An-Najah National University
Faculty of Graduate Studies

Natural Runoff and Development of Infiltration System in Faria Catchment

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Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Water and Environmental Engineering, Faculty of Graduate Studies, at An-Najah National University, Nablus, Palestine.

2008

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Dedicated to

My parents, brothers and sisters

Acknowledgment

First of all, thanks to Allah for making this possible. I would like to express my sincere gratitude to my supervisors Dr. Hafez Shaheen and Dr. Anan Jayyousi for there supervision, guidance and constructive advice. Thanks also go to the water and environmental studies Institute (WESI) that gave me the chance to work on EXACT project. I am also grateful to Dr. Sameer Shadeed for the generous support and guidance he gave me throughout the year whilst working on this research.

Special thanks go to Prof. Delaat and Prof. Nooner of UNESCO-IHE who without their help and support, the completion of the thesis would never have been possible.

Appreciation is also expressed to my family, friends, colleagues and the university staff for their informed constructive criticism and moral support.

الإقـــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Natural Runoff and Development of Infiltration System in Faria Catchment

اقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء مـــا تمـــت الإشارة إليه حيثما ورد، وان هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة علمية أو بحث علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's name:	**اسم الطالب:**
Signature:	**التوقيع:**
Date:	**التاريخ:**

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Abstract

This study suggests proper management of the runoff water in Faria catchment and how to capture the excess rain during the rainy season. The study has been performed in the frame of EXACT project to develop an integrated prediction-optimization model for water harvesting, storage and utilization in Faria catchment.

An integrative study of the methods for rainfall-runoff simulation has been performed. The modeling of the runoff is based here on a presumed strong causal relationship between runoff and rainfall as the only available input data. Hydrometeorigical data such as annual total, annual daily rainfalls and catchment outlet runoff for several events were analyzed through statistical methods and applying EXCEL and GIS program utilities. A regression relation between rainfall intensity and runoff coefficient has been developed. Earth fill dam is proposed to return the surface runoff.

Volume quantification, site selection and design criteria of the earth fill dam were developed and identified. Further hydrograph simulation and routing of the flow were done.

The development of the suggested infiltration system to recharge the groundwater resources by constructing the earth retention dam at the selected site in Upper Faria catchment is seen as an important requirement for the development of the water resources in the area.

CHAPTER ONE

INTRODUCTION

1.1 Background

The lack of a reliable water supply is a serious hindrance to human settlement in rural areas. In the West Bank, Palestine, the Faria catchment is one of the most important rural catchments known by its scarce water resources. Faria catchment has shallow, rocky soils with medium water retention capacity, and medium susceptibility to erosion.

The Faria catchment is located within the Mediterranean semiarid regions. Therefore its surface water resources are scarce and its groundwater is considered the main fresh water resource. Rain water in Faria catchment is lost mostly as runoff towards the Jordan River and further to the Dead Sea. Many solutions have been suggested to solve the problems of shortage and management of surface water in semiarid areas. Among these are: Water harvesting, management of water resources, and development of infiltration systems to recharge the groundwater resources. The development of infiltration systems to recharge the groundwater resources in the Faria catchment is seen as among the most important requirements for the development and management of the catchment water resources.

The Faria catchment, as one of the most important agricultural resources in the West Bank is selected for this study. The springs water and winter flood water in the Faria catchment lack proper management and there is no capture of the rain and runoff water during the rainy storms.

The Palestine Water Authority (PWA) and UNESCO–IHE has agreed to carry out a pilot study on artificial recharge of the groundwater aquifers with surface water. The Faria catchment was selected for this pilot study. The project is funded by the Ministry of Foreign Affairs of the Netherlands and is undertaken in the frame of the **EXACT** project. EXACT project documents distinguish three phases: A first phase of two years for measuring hydrological parameters, a second phase of one year for the construction of infiltration works and a third phase of two years for monitoring the performance of infiltration sites. This study serves as a preparation for phase two.

The thesis is sponsored by EXACT project and is implemented through WESI. It is one of the two MSc thesis agreed between EXACT and WESI to focus on the evaluation and requirements of recharging the groundwater aquifer and wells in the Faria catchment with the surface water and storm water flowing in the upper sub-catchments of the Faria catchment.

1.2 Objectives

Faria catchment lacks storage reservoirs to capture the rain floods during the rainy season in order to be used later or to be artificially recharged into the groundwater (Abu Baker, 2007).

The main objective of this research is to develop proper systems for capturing the runoff resulting from rainfall events and allowing surface water to infiltrate into the ground. The objectives can be summarized as:

- Capturing runoff resulting from rainfall events.
- Study and develop proper infiltration systems for capturing the runoff to recharge the groundwater resources.
- Propose locations for water retention structures within the catchment.

1.3 The Study Area

1.3.1 Location

Faria catchment is located in the Northeastern part of the West Bank, Palestine. Generally, Faria catchment, as shown in **Figure 1**, is completely contained within the Eastern Aquifer, one of the three main West Bank aquifers. The western part of the Faria catchment which is approximately 50 km from the Mediterranean Sea is the area under consideration.

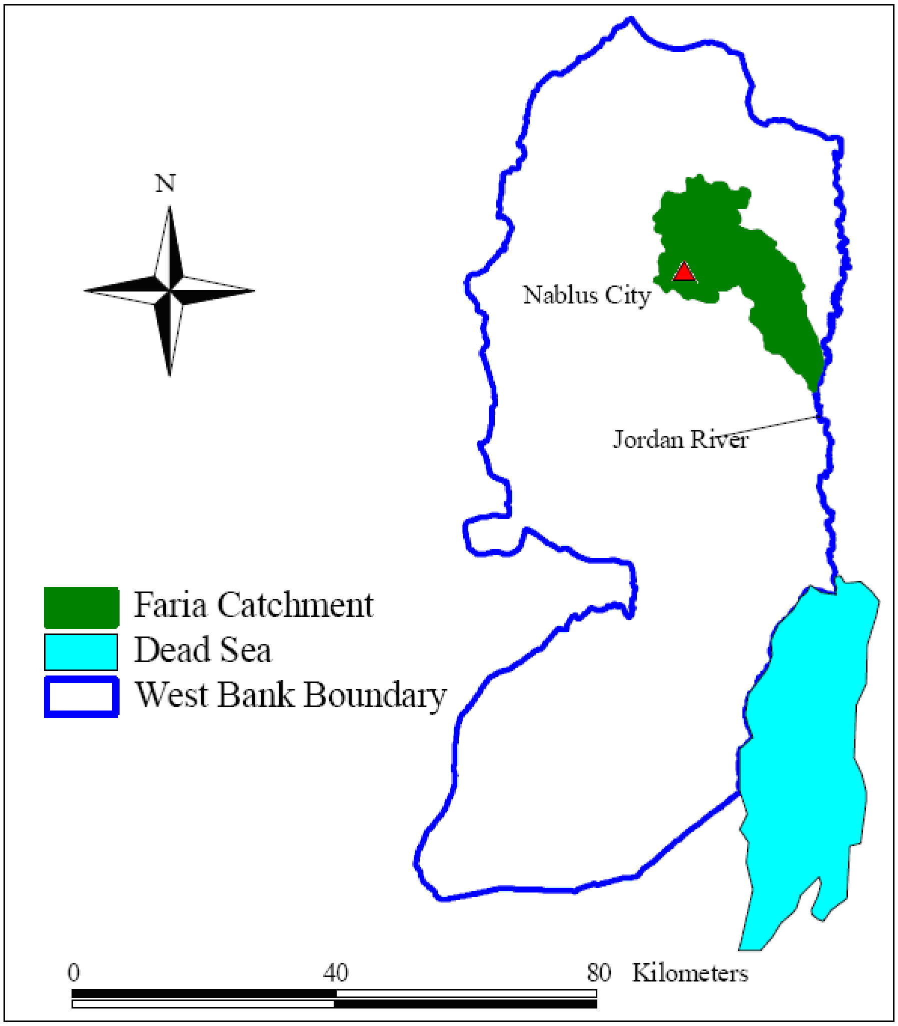

Figure 1: Location of the Faria Catchment within the West Bank

The Faria catchment is divided into three sub catchments which are: Upper Faria, Badan and Malaqi. **Figure 2** shows the boundary of the three sub-catchments of the Faria. The upper Faria and Badan contain most of the water springs and catch most of the rain water falling within the catchment. The springs and rain water flow further down towards Al-Malaqi and further towards the Jordan River and the Dead Sea. Therefore, it is to focus on harvesting the water resources upstream in both Badan and Upper Faria to be recharged into the ground. Most of the groundwater wells are located downstream within Al-malaqi sub-catchment (**see Figure 3).**

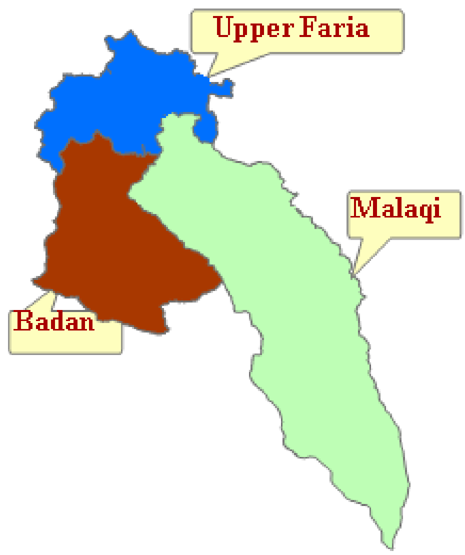

Figure 2: Outline of Faria Sub-Catchments (WESI, 2006)

1.3.2 Area

The total catchment area of the Faria is about 320 km^2, which is 6% of the total area of 5600 km^2 of the West Bank (WESI, 2006). The areas of the three sub-catchments of Faria were measured by GIS software and are presented in **Table 1.**

Table 1: Faria Sub-catchments

Sub catchment	Area (km^2)
Upper Faria	56
Badan	83
Malaqi	181
Total	320

1.3.3 Geology

The Faria catchment is characterized as being composed of complicated and diverse geological structures dominated by small faults. The geological structure of the study area is composed from limestone, dolomite and marl (Shadeed, 2005).

1.3.4 Topography

Faria catchment topographic map is available and is presented in Figure 3.

The topography is a unique factor in the Faria catchment which starts at 900 meters above mean sea level in Nablus Mountains and descends drastically to about 350 meters below mean sea level at the point where the Faria wadi meets the Jordan River. **Figure 3** gives the elevations within the Faria catchment and shows the streams and wadis forming the stream system and order of the Faria drainage basin.

1.3.5 Rainfall-Runoff Gauging

The Faria catchment used to be gauged by five rainfall stations, these stations are located in Nablus, Tallouza, Tubas, Beit Dajan and Tammun, **Table 2** lists the five stations giving their elevations and the annual data available.

Table 2: Faria catchment Rainfall Stations

Rainfall Station	Elevation(m)	Annual Data
Tubas	375	1967 -2007
Tammun	340	1966 - 2007
Tallouza	500	1963 - 2007
Nablus	570	1949 - 2007
Beit Dajan	520	1952 - 2007

These stations were simple rain gauges which measure daily precipitation. In the context of EXACT project four Tipping Bucket Rain gauges were installed in the catchment in 2004. In August 2003 and in context of GLOWA Jordan River project two Parshall flumes have been constructed at the outlets of Badan and upper Faria catchments to measure the water level and the runoff. The rainfall distribution within the Faria catchment ranges from 640 mm at the head water near Nablus city to 150 mm at the vicinity of the Jordan River (Shadeed, 2005).

1.4 Site Visits and Field Exploration

Several sites visits have been paid to investigate and explore the Faria catchment and its features. The visits provided knowledge and information about the location, soil, and flowing water conditions in the wadi due to rainfall and springs water.

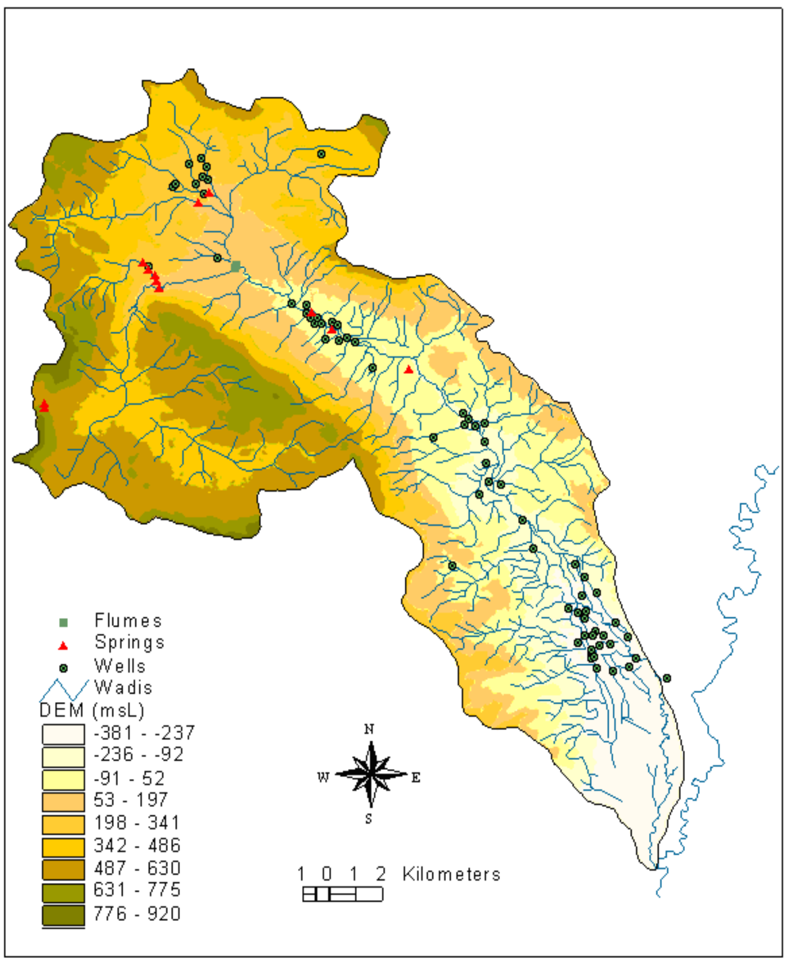

Figure 3: Topography and Stream System of Faria catchment.

