.

The gross margin for 1 m^3 of water in irrigated agriculture in the West Bank was reported (CPF 1997) to range between US $0.5 and 1.4. These estimates suggest that irrigated agriculture, based on current practices and patterns, may not be capable of sustaining potential costs associated with the conceptualized stormwater harvesting schemes. However, if stormwater harvesting schemes are integrated with other water resources management schemes such as the reuse of treated wastewater from the urban areas in the upper reaches of the ESC, it is likely that such projects can become cost-effective and feasible.

CHAPTER 1

INTRODUCTION

General

The Eastern Aquifer Basin (EAB) is one of the most important sources of water supply for Palestinians within the West Bank. Water is accessed at natural springs and by pumping of deep supply wells, and is used for both domestic and agricultural purposes. During the winter season, these sources could be augmented by harvesting stormwater although, to date, no comprehensive or conclusive study has been conducted to assess the potential qualities that may feasibly be captured by intercepting direct runoff and wadi flows within the Eastern Surface Catchment (ESC).

The ESC includes all the major catchments and wadis that drain eastward from the central mountain region in the West Bank toward the Jordan Valley and the Dead Sea. It is defined by a regional topographic ridge that runs from the Fari'a Valley in the north to Hebron in the south.

This report presents the formulation of preliminary concepts for feasible stormwater harvesting schemes in the ESC. The purpose of this study is to provide information to support the development of a conceptual design which will, in turn, be used by the USAID Mission in the preparation of the Request for Proposals for Package 2 of the Integrated Water Resources Management Program.

Objectives and Purpose

This study estimates a range of limits for stormwater quantities in the major catchments and wadis in the ESC and evaluates potential measures that may be implemented to utilize this resource. Specific objectives are to:

- Evaluate the feasibility of stormwater harvesting schemes;
- Develop stormwater harvesting schemes for at least two major catchment areas within the ESC, if deemed feasible; and
- Develop a plan of action for implementing any recommended stormwater harvesting schemes, including conceptual designs, terms of references, and cost estimates.

The most critical task is to define how much stormwater there is, where it flows, and then assess how much of this can be captured and used, taking into consideration factors such as water quality and potential costs of development. This study will also attempt to assess if stormwater can be regarded as a reliable resource. As such, it should be regarded as a screening-level study, or a pre-feasibility study. Items considered include check dams and other terrain altering measures for the purpose of slowing runoff and increasing recharge rates to the deeper aquifer system.

Task Activities

In preparing this report, the following tasks were undertaken:

- Collected relevant background information and data from various sources and reports (see below);
- Interviewed relevant agencies and individuals regarding stormwater in the ESC;
- Conducted field trips to all major wadis in the ESC;
- Evaluated all relevant information and data to independently quantify the total amount of stormwater generated in the various catchment basins;
- assessed the feasibility of potential stormwater harvesting schemes;
- Met with USAID and PWA to present findings of the study and to reach a consensus on the topic of stormwater harvesting; and
- Estimated associated capital and O&M costs for those schemes which represent the most feasible alternatives.

The following agencies and individuals were interviewed:

- PWA - Engineer Fadle Kawash;
- PWA - Dr. Karen Assaf;
- PWA - Ms. Basema Bashir;
- West Bank Water Department - Mr. Mustafa Nuseibeh;
- USAID - Mr. John Starnes;
- USAID - Mr. Tom Delaney;
- An-Najah University - Dr. Anan Jayoussi;
- Palestinian Geographic Center - Mr. Abdulla Abdallah; and
- Municipal Engineer of Jericho - Mr. Basel Hijazi.

Sources of Information and Data

Data were collected from numerous sources:

Rainfall Data From PWA. Daily rainfall totals from different stations within the ESC. These data were supplied electronically and are based on rainfall records collected by the WBWD over a 30 period from the late 1960s. Some of the data extend back to the mid-1950s. All rainfall data obtained are included in Appendix A. Specifically, data were analyzed from stations at the Arroub Agricultural School, Bethlehem, Deir Dibwan, and Al-Bireh. While technically not within the Eastern Aquifer, station data from Beitunya and Salfeet were also used to supplement missing data at Ramallah and Nablus (Salfeet - nearest available station) and to provide a comparison for temporal rainfall patterns between the Eastern and Western catchment basins.

Rainfall Data From ASIR. Total monthly rainfall for the years 1970-1991 based on annual reports published by the Meteorological Services of Israel.

Wadi Flow Data From PWA. Wadi flow data were obtained from PWA's data management unit and are based on measurements and records collected by Mr. Mustafa Nuseibeh at the WBWD. Very limited data exist and are included in Appendix B.

Spring Data. All data used were obtained from the 1995 report by Mustafa Nuseibeh and Taher Nasser Eddin entitled "Palestinian Fresh Water Springs: Spring Description, Flow & Water Quality Data 1970-1994."

Spring discharge data include monthly totals for the major fresh water springs within the EAB.

Topographic Maps. Complete sets of 1:50,000 and 1:100,000 scale topographic maps for the study area were purchased from the Atlas company, based in Nablus. These were used to delineate catchment areas and define contributing areas of the major wadis, as well as describe the physical characteristics of each catchment area.

Land use maps at a scale of 1:100,000 for each of the West Bank districts that cover the ESC were also purchased from PALGRIC.

Other. Other sources of information and data used in this study include:

- Various reports generated under the USAID-funded Water Resources Program, specifically:
  - Task 18: Study of the Sustainable Yield of the Eastern Aquifer Basin: Final Report. February 1998
  - Task 4: Comprehensive Planning Framework for Water Resources in the West Bank and Gaza. September 1997.
  - Task 33: Integrated Water Resources Management Plan: Hebron-Bethlehem Districts. September 1997.
  - Task 43: Integrated Water Resources Management Plan: Jericho District. September 1997.
- General hydrological and hydro-geological data collected by CDM as part of the Water Resources Program
- Geological and other maps collected by CDM under the Water Resources Program

CHAPTER 2

HYDROLOGICAL SETTING OF THE EASTERN SURFACE CATCHMENT

Climate

The study area, shown in Figure 2-1 (figures are found at the end of this chapter), has a predominantly Mediterranean climate to the north and west, and semi-arid to arid climate to the south and east. Figure 2-2 shows the approximate average distribution of rainfall in Israel and the West Bank over a 30 year period from 1951-1980. Within the ESC, rainfall is affected by topography. The central Mountain region creates a rain shadow effect, whereby rain-bearing winds that move eastward from the Mediterranean Sea shed their moisture along the mountain ridge. As the air continues to pass eastward, it warms and rainfall decreases. Mean annual precipitation ranges from about 700 mm/year in the Mountain region to less than 100 mm/year at the Dead Sea. Rainfall occurs mostly from November through April.

The PWA database contains rainfall data from about 80 raingauges around the West Bank. Less than 20 are located within the ESC.

For this study, daily rainfall data were analyzed for stations located in the upper reaches of major catchments: Arroub Agricultural Station (1967-1997), Bethlehem (1967-1997), Deir Dibwan (1967-1997), Al-Bireh (1971-1997), and Salfeet (1953-1997). The daily rainfall data contain some gaps. Additional information were obtained from annual reports by the Israeli Meteorological Service.

The mean annual rainfall at each of the stations mentioned above are 649 mm, 550 mm, 470 mm, 682 mm, and 658 mm, respectively. This compares to about 120 mm in Jericho.

Available literature (ARIJ 1997) suggests that in the Mountain region, evaporation rates exceed rainfall rates for most stations from December through mid-February, resulting in a net water surplus for only about 3 months out of the year. In the Jordan Valley, a net water deficit exists all year around.

Values for potential evapotranspiration (PET) are scarce. From the collected data, it has not been possible to compute PET at representative stations. The only estimates of PET in the ESC were computed by Rofe and Raffety (1965) considering data from twelve climatological stations over a period of only two years: 1963/1964 and 1964/1965. Values obtained are summarized in Table 2.1 below:

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Table 2.1: Summary of Potential Evapotranspiration as Calculated by Rofe and Raffety (1965)

Annual Potential Evapotranspiration (mm)					
Station	**X coord.**	**Y coord.**	**Elevation**	**1963/1964**	**1964/1965**
Fari'a	192.9	178.8	+100	2341	2426
Jericho	193.0	140.0	-163	2163	2243
Daraj	n/a	n/a	n/a	2227	2394
Bani Naim	165.0	102.7	+900	2361	2343
Dahariya	147.0	91.0	+600	1940	2034
Jerusalem	170.0	141.0	+590	1966	2095

Seasonal values and changes are not available. It is, however, clear that total annual PET exceeds total annual rainfall by a factor of about 3 in the mountain region to 20 in the Jordan Valley.

The average temperature within the study area varies between 20-23 degrees centigrade in summer and 10-11 degrees centigrade in winter. There are significant temperature increases from the Mountain regions toward the Jordan Valley and the Dead Sea.

Rainfall Intensity

A major characteristic of rainfall which bears directly on the occurrence and magnitude of runoff is rainfall intensity. Available literature (Rofe and Raffety 1963 and 1965; Ionides 1939; ARIJ 1997) and rainfall/runoff measurements by the WBWD indicate that runoff is likely to occur in the ESC when the total annual rainfall exceeds 200 mm, and daily rainfall exceeds 50 mm in one day or 65-70 mm in two days. These limits are referred to as the "runoff threshold limits."

These studies also indicate that annual runoff within the West Bank constitutes 5 to 20 percent of the total annual rainfall. Moreover, it has been suggested that runoff typically does not occur prior to December, but is generally limited to the period between January and March (Mustafa Nuseibeh, personal communication). Rainfall, which occurs prior to December is likely to readily evaporate or be absorbed by surficial soils. Runoff may subsequently occur after consecutive rainfall events, once the field capacity moisture content is achieved.

To assess the impact of rainfall intensity on the runoff potential for the various wadis, daily rainfall measurements were analyzed based on the runoff threshold limits.

The analysis of the data is summarized graphically in Figures 2-3 though 2-8 for 6 raingauging stations, and are shown in tabular form in Appendix C. They indicate that rainfall occurrences/events which meet the runoff threshold limits constitute, on average, 30 to 40 percent of the total annual rainfall at these locations (Arroub, Deir Dibwan, Bethlehem, Al-Bireh). The total number of occurrences in a year appear to be sporadic, and range between 1 and 7, with an average of 3. The total number of days in a year corresponding to these occurrences was estimated to vary between 1 and 20 days, with

many more such occurrences and days in wet years. The average rainfall associated with these occurrences was also noted to be higher for wet years. The analysis further shows that these events are likely to occur during the months of January and February. Occasionally, such events were observed during March. Several rainfall years were generally identified as wet years including 1991-1992, 1982-1983, 1979-1980, and 1973-1974.

The implications of these observations is that runoff occurs sporadically a few times each year, and is driven by individual storms. There is no regularity in the data which suggests that runoff and stormwater can not be relied on as a resource at any given time during the wet season.

A comparison between rainfall stations located along the eastern and western catchment areas within the ESC suggests that the average total rainfall for occurrences in the west is less than that for those in adjacent eastern catchments. Furthermore, daily rainfall peaks for western measuring stations were observed to be less than peaks at adjacent eastern measuring stations. This is indicative of a flashier rainfall pattern on the eastern areas than that on the western areas. The implication is that the Western Aquifer Basin receives more steady aquifer recharge, while the EAB is more reliant on occasional storm events.

Geology and Infiltration (Aquifer Recharge)

The geology of the ESC has been extensively mapped, and the exposed rocks consist of a 600-800 m thick sequence of dolomites, limestones, marls, and chalk of Albian to Senonian age. An overview of the regional geology, stratigraphy, and outcrop patterns can be found in Rofe and Raffety (1965) and CDM (1998). A generalized map of outcrops is shown in Figure 2-9.

There are currently no specific data for infiltration capacities for the various rock and soil types that cover the ground across the ESC. However, based on lithologies, a relative sense of infiltration capacities can be gained.

The youngest Senonian chalks (of the Abu Dis and Amman Formations) are considered relatively impermeable, while the older limestones and dolomites of Albian to Upper Cenomanian age are more permeable and allow for infiltration. These rocks make up the Upper and Lower Beit Kahil, Hebron, Bethlehem, and Jerusalem Formations.

The more permeable rocks outcrop along the mountain ridge where total annual rainfall is highest. The impermeable Senonian chalks outcrop further east in areas of less rainfall, along the steep eastern slopes of the ESC.

Groundwater in the EAB originates as rain which falls in the central mountains directly on outcrops of karstic limestones and dolomites. A large portion of rainfall never reaches the paretic zone (water table) in the aquifer because of evapotranspiration and surface runoff. Effective recharge (the quantity of water that infiltrates and reaches the water table) is related to the surface geology (outcrops) of the drainage catchments. Effective recharge in the mountain areas range from 10-40 percent, with an estimated average of about 30 percent. During wet years, recharge may be locally higher, about 50 percent. Over the Senonian chalks, recharge is much less, between 0-5 percent of rainfall.

Runoff

Surface runoff occurs only when the rainfall rate exceeds the infiltration capacity of the natural soil. This condition is a function of both soil type, slope, rainfall amount and intensity. Four processes prevent some of the precipitation from becoming immediate runoff and are therefore considered as losses:

- Interception — water that is retained on vegetation and other surfaces;
- Depression storage — water that is retained in depressions on the catchment surface. Although the water held in these depressions may be exchanged during a storm, the volume stored is a loss to runoff and is removed via evaporation and infiltration;
- Infiltration — water percolating vertically into the subsurface soil (i.e., direct recharge to the aquifer system); and
- Evapotranspiration — the loss of water to direct evaporation and plant uptake.

The latter two are generally considered to be the most important factors governing rainfall-runoff relationships. However, another important factor is catchment basin "wetness." The soil water content has to exceed some limit in order for direct runoff to occur. In the West Bank, it has been estimated that runoff occurs only when rainfall exceeds 50 mm in one day or about 65-70 mm over two days (Ionides 1939; Rofe and Raffety 1963; Mustafa Nuseibeh, personal communication).

Surface runoff causes occasional flash floods in wadis which may not last for more than a few days. Wadi flows are ephemeral and typically occur between January-March. While the wet season extends from October through April, runoff typically does not begin until mid-late December (Mustafa Nuseibeh, personal communication), after the catchment surface as a whole has absorbed moisture from early-season rainfalls.

Meteorologic and topographic characteristics control the amount, distribution, and timing of runoff along the ESC. Runoff is also dependent on geology, drainage patterns, losses by evapotranspiration, and so forth. For example, runoff is expected to be significantly higher in areas with outcrops of Senonian chalks (which are impermeable) compared to areas with outcrops of Cenomanian limestones and dolomites (which are permeable and allow for infiltration).

For the most part, runoff is not utilized or controlled in the ESC. Small-scale utilization may occur in villages where cisterns are used to capture rain water or small ponds are built to collect surface runoff. This water is primarily used for domestic and irrigation purposes, mostly in areas that do not have water distribution networks.

Surface Drainage

Surface drainage in the ESC is eastward and direct runoff from rainfall has cut steep-sided wadis from the Mountain region to the Jordan Valley and the Dead Sea. The major wadis and catchment areas within the study area are shown in Figure 2-10, and were

delineated from topographic maps. They are summarized in Table 2.2 below (from south to north):

Table 2.2: Major Catchment Areas and Wadis with the Eastern Surface Catchment

Catchment/Wadi (Arabic Name)[1]	Catchment/Wadi (Hebrew Name)[2]	Total Area (km^2)	Average Rainfall over Catchment[3] (mm/year) 1960-1991
Abu Muradin (Sayal)	Ze'elim	253	200
Abu El Hayyat (Khabra)	Hever	175	250
Al-Ghar	Arugot	235	350
Daraja (Al-Mashash)	Darga	237	300
Nar	Qidron	123	300
Mukallak	Og	137	300
Al-Qilt	Perat	173	400
Nuweima	Nueima	98	350
Auja	Yitav	274	350
Al-Ahmar	Al-Ahmar	178	300
Fari'a	Tirza	331	400

(1) alternate name in parenthesis
(2) as they appear on topographic maps printed by the Israeli Survey
(3) unweighted - e.g., most of the Auja sub-catchments cover an area with average rainfall less than 300 mm

Each major catchment area contains numerous tributaries or sub-catchments/wadis. Their individual characteristics are too numerous to describe in this study.

It is worth noting that the western extent of the ESC, as shown on Figure 2-10, does not coincide with the western extent of the EAB. In fact, the EAB incorporates the uppermost reaches of the western drainage system, and is therefore partly recharged from the western surface catchment system.

Wadi Flows

Wadi flows are derived primarily from direct surface runoff (including urban runoff) and spring return flows. No detailed study of direct runoff (and therefore stormwater) has been published in recent years, and estimates are limited to the following:

- Schneider (1964) cites a study by Downes (1960) who analyzed a 20-year record of runoff and rainfall for a drainage area of 75 km^2 near Jerusalem. Runoff ranged from 0-17 percent of the annual rainfall, with a mean of 6 percent.

- Rofe & Raffety (1963) estimated that the potential "runoff element" varies from 7-14 percent of rainfall in the Jerusalem area (including Bethlehem).

In terms of actual quantities of stormwater, few measurements exist to date, and no systematic gauging is taking place today. Based on literature and discussions with

hydrologists at the WBWD and Tahal, annual total wadi flows within the West Bank may total as much as 50 MCM, including spring return flows. In the ESC alone, the total annual wadi flows are significantly lower. Estimates range from 10-20 MCM/year, although in wet years, these numbers may be higher.

With the exception of Wadi Fari'a, Auja and Al-Qilt, all wadis are seasonal. Wadi Fari'a, Auja and Al-Qilt all receive return flows from springs which discharge along their lengths, but these flows are not sufficiently big to reach the Jordan River during the dry season. In the winter months, wadis flow for variable periods in response to heavy rainfalls, from stormwater and increased spring return flows. Some smaller wadis have no continuation on the floor of the Jordan Valley or along the Dead Sea.

Wadi Nar receives untreated wastewater in its upper reaches from East Jerusalem and Beit Sahour. The point at which the wastewater stops flowing in the summer depends on the amount of wastewater discharged, but in the winter it flows with stormwater to the Dead Sea.

Wadi flows are described in more detail in Chapter 3.

Soil Types

Soil types influence runoff and infiltration. Soil types were considered in this study but were considered to be a less important criteria than geology and slope in terms of runoff, since soil covers are thin and each soil type is derived from a parent rock (i.e., a geological factor). All other factors being constant, the more permeable the soil, the greater the infiltration capacity.

The only soil classification that has been done in the West Bank is based on the work by the Hebrew University in 1969. A 1:250,000 scale map exists which provides a broad overview of different soil types in the West Bank. Soil associations were classified based on topographic and geographic setting, and a brief description of the soil types found within the ESC is provided below. It should be pointed out that field truthing is required and that significant local variability may exist.

Terra Rossa — Brown Rendzina

These occur mainly along the topographic ridge from Hebron to the Fari'a Valley. Parent materials are dolomite and limestone and the soil depth is generally shallow (<2m). The soil has a reddish brown color with sub-angular blocky structure (ARIJ 1997).

The dominant land use pattern on these soils is the cultivation of field crops such as wheat and barley, vineyards, and olive and citrus trees.

Brown Rendzinas and Pale Rendzina

These are similar to the Terra Rossa but the soil structure is more crumbly and the texture is more loamy. They are derived from soft chalks and marls and occupy topographic depressions in the central mountains of the Ramallah, Bethlehem and

Hebron areas. They are typically associated with outcrops of the Yatta Formation, and cultivation of vineyards and grazing.

Brown Lithosols and Loessial Arid Brown Soils

These occupy the steep to moderate rocky and eroded slopes toward the Dead Sea and Jordan Valley. Their parent materials are chalk, marl, flint, and limestone rocks of Senonian age. A salt crust called "nari" commonly forms on these soils which make them relatively impermeable for infiltration. Thus, runoff is high on this type of soil.

In terms of land use, grazing is a common activity although winter crops may be grown in wadi bottoms.

Sand Regosols and Alluvial Soils

These occur along the Jordan Valley and along the escarpment of the Dead Sea. Parent materials are alluvial sands and Loessial deposits. They are intensively used for agriculture in the Jericho and Auja areas, and respond well to irrigation. Common crops grown are subtropical fruits and winter vegetables.

Land Use

Land use patterns in the ESC are determined by natural factors such as topography, geology, slope, climate, etc. For this study, land use was considered an important criterion in evaluating potential stormwater harvesting schemes. For example, dams and check dams may flood environmentally sensitive areas or valuable agricultural lands. Figure 2-11 shows the distribution of "environmentally sensitive lands" in the ESC and the West Bank as a whole. Similarly, hydraulic structures may pose a hazard to downgradient populations/users.

For these reason, land use patterns and potential impacts were examined. Urban areas, villages, roads, archeological sites, and supporting infrastructure were identified and located on maps for each catchment. Socio-economic and political factors (e.g., areas A, B, and C) equally influence land use and land development, and were considered important criteria for this study.

Land use patterns were simplified and categorized as follows:

- Urban and built-up land;
- Agricultural or other sensitive lands; and
- Rural land.

The highest quantity of runoff is expected from urban areas, and all other factors remaining constant, the lowest quantities are expected from rural areas.

Using topographic maps and observations from field trips, each of the catchment areas were assigned a dominant land use category. The dominant land use category was selected based on rainfall distributions within the catchment. For example, in Al-Qilt, an

urban classification was chosen since most of the rainfall occurs over built-up areas along the mountain ridge (e.g., Ramallah). This has implications for the runoff estimates which are provided in Chapter 3.

General Characteristics of Catchment Areas

Each of the catchment areas and wadis shown in Figure 2-10 have distinguishing hydrologic characteristics, but in broad terms they can be separated into 4 categories:

Southern Catchments

The Southern catchments consist of Wadi Muradin, Al-Hayyat, and Al-Ghar. These wadis and their sub-catchments originate quite far east in low rainfall areas (average about 200-250 mm/year).

Other than the escarpment around the Bani Naim area, the Southern catchments have gentle slopes and are covered by both permeable and impermeable rocks. The exception is the main branch of Al-Ghar which has a steep slope in its upper reaches and originates near Beit Fajjar, a high rainfall area (average about 350 mm/year) with outcrops of permeable rock.

Central Catchments

The Central catchments consist of Wadi Daraja, Nar, Mukallak, Al-Qilt, and Nuweima. These are characterized by steep slopes, high rainfall (average about 350-400 mm/year), and outcrops of both permeable and impermeable rocks. Furthermore, their origins are located near the towns of Bethlehem, Jerusalem and Ramallah, and therefore receive urban runoff. Poor water quality due to discharges of untreated wastewater is a potential problem.

Northern Catchments

The Northern catchments consist of Wadi Auja and Al-Ahmer. They receive relatively high rainfall amounts (though less than the Central catchments - average about 300-350 mm/year), and are characterized by relatively gentle slopes and a cover of both permeable and impermeable rocks. One of the distinguishing characteristics of this area is that the major catchments consist of numerous sub-catchments which have no continuation in the Jordan Valley, a testimony to low flows.

Fari'a Valley

Finally, the Fari'a catchment has been separated from all other catchments due to numerous distinguishing characteristics:

- Its size is the largest in the ESC.

- Its hydrology is that most of the stormwater (if not all) originates in the upper reaches of the catchment near the hills of Nablus and Beidan which are very steep and are covered by Eocene chalks (impermeable). This catchment receives high rainfall amounts (more than 450 mm/year on average).

- Its land use is almost entirely agricultural.

- Its flow is along relatively gentle topography and has a constant base flow due to the return flows from two large springs groups; Beidan and Fari'a (combined base flow of about 3 MCM/year in Wadi Fari'a).

A characteristic that most catchments have in common is that in the central mountain region, outcrops of Albian and Upper Cenomanian permeable rocks are exposed and form a terraced landscape on rounded, gentle hills. The bedding of these rocks create natural terraces which are extensively cultivated with olive and citrus trees. Thus, nature has provided for an already efficient stormwater retention system in these areas. This is particularly true near Ramallah, Bethlehem, and Hebron-Halhoul. The steepness of the topography increases towards the east, where the terracing is lost on outcrops of Senonian age chalks. While the runoff potential is higher on these slopes, rainfall is also much lower.

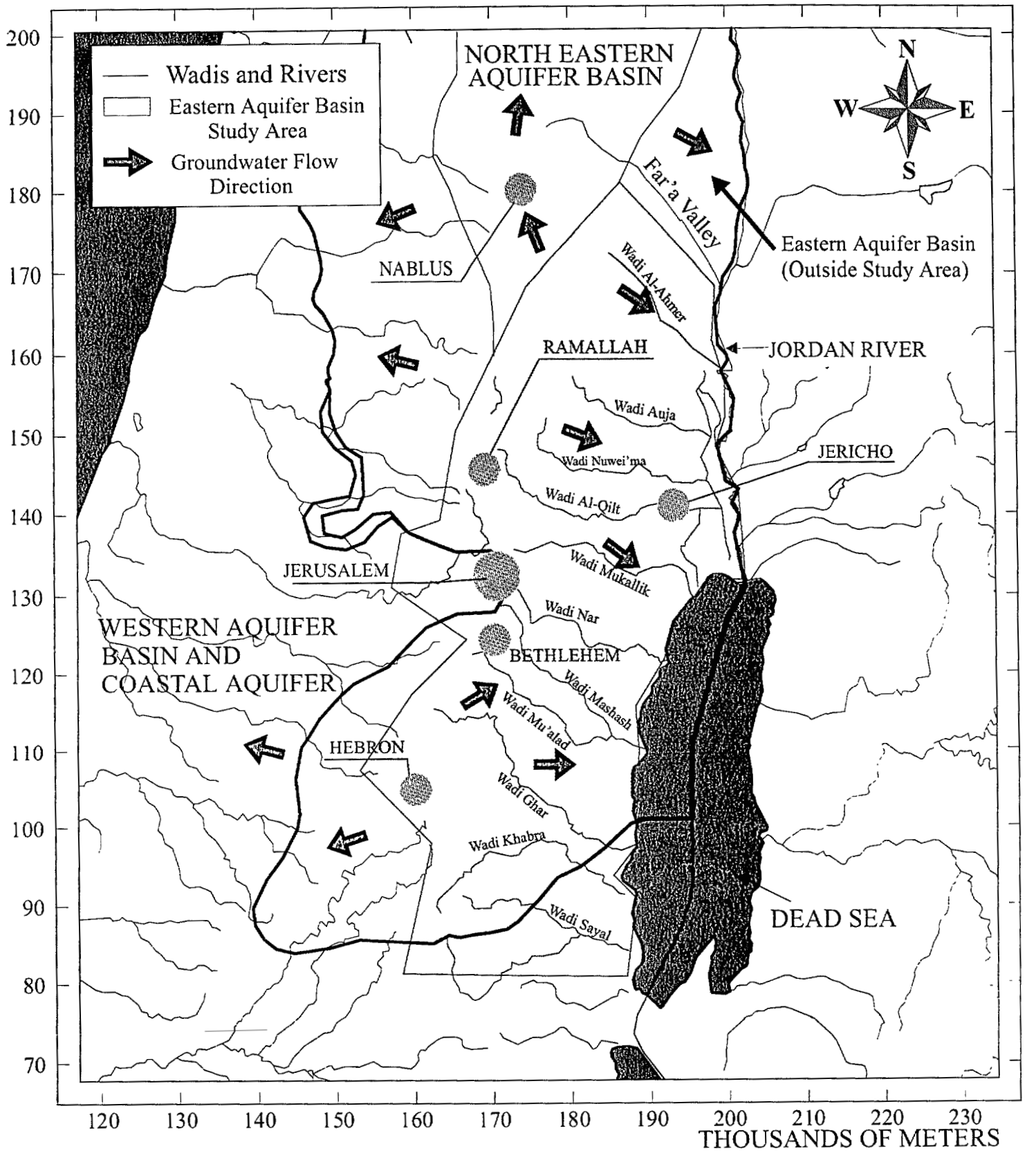

Figure 2-1
Study Area

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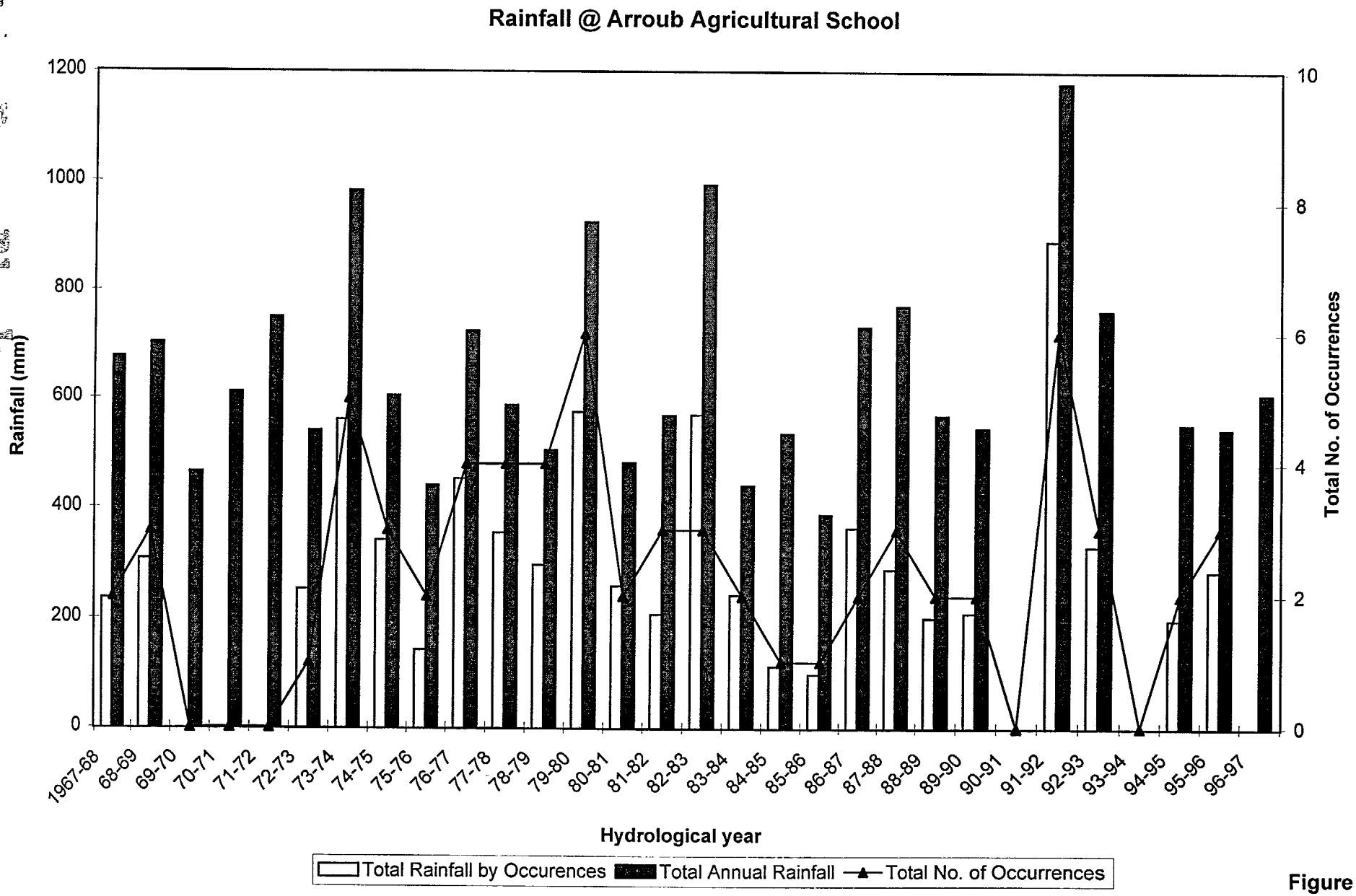