1.5 Methodology

To achieve the objectives of the study, Ms-Excel and GIS were used to perform data entry; statistical analysis and graphical presentations. The following steps were applied to perform the study:

1. The studies performed in Faria catchment are reviewed.
2. Collect, analyze and model the data of the tipping buckets rain gauges since 2004.
3. Collect, analyze and model the data of the runoff measuring since 2003.
4. Statistical analysis of the rainfall time series.
5. Simple rainfall, runoff models were applied.
6. Estimation of runoff volumes and runoff coefficients.
7. Selection criteria for the infiltration systems and site selection of retention structures were defined.

The following chart **(Figure 4)** illustrates the methodology of the study.

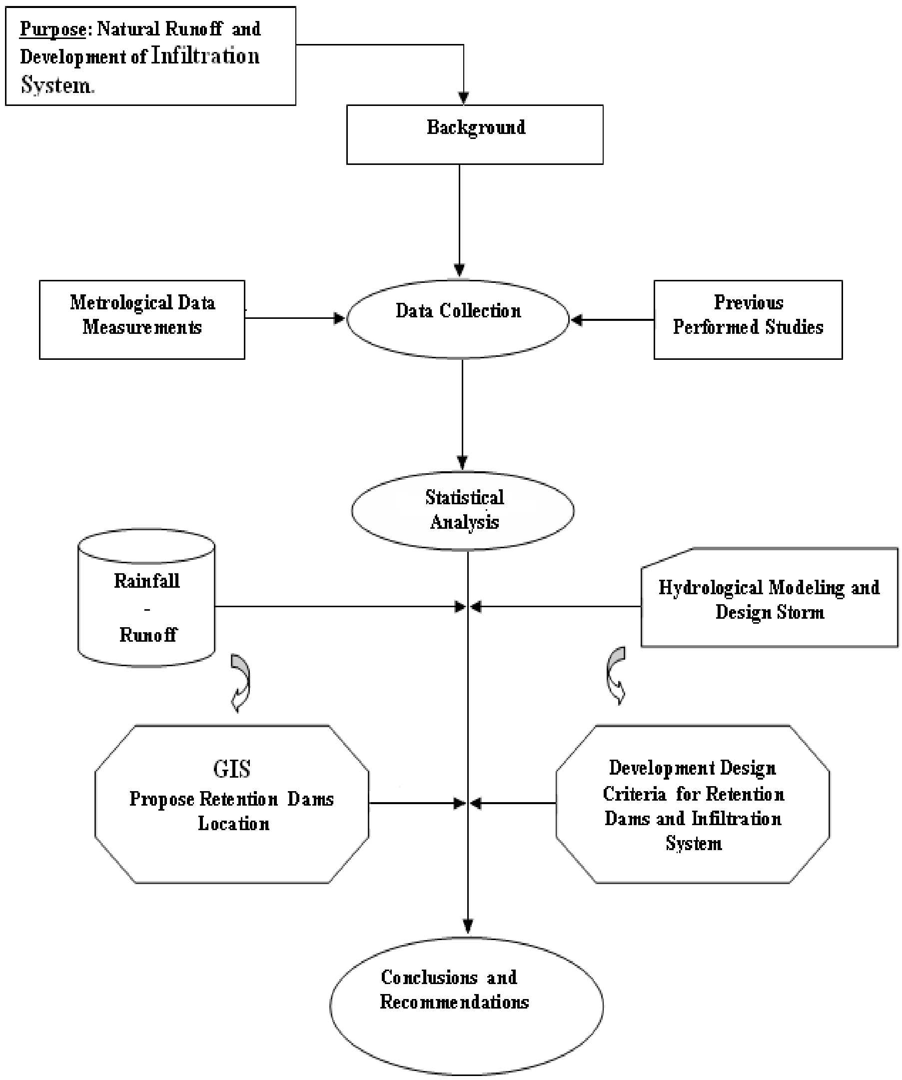

Figure 4: Flow chart of the study methodology

Chapter Two

Literature Review

2.1 Background

West Bank, Palestine, is one of the Mediterranean semiarid areas. The available water resources in the West Bank are limited and insufficient to meet the agricultural and domestic water needs. Rainfall is the main replenishment of surface and groundwater resources in Palestine. Characterization of rainfall magnitudes and patterns is of great importance in the management and development of scarce water resources in the main cities of the West Bank.

In the Mediterranean region, many semiarid catchments are under extreme stresses due to the climate changes and drought conditions that influence water availability in a negative manner when considering the increasing need to boost up the agricultural production rate (Almasri et al., 2006).

In this study it is to focus on the water resources in Al-Faria catchment as one of the most important agricultural areas in the northern West Bank. It is to study the potential for artificial recharge of surface water into the ground as a mean to enhance the management of the water resources in Al-Faria catchment.

2.2 Rainfall Measurements

Rainfall is measured with rain gauge, which is an instrument that captures precipitation and measures its accumulated volume during a certain time period. Rain gauges can be of two types: (1) non-recording or (2) recording. A non-recording gauge measures the total rainfall depth accumulated during one time period, usually one day. A recording rain gauge records the time it takes for rainfall depth accumulation. Therefore, it provides not only a measure of rainfall depth but also of rainfall intensity. Recording rain gauges rely on a tipping bucket device and other devices.

In 2004, four tipping bucket rainfall gauges were installed to replace the non-recording cylinder gauges at Tallouza, Tammun, Tubas and Beit Dajan town within Al-Faria catchment. In Nablus city the rain gauge using recording charts is still working and is available.

2.3 Flow Measurements

The discharge at a given location along a stream can be evaluated by measuring the stage and using a known rating to obtain the discharge. The point along the stream where the measurements are made is called the gauging site, or gauging station. The measurement of discharge and stage is referred to as stream gauging. A recording gauge measure the water stages continuously and records them on a strip chart. This type of gauge is commonly used for continuous measurements of water levels.

In the absence of a natural section control, an artificial control as a concrete weir can be built to force the rating to become single valued. This type of control is very stable under low and average flow conditions.

The hydrologic data most directly useful in determining flood flow records of considerable length at the location of the infiltration systems. Such records are rarely available. The stream flow records available for the general region in which the retention structures are to be situated should be obtained.

In August 2003, **WESI** at An-Najah National University in coordination with GlOWA JR project established two flumes at Malaqi Bridge to measure runoff rates from both upper Faria and Badan catchments. There are two reading gauges using pressure dividers at each flume to measure the flow depths at the critical sections. These are converted into flow rates using the designed empirical formulas (Shadeed, 2005).

Hydrologic analysis aims to develop a methodology to quantify a certain phase or phases of the hydrologic cycle, and to model rainfall runoff process (Chow et al.1988).

Rainfall intensity is an important parameter which must be considered when evaluating the rainfall–runoff process. One of the important processes related to runoff modeling and artificial recharge is infiltration through the soil. Because the soil may not be able to absorb all the water during a heavy rainfall, water may be lost by runoff.

2.4 Spring Flow

The fairly steady flow of a stream from natural storage is determined during non-storm periods. So if a certain amount of this water is expected to be in the channel at the time of surface runoff, it should be added to the inflow design flood as base flow.

Base flow is used to separate surface runoff into direct and indirect runoff. Indirect runoff is surface runoff originating in interflow and groundwater flow, spring flow is a measure of indirect runoff (Bureau of Reclamation, 1977).

Within the Faria catchment there exists 13 fresh water springs that are divided into four groups. These groups are Faria, Badan, Miska, and Nablus. The basic data available on these springs is average annual discharge estimated at 6.5 and 5.17 MCM for upper Faria and Badan streams respectively (Shadeed, 2005).

2.5 Rainfall-Runoff Models

Rainfall runoff models may be grouped in two general classifications that are illustrated in **Figures 5 and 6**. The first approach **(Figure 5)** uses the concept of effective rainfall in which a loss model is assumed that divides the rainfall intensity into losses and an effective rainfall hyetograph. The effective rainfall is then used as input to a catchment model to produce the runoff hydrograph. The infiltration process ceases at the end of the storm duration (Chow et al.1988).

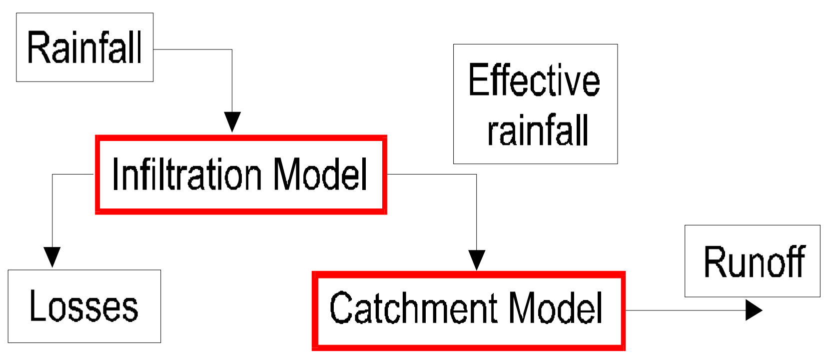

Figure 5: Rainfall-runoff modeling using effective rainfall

An alternative approach that might be termed a surface water budget model **(Figure 6)** incorporates the loss mechanism into the catchment model. In this way, the incident rainfall hyetograph is used as input and the estimation of infiltration and other losses is made as an integral part of the calculation of runoff. This approach implies that infiltration will continue to occur as long as the average depth of excess water on the surface is finite. Clearly, this may continue after the cessation of rainfall (Smith, 2008).

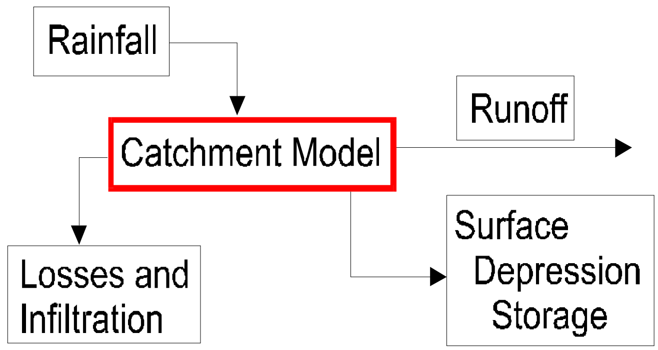

Figure 6: Rainfall-runoff modeling using surface water budget

2.6 Water Harvesting

Water harvesting means capturing rainwater where it falls or capturing the run off. Measures should be taken to keep that water clean by not allowing polluting activities to take place in the catchment.

Water harvesting can be undertaken through a variety of ways:

- Capturing runoff from rooftops.
- Capturing runoff from local catchments.
- Capturing seasonal floodwaters from local streams.
- Conserving water through watershed management.

These techniques can serve the following purposes:

- Provide drinking water.

- Provide irrigation water.
- Increase groundwater recharge.
- Reduce storm water discharges, urban floods and overloading of sewage treatment plants.

Rain is the first form of water that we know in the hydrological cycle, hence is a primary source of water for us. Rivers, lakes and groundwater are all secondary sources of water. In present times, human depend entirely on such secondary sources of water. In the process, it is forgotten that rain is the ultimate source that feeds all these secondary sources and remain ignorant of its value.

Water harvesting means to understand the value of rain, and to make optimum use of the rainwater at the place where it falls. Therefore, water harvesting is the activity of direct collection of rainwater to be stored for direct use or to be recharged into the groundwater.

The total amount of water that is received in the form of rainfall over an area is called the rainwater endowment of the area. Out of this, the amount that can be effectively harvested is called the water harvesting potential.

Water harvesting potential = Rainfall (mm) x Collection efficiency

The collection efficiency accounts for the fact that all the rainwater falling over an area cannot be effectively harvested, because of evaporation, spillage, etc. Factors like runoff coefficient and the first-flush wastage are taken into account when estimating the collection efficiency (ER-ING, 2008).

The advantages of Rain Water Harvesting are:

1. Rainwater is bacteriological pure, free from organic matter and soft in nature.

2. It will help in reducing the flood hazards.

3. It will improve the quality of existing groundwater through dilution.

4. The structures required for harvesting the rainwater are simple, economical and eco-friendly.

In this study, it is to consider water harvesting of rain that falls in Al-Faria catchment and recharging it to replenish the groundwater.

2.7 Artificial Recharge to Groundwater

Artificial recharge is the process by which the groundwater is augmented at a rate much higher than those under natural conditions of replenishment.

Artificial recharge refers also to the movement of water through man-made systems from the surface of the earth to underground water-bearing strata where it may be stored for future use. It is also called planned recharge in which water is stored underground in times of water surplus to meet demand in times of shortage (Groundwater Pollution Primer, 1996).

The techniques of artificial recharge can be broadly categorized as follows:

A. Surface (Spreading) methods

These methods are suitable where large area of basin is available and aquifers are unconfined without impervious layer above it. The rate of infiltration depends on nature of top soil. If soil is sandy the infiltration will be higher than those of silty soil. The presence of solid suspension in water used for recharge clogs the soil pores leading to reduction in infiltration rate. Water quality also affects the rate of infiltration. The various spreading methods are:

1. Flooding

This method is suitable for relatively flat topography. The water is spread as a thin sheet, then it infiltrates into the ground depending on the permeability of the soil.

2. Basin and Percolation Tanks

This is the most common method for artificial recharge. In this method, water is impounded in series of basins or percolation tank. The size of basin may depend upon the topography of the area, flatter area will have large basin. The most effective depth of water in basin is 1.25 m. This method is applicable in alluvial area as well as hard rock formation. The efficiency and feasibility of this method is more in hard rock formation where the rocks are highly fractured.

3. Stream Augmentation

When total water supply available in a stream exceeds the rate of infiltration, the excess is lost as runoff which can be captured through retention structures. The site selected for check.

B. Sub-surface Method

In this method the structure lies below the surface and recharges groundwater directly. The important structures are commonly use recharge wells, Recharge shaft, Dug wells etc.

The basic requirement for recharging groundwater is an available water source. The following information are necessary about the water source (CGWB, 2007):

a. The frequency

b. Number of rainy days.

c. Maximum Rainfall in a day.

d. Rainfall variation in space and time.

2.8 Infiltration

Infiltration plays a major role in abstracting total precipitation. Actual infiltration rates and amounts vary widely, being highly dependent on the initial level of soil moisture.

Catchments with low initial soil moisture, i.e., dry catchments, are not conductive to high runoff response. Conversely, catchments with high initial moisture i.e., wet catchments, are likely to produce large quantities of runoff.

Infiltration systems recharge the groundwater, helping to mitigate the impacts of development on the hydrologic cycle. In addition, they use the soil as a filter, treating polluted runoff as it percolates into the ground. Because the soil may not be able to absorb all the water during a heavy rainfall, water may be lost by runoff.

2.9 Infiltration Systems

It is only in exceptional circumstances that an experienced designer can say that only one type of structure is suitable or most economical for a given retaining structure site. Several factors affect the type to be selected. Among these are:

Topography: It is a measure that dictates the first choice of the type of the retaining structures.

Geology and Foundation conditions:

Foundation conditions depend upon the geological character and thickness of the strata which are to carry the weight of the structure.

Materials available: Materials for retention structure of various types, which may sometimes be available at or near the site.

2.10 Retention Structures

Dam is artificial barrier constructed across flowing water and obstructs, directs or slows down the flow. Retention dam is any structure designed to contain ground flow, from a natural runoff or from an artificial one, built with an impermeable barrier (Bureau of Reclamation, 1977).

Retention dams are constructed to retard flood runoff and minimize the effect of sudden floods. Detention dams fall into two main types; in one type, the water is temporarily stored, and released through outlet structure at a rate which will not exceed the carrying capacity of the channel. In the other type, the water is used to recharge the under groundwater supply.

Earth fill dams are the most common type of dams, principally because their construction involves utilization of materials in the natural state requiring a minimum of processing. Moreover, the foundation requirements for earth fill dams are less stringent than for other types.

2.11 Faria Catchment Studies

Among the most basic challenges of hydrology are the quantitative understanding of the processes of runoff generation and prediction of the flow hydrographs and their transmission to the outlet. Traditional techniques have been widely applied for the estimation of runoff hydrographs at the outlets of gauged watersheds using historical rainfall-runoff data and unit hydrographs derived from them.

(Shaheen, et. al. 2005) concluded that, the non-availability of sufficient rainfall-runoff records has limited the testing of the validity of the above methodology implemented to semiarid nature watersheds.

Shadeed (2005) carried out the rainfall-runoff process in Faria catchment. He conducted statistical analysis including annual average, standard deviation, maximum and minimum rainfall for the six rainfall stations located within Al-Faria catchment. He proved that Gumbel distribution fits the annual rainfall and can be used for future estimations of the floods in the semiarid Faria catchment. The above two literatures provide means to understand and evaluate the distribution characteristics of the rainfall in the Faria catchment.

A relation between the station average annual rainfalls coordinates and elevations within Al-Faria catchment has been developed (Shadeed, et. al. 2000). The resulting equation is:

$$R = 8073.3 - 38.2X - 2.7Y - 0.3H$$

Where:

R: Annual average rainfall (mm)

X: x-coordinate (m)

Y: y-coordinate (m)

H: elevation (m)

Jamil (2006) performed design criteria for the construction of retention dams in Wadi Faria. He concluded that dams constructed for a return period of 2 years, will capture 90.9% of the storm runoff in Wadi Faria to be detained for infiltration. Constructing the dams for a return period of 10 years will capture to value to be 99.1%. The 10 years return period is thus recommended to be applied for the design of the retention structure and/or dam to be constructed in Al-Faria catchment.

Chapter Three

Hydrological Design Parameters

3.1 Hydrologic Design Data

As defined in the objectives of this research, it is necessary to define design criteria for the construction of the retention structures at Upper Faria sub-catchment. Prior to statistical analysis, the data of the three rainfall stations situated in the upper Faria catchment has been collected. The design retention structure requires a certain amount of data; this should include at least field estimates of the drainage area and a description of the terrain type and cover.

As for this study, the data assessed include annual total rainfall; daily rainfall from the five rainfall stations of the whole Faria catchment, the rainfall data from the three tipping bucket rain gauges and water level and flow data from two Parshall flumes. In the absence of long time series of runoff data, a frequency analysis for the available data is carried out to provide necessary information to be used to define the design criteria of the retention structures.

3.1.1 Rainfall Data

In order to carry out the statistical analysis and to estimate the areal rainfall for the Faria catchment, completed series of annual rainfall data were made available to be processed. Annual Rainfall data for the Faria catchment was obtained from the Water and Environmental Studies Institute (WESI) at An-najah National University and are presented in the **Appendices.**

Statistical analysis has been utilized for the rainfall data of the Faria rainfall stations. These include the annual average (AVG), the standard deviation (STD), the maximum (MAX) and the minimum (MIN) rainfalls recorded by these station as tabulated in **Table 3.**

Table 3: Analysis of Faria Catchment Total Annual Rainfall

Rainfall Station	**AVG (mm**	**STD (mm)**	**MAX (mm)**	**MIN (mm)**
Nablus	642.6	203.3	1387.6	315.5
Tallouza	630.5	196	1303.1	292.2
Tubas	415.2	143.9	899.5	201.5
Beit Dajan	379.1	134.8	777	141
Tammun	322.3	106.4	616.1	124.2
Faria	198.6	83	424	30

From the above table, it is noticed that Nablus station has the largest average annual rainfall. In general, rainfall decreases from north to south and from west to east.

3.1.2 Daily Rainfall Data

The daily rainfall data of rainfall stations in the Upper Faria catchment area are available. Length of the records varies from one station to the other.

Table 4 gives the availability of daily rainfall of the stations in the study area and the years where data are missing.

Table 4: Availability of Daily Rainfall Data

Station	Period of records	Period of Missing
Tallouza	1967-2007	1997-2002
Tammun	1967-2007	1987-1990
Tubas	1967-2007	1988

3.1.3 Tipping Bucket Rain Gauge Data

In 2004, Tipping Bucket Rain Gauges were installed at four locations within the Faria catchment to record the rainfall. The four stations were installed in Deir Al-Hatab, Tammun, Tallouza and Tubas under the frame work of EXACT project.

3.1.4 Water Level Data

Two Parshall flumes were constructed in 2003 at the outlet of Upper Faria and Badan Sub-catchments. During the first year, water level was measured using side staff fixed on the wall of the flumes. The automatic data loggers were installed in 2004. Therefore water level data is available since October 2004 (Shadeed, 2005).

3.2 Rainfall Areal Distribution

Precipitation depths vary from location to location during a storm. Areal rainfall is obtained from point data; Rainfall data from the available rainfall stations are used to determine the areal rainfall.

Thiessen method is used to compute the mean areal rainfall. This method assigns an area called a Thiessen polygon to each gauge. The Thiessen polygon of a gauge is the region for which if we choose any point at random in the polygon, that point is closer to this particular gauge than to any other gauge. In effect, the precipitation surface is assumed to be constant and equals to the gauge value throughout the region.

This technique has the advantage of being quick to apply for multiple storms because it uses fixed sub-areas. It is based on the hypothesis that, for every point in the area, the best estimate of rainfall is the measurement physically closest to that point. This concept is implemented by drawing perpendicular bisectors to straight lines connecting each two rain gauges. This yields, when the catchment boundary is included, a set of closed areas known as Thiessen polygons.

To determine Upper Faria catchment average areal precipitation depth, it is possible to do it by hand but it is less time-consuming and easier to do it with GIS.

The Faria catchment Thiessen polygons are presented in **Figure 7**. Also **Figure 8** shows the Thiessen polygons for the Upper Faria catchment.

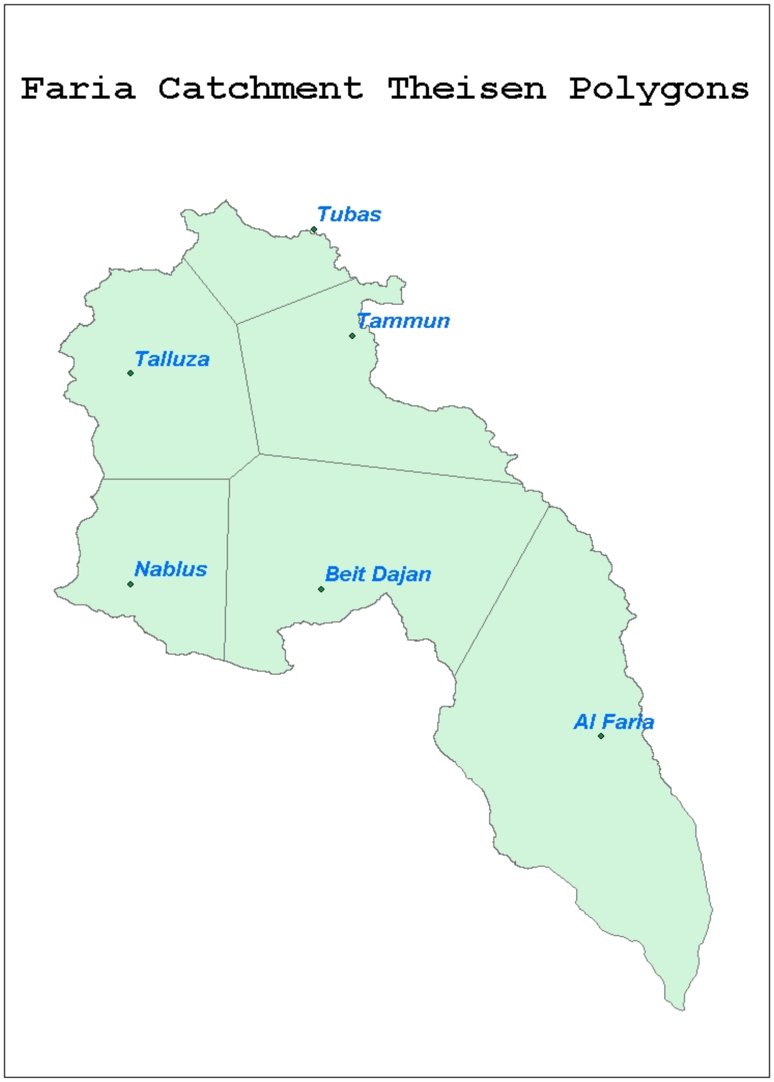

Figure 7: Total Faria catchment Thiessen polygons

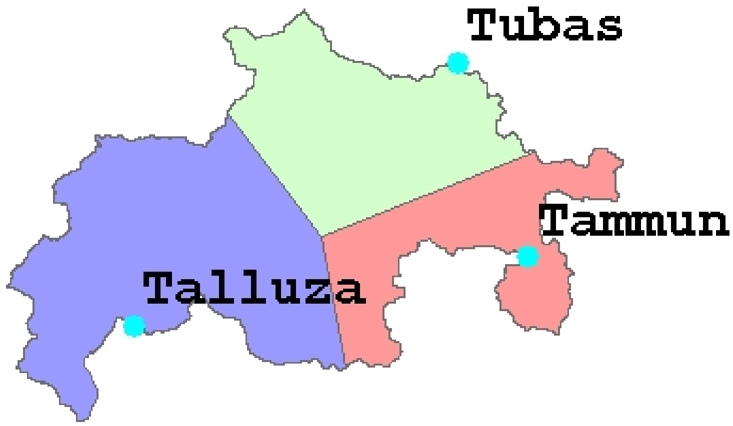

Figure 8: Upper Faria catchment Thiessen Polygons

Table 5 represents the Faria sub-catchment areas as a result of applying Thiessen method.

Table 5: Upper Faria catchment Polygons Area

Polygon	**Area(km^2)**
Tallouza	26.2
Tammun	12.6
Tubas	17.2
Total	56

3.3 Time Series Analysis

A storm event is generally characterized by its size and the frequency of its occurrence. The size of the storm is the total precipitation depth that occurs in a specified duration. How often this size storm is likely to repeat it self is called the return period or frequency of occurrence.

For instance, the total rainfall that comes in a single 24 hour duration storm once every ten years is called the 10-year storm and has a 10% chance of occurring in any given year. A 2-year storm has a 50% chance; a 50-year storm has a 2% chance; a 100-year storm has a 1% chance and so on (Chow et al, 1988).

A rainfall time series is a sequence of rainfall measurements taken over time. Comparison of data between the five rainfall stations is facilitated by the graphical features of Excel. Plots to show the annual total rainfall data for the upper Faria catchment were prepared. The plots showed consistent features and no significant changes are noticed over time. **Figures 9** through **11** compare yearly values of the records of the rainfall stations.