Figure 2-3

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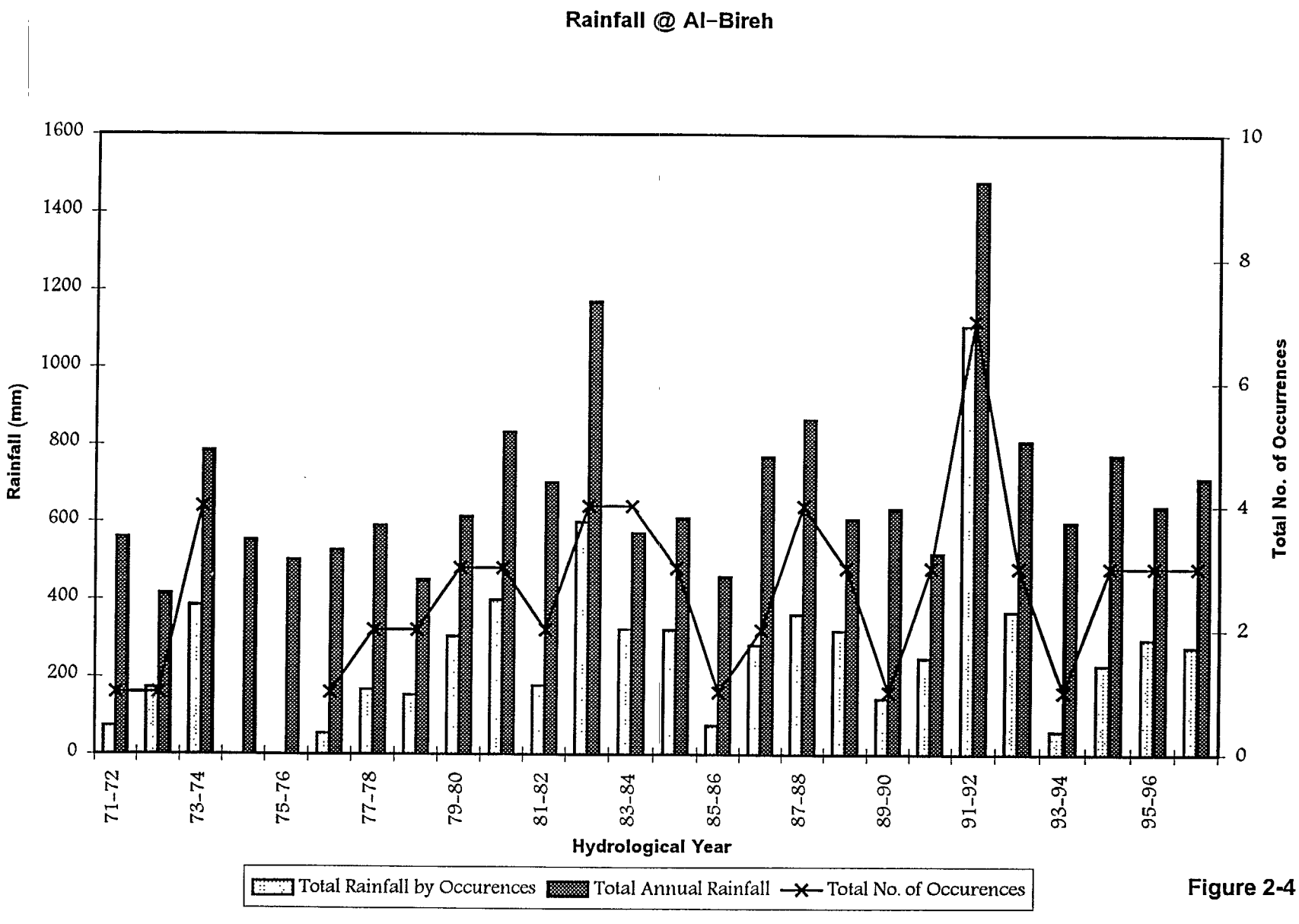

Figure 2-4

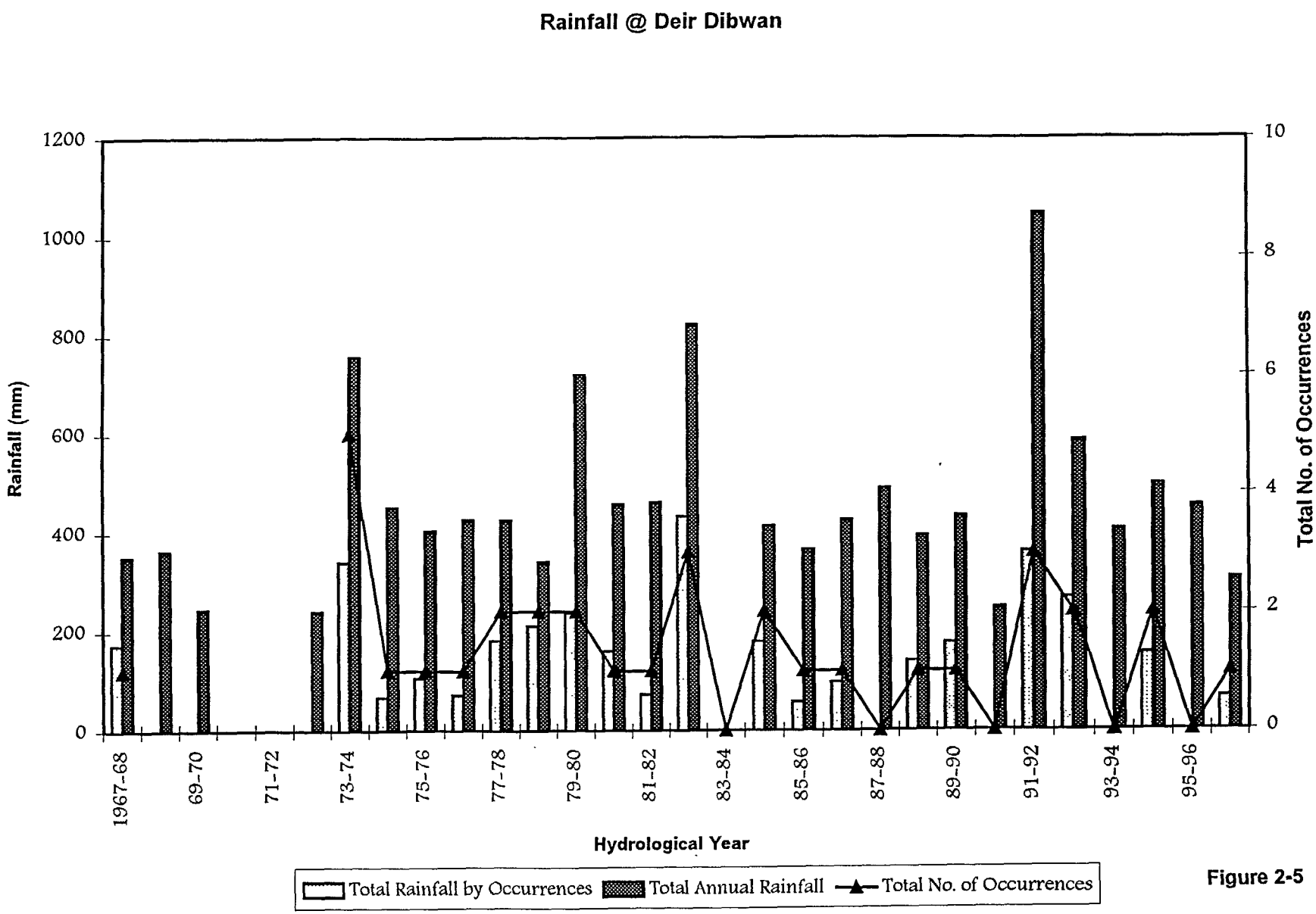
Rainfall @ Deir Dibwan
Rainfall (mm)
1200
1000
800
600
400
200
0
Total No. of Occurrences
10
8
6
4
2
0
1967-68
69-70
71-72
73-74
75-76
77-78
79-80
81-82
83-84
85-86
87-88
89-90
91-92
93-94
95-96
Hydrological Year
Total Rainfall by Occurrences
Total Annual Rainfall
Total No. of Occurrences

Figure 2-5

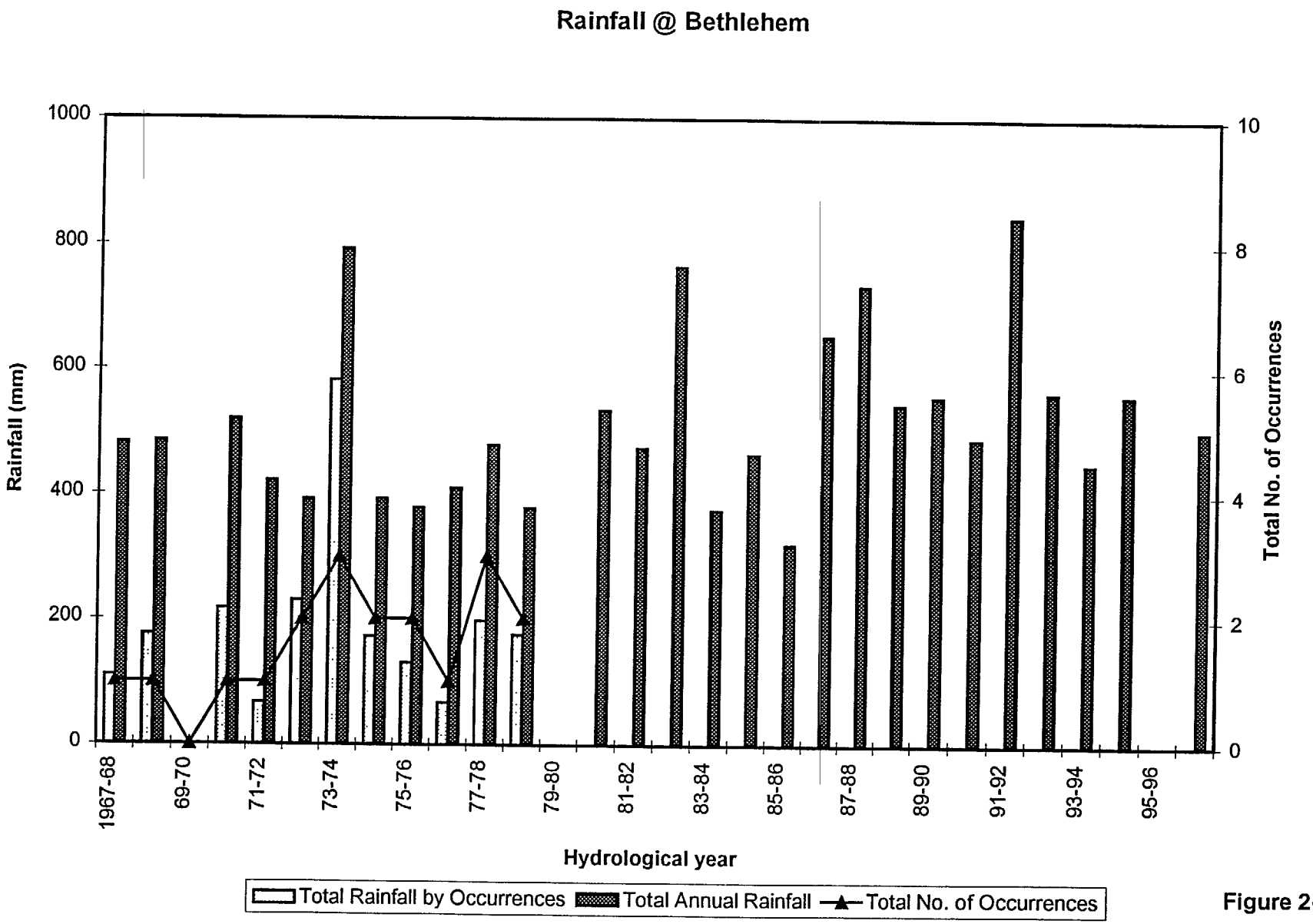
Rainfall @ Bethlehem
Rainfall (mm)
1000
800
600
400
200
0
Total No. of Occurrences
10
8
6
4
2
0
1967-68
69-70
71-72
73-74
75-76
77-78
79-80
81-82
83-84
85-86
87-88
89-90
91-92
93-94
95-96
Hydrological year
Total Rainfall by Occurrences
Total Annual Rainfall
Total No. of Occurrences

Figure 2-6

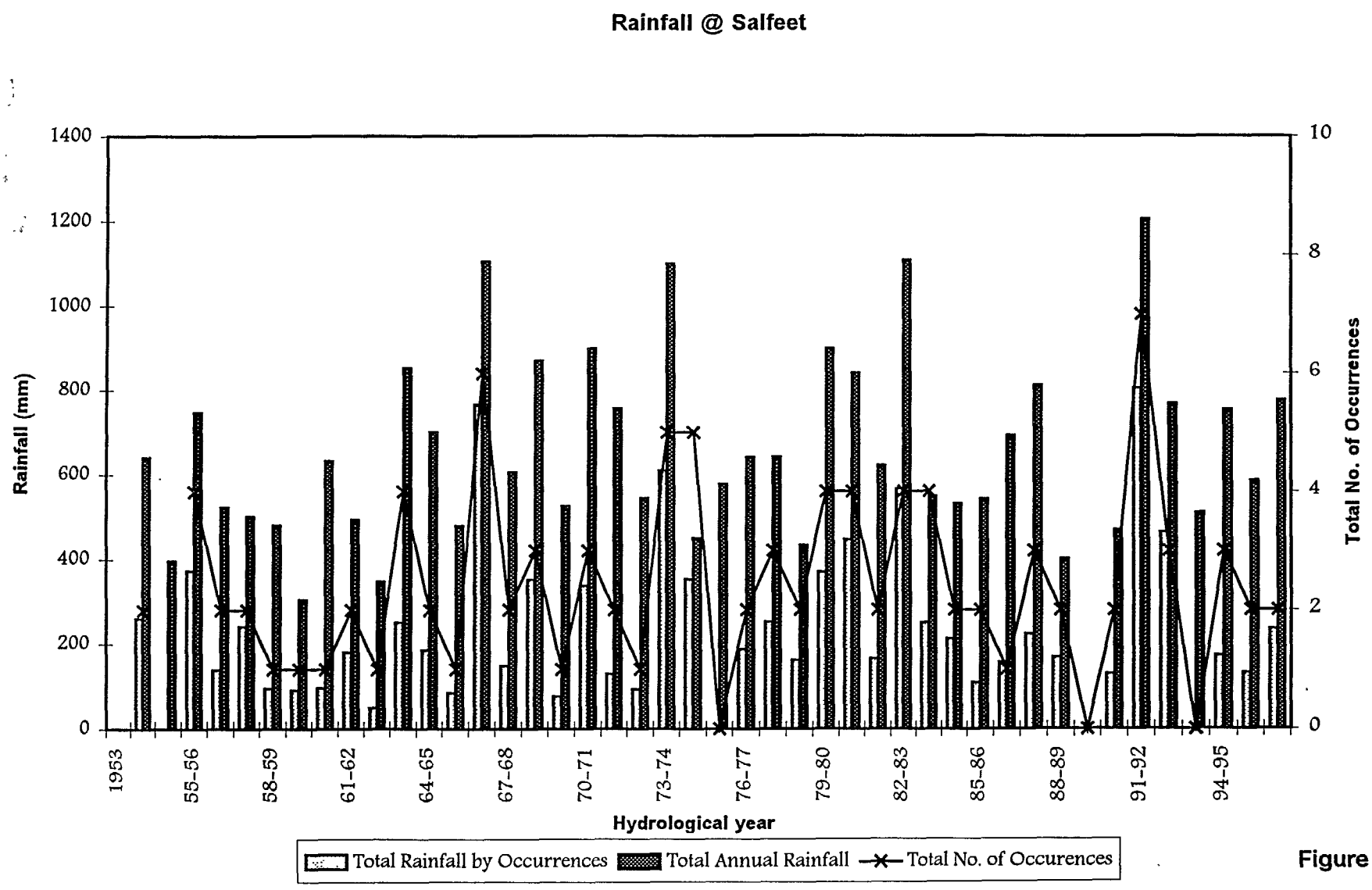
Rainfall @ Salfeet
Rainfall (mm)
1400
1200
1000
800
600
400
200
0
Total No. of Occurrences
10
8
6
4
2
0
1953
55-56
58-59
61-62
64-65
67-68
70-71
73-74
76-77
79-80
82-83
85-86
88-89
91-92
94-95
Hydrological year
Total Rainfall by Occurrences
Total Annual Rainfall
Total No. of Occurences

Figure 2-7

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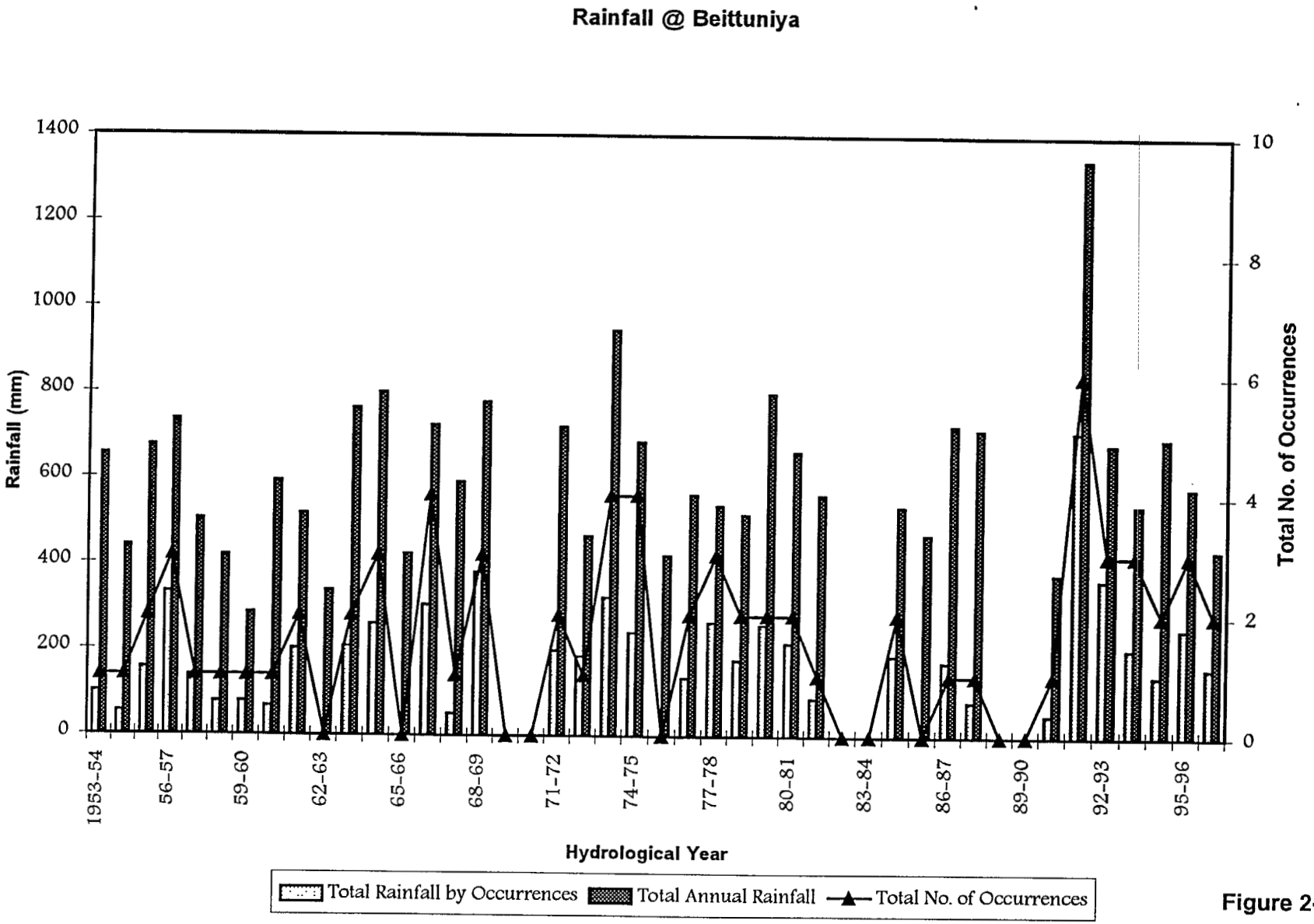

Figure 2-8

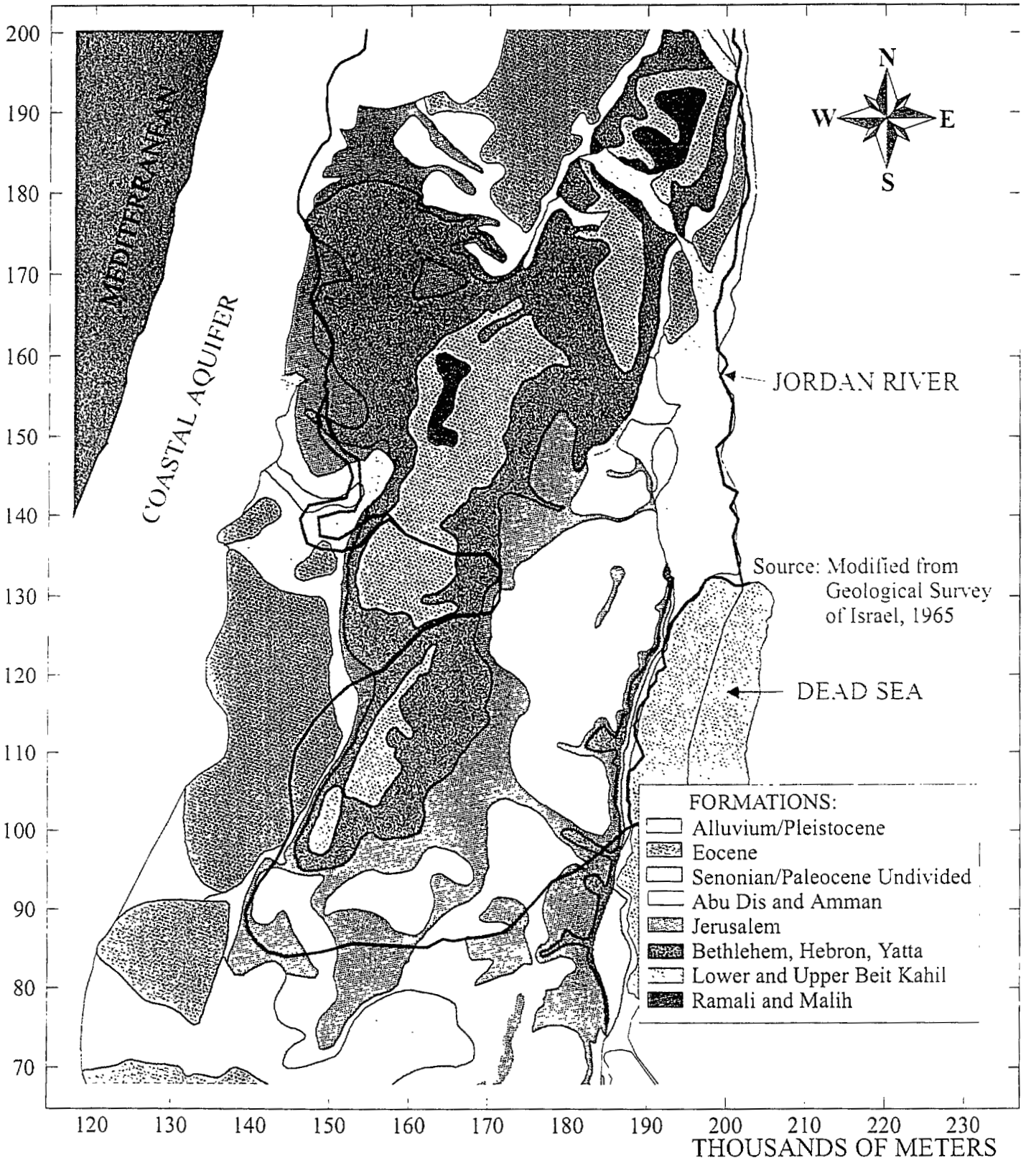

Figure 2-9
Sketch of Geological Outcrops

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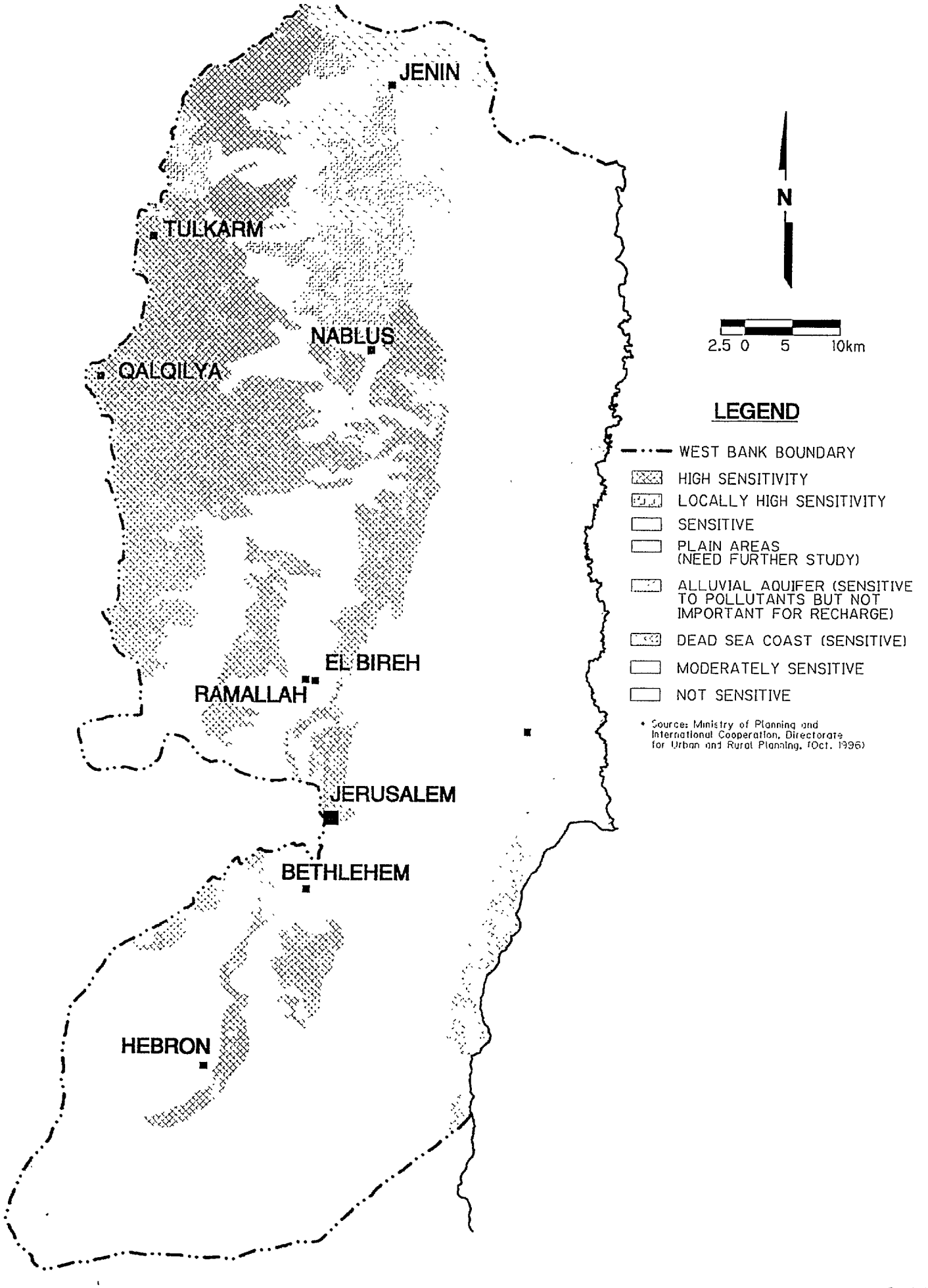

Figure No. 2-11
Enviromentally Sensitive Areas in the West Bank

CHAPTER 3

ASSESSMENT AND SCREENING OF RUNOFF POTENTIAL

Screening Criteria

Prior to developing stormwater harvesting schemes, it is necessary to assess the quantity of stormwater generated on average in the ESC, and specifically in each catchment area. Therefore, an initial assessment of runoff potential in the major catchments is needed. Given the general absence of measured runoff and wadi flow data in the ESC, catchment basin characteristics have been qualitatively evaluated from maps and observations made during field trips. Runoff characteristics for each catchment were calculated based on indices representing physical characteristics of the catchment area and limited measurements of runoff.