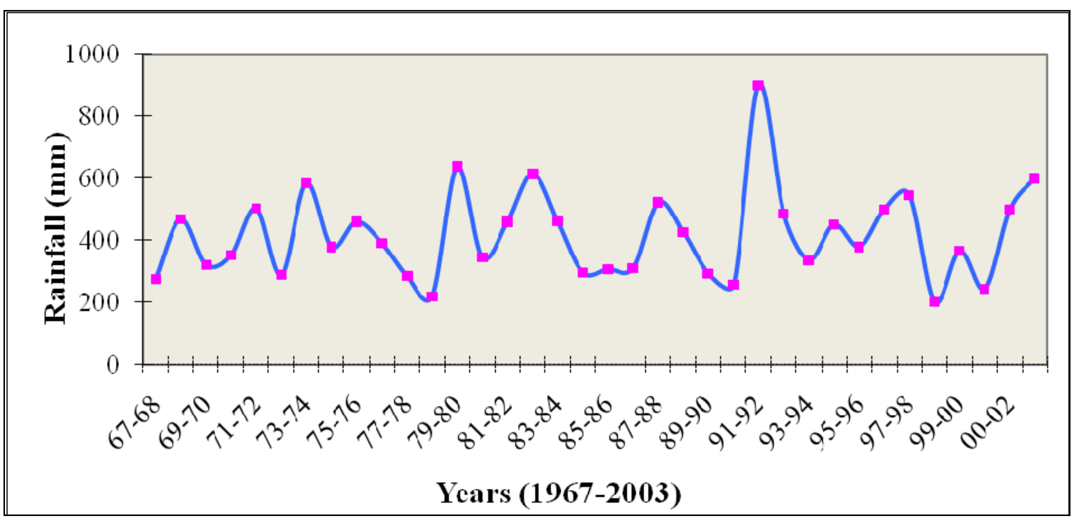

Figure 9: Total Annual Rainfall of Tubas Station

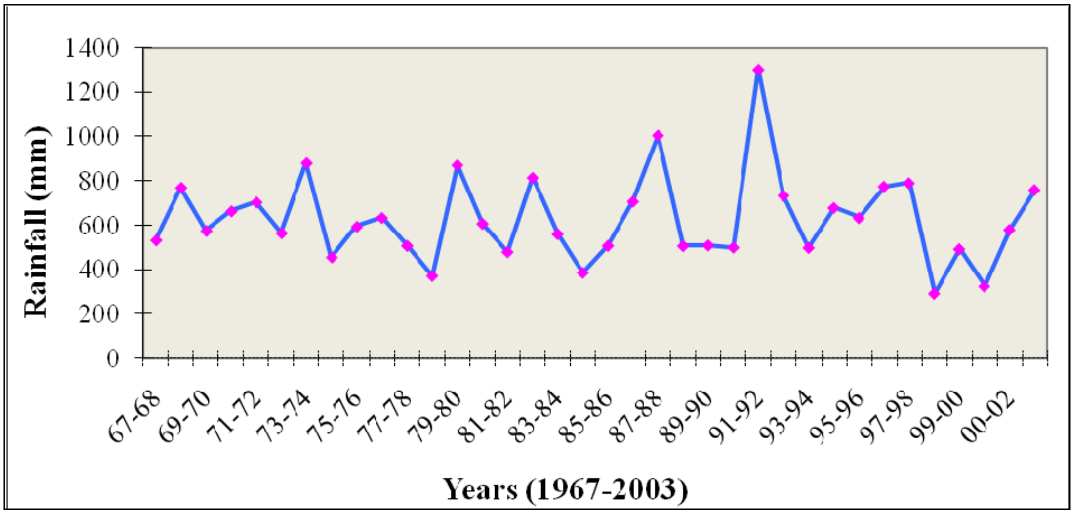

Figure 10: Total Annual Rainfall of Tallouza Station

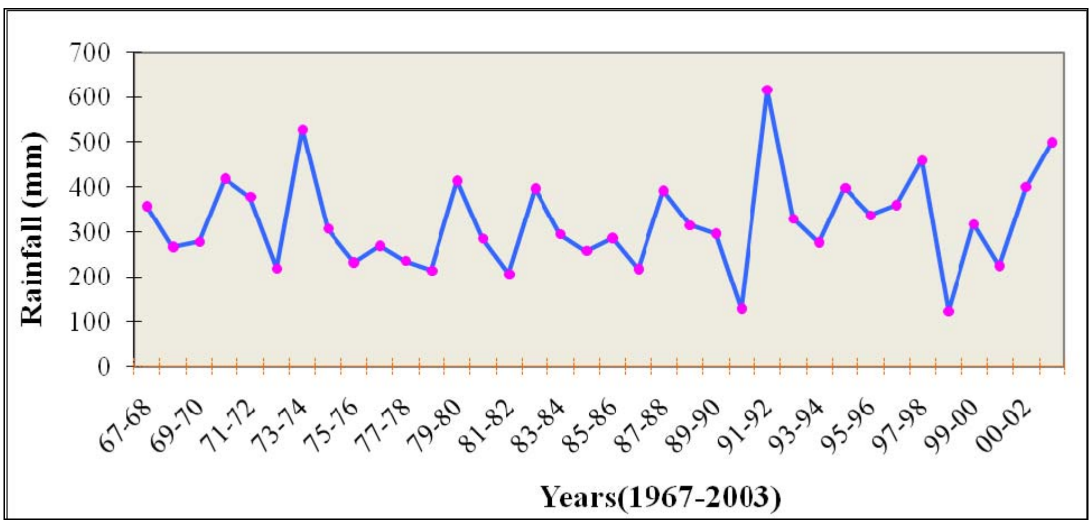

Figure 11: Total Annual Rainfall of Tammun Station

From the figures, it can be concluded that rainfall equal or exceedance of 600 mm occurs five times from 1967 to 2007. This indicates that a return period of seven years is for the 600 mm annual rainfall at Tubas. For

Tallouza rainfall above 800 mm occurred six times during the same period, where as 500 mm annual rainfall occurred four times at Tammun station. These values are (1.3-1.5) above the annual averages of the mentioned rainfall stations.

Comparison of annual rainfall data explained that data are closely correlated so any suspicious data are easily spotted.

3.4 Consistency Analysis

Double mass curve are normally used to check the internal consistency of the rainfall stations. The principle of double mass analysis is to plot accumulated values of the station under investigation against accumulated values of another station, or accumulated values of the average of other stations located nearby.

The consistency for each of the stations was carried out by using the double mass analysis and utility of Excel Spread sheet. Cumulative rainfall data of specific stations is plotted against the accumulative average rainfall of the remaining stations. **Figure 12** through **Figure 16** represent these plots.

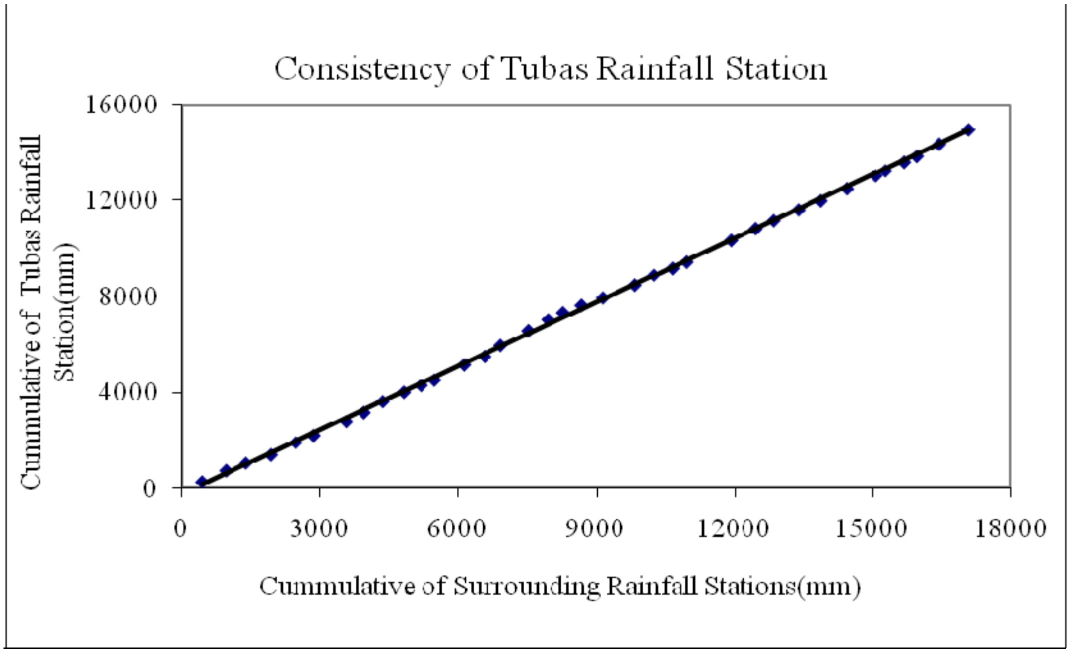

Figure 12: Double Mass Analysis for Tubas Station, (1967-2003)

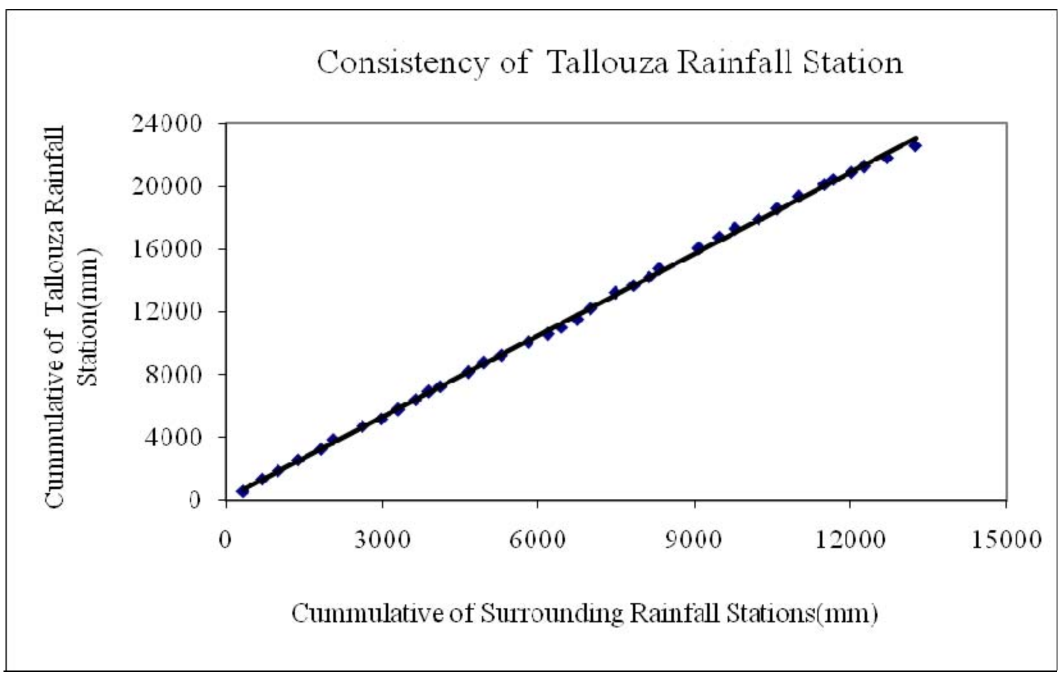

Figure 13: Double Mass Analysis for Tallouza Station, (1967-2003)

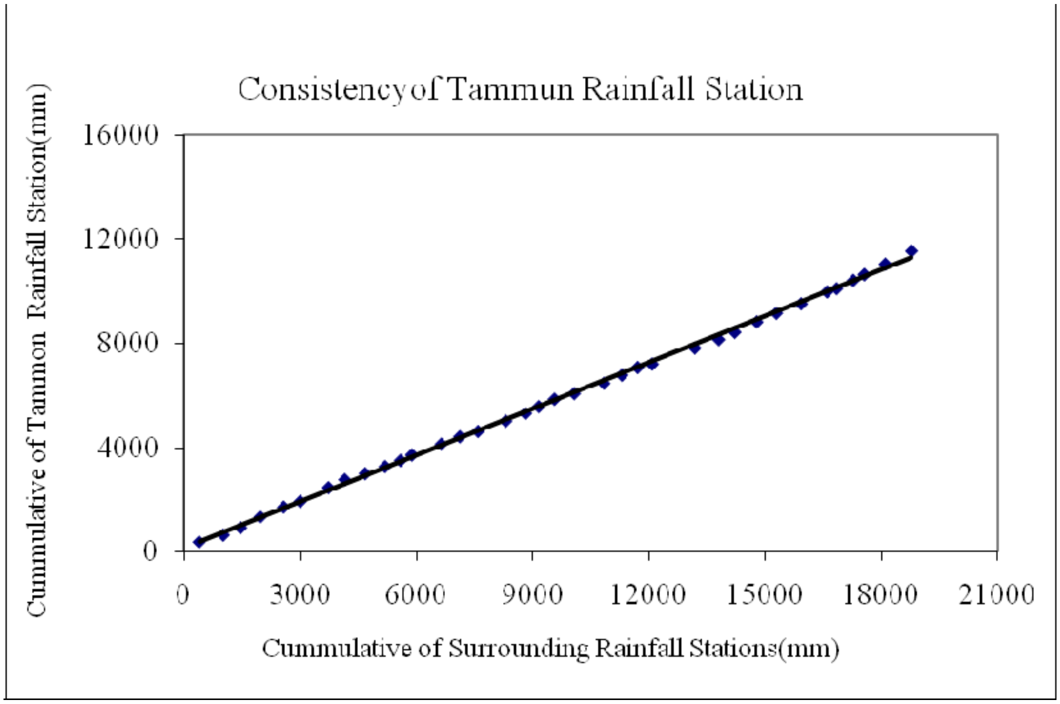

Figure 14: Double Mass Analysis for Tammun Station, (1967-2003)

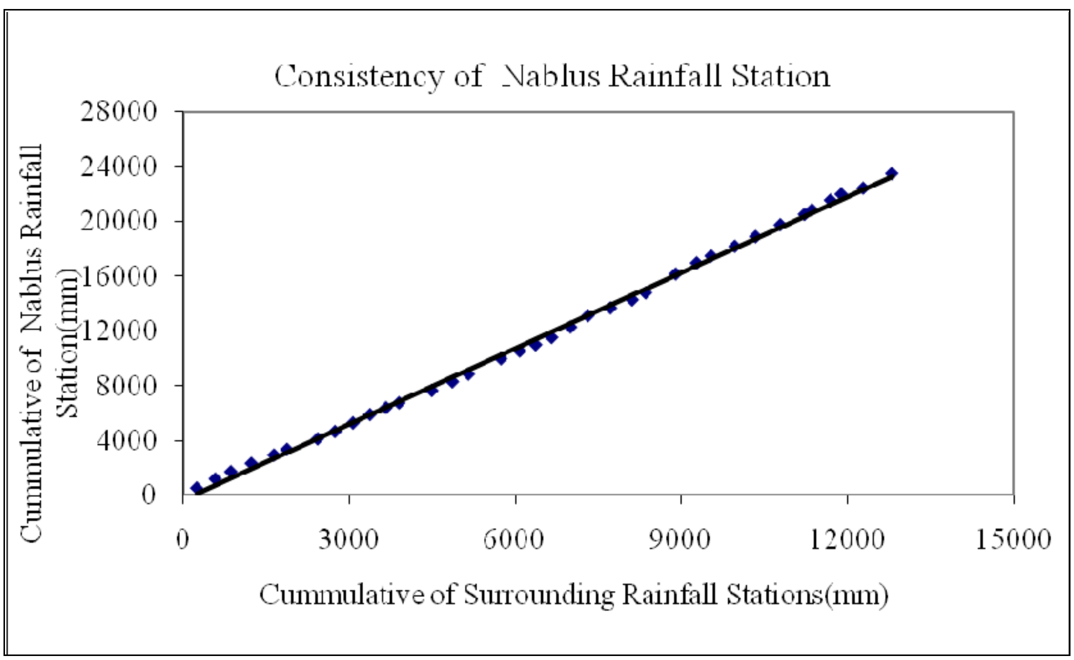

Figure 15: Double Mass Analysis for Nablus Station, (1967-2003)

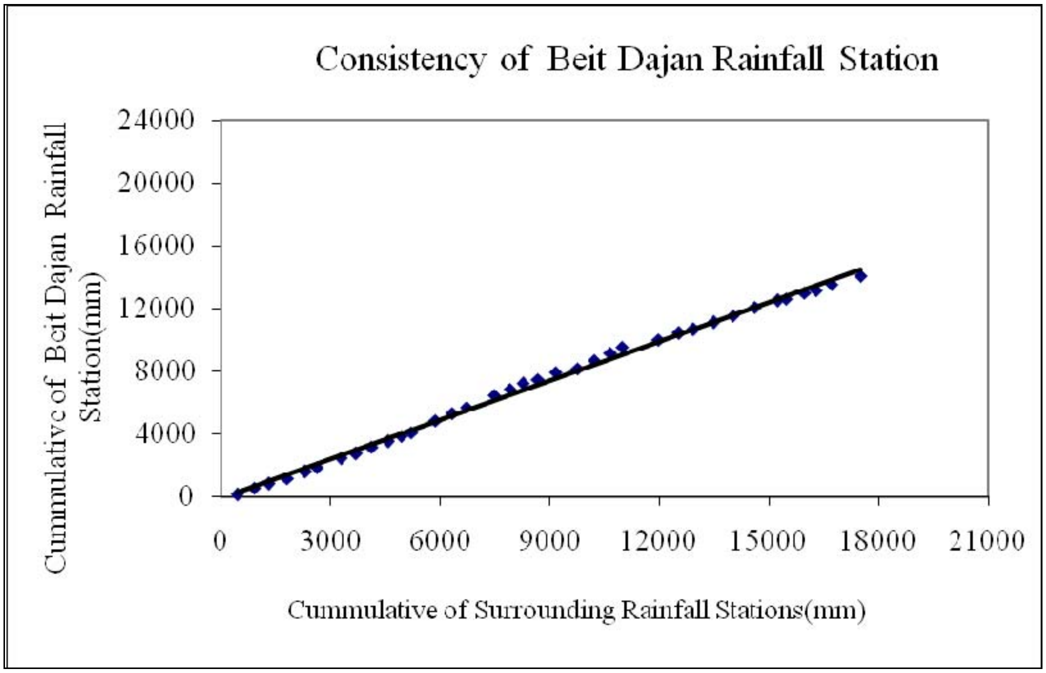

Figure 16: Double Mass Analysis for Beit Dajan Station, (1967-2003)

From the previous figures, it is clear that all the rainfall stations of Faria catchment are internally consistent and the data recorded by these stations can be used for further analysis.

3.5 Analyses of Extremes and Exceedance

One of the most common problems in designing hydraulic structures is estimating the magnitude of the flood corresponding to a given return period. For as long as the available data is sufficiently long, this procedure is reduced to simply fitting a frequency distribution to the annual floods. The estimate is then obtained by extrapolating the fitted frequency distribution to the desired return period.The objective of the frequency analysis of the hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions.

A use will be made of the data for an analysis of extreme rainfalls. For annual daily rainfall series, the maximum daily extreme rainfall events will be analyzed. From each year the maximum value is registered. The extremes for a large number of years are fitted in a distribution of Gumbel.

The frequency analysis will be carried out using Gumbel distribution method, since Gumbel distribution proved to be the best to represent rainfall data of Faria catchment based on the previous research (Shadeed 2005, Jamil 2006).

For the purpose of extreme value analysis, the following procedure has been applied:

1. The annual maximum daily rainfall values were arranged in descending order over the recorded period and each value was given a rank, m.
2. For each value of rainfall, denoted by x, the probability of exceedance, P(x) was calculated using the Gringorten formula.

   $$P = (m - 0.44)/ (n + 0.12)$$

   where,

P: the probability of exceedance

m: the rank of x

n: the total number of records years

3. The probability of non-exceedance was calculated using the following relation:

$$F(x) = 1-P = 1- (m - 0.44) / (n + 0.12)$$

where,

F(x): the probability of non-exceedance

4. The annual maximum daily rainfall can be calculated directly for each return period by using the Gumbel distribution relation:

$$X_{gum} = X_{av} + ((y- y_{av}) /\sigma_y) * S_x$$

Where,

X_{av} and S_x: mean and standard deviation of rainfall series.

y: Gumbel Variate = - ln(-ln (1-p)).

y_{av} and σ_y : mean and standard deviation of variate as a function of record length n.

Annual daily rainfall values for the three stations in the Faria sub-catchment were substituted in the Gumbel distribution equations by the utility of EXCEL spread sheet.

The longer the time series the more confident we have in the derived extreme value distribution. For short series it may be wise to indicate the level of confidence for the data used. The Gumbel plots for all stations and data with confidence level of 95% are presented in **Figure 17** through **Figure 22.**

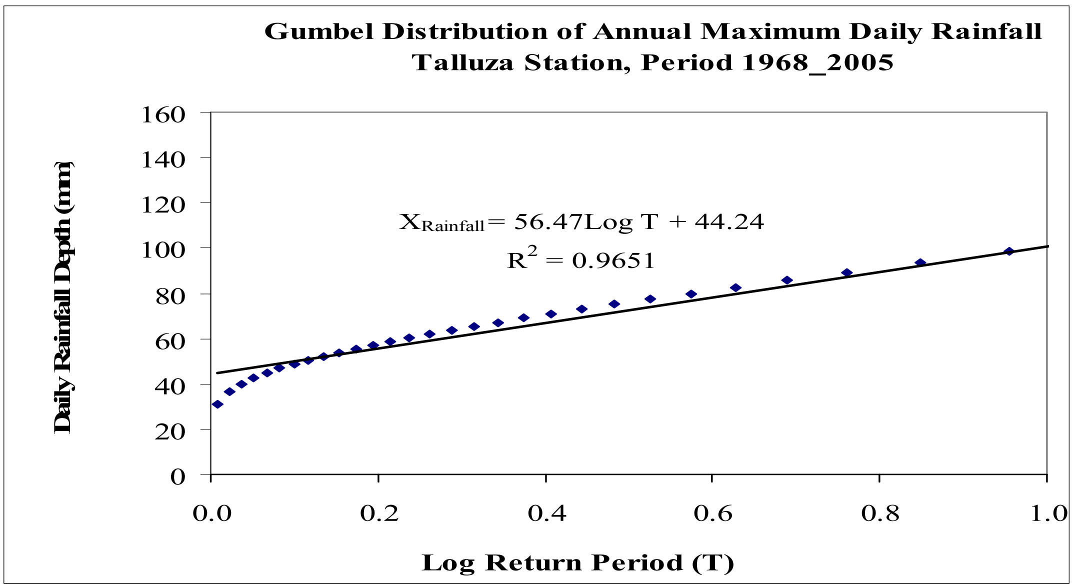

Figure 17: Gumbel Distribution of Annual Max Daily Rainfall-Tallouza.

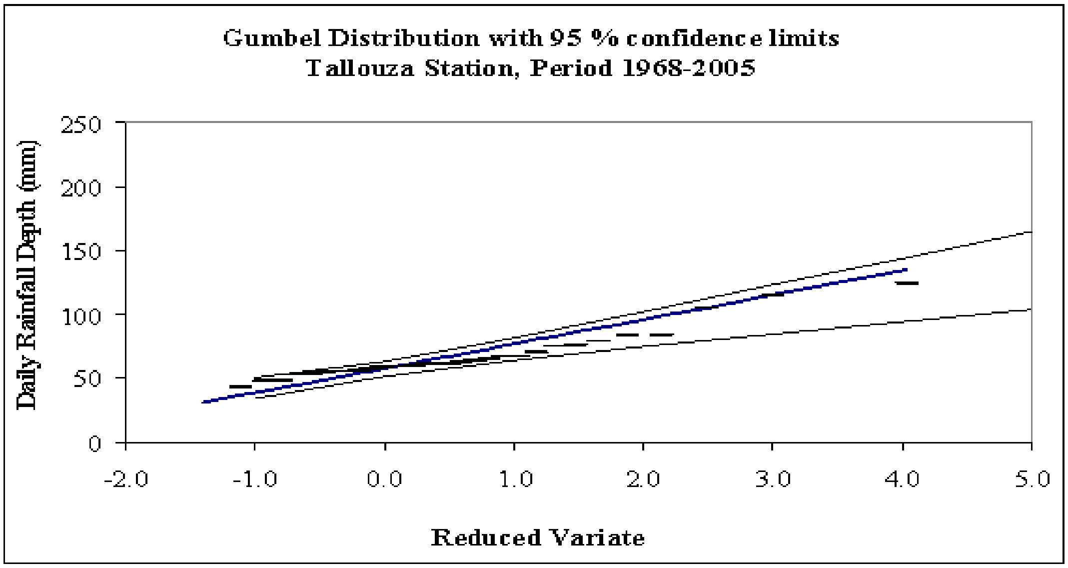

Figure 18: 95% Confidence Limits of Tallouza Rainfall-Gumbel Distribution.

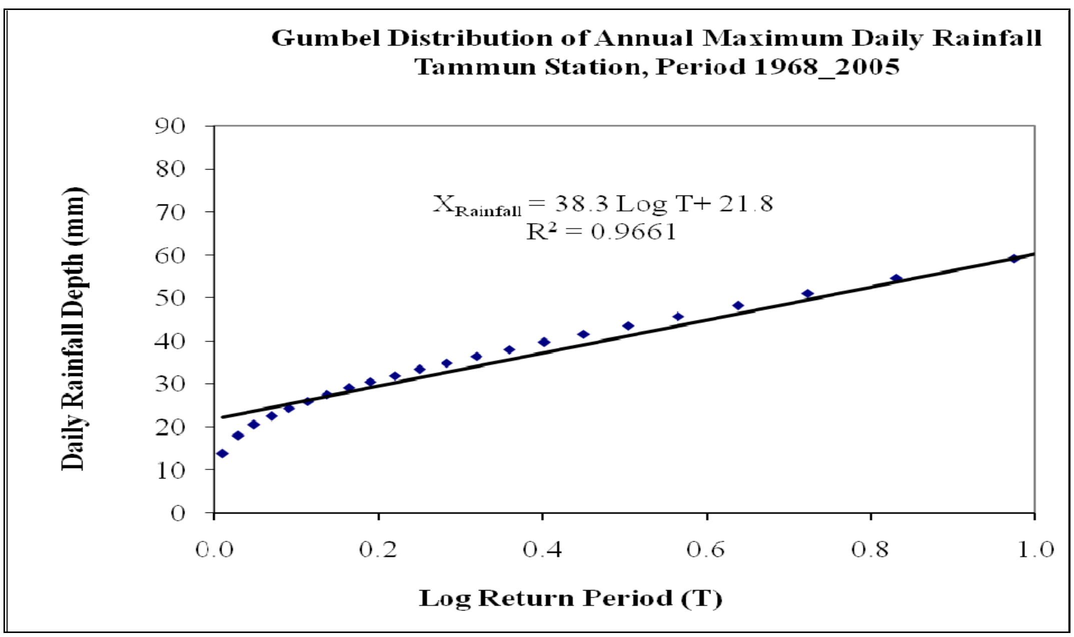

Figure 19: Gumbel Distribution of Annual Max Daily Rainfall- Tammun

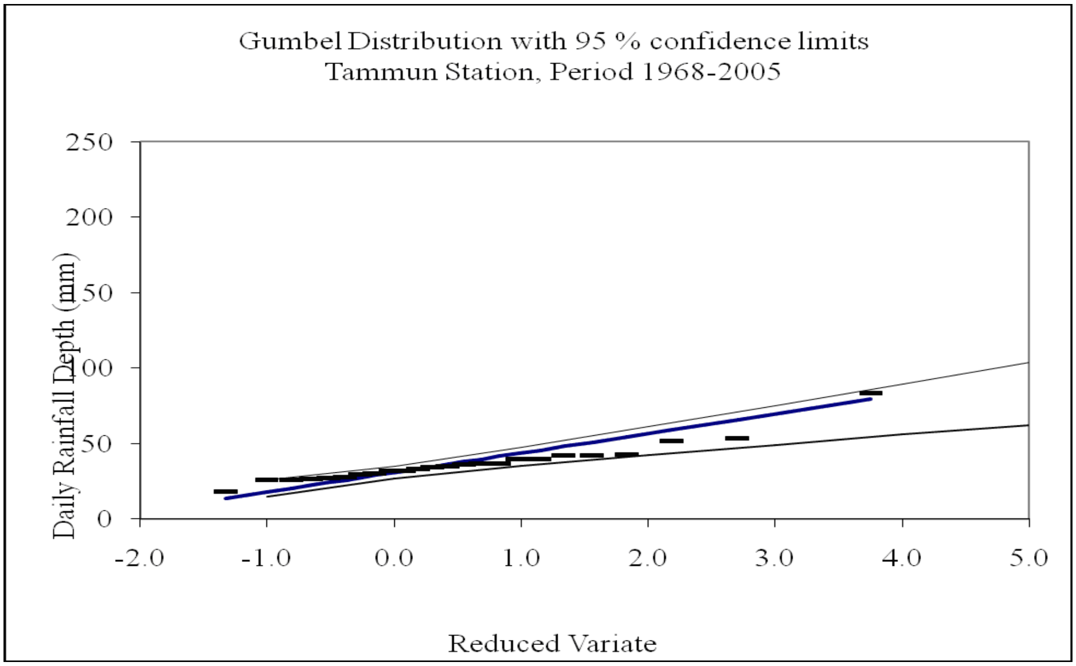

Figure 20: 95% Confidence Limits of Tammun Rainfall-Gumbel Distribution.