Practical limitations of time and the statistical procedure adopted for this study necessitated the selection of a limited set of catchment variables. Variables that were used are based on hydrologic, geologic, meteorologic, environmental and safety factors.

Accordingly, a set of pertinent criteria and sub-criteria was developed to facilitate the estimation of stormwater quantities and the initial screening of wadis. The first criterion, runoff potential, has been divided into 5 sub-criteria, to facilitate the estimation of the total runoff in each catchment area. A summary of these criteria and sub-criteria is presented in Table 3.1.

It should be noted that several factors, which are typically considered when assessing the potential for stormwater harvesting and/or runoff, have been discarded in this screening process. These factors include rainfall intensity, evapotranspiration potential, potential environmental impacts, and financial and economical feasibility.

Rainfall intensity and evapotranspiration potential, which directly impact the magnitude of the runoff, have not been considered in this assessment because of the following reasons:

- Rainfall intensity and evapotranspiration potential appear to be of similar magnitude throughout the various districts ~~in the~~ ESC.
- Lack of daily records or measurements at specific areas of interest.

Thus, rainfall intensity and evapotranspiration potential could not be used to discriminate among the various catchments. However, the overall effects of rainfall intensity and evapotranspiration on the runoff estimates were considered indirectly when quantifying a "runoff coefficient."

Similarly, potential environmental impacts beyond the issues of hazard to population centers and land use were not considered, as most of these impacts were judged to be common among all wadis. A common essential impact is the potential cutoff of stormwater contribution to the Dead Sea, which is the ultimate discharge zone for wadi

runoff in the ESC. This potential impact needs to be considered when assessing the water balance for further water resources development.

Table 3.1: Summary of Screening Criteria and Rating

CRITERIA	RATING[1]			REMARKS
	1	2	3	
C1. Runoff potential	C1 is a product of sub-criteria C1.1 through C1.5			
C1.2. Slope	Mild - flat	Moderate	Steep	Along wadi course
C1.3. Surface Cover	Barren land	Farmland; forests; vegetative cover; suburban areas	Urban/ impervious cover	Impervious or vegetative covers,
C1.4. Geology and soil (runoff potential)	Senonian & Eocene	Yatta&Bethlehem formations or combinations of formations in 1&3	Turonian & Cenomenian	Outcropping formations
C1.5. Catchment area	>50 km^2	50-100 km^2	Æ100 km^2	
C2. Political feasibility	1 (C)	2 (B)	3 (A)	Area designation based on Oslo II Agreement
C3. Distance (d)/ head (h) to reuse/ recharge location	h> 50 m & d>5km	h=50-100 m & d=5-8km	h<50 m & d<2km	Direct reuse for urban or irrigation supplies; recharge at well fields
C4. Land use	Urban/ tourist sites/ major roads	Agricultural	Rural/grazing	Land use at catchment or downstream locations
C5. Hazard Potential (to populated areas and human activities)	Urban/ archaeological sites	Suburban/villages	Rural/Bedouin sites	Based on land use and environmental sensitivity maps
C6. Water Quality	Urban sewage discharges to wadi	Urban/suburban sewage discharges are mixed (diluted) with flows from springs and storm water from sub-catchment areas	No sewage disposal along wadi course	

(1) A higher rating indicates a higher potential for stormwater harvesting and/or runoff. Rating 2 can also indicate combinations of items in ratings 1 and 3.

Financial and economical feasibility was not considered essential at this stage of initial screening of runoff potential. However, these issues were indirectly addressed in criterion C3 and directly considered for those wadis retained for further evaluation.

Criteria Rating and Weights

Since not all screening criteria can be evaluated quantitatively, a protocol, based on a direct weighing approach, was devised to rate those criteria. Each criterion and sub-criterion was assigned a rating from 1 to 3; a higher rating indicates a higher potential for stormwater harvesting and/or runoff at a given wadi. A description of these ratings is presented in Table 3.1.

All criteria and sub-criteria, except for C1, were assigned equal weights. Criterion C1 was assigned a higher weight, to clearly distinguish those wadis with substantial runoff potential based on hydrology and physical characteristics.

Screening of Wadis

The screening procedure involved the specification of a rating of each catchment area/wadi with respect to its consistency or compatibility with each criterion. It should be noted that rating each catchment area against the various criteria was based on gross averaging of the characteristics of contributing sub-catchment areas. For purposes of this study, more than one location for stormwater capture (sub-catchments) was considered for some wadis, to facilitate a wider range of alternatives with varying characteristics (i.e., economy, technical complexity, hydrologic characteristics, etc.). These locations are identified in Figure 2-10.

This qualitative rating was based on analysis of available maps (topographic, land use, geologic and aquifer exposures, rainfall distribution, environmental sensitivity, *etc.*) and available hydrologic data. An overall score was then determined for each wadi by calculating the sum of individual scores (ratings) across all criteria. The score for criterion C1 for each wadi was calculated as the product of sub-criteria (C1.1 through C1.5) ratings (multiplication is more representative of the physical processes than summation, as runoff diminishes when the magnitude or contribution of any of these sub-criteria approaches zero). Wadis with higher scores are ranked higher, and considered more compatible with the screening criteria than those with lower scores.

The results of this rating are presented in Table 3.2. Wadis that are obviously favored for future stormwater harvesting are those with the highest runoff potential. The wadis which ranked the highest are Fari'a, Qilt, and Al-Ghar.

Several wadis and sub-wadis were discarded from this screening due to low annual rainfall (<200 mm, which is indicated in the literature as a threshold rainfall limit for runoff) and/or small catchment areas. Most of these wadis originate close to the eastern foothills or the Dead Sea and are located within the district of Hebron (e.g., Qumran, Muradin, and Hassasa).

The results of this screening were subsequently used to estimate the runoff potential for the various wadis.

Rainfall-Runoff Relations

Rainfall Intensity

A major characteristic of rainfall, which bears directly on the occurrence and magnitude of runoff is rainfall intensity. As discussed in Chapter 2, runoff is likely to occur in the ESC when the total annual rainfall exceeds 200 mm, and daily rainfall exceeds 50 mm in one day or 65-70 mm in two days.

These studies also indicate that annual runoff within the West Bank constitutes 0 to 20 percent of the total annual rainfall. Moreover, it was reported that no runoff typically occurs prior to December, but is generally limited to the period between January and March. Rainfall, which occurs prior to December is likely to readily evaporate or be

absorbed by surficial soils. Runoff may subsequently occur after consecutive rainfall events, once the field capacity moisture content is achieved.

Table 3.2: Rank Order of Runoff Potential

WADI	CRITERIA AND SCORE												Rank
	C1.1	C1.2	C1.3	C1.4	C1.5	C1[1]	C2	C3	C4	C5	C6	Total[2]	
Abu El-hayyat	2	2	1	2	1	8	1	2	3	3	2	19	12
Al-Ghar (I)	3	2	3	1	3	54	1	2	3	1	2	63	4
Al-Ghar (II)	2	2	1	1	1	4	1	1	3	2	1	12	15
Daraja (I)	3	3	3	1	1	27	1	1	1	1	1	32	9
Daraja (II)	1	3	1	2	3	18	1	1	1	2	2	25	11
Daraja (III)	1	3	1	3	1	9	1	1	1	2	3	17	14
Al-Nar (I)	3	3	2	3	1	54	1	2	1	1	1	60	7
Al-Nar (II)	1	2	3	3	3	54	1	1	2	2	1	61	6
Mukallak	1	2	3	3	3	54	1	3	3	1	1	63	5
Qilt (I)	3	3	3	1	3	81	3	3	2	2	1	92	2
Qilt (II)	3	3	3	1	3	81	1	1	1	1	1	86	3
Nuweima	2	2	2	1	2	16	1	3	3	1	1	25	10
Auja	1	2	3	1	3	18	3	3	3	3	2	32	8
Al-Ahmar	1	3	1	1	2	6	1	3	3	3	2	18	12
Fari'a	3	2	3	2	3	108	1	3	3	2	1	118	1

[1] C1.1 *Cl.2 *C1.3 * Cl.4 * Cl.5
[2] Total= C1+C2+C3+C4+C5+C6

To assess the impact of rainfall intensity on the runoff potential for the various wadis, daily rainfall measurements described in Chapter 2, were analyzed based on the runoff threshold limits.

The analysis of the data (Figures 2-3 though 2-7) indicates that rainfall corresponding to occurrences meeting these two limits on average constitutes 30 to 40 percent of the total annual rainfall at these locations (Arrub, Deir Dibwan, Beth Lehem, Al-Bireh). These occurrences appear to be sporadic with a total annual number that ranged between 1 and 7, and an average of 3. The number of days in a year corresponding to these occurrences was estimated to vary between 1 and 20 days, with many more such occurrences and days in wet years. Thus, the ESC receives significant quantities of rainfall in a short term span. This is reflected in the sporadic observations of wadi flows across the ESC (Mustafa Nuseibeh, personal communication).

Runoff Estimates

As indicated above, runoff is likely to develop only during the "threshold occurrences." As such, it can only constitute a percentage of the total rainfall during these occurrences, and not the total annual rainfall. Wadi flows in the ESC, as indicated by the observed durations of these occurrences, may occur a few times a year with short durations that may last for a few days only. Assuming conservatively that rainfall is distributed equally among infiltration, evapotranspiration, and runoff during these occurrences, the total annual runoff can be estimated to constitute approximately 6 to 16 percent of the total

annual rainfall. Hence, the reported range for the average total annual runoff of 0 to 20 percent of the total annual rainfall was confirmed by this study. Higher values are expected for wet years and central and northern catchment areas, and lower values for dry years and southern and eastern catchments in the ESC.

Accordingly, runoff was estimated for the various wadis considered in this study. Three ranges of runoff coefficient (percentage of rainfall, R_c) were selected to account for various ranges of the total annual rainfall and runoff potential (criterion C1). These ranges were 0-5 percent, 5-7.5 percent, and 5-10 percent of the total annual rainfall. A summary of runoff estimates for the various catchment areas is presented in Table 3.3.

Table 3.3: Average Runoff Estimates

Wadi	Rank	Average Rainfall (mm)	Catchment Area (Km^2)	Total [1] Rainfall (I) (MCM)	Runoff [2] Potential Score (C1)	Runoff [3] Ratio (R_c) (%)	Average Runoff [4] (MCM)
Fari'a	1	500	142	71	108	5-15	3.5-11
Qilt (I)	2	400	146	58	81	5-10	3-6
Qilt (II)	3	450	110	50	81	5-10	2.5-5
Al-Ghar (I)	4	400	117	47	54	5-7.5	2-3.5
Mukallak	5	300	100	30	54	5-7.5	1.5-2
Al-Nar (II)	6	350	113	40	54	5-7.5	2-3
Al-Nar (I)	7	450	21	10	54	5-7.5	0.5-1
Auja	8	250	144	36	18	0-5	æ1.8
Daraja (I)	9	450	25	11	27	0-5	æ0.6
Nuweima	10	350	60	21	16	0-5	æ1
Daraja (II)	11	300	100	3	18	0-5	æ0.2
Abu-El hayyat	12	350	15	5	8	0-5	æ0.3
Al-Ahmar	13	250	75	19	6	0-5	æ1
Daraja (III)	14	300	24	7	9	0-5	æ0.4
Al-Ghar (II)	15	350	24	8	4	0-5	0.4

(1) Total Rainfall = Average Annual Rainfall x Catchment Area
(2) From Table 3.2
(3) R_c =0-5 for C1æ 27; R_c = 5-7.5 for C1= 27-80; R_c = 5-10 for C1>80; ranges are based on reported values
(4) R= R_c x I; Total runoff is estimated as percentage of total rainfall

Table 3.3 indicates that runoff for wadis with the three highest rankings (i.e., Fari'a and Qilt) was estimated to range between 3 and 11 MCM/year. Runoff for other wadis, except for Wadi Al-Ghar with an estimated annual runoff of 2 to 3.5 MCM, was estimated to generally be on the order of less than 1 MCM/year.

The runoff estimates for Wadi Fari'a and Qilt were compared to available runoff measurements at formerly installed stations at these wadis by WBWD as a check against actual measurements of wadi flow/runoff. Measuring devices (Parshall Flumes) were installed pursuant to recommendations presented in the Rofe and Rafety studies (1963 & 1965). The measurement data are presented in Appendix B, and a summary is presented in Table 3.4.

The monitoring period of January 19 through 22, 1974 at the Wadi Qilt Station was considered in this study to correlate the runoff to the total rainfall during the monitoring

period, because it provides several measurements during the storm event. The hydrological year 1973-1974, based on assessment of the 30-year rainfall records is a wet year. Daily rainfall and runoff measurements for the monitoring period are summarized in Table 3.5.

Table 3.4: Wadi Discharge Measurements

Station	Date	Time	Flow [1] [2]
Wadi Qilt	1/19/74	10:40	3.08
		12:30	3.987
		13:20	3.856
	1/21/74	10:00	15.388
		11:20	21.276
		12:55	30.276
		13:40	33.77
	1/22/74	9:15	9.394
	3/3/74	11:05	3.8104
	3/4/80	12:00	2.362
	1/16/92	14:10	1.9272
	2/18/92	14:45	2.5122
Wadi Fari'a	1/21/74	10:30	27.91
		11:30	28.052
		13:00	22.05
		14:00	21.4
	1/31/74	12:50	4.247
	2/21/83	13:25	10.3424
	2/20/83	12:40	7.987

[1] Measurements were conducted by WBWD and obtained from PWA
[2] Flow estimates were based on surface velocity measurements

Table 3.5: Rainfall-Runoff Relationship Wadi Qilt Station (January 1974)

Day-Time	Time Interval (second)	Measured Flow Rate [1] (m^3/sec)	Adjusted Flow Rate (m^3/sec) [2]	Incremental Runoff [3] (10^3 m^3)	Date	Daily Rainfall (mm) [4]	Total Rainfall [5] (10^3 m^3)
19/1/74		3.08	0.08				
19/1/74 10:40	6,600	3.987	0.987	3.521	19/1/74	2.2	275
19/1/74 13:20	3,000	3.856	0.856	2.765	20/1/74	32.2	4,025
21/1/74 10:00	160,800	15.388	12.388	1,065	21/1/74	45.2	5,650
21/1/74 11:20	4,800	21.276	18.276	73.594	22/1/74	13	1,625
21/1/74 12:55	5,700	30.276	27.276	129.823			
21/1/74 13:40	2,700	33.77	30.77	78.362			
22/1/74 9:15	70,500	9.394	6.394	1,310			
			Total	**2,663**		**92.6**	**11,575**
			Runoff-Rainfall Ratio (%) [6]	**23**			

[1] Flows were measured by WBWD and obtained from PWA database
[2] Flows were adjusted, by subtracting 3 m^3/sec, to account for runoff from previous storm, and spring base flow
[3] Average adjusted runoff over elapsing time interval
[4] Rainfall data were obtained from PWA database: only 13 mm (out of a total of 36 mm) was considered for 1/22/74
[5] Total rainfall = daily rainfall x catchment area (estimated at 125 km^2 upstream of measuring station)
[6] Ratio Total runoff / total rainfall during monitoring period

Daily rainfall data for this assessment were for Al-Bireh rainfall measuring station (located at the offices of the WBWD).

A review of Table 3.5 indicates that the total rainfall (over the catchment area upstream of the measuring station) during this period was measured to be approximately 12 MCM. The cumulative runoff at the Qilt station during the same period was measured to be approximately 2.7 MCM. This indicates that nearly 23 percent of the total rainfall during the monitoring period occurred as runoff. The total rainfall during these occurrences was estimated, based on rainfall measurements for Al-Bireh station during the year 1973-74, to be approximately 49 percent of the total annual rainfall, which was measured at 784 mm (98 MCM). As such, the total annual runoff for the year 1973-74, which is a wet year, would be approximately 11 percent of the total annual rainfall or 11 MCM. This runoff-rainfall ratio (relationship) compares reasonably well with, and clearly demonstrates the appropriateness of the overall range assigned to Wadi Qilt for estimating the average runoff.

It should be noted, however, that the ratio and value obtained is likely to be an overestimate of the average total annual runoff in Wadi Qilt for the following reasons:

- These measurements represent a wet year, thus represents a maximum runoff.
- According to discussions with WBWD personnel, these measurements may somewhat be in error (overestimated heads) due to clogging and presence of debris and boulders (transported with the flood due to high and scouring velocities) at the Parshall Flume.
- These measurements are based on surface velocity.

Therefore, these measurements are considered herein as an order of magnitude and for comparison purposes only.

Summary of Runoff Potential

The above-mentioned screening and assessment indicates that the potential runoff/wadi flows within the ESC constitute, on average approximately 0 to 10 percent of the total annual rainfall over the ESC. These flows, when they occur, were estimated to range between 0.5 and 11 MCM/year. The estimated average runoff potentials, which were based on qualitative screening and preliminary assessment of rainfall characteristics, are judged to be appropriate based on comparisons with sparsely available wadi flow measurements.

Based on runoff potential, the analysis further indicates that the wadis which may be considered feasible candidates for future stormwater harvesting, based on runoff potential, are Wadi Fari'a and Qilt. The average runoff at the capture locations considered for each of these wadis, was estimated to range approximately between 3 and 11 MCM/year. This runoff occurs sporadically within a short duration that may not last more than a few days a year.

Other wadis were identified with a moderate potential for stormwater harvesting, especially Wadi Al-Ghar and Wadi Al-Nar. Wadi Al-Nar, however, was discarded from further assessment due to concerns about water quality, due to urban raw wastewater discharges.

CHAPTER 4

IDENTIFICATION AND SCREENING OF ALTERNATIVES FOR STORMWATER HARVESTING SCHEMES

The intent of stormwater harvesting schemes is to augment existing water resources. It was assumed that any potential scheme would have to be implemented on a local (village) scale in order to be "effective," both for recharge and direct use. Because of time constraints in which the evaluation of alternatives was performed on a qualitative level. Criteria which were considered are:

- Technical difficulty;
- Cost (order of magnitude);
- Benefit to potential users;
- Water quality;
- Impacts on land use;
- Impact on aquifer recharge;
- O&M considerations;
- Institutional considerations; and
- Environmental impacts.

Six potential stormwater harvesting alternatives have been evaluated in consideration of the analysis in Chapter 3. These are check dams, and detention dams, surface roughing and terracing, vegetative controls, infiltration systems, and rock fracturing.

Check Dams

Check dams are small temporary hydraulic structures constructed across a stream or a wadi with the primary purpose of reducing the velocity of concentrated stormwater flows and partially retain water behind it. In the context of this study, check dams could have two beneficial functions:

- Increase aquifer recharge locally by preventing downstream movement and allowing time for infiltration; and

- Direct use of retained water

In the ESC, check dams may be installed along all wadis, but to be cost effective, they have to serve nearby users or wellfields via recharge. Since there is little stormwater generated locally in the upper reaches, check dams are considered to be relatively ineffective for resource augmentation.

Construction of check dams is low-cost compared to other hydraulic structures and can be constructed with cheap, locally available materials, such as stone. If constructed, check dams would be placed at a sufficient distance and elevation from each other to allow small pools to form along a wadi. They are best suited for the upper reaches of

wadis on gentle slopes. They could not be installed in wadis which have very high and fast flows due to the erosive power of flash floods.

Because of their simplicity, they can easily be reconstructed or repaired. Provided there is no damage to the check dams, the only maintenance required is to inspect for sediment buildup and signs of erosion around the check dam after storm/flood events. A preliminary review of Chapters 2 and 3 indicates that the best suited catchment areas for this type of structure are the upper reaches of Wadi Al-Ahmar and Wadi Al-Ghar. Neither case would significantly contribute to aquifer recharge in the upper reaches, nor would they benefit existing wellfields, since they are located downgradient of existing wells.

However, Al-Ghar, check dams could benefit bedouin populations east and southeast of Beit Fajjar by providing water for livestock. Such check dams would have to be constructed with small storage reservoirs which would consist of small excavated detention ponds along the wadi course.

Dams and Detention Basins

Dams and detention basins offer the opportunity to store significant quantities of stormwater in areas that are suitable for capture. Unless they are underlain by impermeable materials, both will leak and contribute to aquifer recharge.

Such hydraulic structures are only effective if they can collect large quantities of water. As defined in Chapter 3, there are few opportunities in the ESC to collect more than 2-3 MCM of stormwater under average conditions. The only places identified where dams or detention basins may be cost effective are Wadi Fari'a and Wadi Al-Qilt.

Wadi Al-Ghar, Daraja and Nar also have potential, but the structures would have to be located far from any users or wellfields, almost at the Dead Sea (see Figure 2-10). Thus, their feasibility is questionable. Furthermore, Wadi Nar receives untreated sewage from East Jerusalem.

Dams and detention basins in most catchments would not benefit the regional aquifer systems in the EAB. They would have to be located downstream of existing wellfields that are accessible to Palestinians in order to capture significant quantities of stormwater. Therefore, it is concluded that their purpose should be for direct use or irrigation purposes in the lower reaches of suitable wadis.

Because of their size, dams and detention basins are desirable in areas where stormwater resources can be augmented with spring baseflows. The only wadis which classify for this category are Wadi Fari'a, Wadi Al-Qilt, and Wadi Auja. The largest baseflow carried by these wadis is Wadi Fari'a. From a cost/benefit point of view, Wadi Fari'a outranks the other two.

Surface Roughing and Terracing

Surface roughing is a technique commonly applied for erosion control but can also be used to reduce runoff velocity and increase infiltration. While usually implemented as part

of seeding and planting projects on steep slopes, surface roughing could also be used as part of a stormwater harvesting scheme.

Surface roughing can be performed in several ways: stair-step terracing and grading, grooving, furrowing, and tracking. It is a relatively low-cost alternative for construction but may require occasional maintenance and shoring.

While this technique is a simple and short-term control measure, it is of limited effectiveness on its own, and large areas would have to be "treated" to have any effect on aquifer recharge. Besides, the central mountain region in the ESC, where most of the rainfall occurs, is naturally rough with terraces, small-scale depressions, and tracks. The natural terracing is a function of the bedding (near-horizontal layering) of limestone outcrops.

It is not believed that terracing or terrain roughing can significantly improve stormwater harvesting in high rainfall areas. Terracing could be performed on the steep, high-runoff slopes of the Senonian chalks east of Bethlehem and Jerusalem. While such actions might reduce runoff, there is a risk of also loosing water to evaporation, since the chalks are relatively impermeable. Overall, this alternative is not believed to be a feasible means of capturing and recharging stormwater.

Vegetation Controls

Vegetation controls involve altering vegetative covers to reduce needs and losses of water, while mitigating erosion in the area in question. In the ESC, the fauna outside agricultural lands is dominated by two native plants:

- *natish* (scientific Latin name not found)
- *zuhaif* (scientific Latin name not found)

Both of these plants are ideally suited for this region. Neither takes up much water through its root systems and survive by absorbing moisture in the air. Both plants grow on natural terraces and contribute to erosion control. They act as good filters by retaining sediment while allowing water to pass through, laterally and vertically. Thus, there is no incentive to change the natural vegetative pattern. Besides, both plants are regarded as weeds in the sense that they grow back in place very quickly after being removed. Vegetative controls are therefore regarded as an infeasible alternative for capture or retention of stormwater, or increasing aquifer recharge.

Infiltration Systems

Infiltration systems include basins, vaults, trenches, dry wells, porous pavement, and concrete grids. Infiltration (recharge) systems require suitable site soils and geological conditions, favorable hydrogeological conditions, and land availability.

Measures such as vaults and porous pavement are not included in this study since they are applied for urban runoff.

For direct aquifer recharge, infiltration systems should be located upgradient of existing wells or wellfields in order to be reused, and should be located away from urban areas to minimize the risk of contaminating the deeper aquifers.

In the upper reaches of catchments in the ESC, the infiltration capacities of native soils remain largely untested. In the central mountain region, soils are thin and are probably not important in the overall recharge context. The types of outcrop, on the other hand, are important for recharge. Given the nature of rocks in the ESC (limestones), recharge from one location to another is a function of outcrop area, degree of jointing and fracturing (which allows water to infiltrate), slope, and rainfall.

During this study, no suitable locations were found in the upper reaches or along wadis that would allow for feasible capture and recharge of significant quantities of stormwater. In areas of high rainfall and runoff potential, most wadis are very steep. Infiltration basins and trenches cannot be constructed on steep slopes. Other factors which limit the ability to capture and recharge stormwater in the upper reaches are:

- Small subcatchments (therefore runoff quantities are small);
- Proximity to urban areas (which increases the risk of pollution); and
- Geology is generally favorable for infiltration (thus, less runoff).

Furthermore, in the Hebron-Bethlehem area, most stormwater collects in locations that are downgradient of existing wellfields and recharge would therefore not directly benefit the aquifer system.

If collected in downgradient locations, stormwater would have to be pumped against high heads to locations upgradient of existing wellfields for recharge. This reduces the feasibility of such schemes, both in terms of cost/benefit and engineering constraints.

In contrast, infiltration systems may be very effective in the lower reaches of catchments draining to the Jordan and Fari'a Valleys. Areas that could benefit from recharge of stormwater are:

- Jericho;
- Auja; and
- Fari'a Valley.

In each case, recharge of stormwater could be used to augment local water resources for irrigation purposes. The stormwater would have to be diverted from respective wadis and routed to infiltration galleries/basins. The alluvial aquifers of the Jordan and Fari'a Valleys in effect become temporary storage systems for excess water in the winter months. In summer, the water would be extracted and piped to farmers. This would alleviate the growing problem of overexploitation of the alluvial aquifer by reducing the current levels of agricultural pumping. Salinity, caused by upconing of brackish water from deeper formations, is a growing problem for farmers in the area. Hydrogeological conditions in the alluvial aquifer near Jericho is favorable for recharge.
In Jericho, a further possibility for recharge is the excess spring water during the winter season which is currently left flowing to the Jordan River. A stormwater infiltration scheme in Jericho could be combined with recharge of spring water in the same area.

This study concludes that Wadi Al-Qilt, Wadi Auja, and Wadi Fari'a are the only locations where infiltration basins may be feasible. All other wadis have estimated discharges which are too low to be cost beneficial. It may be possible to combine the flows of two or more wadis, but this will increase engineering costs. For example, Wadi Auja and Wadi Nuweima combined transport about 2-3 MCM/year of stormwater. Diversion canals could be constructed to merge the flows. At this time, this potential alternative is not carried further due to the availability of more stormwater from Wadi Al-Qilt and Wadi Fari'a.

Limitations of infiltration (recharge) basins are:

- High maintenance/inspection costs (due to clogging);
- Potential need for pretreatment (risk of ground water contamination); and
- Higher land costs.

Even so, opportunities for significant stormwater harvesting are limited in the ESC, and infiltration systems will be carried as a feasible harvesting scheme in this study.

Rock Fracturing

Rock fracturing involves the mechanical opening of joints, bedding planes, and natural fractures so that rainwater can more easily infiltrate to the aquifer system. The only way to achieve this on a scale which would have any impact on natural recharge is through the use of explosives. An extensive blasting program would have to be implemented in order to cover any significant areas. Even then, rock fracturing is a short term solution. With time, fine soil particles will likely be washed into the "blasted" area unless extensive sediment control systems are emplaced. This is not considered a feasible alternative due to the uncertainty of results, short-term benefits, considerable costs and political sensitivities in the region.

Summary

From the preliminary screening of alternatives and analysis of runoff potential in Chapter 3, it is concluded that Wadi Qilt and Wadi Fari'a offer the highest potential for capture and reuse of stormwater. Both are located in areas which optimize the use of stormwater. While there is uncertainty regarding quantities of stormwater generated each year, this study has produced reasonable estimates of average runoff from available data and information. Two schemes have been selected for development into conceptual designs:

- Recharge and storage via spreading basins in the alluvial aquifer southeast of Jericho; and

- A detention dam at Wadi Fari'a.

CHAPTER 5

CONCEPTUAL DESIGNS OF FEASIBLE STORMWATER HARVESTING SCHEMES

Al-Qilt Conceptual Stormwater Harvesting Scheme

Description

The stormwater harvesting scheme for Wadi Al-Qilt entails diverting stormwater to a series of spreading basins to the southeast of the town of Jericho. In the summer months, recharged water will be extracted from the aquifer and pumped to farmers in the agricultural areas surrounding Jericho. Figure 5-1 (figures are found at the end of this chapter) conceptualizes the layout of the diversion and recharge scheme. The basic features of the proposed scheme is summarized below:

- Stormwater from Wadi Qilt would be diverted near the entrance to the Jordan Valley and led through two separate channels to the recharge area identified in Figure 5-1. The existing channel would continue to be used, but in order to slow the flow in the wadi, a second diversion channel would potentially be constructed to the south of the main channel.

- Check dams (consisting of large boulders and/or gabbions) will be placed in the two channels upstream of the recharge facilities to further slow down the velocity of the stormwater.

- The second, southerly diversion channel will follow the course of a side wadi that enters Al-Qilt at about the location intended for recharge. In this way, excavation costs can be minimized. In other parts, a new channel would have to be excavated, complete with culverts at two identified locations where it crosses roads.

- The diverted water would be directed to a series of spreading basins located in parallel. The intent of some of the basins will be to settle sediments suspended in the stormwater.

- Extraction wells would be installed hydraulically downgradient from the spreading basins to pump waters to the agricultural areas for irrigation purposes. The pipeline to the user areas would have to cross Wadi Al-Qilt with special engineering considerations.

- A series of monitoring wells (<100 m deep) would also be installed surrounding the recharge facilities to monitor water levels and quality in the alluvial aquifer.

Site Selection

The selected location is approximately 2 km southeast of the center of Jericho, on the south side of Wadi Al-Qilt. A photograph of the proposed land is provided in Appendix D.

The location shown on Figure 5-1 was selected based on several criteria including proximity to Wadi Al-Qilt, local land use, and distance to users. Specifically, the site was selected because:

- The scheme optimizes the volume of captured water - and the scheme could be combined with spring water routing during winter months when excess water from Ein Sultan is discharged unused.
- The land is available and easily accessible - in fact, the land currently stands idle. The recharge basins would cover a total area of about 1 km^2.
- The scheme would not flood any of the surrounding farmland.
- The site is less than 3 km from the main agricultural area in Jericho.
- Topography is such that water from Wadi Al-Qilt would flow by gravity to the recharge basins. Thus, pumping of stormwater from the wadi is not needed.
- The site is downstream of population centers
- Hydrogeological conditions are favorable with relatively permeable soils and a depth to ground water of about 30 m.
- The site is located in "Area A" (based on area designation in the Oslo II Agreement).
- The site is located near the planned Jericho wastewater treatment plant, and could be used to recharge treated wastewater in the future.

Hydraulic Design

Based on the screening analysis in Chapter 3, the spreading basins should be sized and designed to handle quantities of stormwater of up to 4 MCM. This flow volume represents the average flow volume calculated from historical rainfall data per year (based on runoff potentials calculated from rainfall data). These estimates are summarized in Appendix C. During wet years, significantly higher flows may occur over the winter season. For most storm events, a capacity of 4 MCM should be sufficient. If stormwater quantities exceed 4 MCM in any single storm event, flow would have to bypass the recharge facilities. Alternatively, the total capacity of the spreading basin system could be increased, simply by constructing additional recharge basins.

In the winter months, excess water from Ein Sultan could be conveyed to the recharge basins instead of being lost. In this way, the excess water could be temporarily stored in the local aquifer system for use in the summer season. Data from CPF (1997) and Nuseibeh and Nasser Eddin (1995) indicate that as much as 1.5 MCM of excess water may be available from Ein Sultan in the winter months.

A further consideration for the hydraulic design of the recharge system is the future Jericho wastewater treatment plant which will be located in the same vicinity. Based on

information contained in the CPF (1997), Jericho will generate about 1 MCM of treated wastewater by the year 2020. These quantities could be integrated with the proposed stormwater harvesting scheme. Treated wastewater, or actually blends of wastewater and stormwater runoff, could be used conjunctively since the aquifer is not important as a source of potable water. This is consistent with recommendations provided in the Integrated Water Resources Management Plan for the district of Jericho prepared under the USAID-funded Water Resources Program.

It is anticipated that some of the water held temporarily in the recharge basins will be lost to direct surface evaporation. Evaporation rates in the Jordan Valley are high, and it is possible that as much as 20 percent of the water will be lost prior to being fully recharged, although this is also a function of the infiltration capacities of the local soils.

Prior to constructing any basins, it will be necessary to conduct a detailed hydrogeological investigation of the area, including large-scale, long-duration infiltration tests. A survey of soil conditions should be conducted, and the infiltration capacity of the suggested areas must be verified with actual field tests. This is further described in Chapter 6.

In addition, before any scheme is implemented, it is necessary to begin the data collection efforts to verify the estimates of stormwater in Wadi Al-Qilt. This includes gauging of rainfall throughout the catchment area as well as measuring the wadi flows at two stations: near the Qilt spring and at the outlet of the wadi into the Jordan Valley. These measurements should ideally be conducted over a couple of winter seasons to build a framework for verifying current estimates of wadi flows and justifying any potential future schemes.

Conceptual Design

It is anticipated that each basin will be 50 m wide at the base, 65 m wide at the top (3:1 slope), and 100 m long. Each basin will be 5 m deep to attain the approximate elevation of the wadi bottom and a 2 m high compacted berm will be placed around each basin for erosion control and stability. For a total capacity of 4 MCM, up to 12 basins would be placed in parallel, or configured based on local conditions to maximize use of available land. The basins would be placed perpendicular to the prevailing ground water flow gradient to minimize ground water mounding.

Designs of recharge facilities are relatively straight-forward, provided that the appropriate studies and tests are conducted prior to implementation. The main challenge will be to engineer the inlet structures such that inflow velocities will be sufficiently low to avoid significant erosion or topping of the recharge structures. Observations made during previous flood events (Mustafa Nuseibeh, personal communication) indicate the occurrence of high intensity floods in the main wadi. The diversion channel to the south and the gabbions in the wadi will contribute significantly to dissipate the energy of the stormwater. In addition, Wadi Al-Qilt flattens and broadens as it enters the Jordan Valley. Careful observations of the flow characteristics of the wadi should be made during the upcoming wet season in the proposed recharge area to evaluate the need for specialized velocity-reduction features. Those will also determine whether a separate southern diversion channel is needed.

Estimated Costs

The total capital costs for major components of the stormwater harvesting scheme in Jericho, including engineering costs and design investigations, were estimated to vary between US $36 and 39 million. Annual O&M costs were assumed to be approximately 4 percent of the total capital costs or about US $1 million. A summary of the cost estimates is presented in Table 5.1.

The normalized unit cost of water was estimated on present worth basis, for a discount rate of 10 percent and a design life of 50 years.

The water quantity that would be captured by the system was also normalized based on the same discount rate. These quantities were estimated based on annual rainfall data for Al-Bireh (which is located at the head of the catchment area of Wadi Al-Qilt where most of the runoff occurs). However, these rainfall measurements were reduced to reflect an average rainfall for the wadi catchment area, as rainfall at Al-Bireh approaches the upper range of rainfall levels in the catchment area. Runoff quantities for the 30-year monitoring period were estimated based on the runoff-rainfall relationship described for Wadi Qilt in Chapter 3.

Table 5.1: Summary of Estimated Costs - Wadi Qilt

Item	Costs[1] (US $ million)
CAPITAL	
Land Cost	10
Excavations for Basins	6
Grade preparation, foundation, abutment, access roads, and relocation of extension road	1
Check dams, dredging, and temporary diversion structures in wadis	2
Gravel bed for recharge basins	5
Extraction and Monitoring Wells	1.25-2
Conveyance mains to agricultural areas	1-1.5
Excavation of 2nd diversion channel with road culverts	1.5-2
Hydrogeological Pre-Investigations	0.75-1
SUBTOTAL CONSTRUCTION	28.5-30.5
Engineering, investigation and supervision (@ 12% of construction)	ca. 3.5
Contingencies (@ 15% of construction)	ca. 4.5
TOTAL CAPITAL	36.5-38.5
ANNUAL O&M (@ 4% of Construction) - includes water quality monitoring	ca. 1

[1] Unit costs are based on CPF 1997

These estimated runoff values were used for the first 30-year period, assuming that rainfall would follow the same pattern of the previous 30 years. For the subsequent 20-year period, the average stormwater runoff of 4 MCM/year was applied. This approach

was considered to conceptually account for variations in the rainfall patterns and magnitude and uncertainty in the runoff potential.

Excess spring water from Ein Sultan and treated wastewater from the future Jericho wastewater treatment plant were not accounted for. On these bases, the average unit water cost was estimated to be approximately US $ 1.5/m^3 (see Appendix E). These costs do not include water treatment. It is assumed that treatment will not be required.

The unit cost of water would be reduced if the engineering features incorporated in the proposal scheme were simplified. For example, it may not be necessary to excavate and construct a second, southern diversion canal to the recharge fields. Similarly, if the recharge basins were simplified with potentially cheaper hydraulic structures (e.g. earth dams), then the construction costs could be reduced, lowering the unit cost of water. It should be noted that consideration of an earth dam would introduce costs which have currently not been calculated or accounted for. However, a preliminary sensitivity analysis on construction costs indicated that simplified structures could lower the average unit water cost to about US $1.1/m^3 .

Influence of O&M Considerations on Design

A potential problem with the proposed scheme is that the recharge basins will become partially clogged after each flood event. This results in a reduction of infiltration capacity with time. In turn, this increases evaporation losses. Thus, cleaning (scraping) of the basins will be necessary periodically . It may not be necessary to do this more than once a year, or even every other year, as the operations of the basins are contingent on rainfall intensity.

To minimize the potential for clogging, the sediment or suspended solids content of the water should be as low as possible when it is admitted into the infiltration basins. This can be achieved with presedimentation basins . The detention time in the presedimentation basins should be large enough to settle the solids but small enough to avoid growths of algae which can also affect infiltration capacity. Figure 5-2 shows a typical plan view of three recharge basins placed in series, whereby the purpose of the first basin is to serve as a sedimentation basin to remove suspended matters before the water is passed on to the infiltration basins. This type of design is recommended as a preventive measure.

Other Considerations

There are a few other factors which have to be considered with respect to the proposed stormwater harvesting scheme of Wadi Qilt runoff:

- Based on topographic maps, the proposed recharge area contains a "khirbeh," or a site with potential archeological significance. This could indicate that there may be a small archeological site within the borders of the recharge area. During the field visit, a specific site was not found. The nature and importance of this marker needs to be further investigated.

- Given the uncertainty surrounding the actual quantities that may be captured, it is imperative that hydrological monitoring of Wadi Qilt commence this winter, and that careful observation of the wadi be made in the proposed recharge area during storm events. Information obtained during this study suggests that runoff flows past the site and reaches the Jordan River in most years, however, the quantities have not been measured at the proposed site.

Fari'a Conceptual Stormwater Harvesting Scheme

Description

The stormwater harvesting scheme for Wadi Fari'a entails the construction of a combined detention-storage dam to retard and store flood runoff and spring water, and mitigate the effect of sudden floods. Water stored temporarily, during winter and part of the spring, would be released during the latter part of the spring and summer for use in irrigation of farms/orchards located nearby and/or downstream of the dam location.

Site Selection

The selected location of the dam is approximately 1.5 km downstream from Jisr Al-Malaki at the confluence of Wadi Fari'a and Wadi Badan. The coordinates of this location are 184.7 east, and 184.5 north. The approximate location of the dam is shown in Figure 5-3. Photographs of the proposed site location are presented in Appendix D.

The site was selected based on several criteria including topography and geometry of the wadi, land use along the wadi, and distance to users.

Specifically, the site was selected because:

- It optimizes the volume of captured water, as it would, in addition to stormwater, capture water of Fari'a and Badan springs, particularly during winter.
- The wadi at the dam location is relatively narrow which minimizes the dimensions of the dam and reduces construction costs.
- The lake behind the dam at that location would have minimal adverse effects on farmlands in that area, because of their limited number and extent.
- The wadi within 1 km downstream of the proposed dam location experiences a sudden change of topography and geometry, where side slopes become milder, the wadi flattens, and the stream splits into more than one branch. These features would, in a case of a dam breach or extensive floods, result in quick dissipation of energy.
- No substantial population centers are located close by. The nearest small village is located approximately more than 2 to 3 km downstream.

- No known archaeological site is located within the flood area downstream of the dam.

- Minimal flooding of roads, if any, should be expected both upstream or downstream. There may be a potential for flooding a limited chapter of approximately 100 to 200 m, of the road extension from Jisr Al-Malaki towards Tubas road.

- Sites downstream would likely result in higher evapotranspiration losses.

- Amenable hydrogeological conditions, where the soil at the wadi bottom in the vicinity of the dam location has relatively low hydraulic conductivity which mitigates water losses due to infiltration to the subsurface.

Hydraulic Design

The discharge from the dam encompasses both stormwater runoff and water from Al-Fari'a and Badan springs. The storage capacity of the dam should, however, consider the stormwater runoff and only the winter flows of Fari'a and Badan (Sidreh, Hamad & Beida, Tabban, Subian, and Qudeira) springs. Spring water during other months is readily used for irrigation, thus, it would not be stored behind the dam, nor would it be considered in estimating the storage capacity of the dam.

The total stormwater runoff at the wadi was estimated in Chapter 3 to vary between approximately 3 and 11 MCM/year. Accordingly, it was assumed that the average total runoff, including evapotranspiration and infiltration losses, is approximately 6 MCM/year.

The average combined flow of Fari'a and Badan springs was estimated to be approximately 10.3 MCM/year, with 5.2 MCM/year for Fari'a spring and 5.1 MCM/year for Badan spring groups (Nuseibeh and Nasser Eddin 1995). The average rainy-season (months of November through March) flow from these springs was estimated to be about 40 percent of the total annual flow at 4 MCM.

Thus, the average total annual discharge of the dam is approximately 17.3 MCM, whereas the total volume of the water that will be stored behind the dam is approximately 10.4 MCM.

This water would be stored during winter months and released during the irrigation season into the Fari'a canal either directly or through a conveyance pipe.

Conceptual Design

The existing setting in the general vicinity of the dam proposed site is a combination of narrow-stream with relatively high rocky slopes in upstream locations, and gradually decreasing heights and rolling plains near and downstream of the proposed site. Such a setting suggests the use of earthfill dam with a separate spillway structure.

Observations made during previous flood events, learned from discussions with Mustafa Nuseibeh and local villagers, indicate occurrence of high intensity floods, which apparently tended to transport large boulders and cobbles for long distances along the wadi. These observations were further corroborated during the recent site visits, where runoff debris of various sizes (boulders, cobbles, and gravel) could be observed throughout the area. It was also reported that a reinforced concrete wall, which was constructed immediately downstream of Ein Shibly as part of the diversion structure for the Fari'a irrigation project, was toppled after the first storm following construction (the broken wall could be observed at the site).

These observations indicate the need to construct a structurally strong and stable dam, which may necessitate the use of concrete as a major element in the core of the dam. As such, it could be a composite earthfill-concrete dam, where the concrete core would be sandwiched within earthfill material with relatively low permeability. It should be noted that if stability analysis indicates that earthfill material with a sufficiently thick riprap layer is sufficient, the concrete core may be replaced by native soils. Soil testing, which was conducted by students from Al-Najah University, on soil samples collected from the wadi at the location of Jisr Al-Malaki indicated that the wadi bottom soil is relatively in pervious (10^{-6} to 10^{-7} cm/sec) and can be used in the dam core. This would likely reduce the construction costs substantially, as this material is prevalent within the study area.

The dam would be protected on both upstream and downstream faces by riprap (large boulders with an average diameter of greater than 1m). Naturally, economic factors and availability of construction material and capacity (*i.e.*, skilled labor and adequate equipment), as well as skilled O&M labor will also play a paramount role in the selection process of the dam type and material. Earthfill material are typically favored over concrete because local material may be used for the construction of the dam which would reduce the overall construction costs.

The dam would be designed as a "non-overflow" dam, where it will not be overtopped. Detained water would be released via a shaft or gallery (pipe) that penetrates the body of the dam. This gallery would also serve to discharge overflow during floods exceeding design storms. A schematic design of the dam is presented in Figure 5-4.

The height of the dam was calculated based on the estimated total storage capacity and surface area of the lake behind the dam. The surface area was estimated with the aid of the topographic map. These estimates are summarized in Table 5.2.

Table 5.2: Estimation of Surface Area and Dam Height

Elevation AMSL [1] (m)	Dam Height (m)	Surface Area [2] (m^2)	Average [3] Surface Area (m^2)	Incremental [3] Storage Capacity (m^3)	Cumulative Storage Capacity (m^3)
10	-	15,000	-	-	-
20	10	75,000	45,000	450,000	450,000
30	20	260,000	167,500	1,675,000	2,125,000
40	30	500,000	380,000	3,800,000	5,925,000
50	40	810,000	655,000	6,550,000	12,475,000

[1] Above mean sea level; the wadi grade elevation at the dam site is 10 m (AMSL)
[2] surface area at the respective elevation contour line, from 1:50,000 topographic map
[3] Average surface area and volume between 10-m contour intervals

Table 5.2 indicates that a dam height of 38 to 40 m would provide the required storage capacity. As such, the elevation of the water at the downstream side of the dam, when it is full, is approximately ±50 m (AMSL), based on a wadi grade elevation of 10 m (AMSL).

Figure 5-3 depicts a general layout and extent of the lake behind the dam. The lake was estimated to extend approximately 2 km downstream, with a decreasing water height. The lake may potentially flood a limited chapter, which is approximately 100 to 200m long, of the extension road from Jisr Al-Malaki to Tubas Road. As such, this Chapter might have to be relocated to a higher ground to avoid potential flooding. The total farmland area, which could potentially be flooded by the lake was estimated to be approximately 600 to 1,000 du.

The total height of the dam has to be increased from the theoretical estimated value to account for the free board and wave action. Assuming 2 to 5 m for both, the total height of the dam would range between 40 and 45 m. The dam side slopes have to be selected such that the dam can be protected against slope failures. Generally, side slopes range between 2(h):1(v) to 3:1. In this conceptual design, side slopes for the compacted earthfill material are assumed to be 2:1 for both upstream and downstream slopes, whereas the side slopes for the riprap are selected to be 3:1. Approximate dimensions of the conceptualized dam are presented in Figure 5-4.

To further improve the harvesting of stormwater runoff, regrading the wadi surface was incorporated into the scheme. This entails minimizing local depressions in the wadi which tend to retain part of the runoff as base flow for these depressions, which would be lost due to infiltration or evapotranspiration.

Estimated Costs

The total and capital costs for major components of the proposed scheme at Wadi Fari'a, including investigation, engineering and contingencies, were estimated to vary between US $72 and 82 million. Annual O&M costs, which account for cleanup, dredging, monitoring, repair, and operations, were assumed to be 4 percent of the total capital costs and were estimated to be about US $2.2 to 2.5 million. These cost estimates are presented in Table 5.3.

The normalized unit cost of water was estimated on present worth basis, for a discount rate of 10 percent and a design life of 50 years.

The water quantity that would be stored by the dam was also normalized based on the same discount rate. These quantities were estimated based on total rainfall data (Chapter 2) during runoff threshold occurrences for Salfeet (the nearest station with available daily and monthly rainfall measurements). It was assumed that 15 percent of the total rainfall during these occurrences occur as runoff.

Table 5.3: Summary of Estimated Costs - Wadi Fari'a

Item	Costs [1] (US $ million)
CONSTRUCTION	
Excavation, and placement of earthfill, concrete and riprap	40 - 46
Mechanical, spillway shaft, and conveyance piping	3.5 - 4
Grade preparation, foundation, abutment, access roads, and relocation of extension road at Jisr Al-Malaki	5.5 - 6
Check dams, dredging and wadi floor modification, and temporary diversion structures for spring flow	2 - 2.5
Land (for dam and lake) and flooded farmlands	4 - 5
SUBTOTAL CONSTRUCTION	55 - 63.5
Engineering, investigation and supervision (15% of construction)	8.3 - 9.5
Contingencies (@ 15% of construction)	8.3 - 9.5
TOTAL CAPITAL	72 - 82
ANNUAL O&M (@ 4% of Construction)	2.2 - 2.5

[1] Unit costs are based on CPF 1997

These estimated runoff values were used for the first 40-year period of the financial calculations, assuming that rainfall would follow the same pattern and magnitude of the past 40 year monitoring period. For the remaining years, the average stormwater runoff of 6 MCM/year was applied. This approach was considered to conceptually account for variations in the rainfall patterns and magnitude and uncertainty in the runoff potential.

Winter spring water that would be stored behind the dam was assumed to be the average volume of 4 MCM/year for all years.

On these bases, the average unit water cost was estimated to be approximately U.S.$1.3/m^3. Details of this unit cost estimate are presented in Appendix E.

Other Considerations

Several other issues must be considered with respect to the proposed stormwater harvesting scheme of Wadi Fari'a runoff. These issues include:

- Recently, the Israelis constructed a reservoir called "Tirza Reservoir," which is located east of Route 90, approximately 25 to 30 km downstream of the proposed location. No data is available about this reservoir, but it is reported to have a capacity of a few MCM. The Tirza Reservoir, is believed to primarily detain and store stormwater runoff and winter water from all upstream springs (including Fari'a, Badan group, Shibli, Miskeh, etc.). In the spring and summer time, this reservoir should not be receiving any water, except for excess flows from Al-Fari'a canal, as spring water is used for irrigated agriculture by upstream lands. The construction of the stormwater harvesting scheme at Wadi Fari'a may potentially impact the Tirza Reservoir. This assessment of this potential impact is out of the scope of this study, and thus was not considered.

- According to Oslo II Accord, the proposed site location, based on the land designation of the West Bank during the Interim Period, is located in "Area C." As such, further development and implementation of the proposed scheme during the Interim Period may have to be reviewed and permitted by Israel.

- The preliminary assessment of potential environmental impacts of the proposed scheme was generally based on the review of available topographic, land use, and environmentally sensitive areas (draft map prepared by MOPIC 1996). This assessment indicates that the general vicinity of the proposed dam site may not be located in an environmentally sensitive area. An old "Khirbeh" (ruins of a former small village or structure with potential archaeological significance) was identified on the topographic map near Jisr Al-Malaki. Based on the estimated elevation of the lake water surface, the proposed scheme may not have any impact on this "Khirbeh." However, this issue should be evaluated further. No other structure of feature that may potentially be impacted could be identified during our preliminary assessment.

- Historically, due to political and financial reasons the stormwater runoff and winter spring water was never exploited in the study area as a potential water resource. This resource, if tapped for irrigated agriculture is expected to result in a notable increase in the size of irrigated lands. The area of lands that can be irrigated by the harvested stormwater runoff and winter spring water downstream of the dam, which was estimated at an average of 10 MCM/year, could reach up to 10,000 to 12,000 du. This estimate was based on an average water crop demand in the study area of 800 to 1,000 m^3/du (CPF 1997). Reclamation of these lands for purposes of viable exploitation is likely to require an extended period of time, and substantial technical, financial and institutional resources. Since the proposed dam has a limited storage capacity, it may be more viable to construct the dam in stages to facilitate the gradual development and reclamation of potentially irrigable lands. During the interim period (and after completion of all stages of the dam), water in excess of the dam storage capacity can be diverted downstream as a runoff down the wadi.

- The quality of stormwater was not addressed in this study. This issue should be evaluated in order to determine the need for treatment, if any.

- Given the uncertainty surrounding the actual quantities that may be captured, it is imperative that hydrological monitoring of Wadi Fari'a commence this winter, and that careful observation of the wadi be made in the proposed recharge area during storm events. Information obtained during this study suggests that runoff flows past the site and reaches the Jordan River in most years, however, the quantities have not been measured in the vicinity of the proposed site.