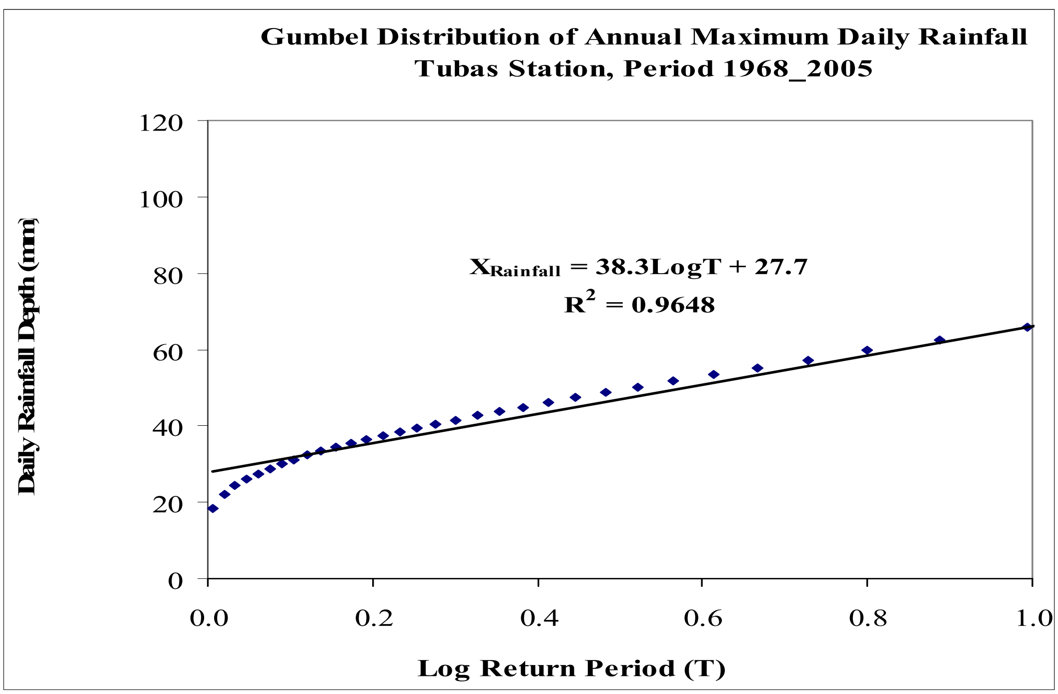

Figure 21: Gumbel Distribution of Annual Max Daily Rainfall-Tubas

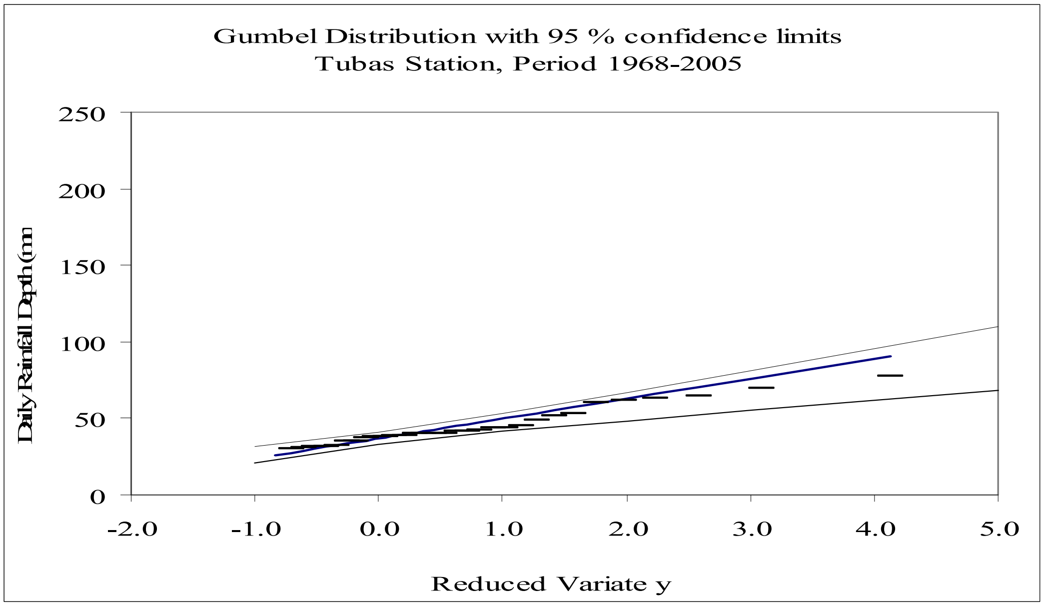

Figure 22: 95% Confidence Limits of Tubas Rainfall-Gumbel Distribution

From the figures above and the tabulated results **(Appendices)**, it is confirmed that Gumbel distribution can be applied to model the annual maximum daily rainfall for the rainfall stations of the Faria catchment. From a statistical point of view, all values of r^2 are high enough to assume the suitability of Gumbel distribution for the analysis. **Table 6** shows the estimated rainfall values for each rainfall station in Upper Faria catchment for return periods of 2, 10 and 50 years.

Table 6: Estimated Annual Maximum Daily Rainfall

Return Period	Tallouza(mm)	Tammun(mm)	Tubas(mm)
2	61.2	33.3	39.2
10	100.7	60.1	66.0
50	140.2	86.9	92.8

In order to design the retention structure, the annual maximum daily rainfall for certain return periods must be obtained. Therefore the statistical analysis was carried out to produce estimates of annual extreme daily rainfall of 2, 10, 50 years return periods. **Table 7** shows the estimated rainfall values for the rainfall stations of Upper Faria catchment for return periods of 2, 10 and 50 years. **Figure 23** and **Figure 24** are the Gumbel distribution and the 95% confidence limits respectively of the areal average rainfall data of the Upper Faria catchment

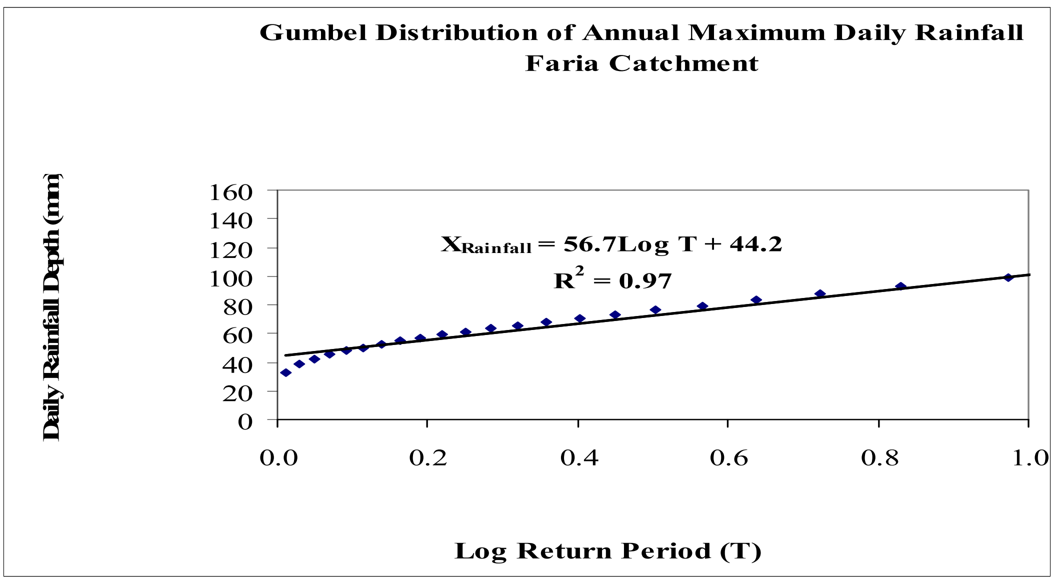

Figure 23: Gumbel Distribution of Upper Faria Catchment-Areal Average

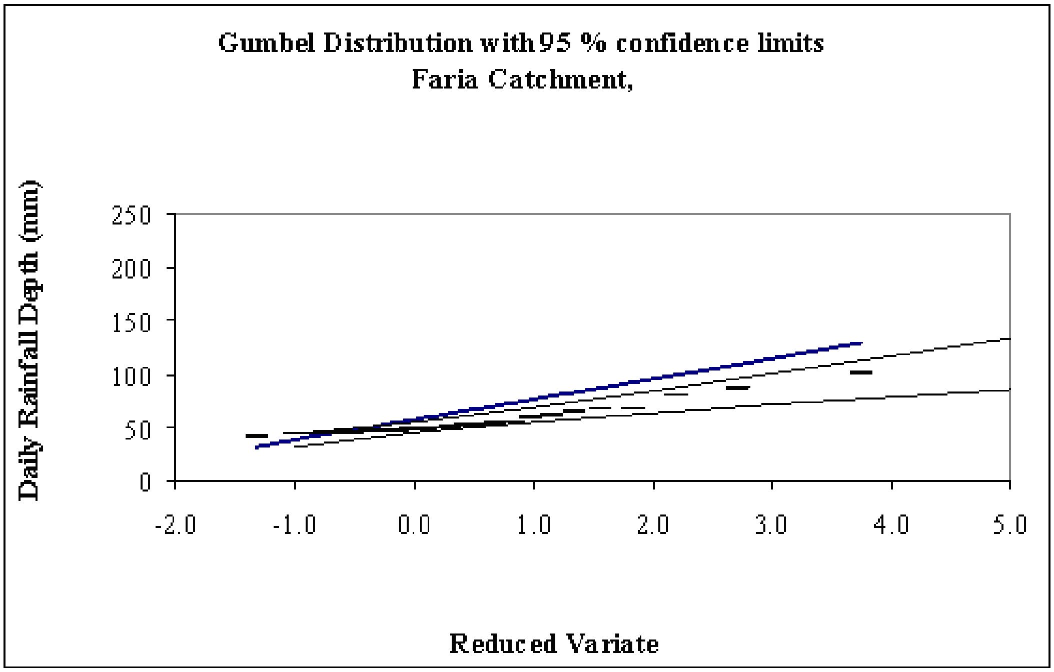

Figure 24: 95% Confidence Limits of Upper Faria catchment-Gumbel Distribution

Table 7 Shows the estimated rainfall values for return period of 2, 10, 50 years for the Upper Faria Catchment. These rainfall data have been utilized in the analysis of the size of the required retention structure.

Table 7: Upper Faria Catchment Annual Maximum Daily Rainfall

Return Period	Areal Rainfall (mm)
2	61.3
10	100.9
50	140.5

3.6 Rainfall-Runoff Modeling

Tipping buckets within Upper Faria catchment were installed on the roof of Tallouza, Tubas and Tammun schools to work as rain gauges; these devices produce a record for rainfall depths each 0.2 millimeters of rainfall.

In the outlet of the Faria catchment at Al- Malaqi Bridge, the installed Parshall flumes measure the flow level each certain time period (10 min or 12 min) from both catchments at the confluence near Al- Malaqi Bridge.

Surface runoff in the eastern slopes of the West Bank where the Faria catchment is located is mostly flash floods and occurs when rainfall exceeds 50 mm in one day or 70 mm in two consecutive days (Shadeed, 2005).

As for Upper Faria catchment, the discharge is calculated from water levels recorded in the Parshall flume during the winter periods of 2004/2007.

Water levels data are available since November, 2004. Increasing in runoff water level in flumes above the steady water level means that a rainfall event took place and caused a runoff.

Tipping buckets readings series equal to or greater than 50 mm for one rainfall day or 70 mm for two consecutive rainfall days and its corresponding water level were analyzed.

Corresponding rainfall events recorded by tipping bucket each 0.2 millimeters were adjusted considering the frequency of rainfall measurements each ten minute period. This has been done for each rainfall station to cope with the runoff records. After that, the number of frequency for each ten minutes is multiplied by 0.2 millimeters to give the total depth in each ten minutes. In order to find the areal rainfall, the weighted average formula of Thiessen polygons method is used:

$$P_{areal} = \sum (P*A) / \sum A$$

Where,

P: Polygon point precipitation.

A: polygon area.

The diver readings for runoff level at the outlet is converted to discharge, the equation relating the discharge and the water level in the flume is given by (Jamil, 2006) :

$$\mathbf{Q = k\, H^n}$$

Where,

Q: flow (m^3/sec)

H: depth of water level (m)

K: constant depends on the size of flume.

n: empirical constant.

The flume at Faria has a throat width of 3.65 m, and k equals 8.859 and designed for a maximum discharge of 15 m^3/ sec. This makes the above equation in the form Q = 8.859 $H^{3.65}$. This equation was applied to estimate the flow rate of certain events using the diver readings.

3.6.1 Flow Hydrograph

Runoff hydrograph were derived for the Upper Faria catchment. Flow in the Parshall flumes varies from time to time, particularly during and in response to storm events. As rainfalls moves through the catchment, water levels in the Parshall flumes rise and may continue to do so after the rainfall has ceased (Jamil, 2006).

The available diver data for the Parshall flume covers a period of three years. There are about three events which cause floods within this period. These events are taken into consideration in processing the runoff data. **Figure 25** through **Figure 27** show these events.

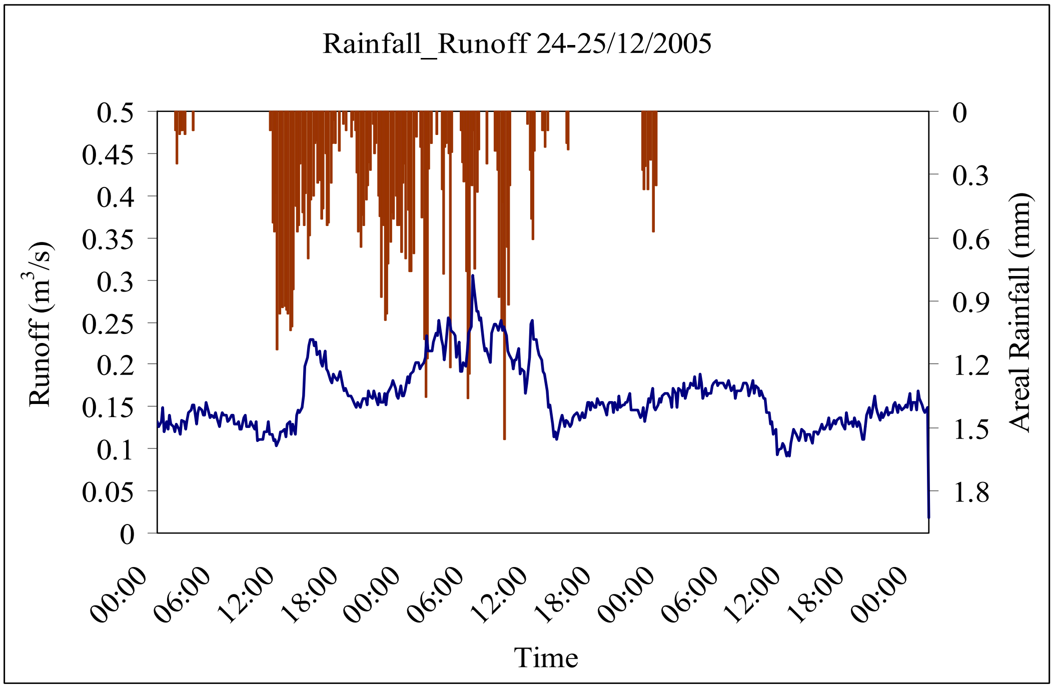

Figure 25: 24-25 Dec 2005 Rainfall-Runoff Event (Faria Flume).