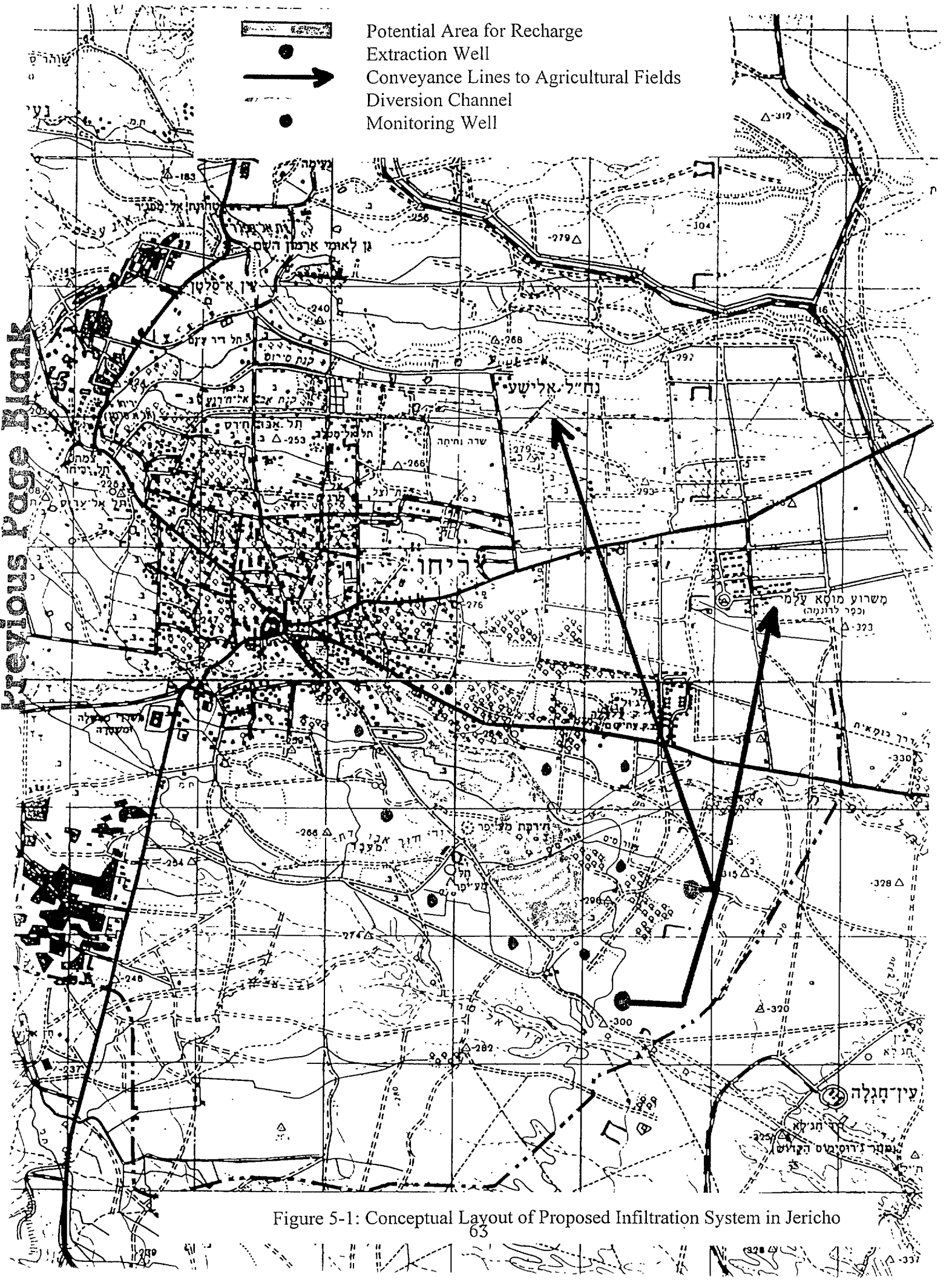

Figure 5-1: Conceptual Layout of Proposed Infiltration System in Jericho

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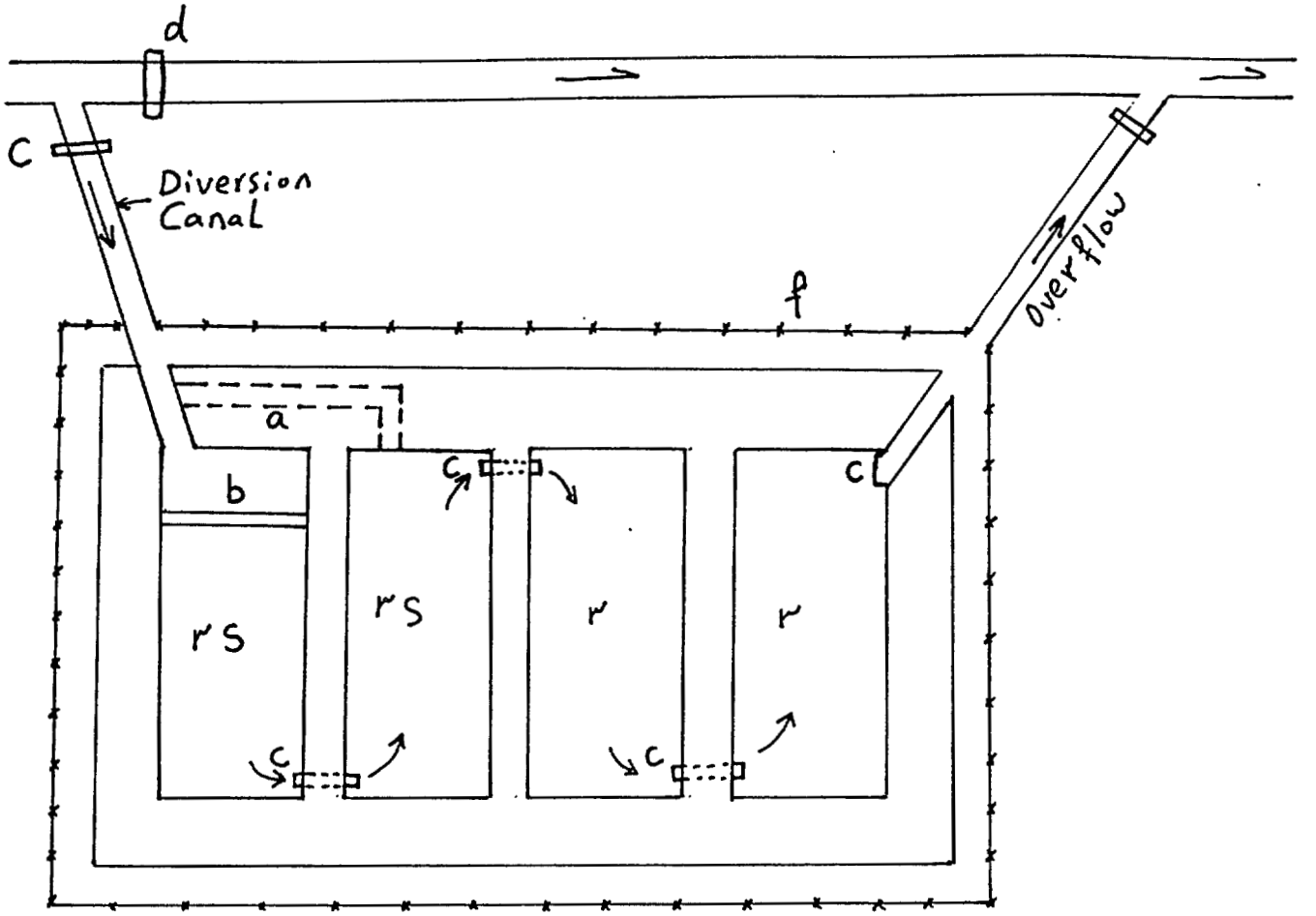
Plan View



a- Bypass as required
b- Baffle as required
c- Control Structure
d- Diversion
f- Fence as required
r- Recharge Basin
rs- Recharge and settling basin

Cross Section

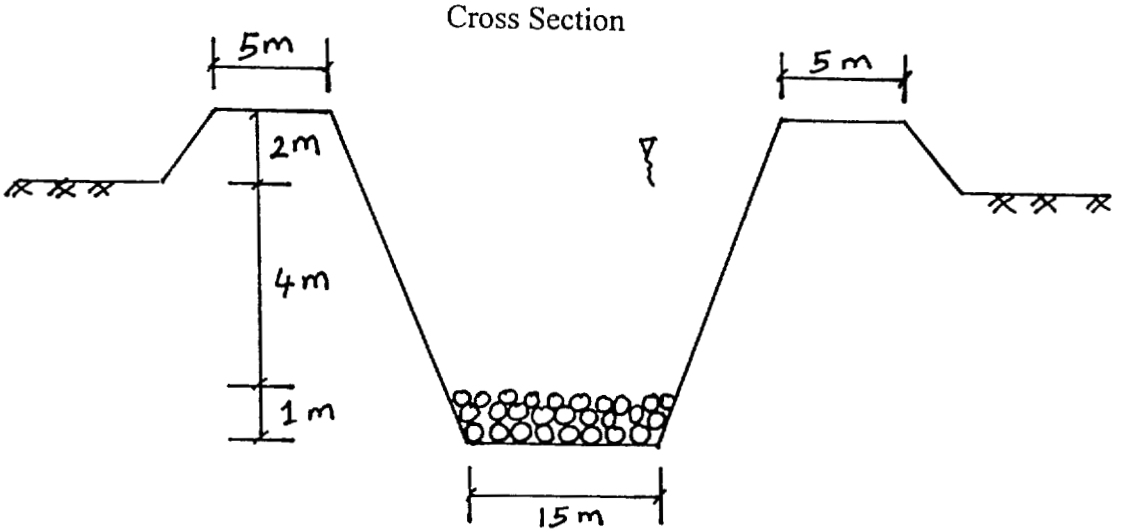


Figure 5-2: Conceptual Design of Recharge Basins

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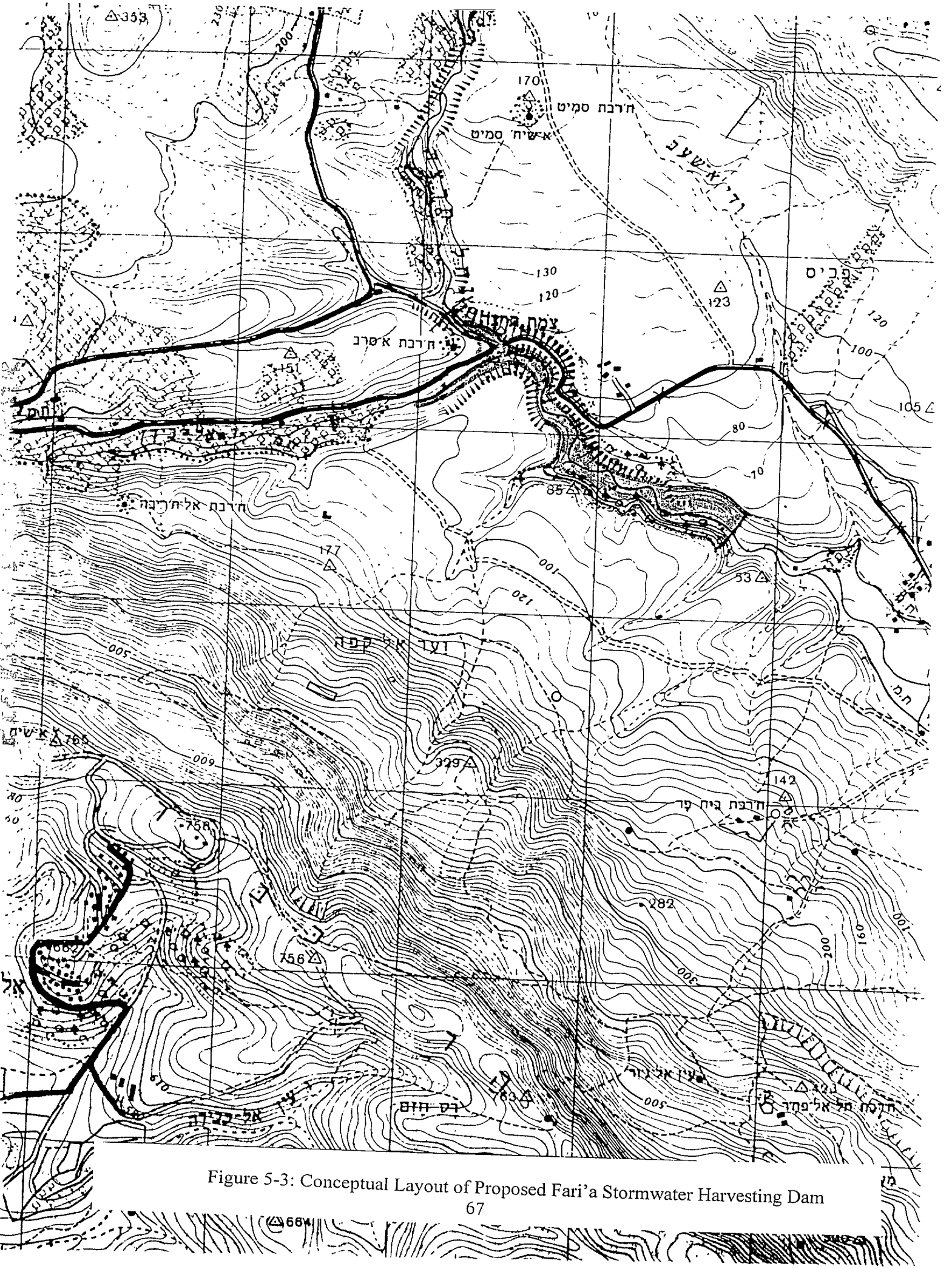
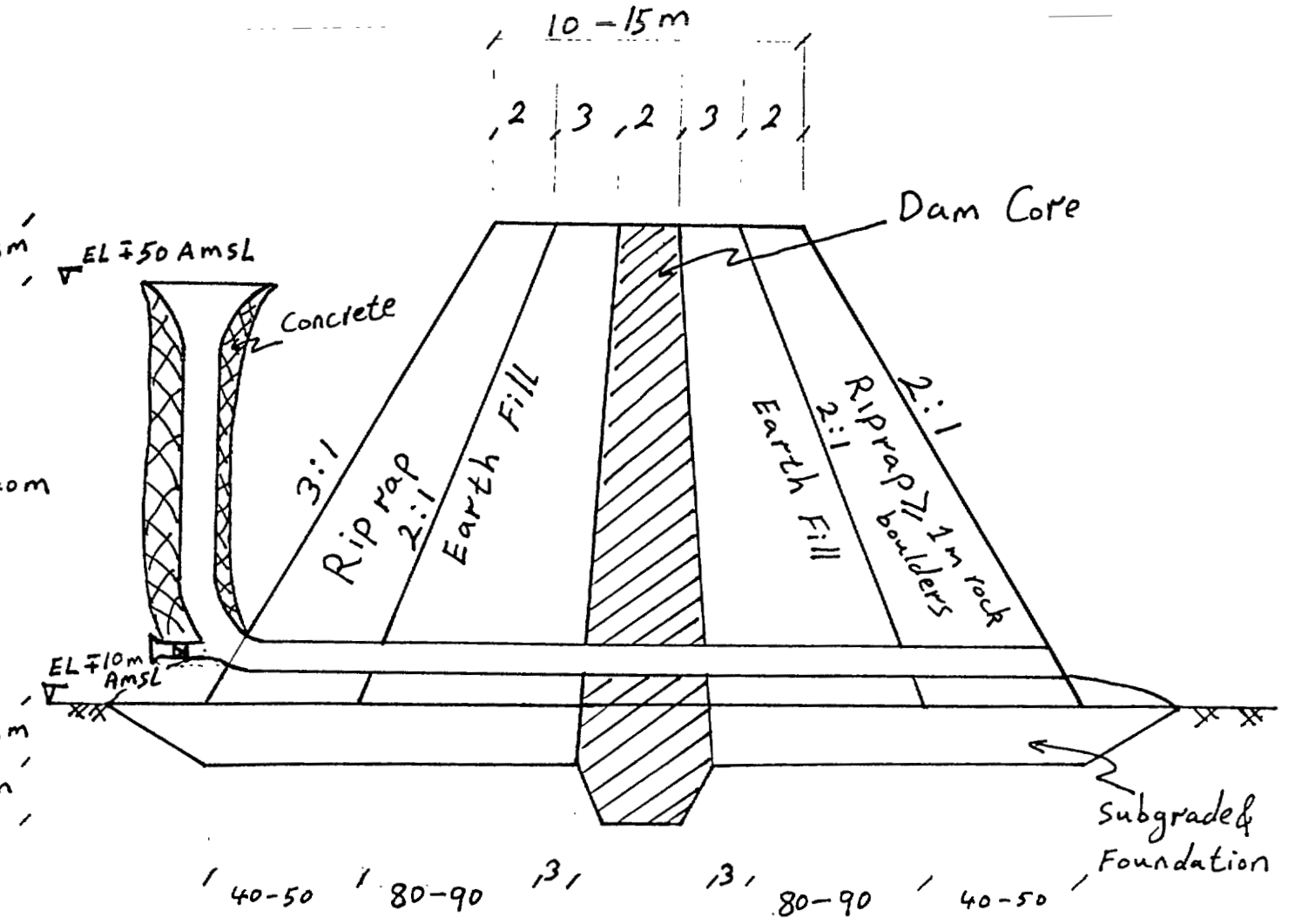


Figure 5-3: Conceptual Layout of Proposed Fari'a Stormwater Harvesting Dam



AmsL = Above mean sea Level

Dam core consisting of concrete or cement bentonite or other impervious earth fill

Figure 5-4
Schematic of Detention Dam at Wadi Fari'a

CHAPTER 6

TERMS OF REFERENCES

Wadi Al-Qilt Stormwater Harvesting Scheme

Background

The US Agency for International Development (USAID) intends to recruit an A/E consulting firm to provide services associated with the implementation of the Wadi Al-Qilt Stormwater Harvesting Scheme in Jericho.

Stormwater harvesting of Wadi Al-Qilt offers an opportunity to augment existing water resources in the Jericho area. The intent of this scheme is to reuse stormwater for agricultural purposes. Stormwater will be captured and recharged at a location near Jericho in the winter months and will be extracted/conveyed to local farmers in the summer months when demands for water are higher.

Recharge to the local alluvial aquifer will alleviate the growing problem of induced salinity from overpumping in the agricultural sector. Mitigation measures are necessary to minimize or eliminate existing water quality concerns. Resource augmentation for supply to local farmers is regarded as a pragmatic, partial solution to the water quality problem.

The total capacity of the intended recharge system is 4 million cubic meters. The project will be sized and implemented in phases. Besides stormwater, an opportunity exists to integrate the conveyance of excess spring water and future treated wastewater to the system. Conjunctive use is feasible since the alluvial aquifer is not an important source of potable water.

Scope of Work

The Consultant will provide feasibility, design, and construction services necessary to formulate, evaluate, and construct the proposed stormwater harvesting scheme in Jericho. The services will be provided in three stages:

- Stage I - Detailed Feasibility Study and Pre-Design;
- Stage II - Hydrogeological Investigation and Testing; and
- Stage III - Design and Construction.

The performance of Stages II and III are contingent on the result of the preceding stages.

Stage I: Detailed Feasibility Study and Pre-Design

Basic Data Collection and Analysis

- Catchment study of Wadi Al-Qilt, including monitoring
- Flow characteristics of Wadi Al-Qilt
- Review of hydrologeological conditions in Jericho area
- Land surveys
- Assessment of compatibility with other ongoing projects in Jericho
- Preliminary field investigations

Conceptual Designs

- Perform a preliminary hydrogeological assessment of the recharge system, including hydraulic modeling and ground water flow modeling
- Prepare a conceptual design
- Identify likely engineering requirements for the cost analysis

Agricultural Studies

- Identify users of recharged and extracted stormwater
- Identify crop types grown locally that are suitable for irrigation by re-cycled stormwater
- Establish likely treatment requirements
- Estimate water use patterns during winter and summer months
- Estimate water demand during summer months when stormwater would be delivered

Environmental Impact Assessment

- Identify potential environmental receptors
- Identify archaeological sites of interest
- Characterize local flora and fauna
- Evaluate potential impacts of the proposed scheme to local environment, including wildlife and vegetation
- Identify mitigation measures, if needed

Socio-Economic Assessment

- Carry out a field survey of potential users
- Evaluate the willingness and ability of farmers to use and pay for the stormwater
- Participate in public hearings

Identification of Hydrogeological Testing and Design Requirements

- Prepare detailed design analysis of required pre-construction testing of the infiltration system

- Prepare detailed design drawings of testing system
- Prepare technical specifications for testing program and required equipment
- Prepare tender documents for needed subcontractors

Cost Estimates

- Prepare detailed estimates for required hydrogeological and other testing prior to implementation
- Prepare detailed (capital and O&M) cost analysis of the large-scale infiltration system
- Estimate unit water costs for full recoverability

Economic and Financial Analysis

- Optimize the land requirements and layout for the infiltration system
- Evaluate the economic and financial feasibility of the project
- Perform cost/benefit analysis of the project
- Identify possibilities for privatization of development and other financing options
- Evaluate options for staging construction

Stage II: Hydrogeological Investigation and Testing

- Procure subcontractors
- Conduct oversight of testing and other work. During construction, the Consultant shall be responsible for contact administration, monitoring of progress and payment, quality assurance/control, technical support, and design revisions required by actual site conditions
- Prepare a test results report complete with analyses (including modeling) and recommendations for full-scale implementation, including any design changes

Stage III: Design and Construction

Final Design and Tender Documents

- Review Stage II results
- Establish design criteria
- Evaluate existing project designs and make appropriate corrections and/or modifications to the pre-design documents and calculations
- Prepare technical specifications for final design, incorporating results of Stage II activities
- Prepare bills of quantities and an engineer's estimate of the construction costs
- Prepare a construction program and schedule

- Prepare tender documents for construction of large-scale infiltration system, in accordance with USAID procurement regulations

Pre-Construction Services

- Assist USAID and PWA with the prequalification of contractors, bid evaluation, bid award, contract negotiations, and obtaining permits and easements
-

Construction Services

- Prepare construction drawings
- Manage the construction activities. During construction, the Consultant shall be responsible for contract administration, monitoring of progress and payment, quality assurance/control, technical support, and design revisions required by actual site conditions
- Prepare record drawings for the civil works and review record drawings prepared by the equipment contractors

Institutional and Extension Services

Based on conclusions from the Stage I Feasibility Study, the Consultant shall explore and identify opportunities for participation from the private sector in the operation and management of these systems. The Consultant shall also facilitate the transfer of technology and extension services during the contract period with PWA, local agencies and NGOs. The activities shall include:

- Plan and implement studies and potential training programs to evaluate equipment requirements, best management practices, and technologies associated with artificial recharge and irrigated agriculture using stormwater and stormwater mixed with other sources of water (e.g., excess water from Ein Sultan and treated wastewater)

- Develop extension programs to other potential systems making use of stormwater and/or mixed sources of water for irrigation

- Identify O&M and personnel and training requirements

- Attend and support public meetings

Schedule

It is anticipated that from start to finish, the project will take approximately 5 years: 6-9 months for Stage I, 1-1.5 years for Stage II, and three years for Stage III.

Wadi Fari'a Stormwater Harvesting Scheme

Background

The US Agency for International Development (USAID) intends to recruit an A/E consulting firm to provide services associated with the implementation of the Wadi Fari'a Stormwater Harvesting Scheme.

Stormwater harvesting of Wadi Fari'a offers an opportunity to augment existing water resources in the Fari'a Valley. The intent of this scheme is to intercept and reuse stormwater and winter water from the Beidan and Fari'a springs for agricultural purposes. Stormwater will be captured and released from the dam during the irrigation seasons, and will be conveyed to the Fari'a canal.

The total capacity of the proposed detention structure is 10 million cubic meters. The proposed site is located about 2 km downstream of Jisr Al Malaki at the confluence of Wadi Fari'a and Badan.

Scope of Work

The Consultant will provide feasibility, design, and construction services to develop and construct a detention dam for stormwater harvesting at Wadi Fari'a. The services will be provided in three stages:

- Stage I - Detailed Feasibility Study and Pre-Design;
- Stage II - Hydrological, Hydrogeological and Geotechnical Investigations; and
- Stage III - Design and Construction.

The performance of Stages II and III are contingent on the result of the preceding stages.

Stage I: Detailed Feasibility Study and Pre-Design

Basic Data Collection and Analysis

- Catchment study (including monitoring) of Wadi Fari'a and associated springs
- Flow characteristics of Wadi Fari'a
- Review of hydrologeological conditions in the Fari'a Valley
- Land surveys
- Seismic analysis
- Assessment of compatibility with other ongoing projects in the Fari'a Valley
- Preliminary field investigations
- Population and land use study for the Fari'a Valley
- Assessment of material availability

Conceptual Designs

- Perform a preliminary hydrological and engineering assessment of the dam and appurtenances
- Perform hydraulic modeling including flood routing, seepage analysis, and sediment transport
- Prepare a conceptual design
- Identify likely engineering requirements for the cost analysis

Agricultural Studies

- Identify current and potential demand and usage of stormwater and spring water
- Identify crop types grown locally that are suitable for irrigation by stormwater
- Establish potential treatment requirements
- Estimate water use patterns during winter and summer months

Environmental Impact Assessment

- Identify potential environmental receptors
- Identify archaeological sites of interest
- Characterize local flora and fauna
- Evaluate potential impacts of the proposed scheme to local environment, including wildlife and vegetation
- Conduct a hazard analysis in case of dam breach
- Identify mitigation measures, if needed
-

Socio-Economic Assessment

- Carry out a field survey of potential users
- Evaluate the willingness and ability of farmers to use and pay for the stormwater
- Participate in public hearings
-

Identification of Hydrological and Geotechnical Testing and Design Requirements

- Prepare detailed design analysis of required pre-construction testing for the detention system
- Design the required testing program
- Prepare technical specifications for testing program with required equipment
- Prepare tender documents for needed subcontractors

Cost Estimates

- Prepare detailed estimates for the required exploration and testing program
- Prepare detailed (capital and O&M) cost analysis of the detention system
- Estimate unit water costs for full recoverability

Economic and Financial Analysis

- Optimize the land requirements and layout for the detention system

- Evaluate the economic and financial feasibility of the project
- Perform cost/benefit analysis of the project
- Identify possibilities for privatization of development and other financing options
- Evaluate options for staging construction

Stage II: Hydrological and Geotechnical Investigation

- Procure subcontractors
- Conduct oversight of testing and other work. During construction, the Consultant shall be responsible for contact administration, monitoring of progress and payment, quality assurance/control, technical support, and design revisions required by actual site conditions
- Prepare a test results report complete with analysis and recommendations for full-scale implementation, including any design changes

Stage III: Design and Construction

Final Design and Tender Documents

- Review Stage II results
- Establish design criteria
- Prepare technical specifications
- Identify construction equipment needs
- Prepare bills of quantities and an Engineer's estimate of the construction costs
- Prepare a construction program and schedule
- Prepare tender documents for construction of the detention dam, in accordance with USAID procurement regulations

Pre-Construction Services

- Assist USAID and PWA with the prequalification of contractors, bid evaluation, bid award, contract negotiations, and obtaining permits and easements

Construction Services

- Prepare construction drawings
- Manage the construction activities and during construction, the consultant shall be responsible for contract administration, monitoring of progress and payment, quality assurance/control, technical support, and design revisions required by actual site conditions
- Prepare record drawings for the civil works and review record drawings prepared by the equipment contractors

Institutional and Extension Services

Based on conclusions from the Stage I Feasibility Study, the Consultant shall explore and identify opportunities for participation from the private sector in the operation and management of these systems. The Consultant shall also facilitate the transfer of technology and extension services during the contract period with PWA, local agencies and NGOs. The activities shall include:

- Plan and implement studies and training programs to evaluate equipment requirements, best management practices, and technologies associated with artificial recharge and irrigated agriculture using stormwater, and potentially stormwater mixed with excess spring water and/or treated wastewater.

- Develop extension programs to other potential systems making use of stormwater and/or mixed sources of water for irrigation.

- Attend and support public meetings.

Schedule

It is anticipated that from start to finish, the project will take approximately 5 years: 6-9 months for Stage I, one year for Stage II, and three years for Stage III.

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APPENDIX A
DAILY RAINFALL DATA

(The zipped files are on a diskette in the attached pocket)

80

APPENDIX B
WADI FLOW MEASUREMENTS

81

STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District _____ No. of Measurement CM/ 1

Name of Site: Nahal Gilit Flood Spr. Coordinates East _____ North _____

Date Hour	Current Meter Type & No.	Last calibr.	Ring every 5 revolutions	Stop Watch No.	Weather	Wind with, against the flow none	Colour of Water
19.1.74 10:40	Scientific	C					

Bed covered with Large stones/small stones/pebbles/ sand/mud/concrete floor/stone floor	Vegetation in channel. Shrubs/ Grass Clean	Type of Flow Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks W.L. = 0.81 m.

Results of the present measurement.	Result of the last measurement.
Q 3.080 m^3/sec.	Date _____ No. _____
Add or deduct:	_____ m^3/sec.
Total _____ m^3/sec.	

Sign. of Observer M. Nusseibeh, I. Shaheen, I. Shalami Sign. of Computer M. Nusseibeh

Date 3.2.74

Sign of Distr. Eng. M. Nusseibeh

Date 3.2.74

Dist. from initial point in m.	Depth of Water in m.	Depth of Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec. At Instr. m/sec. V	Mean in Vertic Vm	Mean betw. two Vertic Vm	A Area of wetted cross section m^2	q. Vm.A in m^3/sec.
0.00	0.00	W/E				1.132				
2.00	0.50	0.25	100	19.5		1.501		1.320	0.50	0.660
3.00	0.40	0.20	100	43		1.579		1.544	0.45	0.695
4.00	0.40	0.20	100	44		[illegible]		1.560	0.40	0.624
5.00	0.35	0.175	100	42		[illegible]		1.578	0.375	0.592
6.00	0.28	0.14	80	53		[illegible]		1.319	0.315	0.415
6.75	0.00	W/E				0.768		0.596	0.165	0.094
										3.080

Cross Sectional Area 2.145 m^2 ; Q(m^3/sec)

Gauge reading at the parshall is 0.81 m at beginning and end of measurement

B-3

82

STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District _____ No. of Measurement CM/ 2

Name of Site: Wadi Qilt Flood Sta. Coordinates East _____ North _____

Date Hour	Current Meter: Type & No.	Last calibr	Ring every 5 revolutions	Stop Watch No.	Weather	Wind with, against the flow none	Colour of Water
19.1.74 12:30	Scientific						Turbid muddy

Bed covered with: Large stones/small stones/pebbles/sand/mud/concrete floor/stone floor	Vegetation in channel: Shrubs/ Grass Clean	Type of Flow: Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks W.L. - 0.81 m

Dist. from initial point in m.	Depth of: Water in m.	Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec: At Instr. m/sec. V	Mean in Vertic Vm	Mean betw. two Vertic Vm	A Area of wetted cross section m²	q. Vm.A in m³/sec.
0.00	0.00	W/E				0.017		1.187	0.300	0.594
2.00	0.50	0.25	120	50		1.356		1.523	0.475	0.723
3.00	0.45	0.225	100	45		1.509		1.526	0.450	0.687
4.00	0.45	0.225	100	44		1.543		1.153	0.400	0.461
5.00	0.35	0.175	130	50		1.763		1.619	0.350	0.567
6.00	0.35	0.175	100	46		1.475		1.445	0.365	0.527
7.00	0.38	0.19	100	48		1.414		1.238	0.430	0.594
9.00	0.10	W/E				1.061				

Results of the present measurement.	Result of the last measurement.
Q 4.153 m³/sec.	Date _____ No. _____
Add or deduct: 0.166	_____ m³/sec.
Total 3.987 m³/sec.	

Sign. of Observer M. Nuseibeh / T. Shahaan / T. Shahami Sign. of Computer E. Ahmad

Date 3.2.74

Sign of Distr. Eng. M. Nuseibeh

Date 3.2.74

Cross Sectional Area 3.020 m² ; Q(m³/sec) 4.153

Gauge reading at parshall at beginning of measurement = 0.81 m
" " " " " end " " = 0.51 m

STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District _____ No. of Measurement CM/ 3

Name of Site: Wadi Qelt Flood Step Coordinates

East _____ North _____

Date Hour	Current Meter Type & No.	Last calibr	Ring every	Stop Watch No.	Weather	Wind with, against the flow	Colour of Water
19.1.74 13:20	Scientific		5 revolutions			none	Turbid Muddy

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/ sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks W.L. = 0.80 m

Results of the present measurement.	Result of the last measurement.
Q 4.017 m^3/sec.	Date _____ No. _____
Add or deduct: 0.161	_____ m^3/sec.
Total 3.856 m^3/sec.	

Sign. of Observer M. Nusenbeh / Y. Shaham / E. Shalom Sign. of Computer M. Nusenbeh

Date 3.2.74

Sign of Distr. Eng. M. Nusenbeh

Date 3.2.74

Dist. from initial point in m.	Depth of Water in m.	Depth of Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec At Instr. m/sec. V	Water Velocity m/sec Mean in Vertic Vm	Water Velocity m/sec Mean betw. two Vertic Vm	A Area of wetted cross section m^2	q. Vm.A in m^3/sec.
0.00	0.00	W/E				0.713				
1.00	0.23	0.14	70	50		0.951		0.832	0.14	0.116
2.00	0.40	0.20	90	48		1.271		1.111	0.34	0.378
3.00	0.37	0.185	110	44		1.696		1.484	0.385	0.571
4.00	0.32	0.16	120	43		1.850		1.773	0.345	0.612
5.00	0.45	0.225	100	40		1.695		1.773	0.385	0.683
6.00	0.48	0.24	100	46		1.475		1.585	0.465	0.737
6.50	0.50	0.25	90	47		1.298		1.386	0.245	0.340
8.50	0.00	W/E				0.974		1.136	0.50	0.580
										4.017

Cross Sectional Area 2.805 m^2 ; Q(m^3/sec)

Gauge reading at passhall is 0.80 m at beginning and end of measurement

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Surface velocity

STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District _____ No. of Measurement CM/ 4

Name of Site: Wadi Qilt Flood Sta. Coordinates East _____ North _____

Date Hour	Current Meter: Type & No.	Last calibr.	Ring every	Stop Watch No.	Weather	Wind with, against the flow	Colour of Water
21.1.74 10:00	Scientific		5 revolutions			none	Muddy

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/ sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks _____

Results of the present measurement.	Result of the last measurement.
Q 16.029 m^3/sec.	Date _____ No. _____
Add or deduct: 16.029 − 0.641	_____ m^3/sec.
Total 15.388 m^3/sec.	

Sign. of Observer M. Nusseibeh Tawfiq Fayiz Sign. of Computer F. Ahmad

Date 3.2.74

Sign of Distr. Eng. M. Nusseibeh

Date 3.2.74

Dist. from initial point in m.	Depth of: Water in m.	Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec: At Instr. m/sec. V	Mean in Vertic. Vm	Mean betw. two Vertic. Vm	A Area of wetted cross section m^2	q. Vm.A in m^3/sec.
0.00	0.10	W/E				0.394	0.319			
0.50	0.60		100	57		1.192	1.025	0.397	0.175	0.157
2.50	0.75	0.25	225	40		3.369	2.915	1.970	1.350	2.660
3.50	0.85		225	40		3.912	3.356	3.136	0.775	2.430
4.50	0.95		225	40		3.912	3.356	3.356	0.875	2.937
5.50	0.70		225	40		3.912	3.356	3.356	0.825	2.769
6.50	0.65		120	41		3.307	2.844	3.100	0.675	2.093
7.50	0.55		175	41		2.797	2.448	2.666	0.615	1.640
8.00	0.50		105	41		2.296	2.005	2.447	0.270	0.661
8.50	0.40		175	45		1.388	1.194	1.800	0.225	0.405
9.00	0.30		50	47		0.725	0.624	0.959	0.175	0.168
10.00	0.10	W/E				0.544	0.468	0.546	0.200	0.109
										16.029

Cross Sectional Area 6.160 m^2 ; Q(m^3/sec)

Gauge reading at parshall 1.15 m at beginning of measurement
" " " " 1.15 m " end " "

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Surface Velocity

STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District _____ No. of Measurement CM/ 5

Name of Site: Wadi Qilt Flood Station Coordinates

East _____ North _____

Date Hour	Current Meter Type & No.	Last calibr	Ring every	Stop watch No.	Weather	Wind with, against the flow	Colour of Water
21.1.74 11:20	Scientific		5 revolutions			none	

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/ sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks

Results of the present measurement.	Result of the last measurement.
Q 21.276 m^3/sec.	Date _____ No. _____
Add or deduct:	m^3/sec.
Total 76,593 m^3/~~sec.~~ hr.	

Dist. from initial point in m.	Depth of Water in m.	Depth of Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec At Instr. m/sec. V	Water Velocity m/sec Mean in Vertic Vm	Mean betw. two Vertic Vm	A Area of wetted cross section m^2	Q. Vm.A in m^3/sec.
0.00	0.55	W/E								
0.50	0.65					2.668	2.29			
2.50	1.00		210	40		3.558	3.06	2.675	1.94	5.190
3.50	1.00		245	40		4.102	3.53	3.30	1.00	3.300
4.50	0.90		265	40		4.440	3.86	3.695	0.95	3.510
5.50	0.75		245	40		4.102	3.53	3.695	0.825	3.048
6.50	0.75		210	40		3.558	3.06	3.295	0.75	2.471
7.50	0.65		200	40		3.389	2.91	2.985	0.70	2.090
8.50	0.40		120	42		2.032	1.75	2.33	0.525	1.223
9.00	0.30		80	42		1.292	1.11	1.43	0.175	0.250
10.00	0.10	W/E				0.969	0.83	0.97	0.20	0.194

Cross Sectional Area 7.065 m^2 ; Q(m^3/sec) 21.276

Sign. of Observer M. Nuseibeh, I. Shaheen, F. Ahmad Sign. of Computer Y. Sulah

Date 30.1.74

Sign of Distr. Eng. M. Nuseibeh

Date 30.1.74

Gauge reading at parshall at beginning of measurement 1.20 m

" " " " " end " " 1.15 m

W.L. in well : 1.52 m

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Surface velocity

STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District _____ No. of Measurement CM/ 6

Name of Site: Wadi Qelt Flood Sta. Coordinates East _____ North _____

Date Hour	Current Meter: Type & No.	Last calibr	Ring every 5 revolutions	Stop Watch No.	Weather	Wind with, against the flow none	Colour of Water
21.1.74 12:55	Scientific						

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/ sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks _____

Results of the present measurement. Q 30.276 m^3/sec.

Add or deduct: _____

Total _____ m^3/sec.

Result of the last measurement.

Date _____ No. _____

_____ m^3/sec.

Sign. of Observer M. Nuseibeh, Y. Shahaan, F. Ahmad

Sign. of Computer Y. Subeh

Date 2.2.74

Sign of Distr. Eng. M. Nuseibeh

Date 2.2.74

Dist. from initial point in m.	Depth of: Water in m.	Depth of: Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec: At Instr. m/sec. V	Water Velocity m/sec: Mean in Vertic Vm	Water Velocity m/sec: Mean betw. two Vertic Vm	A Area of wetted cross section m^2	q. Vm.A in m^3/sec.
0.00	0.40					0.871	0.649	0.374	0.338	0.295
0.50	0.95		70	41		1.161	0.993	1.316	0.839	1.497
1.50	0.70		185	41		3.060	2.652	2.[illegible]	0.9[illegible]	2.72[illegible]
2.50	1.10		240	41		3.963	3.412	3.464	1.200	4.277
3.50	1.30		250	40		4.301	3.716	3.835	1.175	4.494
4.50	1.05		77	40		4.436	3.934	3.744	1.050	3.931
5.50	1.05		250	41		4.134	3.595	3.672	1.000	3.672
6.50	0.95		260	40		4.406	3.739	3.606	0.950	3.426
7.50	0.95		235	40		3.932	3.424	3.206	0.825	2.645
8.50	0.70		205	40		3.474	2.993	2.403	0.600	1.442
9.50	0.50		125	40		2.114	1.818	1.444	0.425	0.614
10.50	0.35		75	41		1.244	1.070	1.294	0.350	0.453
11.50	0.35		110	40		1.764	1.517	1.220	0.375	0.458
15.50	0.40		65	41		1.075	0.924	0.691	0.350	0.242
16.00	0.30		35	40		0.533	0.453	0.401	0.275	0.110
17.00	0.25					0.400	0.344			
										30.276

Cross Sectional Area 10.638 m^2 ; Q(m^3/sec)

Gauge reading at parshall 1.55 m beginning of measurement

" " " " 1.40 m end " "

W.L. in well was 1.85 m

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Surface velocity

STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District _____ No. of Measurement CM/ 7

Name of Site: Wadi Qilt Flood Sta. Coordinates East _____ North _____

Date Hour	Current Meter Type & No.	Last calibr	Ring every 5 revolutions	Stop Watch No.	Weather	Wind with, against the flow none	Colour of Water
21.1.74 13.40	Scientific						Turbid + Muddy

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/ sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks _____

Results of the present measurement.	Result of the last measurement.
Q 33.77 m^3/sec.	Date _____ No. _____
Add or deduct:	_____ m^3/sec.
Total _____ m^3/sec.	

Sign. of Observer M. Nusseibeh, T. Shaheen, F. Ahmad Sign. of Computer Y. Sabah

Date 2.2.74

Sign of Distr. Eng. M. Nusseibeh

Date 2.2.74

Dist. from initial point in m.	Depth of Water in m.	Depth of Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec At Instr. m/sec. V	Water Velocity m/sec Mean in Vertic Vm	Water Velocity m/sec Mean betw. two Vertic Vm	A Area of wetted cross section m^2	q. Vm.A in m^3/sec.
17.00	0.20						0.423			
16.00	0.30		40	41		0.664	0.571	0.499	0.275	0.137
15.50	0.35		70	40		1.139	1.022	0.797	0.175	0.139
15.00	0.30		120	40		2.723	2.202	2.114	0.165	0.345
10.50	0.30		100	40		1.655	1.423	2.314	1.350	3.124
9.50	0.50		170	40		2.812	2.418	1.920	0.425	0.816
8.50	0.80		210	40		3.555	3.060	2.739	0.675	1.849
7.50	0.90		230	40		3.897	3.351	3.205	0.850	2.724
6.50	1.10		270	40		4.575	3.934	3.642	1.000	3.642
5.50	1.20		270	40		4.575	3.934	3.934	1.150	4.524
4.50	1.20		300	40		5.083	4.371	4.152	1.200	4.982
3.50	1.30		260	40		4.406	3.789	4.080	1.250	5.100
2.50	0.90		205	40		3.474	2.983	3.338	1.100	3.672
0.50	0.50		100	41		0.756	0.650	1.819	1.400	2.547
0.00	0.50						0.483	0.569	0.200	0.114
										33.77

Cross Sectional Area 11.213 m^2 ; Q(m^3/sec)

Gauge reading at parshall at beginning of measurement = 1.30 m

" " " " " end of " " = 1.45 m

W.L. in well 1.92 m

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MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District _____ No. of Measurement CM/ 8

Name of Site: Wadi Qilt Flood Sta. Coordinates

East _____ North _____

Date Hour	Current Meter Type & No.	Current Meter Last calibr	Current Meter Ring every 5 revolutions	Stop Watch No.	Weather	Wind with, against the flow none	Colour of Water
22.1.1974 9.15	Scientific						

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/ sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks W.L. = 0.97 m

Results of the present measurement.	Result of the last measurement.
Q 9.794 m^3/sec.	Date _____ No. _____
Add or deduct:	m^3/sec.
− 0.4 m^3	
Total 9.394 m^3/sec.	

Sign. of Observer [illegible] Sign. of Computer [illegible]

Ilan Sim Date 4.2.1974

Sami Sign of Distr. Eng.

Date _____

Dist. from initial point in m.	Depth of Water in m.	Depth of Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec. At Instr. m/sec. V	Mean in Vertic Vm	Mean betw. two Vertic Vm	A Area of wetted cross section m^2	q. Vm.A in m^3/sec.
0.00	0.00	W/E				1.703				
								1.487	0.900	1.338
2.50	0.72	0.43	130	1.5		2.270				
								2.578	0.770	1.985
3.50	0.82	0.50	170	1.0		2.775				
								2.802	0.560	2.130
4.50	0.70	0.42	160	1.0		2.518				
								2.938	0.450	1.000
5.50	0.60	0.36	190	1.1		3.157				
								2.791	0.550	1.535
6.50	0.50	0.30	160	1.3		2.615				
								1.697	0.375	0.636
7.50	0.35	0.5	10	1.3		0.928				
								0.830	0.313	0.260
10.00	0.00	W/E				0.711				
										9.794

Cross Sectional Area 4.319 m^2 ; Q(m^3/sec)

Gauge reading at parshall is 0.97 m at beginning and end of measurement.

STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District Jerusalem No. of Measurement CM/ 9

Name of Site: Wadi Qilt Flood Station Coordinates East _____ North _____

Date Hour	Current Meter: Type & No.	Last calibr	Ring every 30 revolutions	Stop Watch No.	Weather	Wind with, against the flow none	Colour of Water
3.3.74 11:05							

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/ sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks W.L. = 0.55 m.

Results of the present measurement.	Result of the last measurement.
Q 3.8104 m^3/sec.	Date _____ No. _____
Add or deduct:	m^3/sec.
Total 3.8104 m^3/sec.	

Sign. of Observer Jawad Shaheen S. Ahmad Sign. of Computer J. Shalami

Date 28.3.74

Sign of Distr. Eng. M. Nurslin

Date _____

Dist. from initial point in m.	Depth of: Water in m.	Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec: At Instr. m/sec. V	Mean in Vertic Vm	Mean betw. two Vertic Vm	A Area of wetted cross section m^2	q. Vm.A in m^3/sec.
0.00	0.55	W/E					0.635			
0.20	0.67	0.10	50	40	0.60	0.847	0.847	0.741	0.122	0.0941
0.70	0.85	0.51	150	57	0.60	1.784	1.784	1.316	0.380	0.5[illegible]1
1.20	0.85	0.51	90	45	0.60	1.356	1.356	1.571	0.125	0.1[illegible]7
1.70	0.65	0.39	90	41	0.60	1.387	1.387	1.372	0.375	0.5141
2.20	0.55	0.11	150	57	0.20	1.784	1.536	1.462	0.300	0.1[illegible]5
2.70	0.50	0.10	100	42	0.20	1.615	1.384	1.462	0.262	0.38[illegible]
3.20	0.33	0.07	150	57	0.20	1.784	1.536	1.462	0.208	0.304
3.70	0.38	0.08	90	42	0.20	1.454	1.250	1.393	0.178	0.248
4.20	0.31	0.06	90	42	0.20	1.154	1.250	1.250	0.172	0.215
4.70	0.28	Surface	90	41	Surface	1.490	1.118	1.184	0.148	0.175
6.70	0.00						0.838	0.978	0.280	0.273

Cross Sectional Area 2.850 m^2 ; Q(m^3/sec) 3.8104

STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District Jerusalem No. of Measurement CM/ _____
Coordinates
Name of Site Wadi Qilt Flood Station
East _____ North _____

Date Hour	Current Meter: Type & No.	Current Meter: Last calibr	Current Meter: Ring every revolutions	Stop Watch No.	Weather	Wind with, against the flow none	Colour of Water
4.3.80 12:00	S.						

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken
Remarks _____

Results of the present measurement.	Result of the last measurement.
Q 2.779 m³/sec.	Date _____ No. _____
Add or deduct:	_____ m³/sec.
Total 2.779 m³/sec.	

Sign. of Observer _____ Sign. of Computer _____
Date _____
Sign of Distr. Eng. _____
Date _____

Dist. from initial point in m.	Depth of: Water in m.	Depth of: Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec: At Instr. m/sec. V	Water Velocity m/sec: Mean in Vertic Vm	Water Velocity m/sec: Mean betw. two Vertic Vm	A Area of wetted cross section m²	q. Vm.A in m³/sec.
4.30	0.35	M/E								
4.80	0.30	Surf.	30	49		1.471			0.167	
5.80	0.30	"	80	46		1.180			0.300	
6.80	0.30	"	100	47		1.445			0.300	
7.80	0.25								0.275	
8.30	0.20								0.112	
8.80	0.23					1.010			0.108	
9.80	0.30								0.265	
10.80	0.20								0.250	
11.80	0.25								0.225	
12.50	0.15	M/E							0.740	
										2.779

Cross Sectional Area 2.778 m² Q(m³/sec)

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STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District: Jericho No. of means. CM:

Name of site: Wadi Qilt Coordinates: East ____ North ____

Date / Hour	Current Meter: Type & No.	Last Calibr.	Ring Every	Stop Watch No.	Weather	Wind With Against Flow	Colour of Water
16.1.92 14[10]	Ott 4/97497						Clear

Bed Covered With	Vegetation In Channel	Type of Flow
Large Stones/Small Stones, Pebbles	Shrubs	Quiet
Sand, Mud/Concrete	Grass	Turbulent
	Clean	Disturbed

Water Sample Taken / Not Taken

Remarks: Height On Gauge At Parshall = 0.68 m

Result of the present measurement: = 2.0075 m³/Sec.

Result of the last Measurement: Date ____ m³/Sec.

Add or Deduct: - 0.0503 m³/Sec

Total: 1.9272 m³/Sec.

Sign. of Observer: I. Shalom Sign of Computer: I. Shalom

Date: 25.1.92

Sign of Distr. Eng.: M. Nuseibeh

Date: 25.1.92

Dist. from Initial Point in M.	Depth of Water In M.	Depth of Instr. Below Surface M.	No. of Revolutions N.	Time In Sec.	Rev/Sec.	Water Velocity M/Sec: At Instr. M³/Sec. V	Mean In Vertical Vm	Mean Betw. Two Vertic. Vm	Area of Wetted cross Section M²	Vm.A In M³/Sec.
1.00	0.26	W/E					0.343			
1.05	0.30	0.18	28	30	0.9		0.458	0.401	0.014	0.0056
2.05	0.20	0.12	38	30	1.3		0.665	0.561	0.250	0.1403
3.05	0.26	0.16	42	30	1.4		0.717	0.691	0.230	0.1589
4.05	0.24	0.14	42	30	1.4		0.717	0.717	0.250	0.1793
5.05	0.25	0.15	66	30	2.2		1.131	0.924	0.245	0.2264
6.05	0.15	0.09	33	30	1.1		0.562	0.847	0.200	0.1694
7.05	0.20	0.12	39	30	1.3		0.665	0.613	0.175	0.1073
8.05	0.25	0.15	54	30	1.8		0.924	0.795	0.225	0.1789
9.05	0.25	0.15	60	30	2.0		1.028	0.976	0.250	0.2440
10.05	0.23	0.14	48	30	1.6		0.821	0.925	0.240	0.2220
11.05	0.23	0.14	47	30	1.6		0.821	0.821	0.230	0.1533
12.05	0.17	0.10	26	30	0.9		0.455	0.639	0.200	0.1278
13.05	0.13	0.08	19	30	0.6		0.303	0.381	0.150	0.0572
13.10	0.10	W/E					0.227	0.265	0.006	0.0016
										2.0075

Cross Sectional Area: 2.665 M² Q (M³/Sec.) = 2.0075

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STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District Jericho No. of means. CK 2

Name of site Wadi Qilt

Coordinates East _____ North _____

Date Hour	Current Meter Type & No.	Last Calibr	Ring every	Stop Watch No.	Weather	Wind With Against Flow	Colour of Water
18.2.92 14 45	ott 4/97497				Fair		

Bed Covered With	Vegetation In Channel	Type of Flow
Large Stones/Small	Shrubs	Quiet
Stones/Pebbles	Grass	Turbulent
Sand/Mud/Concrete	Clean	Disturbed

Water Sample Taken / Not Taken .

Remarks Measurement Site is 75 m upstream from Parshall Flume

Result of the present measurement 2.6169 m³/Sec.

Add or Deduct: 0.1047

= 2.5122 m³/Sec.

Result of the last Measurement Date 16.1.92 No. 1 1.9272 m³/Sec.

Sign. of Observer I. Shalami Sign. of Computer I. Shalami

Date _____

Sign of Distr. Eng. M. Nuseibeh

Date 19.2.92

Dist. from Initial Point in M.	Depth of Water in M.	Depth of Instr. Below Surface M.	No. of Revolutions N.	Time in Sec.	Rev/Sec.	Water Velocity M/Sec At Instr. M³/Sec. V	Mean In Vertic Vm	Mean Betw. Two Vertic Vm	Area of Wetted cross Section M²	Vm.A In M³/Sec.
2.00	0.11	W/E					0.460			
2.05	0.14	0.08	30	30	1.2		0.613	0.536	0.006	0.0032
2.85	0.35	0.21	42	30	1.4		0.717	0.665	0.245	0.1629
3.85	0.40	0.34	63	30	2.1		1.080	0.898	0.375	0.3368
4.85	0.46	0.28	89	30	3.0		1.540	1.067	0.430	0.4588
5.85	0.47	0.28	57	30	1.9		0.976	1.258	0.465	0.5850
6.85	0.44	0.26	59	30	2.0		1.028	1.002	0.455	0.4559
7.85	0.25	0.15	50	30	1.7		0.872	0.950	0.345	0.3278
8.85	0.22	0.13	39	30	1.3		0.665	0.768	0.235	0.1805
9.15	0.13	0.08	30	30	1.0		0.510	0.588	0.175	0.1029
9.70	0.13	W/E					0.382	0.446	0.007	0.0031
										2.6169

Cross Sectional Area 2.738 m² Q (m³/Sec.)

Note: Water_Level at Parshall : 1.23 m
height (H) of Water : 0.77 m

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STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District Nablus No. of Measurement CM/ 1
Name of Site: Fasi'a Flood Station Coordinates
East _____ North _____

Date Hour	Current Meter Type & No.	Last calibr.	Ring every	Stop Watch No.	Weather	Colour of Water
21.1.74 10:30	Watts 40385		5 revolutions		Wind with, against the flow none	

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/ sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken
Remarks

Results of the present measurement.	Result of the last measurement.
Q 27.91 m^3/sec.	Date _____ No. _____
Add or deduct: ~~e Kanaa~~	_____ m^3/sec.
Total 27.91 m^3/sec.	

Sign. of Observer Y. Sabri S. Ahmad Sign. of Computer M. Nuseibeh
Date 4.2.74
Sign of Distr. Eng. M. Nuseibeh
Date 4.2.74

Dist. from initial point in m.	Depth of Water in m.	Depth of Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec At Instr. m/sec. V	Water Velocity m/sec Mean in Vertic Vm	Mean betw. two Vertic Vm	A Area of wetted cross section m^2	q. Vm.A in m^3/sec.
0.00	0.00	W/E				0.107				
2.50	0.55	0.33	10	50		0.142		0.124	0.688	0.085
3.50	1.00	0.60	150	43		2.353		1.262	0.775	0.975
4.50	1.15	0.69	140	42		2.272		2.327	1.075	2.50
5.50	1.00	0.60	170	42		2.754		2.528	1.075	2.718
6.50	1.35	0.81	220	41		3.729		3.256	1.175	3.826
7.50	1.30	0.78	210	41		3.554		3.641	1.325	4.824
8.50	1.00	0.60	190	40		3.253		3.421	1.150	3.934
9.50	0.85	0.51	180	41		3.030		3.159	0.925	2.922
10.50	0.80	0.48	120	40		2.033		2.531	0.825	2.088
11.50	0.60	0.36	120	43		1.833		1.958	0.700	1.371
12.50	0.50	0.25	90	42		1.434		1.658	0.550	0.911
13.50	0.50	0.25	80	43		1.244		1.339	0.500	0.670
14.50	0.50	0.25	60	47		0.851		1.045	0.500	0.524
~~15.50~~	~~0.35~~					0.638		0.744	0.750	0.558
17.50	0.00	W/E								
										27.91

Cross Sectional Area 12.013 m^2 ; Q(m^3/sec)
12.013

te: W.L on Primary Gauge at beginning of measurement : 1.06 m
" " " " " end " " : 1.06 m
End of measurement : 11.30

B-15

CURRENT METER DISCHARGE OBSERVATION

Name of Stream Wadi Farafleed station
Site
Date 21-1-74
Time: From 10:30 To 11:30
Gauge Readings: U.S. 1.06
D.S. 1.06
Reduced water Level 1.06
Type and No. of Instrument Watts 40385
Weather Conditions Raining
Observer Yousef Sabah
Remarks

Total Surface Width 17.50 M
Total Sectional Area 12.00 M²
Mean Depth M
Maximum Depth 1.35 M
Mean Velocity M/S
Adjusted Discharge 28.052 M³/S
Computer Y Sabah
Date Computed 22-1-74

A Distance from Initial point M	B Width M	C Depth M	D Observation Method	E Observation Depth From w/Surface M	F Revolutions No	G Time Secs.	H Velocity at Point M/Sec.	I Velocity mean at vertical M/Sec	J Area M²	K Discharge M³/Sec.	L Remarks
0.00	1.25	0.00									
2.50	1.75	0.55	0.6	0.50	10	50	0.142		0.344	0.0488	
3.50	1.00	1.00	0.6	0.60	150	43	2.383		1.356	3.2313	
4.50	1.00	1.15	0.6	0.69	140	42	2.272		1.075	2.4434	
5.50	1.00	1.00	0.6	0.60	170	42	2.784		1.075	2.9938	
6.50	1.00	1.35	0.6	0.81	220	41	3.729		1.175	4.3816	
7.50	1.00	1.30	0.6	0.78	210	41	3.564		1.325	4.7201	
8.50	1.00	1.00	0.6	0.60	190	40	3.289		1.150	3.7812	
9.50	1.00	0.95	0.6	0.57	180	41	3.030		0.925	2.8027	
10.50	1.00	0.80	0.6	0.48	120	40	2.035		0.825	1.6777	
11.50	1.00	0.60	0.6	0.36	120	43	1.853		0.700	1.3191	
12.50	1.00	0.50	0.5	0.25	90	42	1.434		0.550	0.7887	
13.50	1.00	0.50	0.5	0.25	80	43	1.244		0.500	0.6220	
14.50	2.00	0.50	0.5	0.25	60	47	0.851		0.500	0.4255	
17.50	1.50	0.00							0.500		

Total 23.221

Checked by:

Date

ADJUSTED DISCHARGE (TOTAL X 96) = 23.052

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STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District Nablus No. of Measurement No. 2

Name of Site: Fara Flood Station

Coordinates East _____ North _____

Date Hour	Current Meter Type & No.	Last calibr.	Ring every	Stop Watch No.	Weather	Wind with, against the flow	Colour of Water
21.1.74 13:00	Watts 40585		5 revolutions			none	

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks _____

Results of the present measurement.	Result of the last measurement.
Q 22.05 m^3/sec.	Date _____ No. _____
Add or deduct:	_____ m^3/sec.
Total 22.05 m^3/sec.	