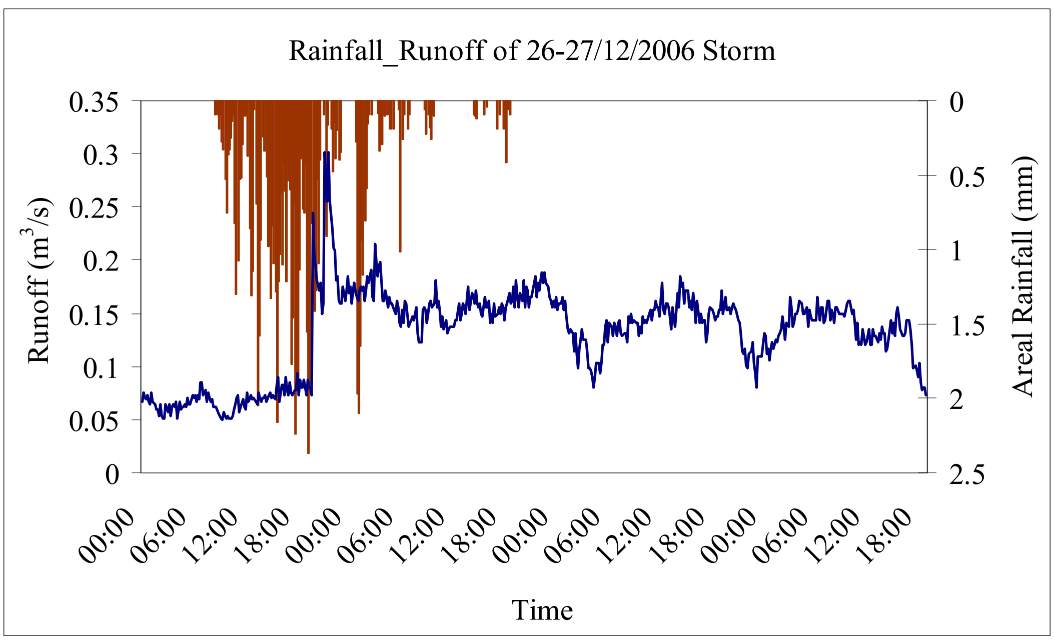

Figure 26: 26-27 Dec 2006 Rainfall-Runoff Event (Faria Flume)

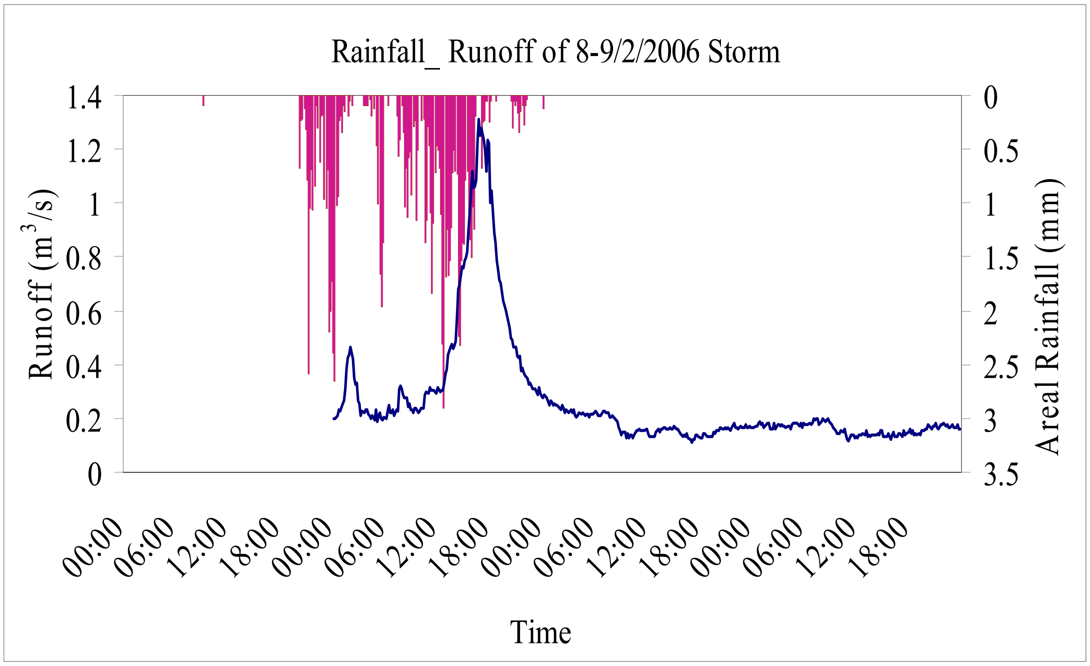

Figure 27: 8-9 Feb 2006 Rainfall-Runoff Event (Faria Flume)

The measured hydrographs consists of base flow and the other part originates from the rainfall excess. Base flow is very minimal and sometimes decreases to about zero**.** In this study, no separation of the base flow has been applied, the total runoff volume has been considered in the analysis.

3.6.2 Runoff Coefficient and Rainfall Intensity

Runoff coefficient represents the percentage of rainfall water that will be generated as runoff on the ground surface during and after certain storm.

An analysis of the rainfall-runoff relationship and subsequently an assessment of the relevant runoff coefficient are based on actual measurements of both rainfall and runoff. The runoff coefficients are determined from the storms that have been selected from the tipping bucket rain gauges and the corresponding runoff measured by the Parshall flume.

Rainfall intensity is another parameter which must be considered when evaluating the rainfall runoff process. The high variability of rainfall both in time and space, leads to very high variability of runoff. Small values of the effective rainfall are not considered to generate runoff. The rainfall records of the storms which produced the direct runoff hydrographs of the upper Faria catchment were analyzed. A relation between runoff coefficient and rainfall intensity has been developed. **Tables 8** summarize the calculations of the runoff coefficients.

Table 8: Runoff Coefficients for Upper Faria catchment

Date	Duration (hrs)	Runoff (mm)	Rainfall (mm)	Rainfall Intensity	Runoff Coefficient
5-6 Feb 2005	12	2.6	147.7	12.3	1.70
24-25 Dec 2005	13.1	0.75	60.6	4.6	1.20
8-9 Feb 2006	13	1.26	90.2	6.9	1.40
26-27 Dec 2006	12.6	0.82	78.4	6.2	1.05
3-4 Feb 2007	13.2	0.58	54	4.1	1.08

With the availability of several rainstorms, it is possible to derive a relationship between rainfall intensity and runoff coefficient as shown in **Figure 28.** The runoff coefficient increases with the rainfall intensity and this relationship is:

$$\mathbf{C = 0.053*I + 0.95}$$

Where C is the runoff coefficient and I is the rainfall intensity (mm/hr).This runoff coefficient is based on rainfall depths which occurred each ten minutes recorded by the rainfall buckets and its corresponding runoff measured at the flumes.

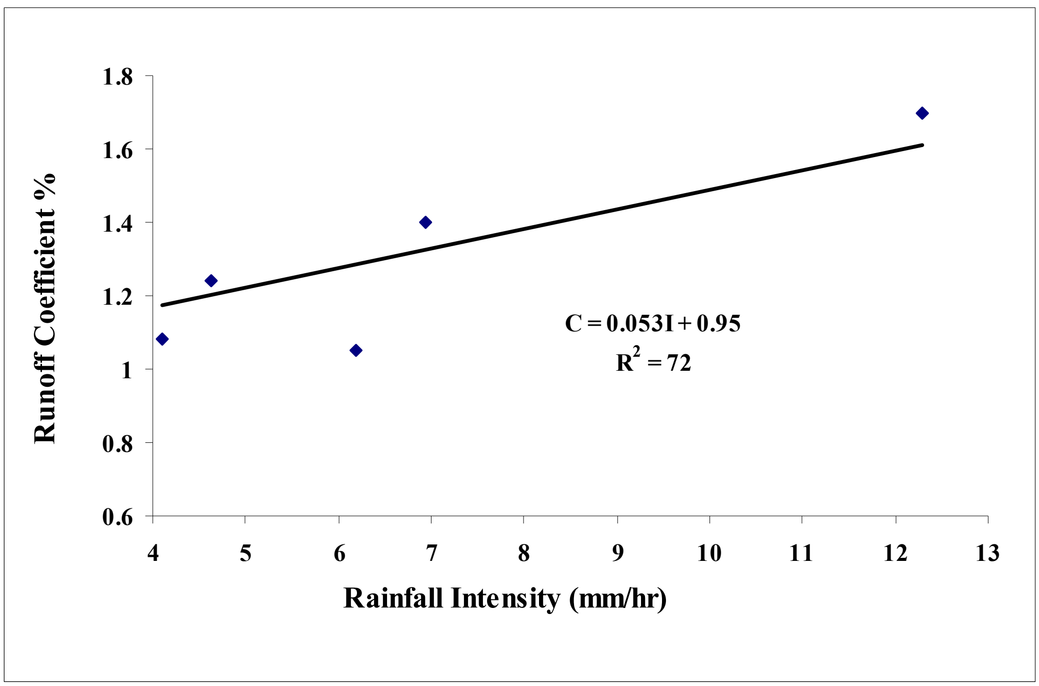

Figure 28: Intensity-Runoff Coefficient

3.6.3 Runoff Volume

The design of a retention Structure requires the knowledge of the quantity of runoff to be produced by storms in a Faria catchment area. It is commonly assumed that the quantity (volume) of runoff is a proportion of the rainfall depth.

Prior to the calculation of the runoff volume, it should be realized that the statistical analysis of daily rainfall does not mean the actual duration of the rainfall is 24 hours (Jamil, 2006). In this study it is assumed that actual duration of the rainfall equals 50% of the considered time.

Runoff volumes were estimated for return periods of 2, 10 and 50 years based on 12 hour duration rainfall. The intensity for areal rainfall estimated and the corresponding runoff coefficients were used to find the effective precipitation. The tabulated values of runoff volumes are tabulated in **Table9.**

Table 9: Runoff Volume for upper Faria Catchment

Return Period (Year)	Areal Rainfall (mm)	Rainfall Intensity (mm/hr)	Runoff Coefficient **C= 0.053*I +0.95**	Runoff Volume (m^3)
2	61.3	5.1	1.2	41000
10	100.9	8.4	1.4	80000
50	140.5	11.7	1.6	126000

As for study purpose, the interested runoff volume is for the 2-year and 10 year return periods. Hence, the runoff volumes from both return periods will be used to estimate the height of the crest of the dam spillway.

Chapter Four

Retention Structure Design Criteria

4.1 Introduction

Within the framework of the artificial recharge project in the upper Faria catchment, a number of sites for artificial recharge were selected. The purpose of these structures is enhancing the infiltration of flood water from rain storms into the underlying sediments and (mostly) limestone rocks (UNESCO-IHE, 2007).

4.2 Retention Structures Suggested Locations

The first step in building a dam is to identify the suitable location. There are many factors that affect this. Ultimately it is up to the judgment of the engineer to balance all the trade-offs involved in the site selection. There are some tools that can assist in the decision.

In view of the geological complexity of the area and the permanent presence of poor water quality of the base flow in parts of the area (wastewater and solid waste in Wadi Badan and to some extent in Wadi Faria), proper site of the infrastructure is not easy. Nevertheless, three main criteria have been set for the identification of the sites where infiltration could take place:

a) Infiltration capacities of the sediments, especially near surface water courses.

b) The existing water quality situation.

c) The land use distribution and the administrative regulations applying to the area (UNESCO-IHE, 2007).

Land use distribution and administrative rules are also criteria for site selection. Most of the area consists of hard mountainous rocks with only sparse vegetation. These areas are rather away from the flood generating wadi and also, in view of their generally steep slopes; do not qualify easily for the location of artificial recharge schemes. Unfortunately, these areas, including the alluvial terraces are heavily used by farmers and the production of crops is practiced on a large scale (UNESCO-IHE, 2007).

More sophisticated dams may be constructed; Construction in Wadi Faria seems to be the better option, because of the lower sediment load of the flood water and the better water quality properties of the base flow. However, flood discharges in Wadi Faria are considerably lower than in Wadi Badan which would raise the costs of such a scheme when a construction cost price per m^3 of infiltrated water is being calculated.

An effort has been done to prepare a map showing the locations of artificial recharge infrastructure. The proposed infrastructure and locations are of a preliminary nature and further evaluations need to be done to take final decisions. Not all sites need to be realized. The infiltrating water at the proposed sites will benefit the local aquifer systems and may (partly) restore the natural characteristics of the system including groundwater levels and groundwater quality. Several locations were suggested to store water as shown in **Figure 29**. These are (UNESCO-IHE, 2007):

1. The North of Malaqi Bridge area. A possibly, suitable site for a dam was identified just north of the Malaqi Bridge in the Wadi Faria.
2. The Malaqi Bridge area. Downstream the confluence at Malaqi Bridge, the construction of gabions could be considered.
3. The Beit Hassan area. In this agricultural area further downstream from Malaqi Bridge the placement of gabions across the wadi channel could be an option.

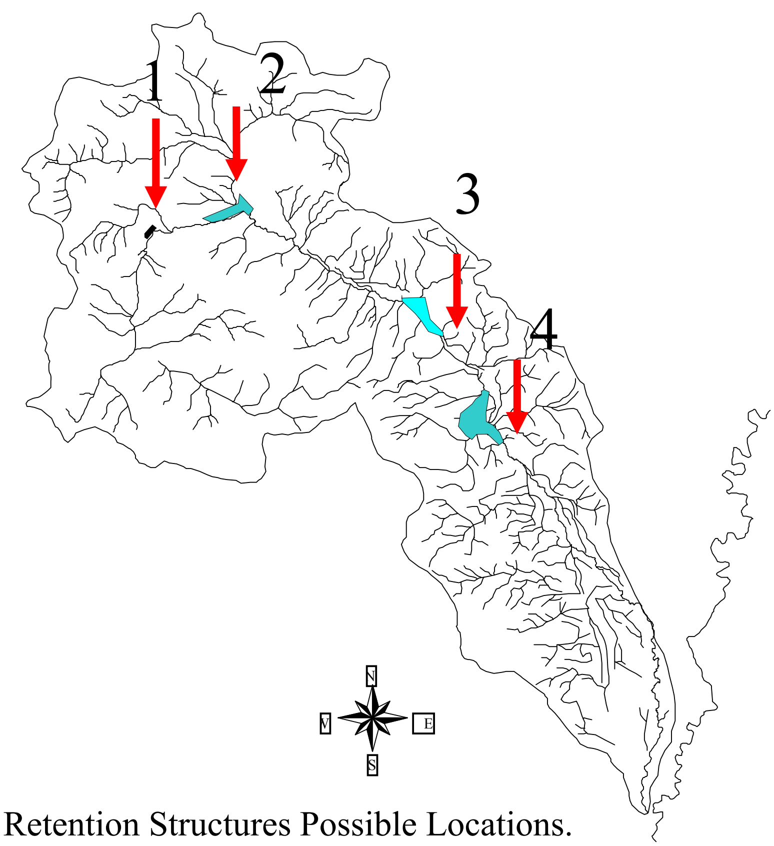

Figure 29: Retention Structures Possible Locations.