Sign. of Observer Y. Sulek, S. Ahmad Sign. of Computer Y. Sulek

Date 4.2.74

Sign of Distr. Eng. M. Nuseibeh

Date 4.2.74

Dist. from initial point in m.	Depth of Water in m.	Depth of Instr. below surface m	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec. At Instr. m/sec. V	Mean in Vertic. V_m	Mean betw. two Vertic. m	Area of wetted cross section m^2	q. in m^3/sec.
0.00	0.00	W/E				0.517				
2.50	0.60	0.36	50	49		0.633		0.597	0.750	0.48
4.00	1.10	0.66	150	42		2.443		[illegible]	[illegible]	[illegible]
6.50	1.00	0.60	210	42		3.467		[illegible]	[illegible]	[illegible]
8.50	0.95	0.57	150	41		2.506		[illegible]	[illegible]	[illegible]
10.50	0.85	0.51	110	43		1.716		[illegible]	[illegible]	[illegible]
12.50	0.48	0.20	3	[illegible]		1.173		1.4[illegible]	[illegible]	[illegible]
14.50	0.45	0.20	40	43		0.559		0.916	0.900	0.324
17.00	[illegible]	W/E				0.419		[illegible]	[illegible]	[illegible]
										22.05

Cross Sectional Area 10.777 m^2 ; Q(m^3/sec)

Note: W.L. on Primary Gauge at beginning of measurement = 1.04 m
" " " " " end " " = 1.03 m
end of measurement : 14.00

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CURRENT-METER DISCHARGE OBSERVATION

Name of Stream Wad. Faa Well Station
Site
Date 21 1 74
Time: From 15.00 To 14.00
Gauge Readings: U. S. 1.04
D. S. 1.03
Reduced water Level 1.035
Type and No. of Instrument Watt. 11.534

Weather Conditions Cloudy + Raining

Observer Y. Sabah
Remarks

Total Surface Width 17.40 M
Total Sectional Area ~~4.814~~ 10.888 M²
Mean Depth M
Maximum Depth 1.10 M
Mean Velocity M/S
Adjusted Discharge 24.040 M³/S
Computer Y. Sabah
Date Computed 22 1.74

A Distance From Initial point M	B Width M	C Depth M	D Observation Method	E Depth From % Surface M	F Revolutions No	G Time Secs	H Velocity at Point M/Sec	I velocity mean at vertical M/Sec	J Area M²	K Discharge M³/Sec.	L Remarks
0.00	1.25	0.00									
2.50	2.25	0.60	0.6	0.36	50	49	0.683		0.34	0.231	
4.50	2.00	1.10	0.6	0.66	150	42	2.443		1.412	4.6710	
6.50	2.00	1.00	0.6	0.60	210	42	3.467		2.100	7.2[illegible]	
8.50	2.00	0.99	0.6	0.57	150	41	2.506		1.980	4.9867	
10.50	2.00	0.85	0.6	0.51	110	43	1.716		1.700	3.0998	
12.50	2.00	0.45		0.20	80	42	1.273		1.300	1.6547	
14.50	2.45	0.45		0.20	40	48	0.559		0.900	0.5031	
17.40	1.45	0.00							0.551		

Total 22.29 ~~25.042~~

Checked by:
Date

ADJUSTED DISCHARGE (TOTAL X 96) = ~~24.040~~ 2140

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MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT-METER

District [illegible] No. of Measurement CM/ 3

Name of Site: [illegible]

Coordinates East _____ North _____

Date Hour	Current Meter Type & No.	Last calibr.	Ring every	Stop watch No.	Weather	Wind with, against the flow	Colour of Water
31.1.74 12:50	Watt. 4038		5.0 revolutions			none	

Bed covered with	Vegetation in channel	Type of Flow
Large stones/small stones/pebbles/ sand/mud/concrete floor/stone floor	Shrubs/ Grass Clean	Quiet, Turbulent, Disturbed by

Water Sample taken/not taken

Remarks _____

Dist. from initial point in m.	Depth of Water in m.	Depth of Instr. below surface m.	No. of revolutions n.	Time in sec.	Revolutions per second	Water Velocity m/sec. At Instr. V	Water Velocity m/sec. Mean in Vertic Vm	Water Velocity m/sec. Mean betw. two Vertic Vm	A Area of wetted cross section m²	q. Vm.A in m³/sec.
[illegible]	[illegible]	[illegible]				0.743	[illegible]			
[illegible]	0.30	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	0.716	0.3[illegible]	[illegible]
[illegible]	0.[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	0.182
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		1.327	[illegible]	1.287	[illegible]	0.435
[illegible]	0.35	[illegible]	[illegible]	[illegible]		1.356	1.571	1.366	0.350	0.478
5.00	0.35	[illegible]	130	[illegible]		1.100	1.806	1.699	0.350	0.595
6.00	0.35	[illegible]	150	52		1.920	1.671	1.739	0.350	0.605
7.00	0.35	[illegible]	[illegible]	[illegible]		1.695	1.449	1.555	0.350	[illegible]
[illegible]	0.30	[illegible]	[illegible]	[illegible]		1.935	1.6[illegible]	1.563	0.325	0.508
[illegible]	0.30	[illegible]	70	[illegible]		1.054	0.916	1.259	0.300	0.387
11.70	[illegible]	N/F				0.796	0.685	0.798	0.485	0.323

Cross Sectional Area 3.263 m² ; Q(m³/sec) 4.247

Results of the present measurement. Q 4.247 m³/sec.

Add or deduct: _____

Total _____ m³/sec.

Result of the last measurement. Date _____ No. _____ _____ m³/sec.

Sign. of Observer S. Shalom S. Ahmad Sign. of Computer E. Ahmad

Date 5.2.74

Sign of Distr. Eng. M. Nassel

Date 5.2.74

Note: W.L on Primary gauge at beginning of measurement = 0.75 m
" " " " " end of " " = 0.74 m
Measurement ended at 13:20

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STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT METER

District: Nablus No. of meas. CN

Name Of Site: Wadi Faria Flood station / Coordinates East North

Date Hour	Current Meter Type & No	Last Calibr	Ring every	Stop Watch No.	Weather Wind With, Against Flow	Colour Of Water
20.83 12:40	Watts 40385				None	

Bed Covered With	Vegetation In Channel	Type Of Flow
Large Stone/Small Stones/Pebbles Sand/Mud/Concrete	Shrubs/ Grass Clean	Quiet Turtulent Disturbed

Water Sample Taken/Not Taken

Remarks H. = 0.80 m.

Result Of The Present Measurement Q. ____ M³/Sec.

Add of Deduct: 9.1337

7.1467

Total 7.987 M³/Sec.

Result Of The Last Measurement

Date ____ No. ____

____ M³/Sec.

Sign. Of Observer: I. Shalan, Y. Sawan, S. Ahmed

Sign. Of Computer: I. Shalan

Date 21-2-72

Sign Of Distr. Eng. ____

Date ____

Dist From Initial Point In M.	Depth of Water In M.	Instr. Below Surface M.	No. Of Revolutions N.	Time In Sec.	Revolution Per Second	Water Velocity M³/Sec At Instr M/Sec. V	Mean In Vertic VM	mean Betw. Two Vertic VM	A Area Of Watted Cross Section M²	Q. Vm.A In M³/Sec.
0.00	0.00	WE				0.955		1.114	0.275	0.3064
1.00	0.55	Surface	80	42		1.273		1.474	0.550	0.8107
2.00	0.55	"	100	40		1.676		1.676	0.575	0.9637
3.00	0.60	0.30	100	40		1.676		1.676	0.64	1.0475
4.00	0.65	0.32	100	40		1.676		1.573	0.65	0.9571
5.00	0.60	0.30	90	41		1.470		1.242	0.550	0.6831
6.00	0.50	Surface	70	46		1.015		1.591	0.525	0.8353
7.00	0.55	"	120	42		2.167		2.167	0.525	1.1377
8.00	0.50	"	120	42		2.167		2.576	0.450	1.1592
9.00	0.40	"	160	40		2.986		2.613	0.460	1.2020
11:30	0.00	WE				2.240				
										9.1337

Cross Sectional Area 5.46 M²

Q(M³/Sec.)

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STATE OF ISRAEL
MINISTRY OF AGRICULTURE
WATER COMMISSION
HYDROLOGICAL SERVICE

COMPUTATION OF DISCHARGE MEASURED IN SPRINGS BY MEANS OF CURRENT METER

District; Nablus No. of meas. CM

Name Of Site Wadi Faria / Flood station

Coordinates East ____ North ____

Date Hour	Current Meter Type & No	Last Calibr	Ring every	Stop Watch No.	Weather Wind With, Against Flow	Colour Of Water
21.2.83 13:25	Scientific 21				None	

Bed Covered With	Vegetation In Channel	Type Of Flow
Large Stone/Small Stones/Pebbles Sand/Mud/Concrete	Shrubs/ Grass Clean	Quiet Turtulent Disturbed

Water Sample Taken/Not Taken

Remarks H. = 0.83 m.
H. = 0.82 m.

Result Of The Present Measurement Q 10.8301 M^3/Sec.

Add of Deduct:
= 0.4877

Total 10.3424 M^3/Sec.

Result Of The Last Measurement
Date ____ No. ____
____ M^3/Sec.

Dist From Initial Point In M.	Depth of Water In M.	Depth of Instr. Below Surface M.	No. Of Revolutions N.	Time In Sec.	Revolution Per Second	Water Velocity M^3/Sec At. Instr M/Sec. V	Mean In Vertic VM	mean Betw. Two Vertic VM	A Area Of Watted Cross Section M^2	Q. Vm.A In M^3/Sec.
0.00	0.00	W/E				0.281				
1.50	0.45	Surface	30	55		0.375		0.328	0.338	0.1109
2.50	0.70	0.42	140	43		2.224		1.300	0.575	0.7475
3.50	0.80	0.48	170	42		2.762		2.493	0.750	1.8698
4.50	0.70	0.42	200	40		3.389		3.076	0.750	2.3070
5.50	0.70	0.42	150	42		2.423		2.906	0.700	2.0342
6.50	0.55	Surface	120	42		1.953		2.188	0.625	1.3675
7.50	0.55	"	100	45		1.509		1.731	0.550	0.9520
8.50	0.50	"	80	49		1.106		1.308	0.525	0.6867
9.50	0.40	"	50	46		0.741		0.924	0.450	0.4158
10.50	0.35	"	40	55		0.497		0.619	0.375	0.2321
11.90	0.00	W/E				0.373		0.435	0.245	0.1066
										10.3424

Cross Sectional Area 5.553 M^2

Q(M^3/Sec.)

Sign. Of Observer T. Shalami / S. Ahmad Sign. Of Computer T. Shalami
Date 22-2-83

Sign Of Distr. Eng. ____
Date ____

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APPENDIX C
RAINFALL DATA - SUMMARY OF OCCURRENCES
ABOVE THRESHOLD OCCURRENCES

Al-Bireh

Year	Potential Runoff Occurrences						Total Annual Rain (mm)	Ratio
	>65 mm in 2 days		>50 mm in 1 day		Total			
	Occurrences (#)	Rainfall (mm)	Occurrences (#)	Rainfall (mm) (#)	Occurrences (#)	Rain (mm)		
1967-68								
68-69								
69-70								
70-71								
71-72			1	73	1	73	560	13
72-73			1	171	1	171	414	41
73-74	3	328	1	57	4	384	784	49
74-75							552	
75-76							501	
76-77			1	54	1	54	526	10
77-78	2	167			2	167	590	28
78-79	1	74	1	79	2	153	449	34
79-80	2	254	1	50	3	304	614	49
80-81	2	335	1	62	3	397	831	48
81-82	1	124	1	52	2	177	701	25
82-83	4	599			4	599	1170	51
83-84	3	235	1	87	4	322	571	56
84-85	3	320			3	320	610	53
85-86	1	75			1	75	459	16
86-87	2	281			2	281	768	37
87-88	4	361			4	361	866	42
88-89	3	318			3	318	608	52
89-90	1	144			1	144	635	23
90-91	2	181	1	67	3	247	519	48
91-92	7	1108			7	1108	1479	75
92-93	2	309	1	58	3	367	809	45
93-94			1	60	1	60	598	10
94-95	2	164	1	65	3	229	773	30
95-96	3	296			3	296	640	46
96-97	2	194	1	82	3	276	712	39
				Average	3	287	682	38
				Median	3	279	612	41
				Min	1	54	414	10
				Max	7	1108	1479	75

1. Occurrences with rainfall exceeding 65 mm in 2 days may include occurrences with rainfall > 50 mm in 1 day.
2. Occurrences with rainfall > 50 mm in 1 day are not double-counted.
3. The cutoff limit for a beginnig and the end of a 65-mm occurrence in two days is 20 mm in a day
4. Summary is based on daily rainfall data from the PWA database
5. Ratio = Total rainfall during threshold occurrences/total annual rainfall

Year	Potential Runoff Occurrences						Total Annual Rain (mm)	Ratio
	>65 mm in 2 days		>50 mm in 1 day		Total			
	Occurrences (#)	Rainfall (mm)	Occurrences (#)	Rainfall (mm)	Occurrences (#)	Rain (mm)		
1967-68	2	235			2	235	676	35
68-69	3	307			3	307	702	44
69-70							464	
70-71							611	
71-72							749	
72-73	1	251			1	251	539	47
73-74	4	506	1	53.5	5	559	981	57
74-75	3	340			3	340	604	56
75-76	2	141			2	141	440	32
76-77	3	394	1	57.9	4	452	724	62
77-78	3	288	1	65.7	4	354	587	60
78-79	3	244	1	51.3	4	295	504	59
79-80	4	462	2	112	6	574	924	62
80-81	2	257			2	257	481	53
81-82	2	154	1	52	3	206	568	36
82-83	2	482	1	87	3	569	993	57
83-84	2	241			2	241	440	55
84-85	1	111			1	111	535	21
85-86	1	97			1	97	387	25
86-87	2	363			2	363	732	50
87-88	2	186	1	102.1	3	288	771	37
88-89	2	200			2	200	568	35
89-90	2	209			2	209	545	38
90-91								
91-92	6	890			6	890	1179	76
92-93	2	273	1	56	3	329	762	43
93-94								
94-95	2	196			2	196	552	35
95-96	3	284			3	284	543	52
96-97							607	
				Average	3	323	649	47
				Median	3	286	596	48
				Min	1	97	387	21
				Max	6	890	1,179	76

1. Occurrences with rainfall exceeding 65 mm in 2 days may include occurrences with rainfall > 50 mm in 1 day.
2. Occurrences with rainfall > 50 mm in 1 day are not double-counted.
3. The cutoff limit for a beginnig and the end of a 65-mm occurrence in two days is 20 mm in a day
4. Summary is based on daily rainfall data from the PWA database
5. Ratio = Total rainfall during threshold occurrences/total annual rainfall

Beitunniya

Year	Potential Runoff Occurrences						Total Annual Rain (mm)	Ratio
	>65 mm in 2 days		>50 mm in 1 day		Total			
	Occurrences (#)	Rainfall (mm)	Occurrences (#)	Rainfall (mm)	Occurrences (#)	Rain (mm)		
1953-54	1	100.8			1	101	655	15
54-55			1	54.2	1	54	440	12
55-56	2	156			2	156	675	23
56-57	3	332.8			3	333	736	45
57-58	1	138			1	138	504	27
58-59			1	77	1	77	418	18
59-60	1	78			1	78	285	27
60-61	1	67.2			1	67	592	11
61-62	2	201.5			2	202	516	39
62-63							337	
63-64	2	207.1			2	207	764	27
64-65	2	173.7	1	85.6	3	259	800	32
65-66							423	
66-67	3	245.9	1	57.5	4	303	724	42
67-68			1	50	1	50	590	8
68-69	3	380			3	380	779	49
69-70								
70-71								
71-72	2	198			2	198	721	27
72-73	1	185			1	185	465	40
73-74	2	208	2	114.7	4	322	947	34
74-75	1	67	3	173.1	4	240	686	35
75-76							420	
76-77	1	73	1	62	2	135	563	24
77-78	2	190	1	75	3	265	537	49
78-79	2	176			2	176	516	34
79-80	2	259			2	259	799	32
80-81	2	216			2	216	663	33
81-82	1	88			1	88	561	16
82-83								
83-84								
84-85	1	110	1	78	2	188	535	35
85-86							470	
86-87	1	173			1	173	726	24
87-88	1	82			1	82	716	11
88-89								
89-90								
90-91			1	50	1	50	379	13
91-92	2	425	4	286	6	711	1347	53
92-93	2	299	1	67	3	366	683	54
93-94	2	149	1	55	3	204	540	38
94-95	1	89	1	53	2	142	697	20
95-96	2	197	1	55	3	252	581	43
96-97			2	160	2	160	435	37
				Average	2	200	611	30
				Median	2	186	586	32
				Min	1	50	285	8
				Max	6	711	1347	54

Bethlehem

Year	Potential Runoff Occurrences						Total Annual Rain (mm)	Ratio
	>65 mm in 2 days		>50 mm in 1 day		Total			
	Occurrences (#)	Rainfall (mm)	Occurrences (#)	Rainfall (mm)	Occurrences (#)	Rain (mm)		
1967-68	1	110			1	110	482	23
68-69	1	175			1	175	485	36
69-70								
70-71	1	217			1	217	520	42
71-72	1	67			1	67	422	16
72-73	2	230			2	230	392	59
73-74	3	583			3	583	793	74
74-75	1	100	1	72	2	172	393	44
75-76	1	69	1	61	2	130	378	34
76-77	1	67			1	67	410	16
77-78	1	91	2	106	3	197	479	41
78-79	1	123	1	52	2	175	378	46
79-80								
80-81							535	
81-82							475	
82-83							765	
83-84							375	
84-85							465	
85-86							320	
86-87							655	
87-88							735	
88-89							545	
89-90							558	
90-91							490	
91-92							845	
92-93							565	
93-94							450	
94-95							560	
95-96								
96-97							503	
				Average	2	193	518	39
				Median	2	175	485	41
				Min	1	67	320	16
				Max	3	583	845	74

1. Occurrences with rainfall exceeding 65 mm in 2 days may include occurrences with rainfall > 50 mm in 1 day.
2. Occurrences with rainfall > 50 mm in 1 day are not double-counted.
3. The cutoff limit for a beginnig and the end of a 65-mm occurrence in two days is 20 mm in a day
4. Summary is based on daily rainfall data from the PWA database
5. Ratio = Total rainfall during threshold occurrences/total annual rainfall

Deir Dibwan

Year	Potential Runoff Occurrences						Total Annual Rain (mm)	Ratio
	>65 mm in 2 days		>50 mm in 1 day		Total			
	Occurrences (#)	Rainfall (mm)	Occurrences (#)	Rainfall (mm)	Occurrences (#)	Rain (mm)		
1967-68	1	174			1	174	352	49
68-69							365	
69-70							245	
70-71								
71-72								
72-73							241	
73-74	2	187	3	154	5	341	757	45
74-75	1	67			1	67	452	15
75-76			1	105	1	105	404	26
76-77	1	72			1	72	427	17
77-78	2	182			2	182	426	43
78-79	1	145	1	66	2	211	341	62
79-80	2	238			2	238	721	33
80-81	1	160			1	160	457	35
81-82			1	73	1	73	461	16
82-83	3	433			3	433	822	53
83-84								
84-85	2	179			2	179	412	43
85-86			1	57	1	57	365	16
86-87	1	97			1	97	425	23
87-88							490	
88-89	1	140			1	140	393	36
89-90	1	176			1	176	433	41
90-91							247	
91-92	3	361			3	361	1047	34
92-93	2	268			2	268	588	46
93-94							406	
94-95	2	155			2	155	498	31
95-96							454	
96-97	1	66			1	66	306	22
				Average	2	178	464	34
				Median	1	167	426	35
				Min	1	57	241	15
				Max	5	433	1047	62

1. Occurrences with rainfall exceeding 65 mm in 2 days may include occurrences with rainfall >
2. Occurrences with rainfall > 50 mm in 1 day are not double-counted.
3. The cutoff limit for a beginnig and the end of a 65-mm occurrence in two days is 20 mm in a day
4. Summary is based on daily rainfall data from the PWA database
5 Ratio = Total rainfall during threshold occurrences/total annual rainfall

Salfeet

Year	Potential Runoff Occurrences						Total Annual Rain (mm)	Ratio
	>65 mm in 2 days		>50 mm in 1 day		Total			
	Occurrences (#)	Rainfall (mm)	Occurrences (#)	Rainfall (mm) (#)	Occurrences (#)	Rain (mm)		
1953								
53-54	2	261			2	261	641	41
54-55							397	
55-56	3	258	1	115	4	373	749	50
56-57	1	75	1	64	2	139	524	27
57-58	2	242			2	242	502	48
58-59			1	95	1	95	480	20
59-60	1	91			1	91	304	30
60-61	1	96			1	96	633	15
61-62	2	180			2	180	495	36
62-63			1	50	1	50	347	14
63-64	1	88	3	162	4	250	853	29
64-65	1	129	1	57	2	186	702	26
65-66	1	85			1	85	479	18
66-67	6	767			6	767	1105	69
67-68	1	99	1	50	2	149	606	25
68-69	3	351			3	351	871	40
69-70	1	77			1	77	526	15
70-71	2	279	1	58	3	337	898	38
71-72	1	72	1	57	2	129	758	17
72-73	1	93			1	93	545	17
73-74	3	488	2	121	5	609	1100	55
74-75	3	249	2	103	5	352	450	78
75-76							578	
76-77	1	121	1	66	2	187	641	29
77-78	3	251			3	251	642	39
78-79	1	108	1	53	2	161	433	37
79-80	2	241	2	129	4	369	899	41
80-81	2	290	2	156	4	446	841	53
81-82	1	85	1	80	2	165	621	27
82-83	4	566			4	566	1108	51
83-84	1	78	3	172	4	250	548	46
84-85	2	212			2	212	531	40
85-86			2	109	2	109	541	20
86-87	1	156			1	156	693	23
87-88	2	164	1	60	3	224	812	28
88-89	2	168			2	168	401	42
89-90								
90-91	1	73	1	56	2	129	468	28
91-92	6	747	1	57	7	804	1205	67
92-93	3	464			3	464	769	60
93-94							510	
94-95			3	171	3	171	754	23
95-96	1	82	1	50	2	132	585	23
96-97	1	184	1	51	2	235	776	30
				Average	3	253	659	35
				Median	2	186	621	30
				Min	1	50	304	14
				Max	7	804	1205	78

1. Occurrences with rainfall exceeding 65 mm in 2 days may include occurrences with rainfall > 50 mm in 1 day
2. Occurrences with rainfall > 50 mm in 1 day are not double-counted.
3. The cutoff limit for a beginnig and the end of a 65-mm occurrence in two days is 20 mm in a day
4. Summary is based on daily rainfall data from the PWA database
5. Ratio = Total rainfall during threshold occurrences/total annual rainfall

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APPENDIX D
PHOTOGRAPHS

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Coarse alluvial sediments along Wadi Qilt in Jericho

Wadi Qilt south of Jericho City (looking east)

Wadi Qilt through Jericho showing meandering course and debris
(Looking west)

Wadi Qilt through Jericho showing coarse alluvial sediments
and erosive power of the stormwater
(Looking northeast)

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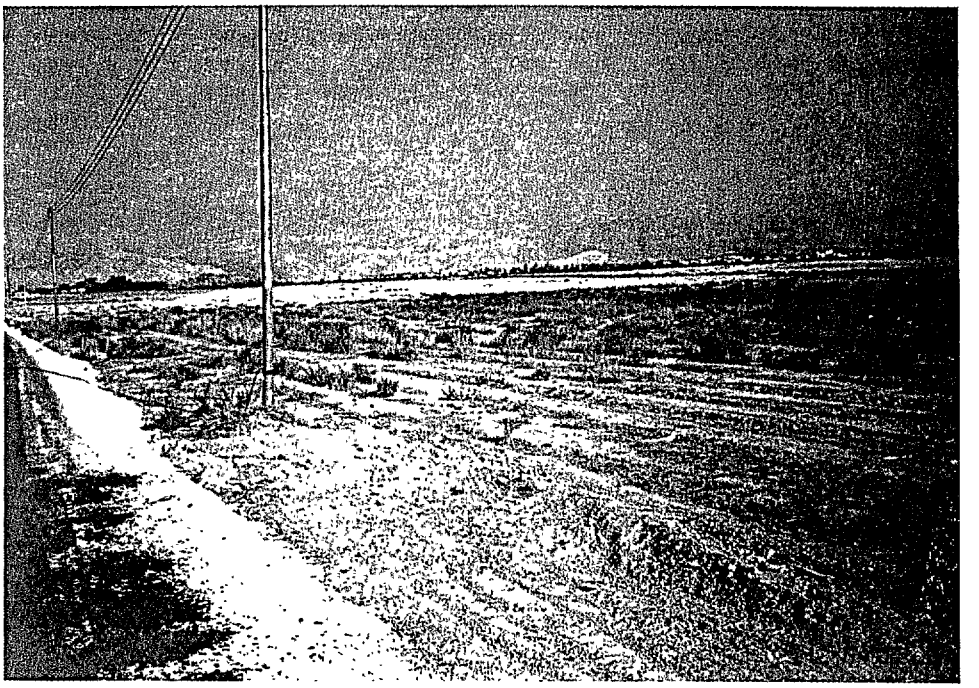
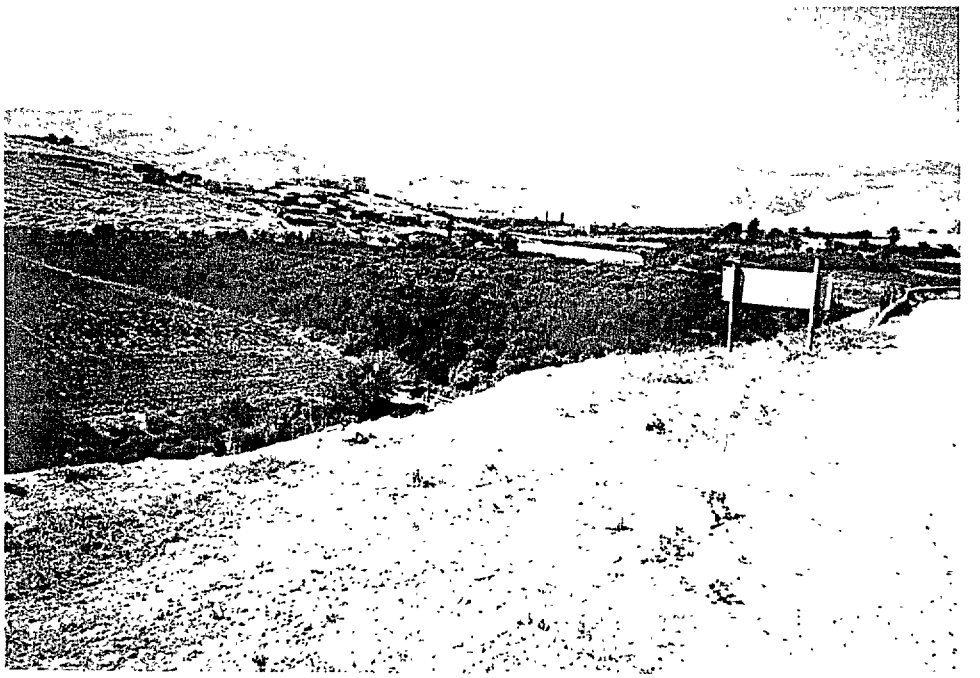
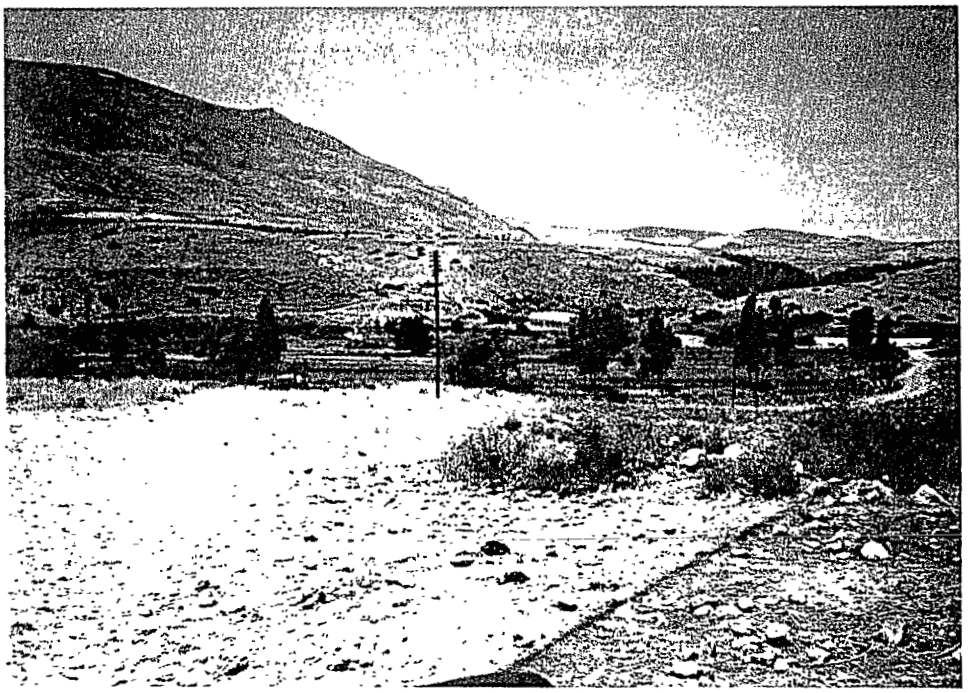


Selected site for potential recharge of Wadi Qilt runoff, south of Jericho



Farms and orchards along Wadi Fari'a, several kilometers downstream of the proposed dam

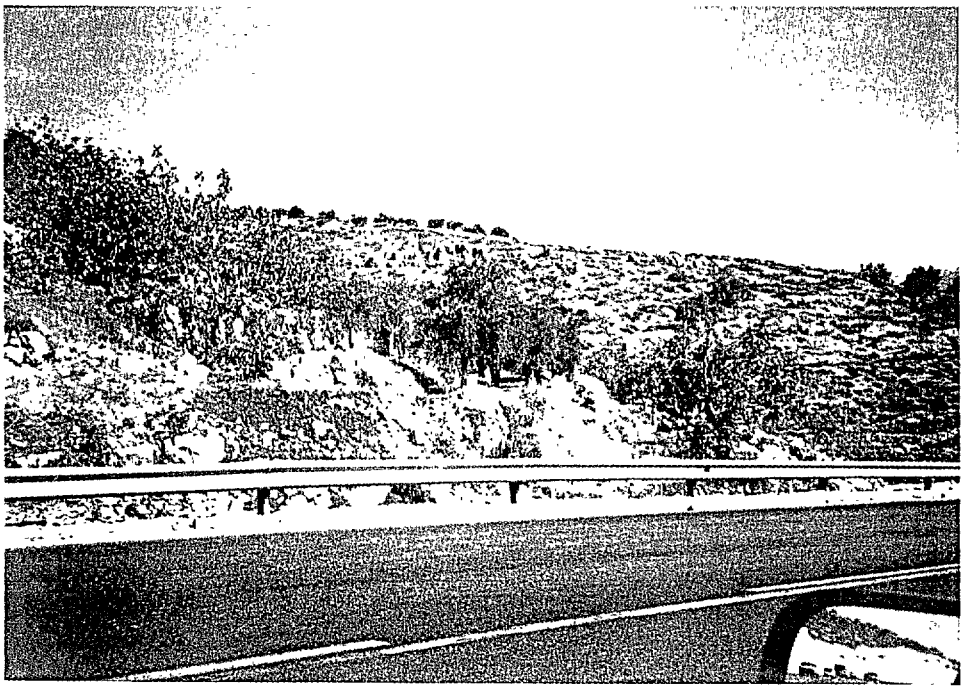


The village of Nassarieh immediately downstream of the selected dam site location at Wadi Fari'a (showing rolling plains and gentler slopes near the wadi). Looking northwest.

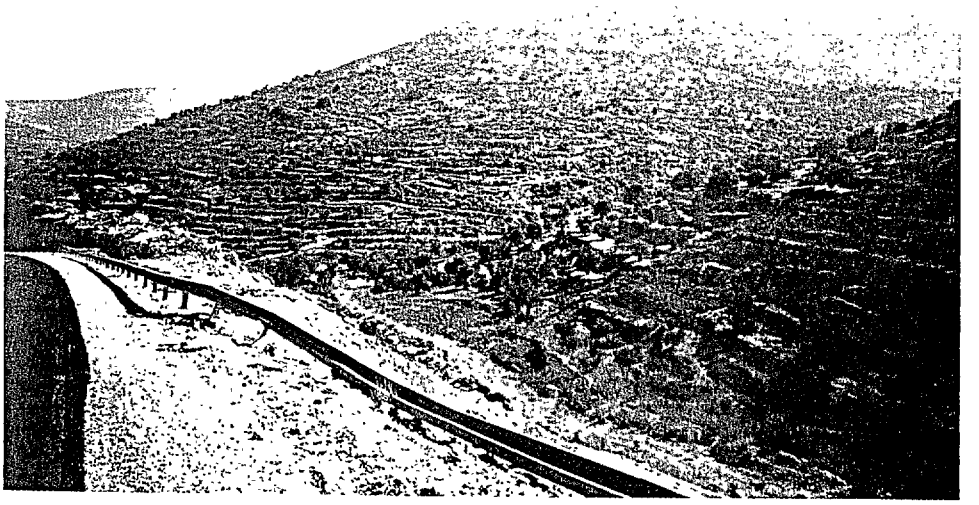
Wadi Fari'a at the selected location of the proposed dam
(showing relatively steep and rocky side slopes)

Wadi Fari'a at the village of Nassarieh
(photo shows lush vegetation along stream with birds - the white dots in the grass in the background are cranes - fish were also observed)

Wadi Fari'a at the village of Nassarieh
(the approximate flood line of the 1991/92 storm season is marked by the green vegetation line in the background)



Natural terraces along side slopes in the Hebron-Bethlehem area



Natural terracing and local depressions in the upper reaches of the Wadi Auja catchment

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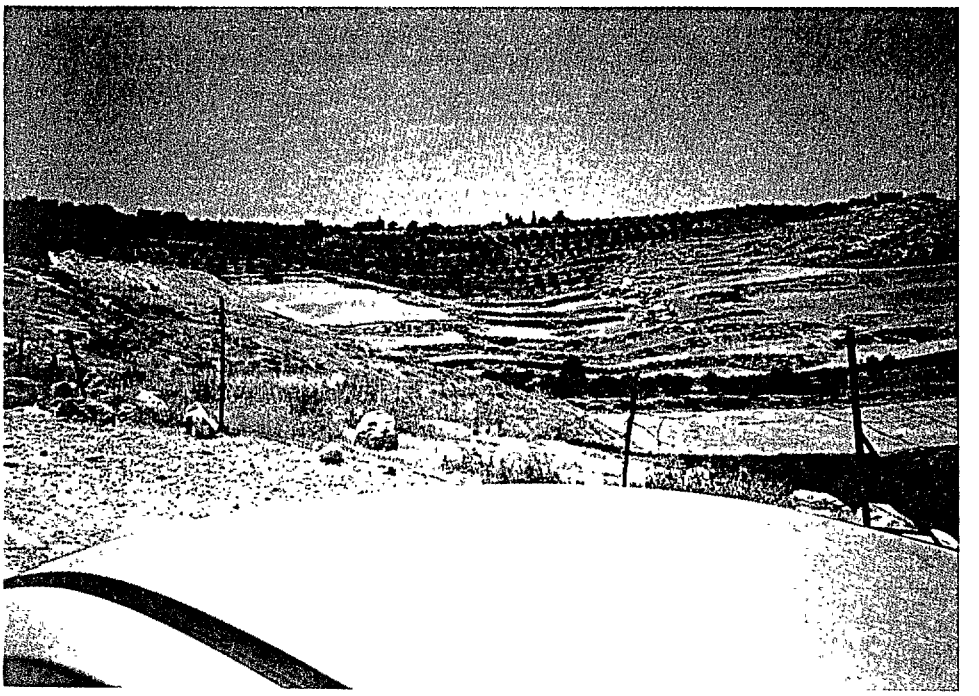
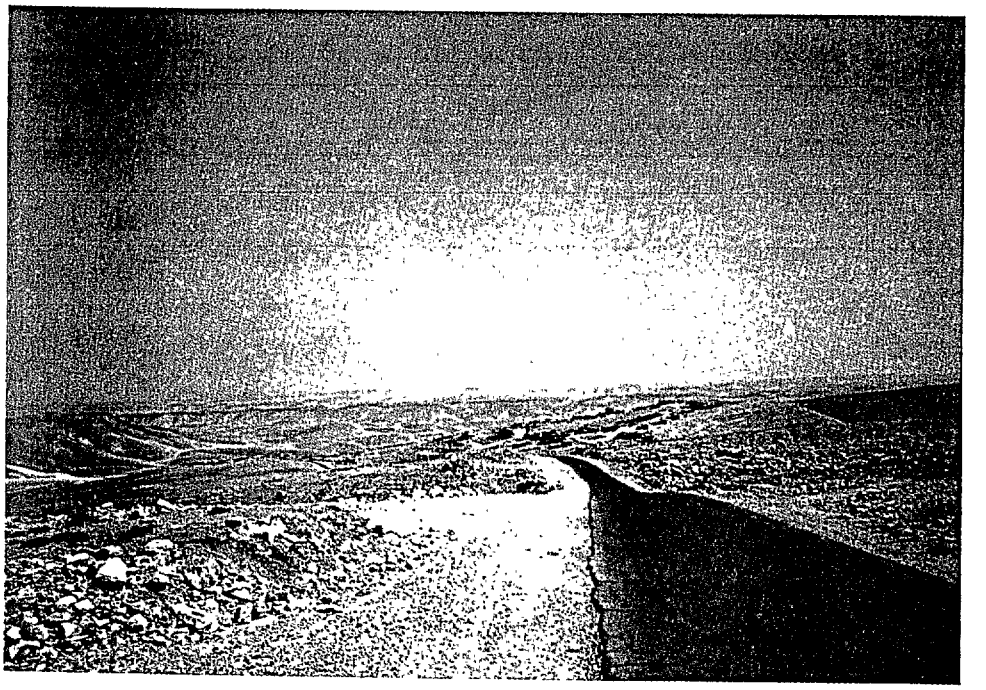
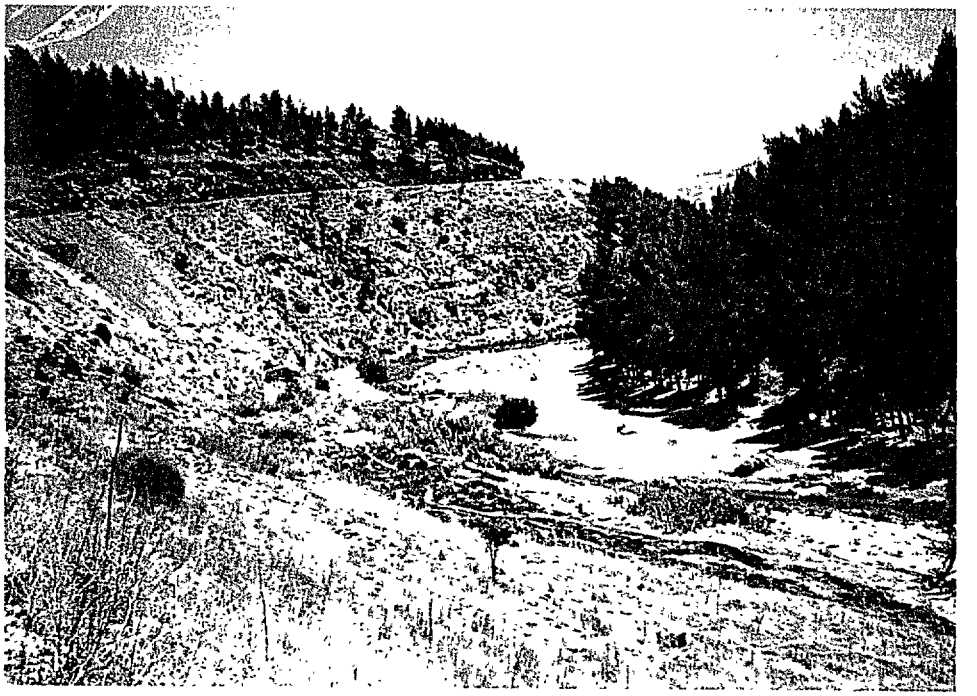


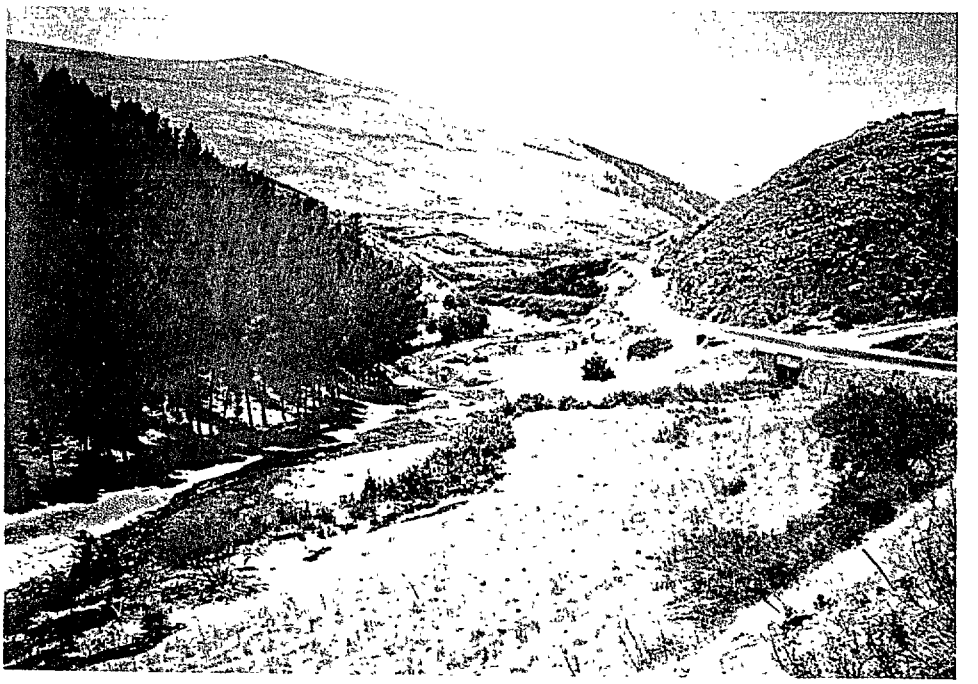
Upper reaches of Wadi Daraja (Mashash) near Tqu'
(Man-made terracing on Senonian chalks and the natural vegetation cover of "Netish")



Gentle slopes of Southern catchments with impermeable Senonian outcrops
(low rainfall catchments)

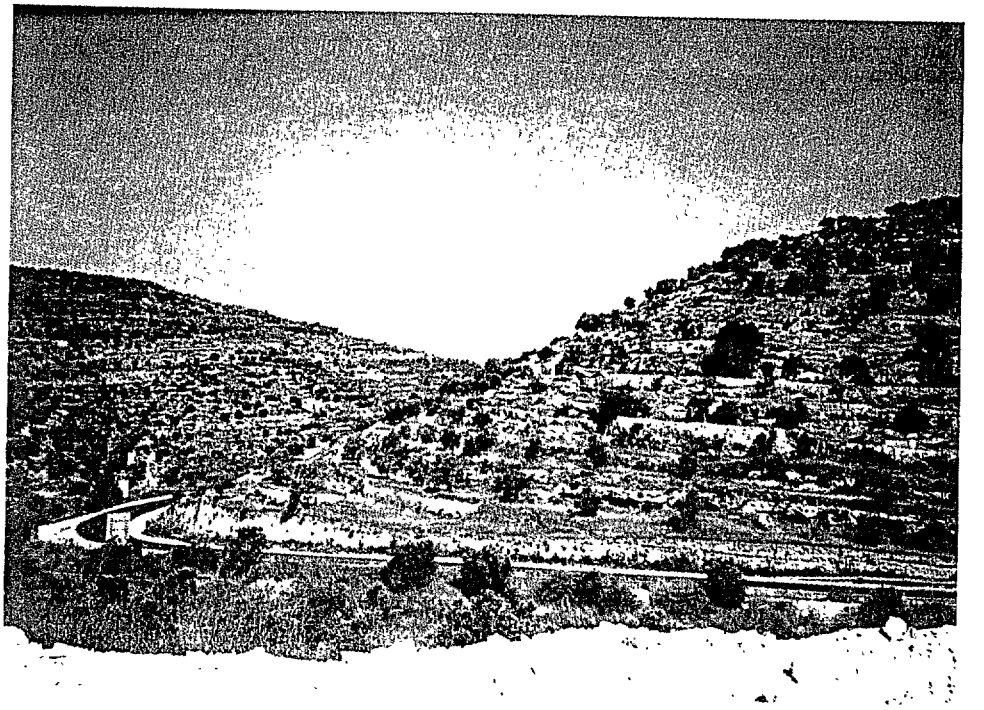


Wadi Fari'a, immediately downstream of the confluence of Wadi Fari'a and Badan;
about 1.5 km upstream of the proposed dam location
(the upstream extent of the lake behind the proposed dam)



Wadi Fari'a at Jisr Malaki (shown on the right of the photo)
at the confluence of Wadi Fari'a and Badan (looking southwest)

BEST AVAILABLE COPY



Natural terracing and vegetative cover (including "Zuhaif") along side slopes near Yabrud

Natural terracing with man-made retaining walls (made from stone) near Deir Dibwan

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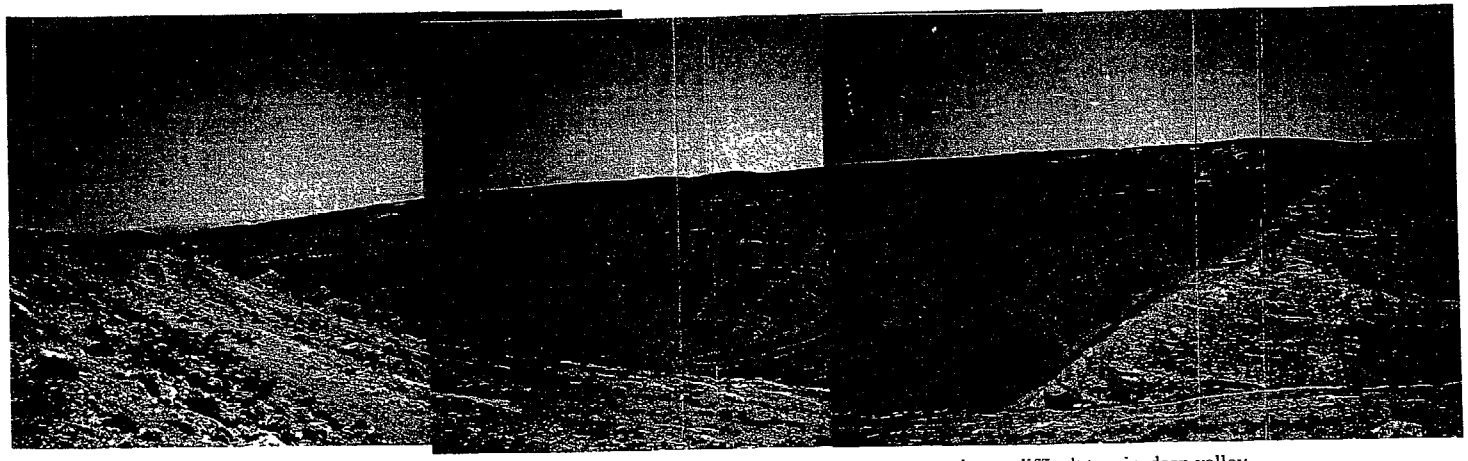
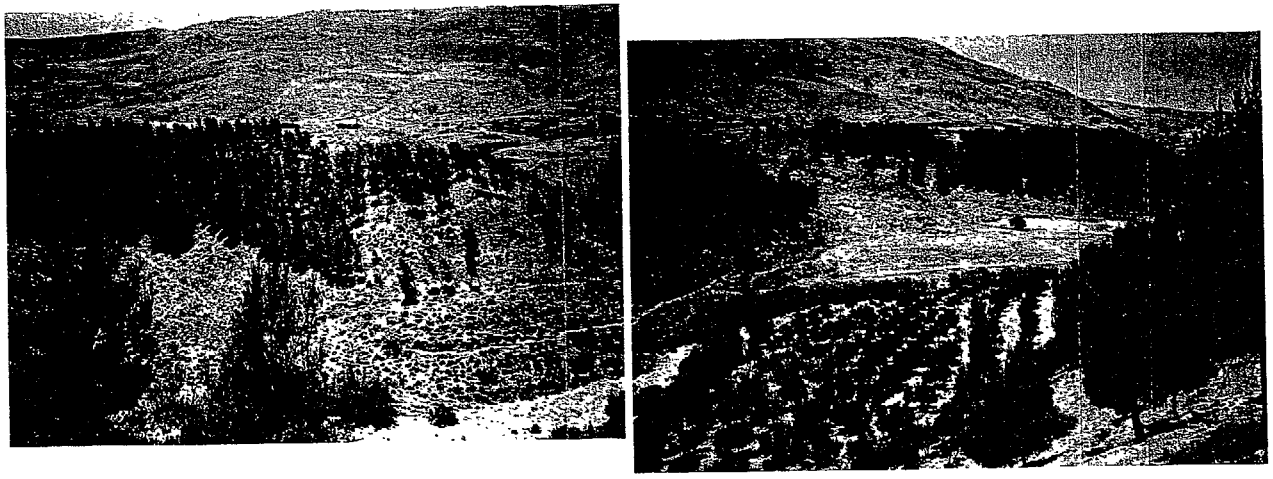


Wadi Ghar (looking south), southwest of Tqu' and downgradient of Beit Fajjar, showing steep slopes, difficult terrain, deep valley, natural vegetative cover ("Netish"), natural terracing, and outcrops of Upper Cenomanian rocks



Wadi Fari'a at the selected location of the proposed dam
(Looking west)

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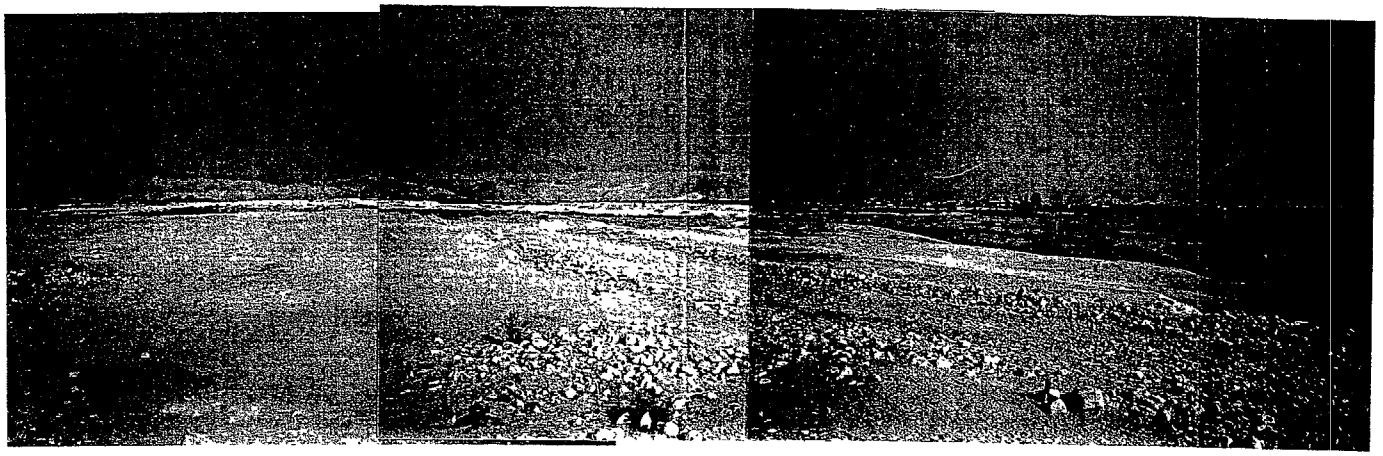

Proposed location of the infiltration system for Wadi Qilt runoff/stormwater
(Looking west, Jericho in the background right, Wadi Qilt in the middle right)

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APPENDIX E
SUMMARY OF WATER UNIT COSTS OF WATER FOR EVALUATED STORMWATER HARVESTING SCHEMES

ESTIMATED UNIT COST OF WATER - WADI Al-QILT SCHEME

Year	Flow (Mcm/yr)	Capital Cost (US $ M)	O&M Cost (US $ M)	PWF (i=10%)	Present Worth Value: Capital (US $ M)	O&M (US $ M)	Subtotal (US $ M)	Flow (Mcm/yr)
1		2		1	2			
2		5		0.90909	4.55		4.55	
3		12		0.82645	9.92		9.92	
4		12		0.75131	9.02		9.02	
5		5		0.68301	3.42		3.42	
6	1.1		1	0.62092		0.62	0.62	0.66
7	2.5		1	0.56447		0.56	0.56	1.41
8	5.6		1	0.51316		0.51	0.51	2.88
9	1.0		1	0.46651		0.47	0.47	0.47
10	1.0		1	0.42410		0.42	0.42	0.42
11	0.8		1	0.38554		0.39	0.39	0.30
12	2.4		1	0.35049		0.35	0.35	0.85
13	2.2		1	0.31863		0.32	0.32	0.71
14	4.4		1	0.28966		0.29	0.29	1.28
15	5.8		1	0.26333		0.26	0.26	1.53
16	2.6		1	0.23939		0.24	0.24	0.62
17	8.7		1	0.21763		0.22	0.22	1.90
18	4.7		1	0.19784		0.20	0.20	0.93
19	4.7		1	0.17986		0.18	0.18	0.84
20	1.1		1	0.16351		0.16	0.16	0.18
21	4.1		1	0.14864		0.15	0.15	0.61
22	5.3		1	0.13513		0.14	0.14	0.71
23	4.6		1	0.12285		0.12	0.12	0.57
24	2.1		1	0.11168		0.11	0.11	0.23
25	3.6		1	0.10153		0.10	0.10	0.37
26	16.2		1	0.09230		0.09	0.09	1.49
27	5.4		1	0.08391		0.08	0.08	0.45
28	0.9		1	0.07628		0.08	0.08	0.07
29	3.3		1	0.06934		0.07	0.07	0.23
30	4.3		1	0.06304		0.06	0.06	0.27
31	4.0		1	0.05731		0.06	0.06	0.23
32	4.0		1	0.05210		0.05	0.05	0.21
33	4.0		1	0.04736		0.05	0.05	0.19
34	4.0		1	0.04306		0.04	0.04	0.17
35	4.0		1	0.03914		0.04	0.04	0.16
36	4.0		1	0.03558		0.04	0.04	0.14
37	4.0		1	0.03235		0.03	0.03	0.13
38	4.0		1	0.02941		0.03	0.03	0.12
39	4.0		1	0.02673		0.03	0.03	0.11
40	4.0		1	0.02430		0.02	0.02	0.10
41	4.0		1	0.02209		0.02	0.02	0.09
42	4.0		1	0.02009		0.02	0.02	0.08
43	4.0		1	0.01826		0.02	0.02	0.07
44	4.0		1	0.01660		0.02	0.02	0.07
45	4.0		1	0.01509		0.02	0.02	0.06
46	4.0		1	0.01372		0.01	0.01	0.05
47	4.0		1	0.01247		0.01	0.01	0.05
48	4.0		1	0.01134		0.01	0.01	0.05
49	4.0		1	0.01031		0.01	0.01	0.04
50	4.0		1	0.00937		0.01	0.01	0.04
				Total	**28.89**	**6.74**	**33.63**	**22.14**
		Unit Cost of Water (US $/m³)						**1.52**

(1) Flows were estimated based on rainfall during threshold occurrences for Al-Bireh; a ratio of 0.1 was used to estimate runoff from total rainfall during these occurrences (catchment area = 146 km²)

(2) A discount rate of 10% was used for calculating the present worth values

(3) An economic life of 50 years was assumed; depreciation was not considered

(4) Water Unit Cost = Total present worth capital and O&M costs/Total present worth flow

ESTIMATED UNIT COST OF WATER - WADI FARI'A SCHEME

Year	Flow (Mcm/yr)	Capital Cost (US $ M)	O&M Cost (US $ M)	PWF (i=10%)	Present Worth Value: Capital (US $ M)	O&M (US $ M)	Subtotal (US $ M)	Flow (Mcm/yr)
1		5		1	5			
2		5		0.90909	4.55		4.55	
3		30		0.82645	24.79		24.79	
4		25		0.75131	18.78		18.78	
5		10		0.68301	6.83		6.83	5.85
6	8.6		2.3	0.62092		1.43	1.43	1.86
7	3.0		2.3	0.56447		1.30	1.30	6.18
8	10.9		2.3	0.51316		1.18	1.18	3.06
9	6.0		2.3	0.46651		1.07	1.07	3.80
10	8.1		2.3	0.42410		0.98	0.98	2.13
11	5.0		2.3	0.38554		0.89	0.89	1.90
12	4.9		2.3	0.35049		0.81	0.81	1.77
13	5.0		2.3	0.31863		0.73	0.73	2.17
14	6.8		2.3	0.28966		0.67	0.67	1.18
15	4.1		2.3	0.26333		0.61	0.61	2.19
16	8.3		2.3	0.23939		0.55	0.55	1.67
17	7.0		2.3	0.21763		0.50	0.50	1.04
18	4.8		2.3	0.19784		0.46	0.46	3.82
19	19.3		2.3	0.17986		0.41	0.41	1.11
20	6.2		2.3	0.16351		0.38	0.38	1.71
21	10.5		2.3	0.14864		0.34	0.34	0.69
22	4.6		2.3	0.13513		0.31	0.31	1.38
23	10.2		2.3	0.12285		0.28	0.28	0.71
24	5.8		2.3	0.11168		0.26	0.26	0.56
25	5.0		2.3	0.10153		0.23	0.23	1.62
26	16.0		2.3	0.09230		0.21	0.21	0.97
27	10.5		2.3	0.08391		0.19	0.19	0.50
28	6.0		2.3	0.07628		0.18	0.18	0.53
29	7.0		2.3	0.06934		0.16	0.16	0.58
30	8.4		2.3	0.06304		0.14	0.14	0.40
31	6.4		2.3	0.05731		0.13	0.13	0.62
32	10.9		2.3	0.05210		0.12	0.12	0.65
33	12.5		2.3	0.04736		0.11	0.11	0.31
34	6.5		2.3	0.04306		0.10	0.10	0.65
35	15.0		2.3	0.03914		0.09	0.09	0.33
36	8.3		2.3	0.03558		0.08	0.08	0.27
37	7.5		2.3	0.03235		0.07	0.07	0.17
38	5.3		2.3	0.02941		0.07	0.07	0.19
39	6.3		2.3	0.02673		0.06	0.06	0.21
40	7.8		2.3	0.02430		0.06	0.06	0.16
41	6.6		2.3	0.02209		0.05	0.05	0.18
42	8.0		2.3	0.02009		0.05	0.05	0.12
43	5.7		2.3	0.01826		0.04	0.04	0.37
44	20.1		2.3	0.01660		0.04	0.04	0.21
45	12.9		2.3	0.01509		0.03	0.03	0.09
46	6.0		2.3	0.01372		0.03	0.03	0.09
47	6.6		2.3	0.01247		0.03	0.03	0.07
48	5.8		2.3	0.01134		0.03	0.03	0.09
49	8.0		2.3	0.01031		0.02	0.02	0.08
50	8.0		2.3	0.00937		0.02	0.02	0.00
				Total	**59.95**	**15.49**	**70.45**	**54.24**
		Unit Cost of Water (US $/m³)						**1.30**

(1) Flows were estimated based on rainfall during threshold occurrences for Salfit; a ratio of 0 15 was used to estimate runoff from total rainfall during these occurrences (catchment area =142 km²) ; a 3 Mcm was added to account for the average winter spring flow

(2) A discount rate of 10% was used for calculating the present worth values

(3) An economic life of 50 years was assumed; depreciation was not considered

(4) Water Unit Cost = Total present worth capital and O&M costs/Total present worth flow

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