4.3 Earth Fill Dam

Earth fill dams are used where concrete dams are unsuitable due to abutment or foundation conditions. Suitable materials for the fill need to be accessible and close at hand. At Jisr- Malaqi site, the proposed site for the construction of the retention structure meet the requirements and criteria for earth fill dams. Therefore an earth fill dam is selected as the retention structure to be constructed to retain the storm water and provide a small reservoir to allow the artificial recharge into the aquifer. The design criteria of the dam and the storage reservoir are presented in the next sections.

4.4 Design Criteria

4.4.1 Storage Volume

For the quickest and easiest method for determining the storage capacity find the length of the dam, the fetch (this is the longest distance on the reservoir measured straight back from the dam face, sometimes called the throwback), and the maximum depth. These values can be found using either a topographical map or during a simple survey using a hand level.

The Faria valley at its neck at Malaqi site is of a trapezoidal shape and dimensions of cross section were measured, the following formula may provide a better estimate of the geometry of the trapezoidal section:

$A = bd + zd^2$

Where:

b= bottom width (m).

d= depth of flow is measured perpendicular to the stream (m).

z= side slope (2:1 slope, z=2).

The volume of the capacity of the reservoir behind the dam is calculated using:

Volume of Storage (m^3) = (Fetch) (Area of cross section)

The cross section area of the proposed location is increased with depth increasing. By simple surveying of the site, the elevations of the proposed cross section and its corresponding width were determined and are represented in **Figure 30**.

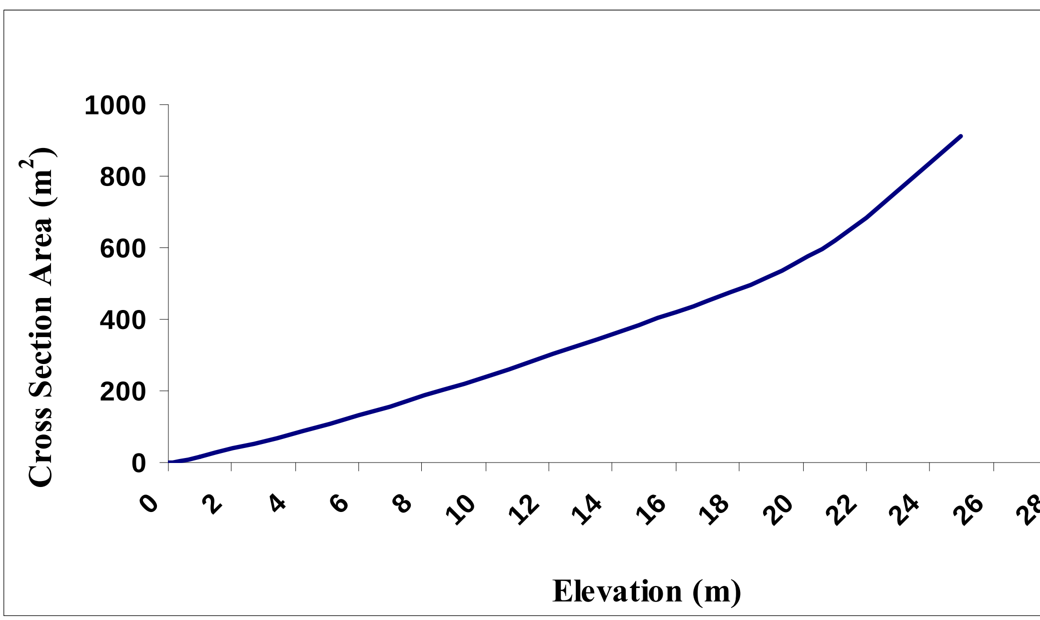

Figure 30: Elevation and Cross Section Area of the Proposed Site

The volume of water which will be stored behind the retention earth fill dam and the cross section area were determined. The volume of the dam with respect to elevation varies as in **Figure 31** depending on the required fetch of the retention dam.

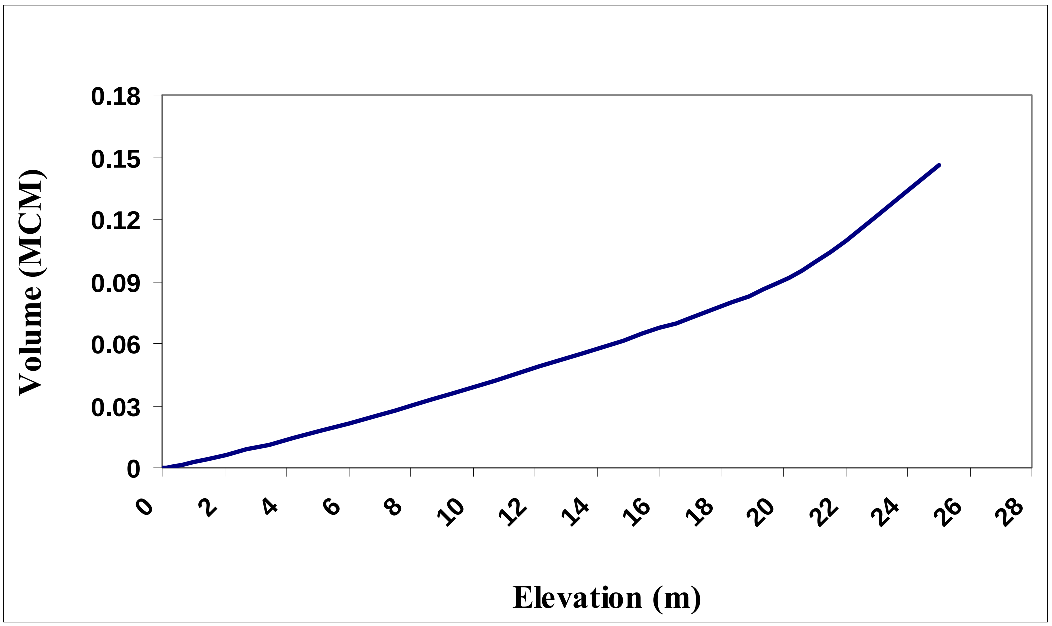

Figure 31: Elevation and Storage Volume of the Proposed Dam

4.4.2 Zoned Dam

The dam body is proposed to be constructed in zones. The zoned dam can provide most efficient use of soil. Each material is used to its greatest potential. The core retains the water and the shoulders stabilize the core. The slope protection is to stop the effects of erosion and wave action. This can be rip-rap (large rocks). **Figure 32** is a sketch of the proposed zoned dam to be constructed.

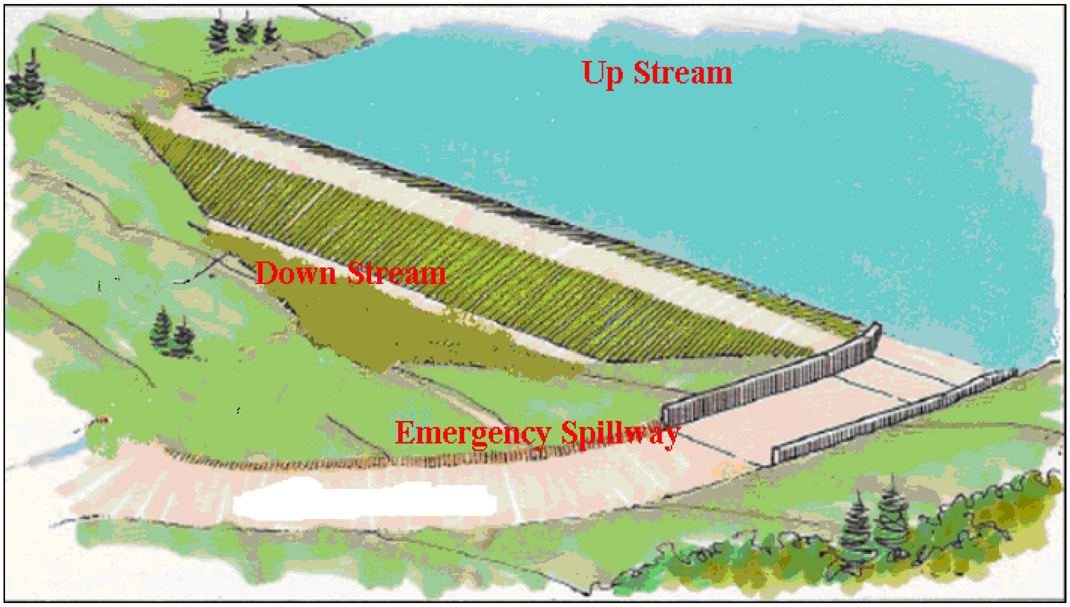

Figure 32: A sketch of the proposed zoned dam to be constructed**.**

4.4.3 Crest Width

The crest width of the earth fill dam depends on several considerations such as:

1. Nature of embankment materials.
2. Height and importance of structure.
3. Possible roadway requirements.
4. Practicability of construction.

A minimum crest width should be that width which will provide a safe percolation gradient through the embankment at the level of the full reservoir.

4.4.4 Free Board

It is the vertical distance between the crest of the embankment and the reservoir water surface. In the case of Upper Faria Storage dam, the free board is selected at 1.2 meter.

4.4.5 Spillway

Water will have to be removed from the reservoir under two conditions, infiltration and emergency spillway. All earth fill dams will require an emergency spillway to prevent overtopping.

The purpose of the spillway is to direct the flow that would exceed the design full storage level around the dam. The easiest form of the spillway is just a channel that by passes the dam at the full storage elevation. Small flows over a channel spillway can erode it over time; therefore the channel should have good erosion protection. The best erosion protection is a creeping type of grass that covers the spillway. But for our case and as grass will not grow well, riprap protection is proposed to be used.

It is recommended that the sides be constructed at a slope of 2:1. The inlet size of the spillway is based on the amount of flow. The outlet width is based on the flow and the slope that the flow takes to return to the natural streambed. It is important that the flood flow is returned in such a way that it will not erode the downstream face of the dam.

4.4.6 Specific Considerations

Site selection of the earth fill dam is a critical component to the success or failure of the dam. Therefore the following points should be considered:

1. The dam must have the potential to fill with runoff or store sufficient water between runoff events that fill the reservoir. Since the case in our project is only to retain the runoff and allow it to infiltrate into the soil. Therefore it is expected that the reservoir will be empty during the non-rainy seasons.

2. Topographical features such as slope, width and height of dam, as well as reservoir capacity will influence the construction costs. A topographical survey of the proposed dam site will be required to estimate the costs.

3. Soil conditions must be suitable for both compaction and the prevention of seepage losses through the dam. It is highly recommended that some pre-construction soil testing be done at the proposed site.

4.5 Dam Hydrograph Routing

A flood hydrograph when propagating through a stream reach or a reservoir is subject to deformation. If lateral and tributary inflow can be neglected, comparison of an upstream flood hydrograph with the related downstream hydrograph, the latter will show a reduced peak flow and increased time base.

Upper Faria catchment inflow hydrograph is routed using Muskingum method with the aid of the unit hydrograph method. This method enables us to predict outflow hydrograph that is expected to route into the dam reservoir. The unit hydrograph (1hUH) which represent the runoff from Upper Faria catchment is used to derive 12hUH. This is multiplied with 50 years return period effective rainfall depth of runoff hydrograph as shown in **Figure 33** and **Figure 34**.

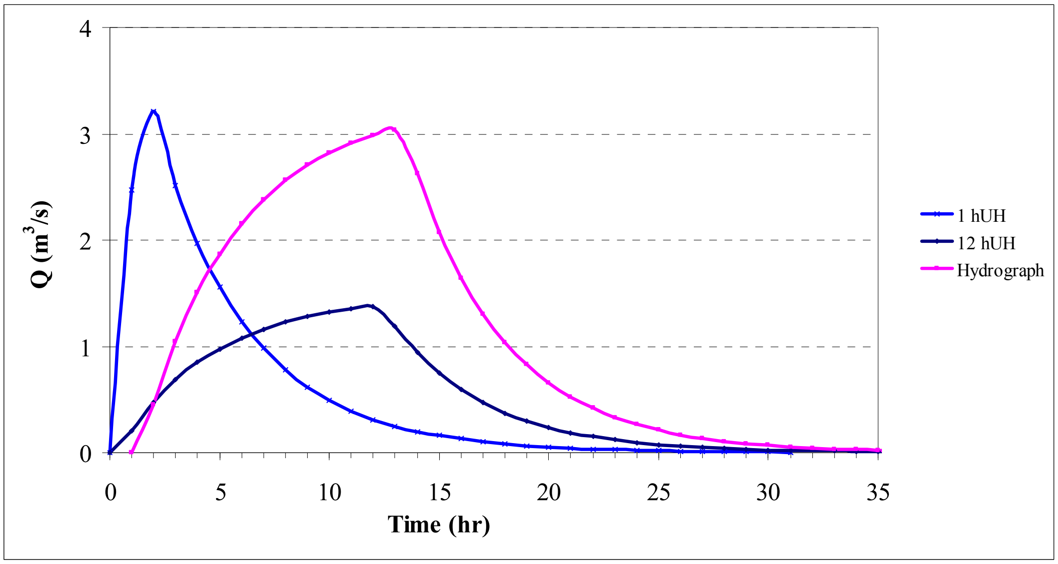

Figure 33: Routing of the Upper Faria Unit Hydrograph

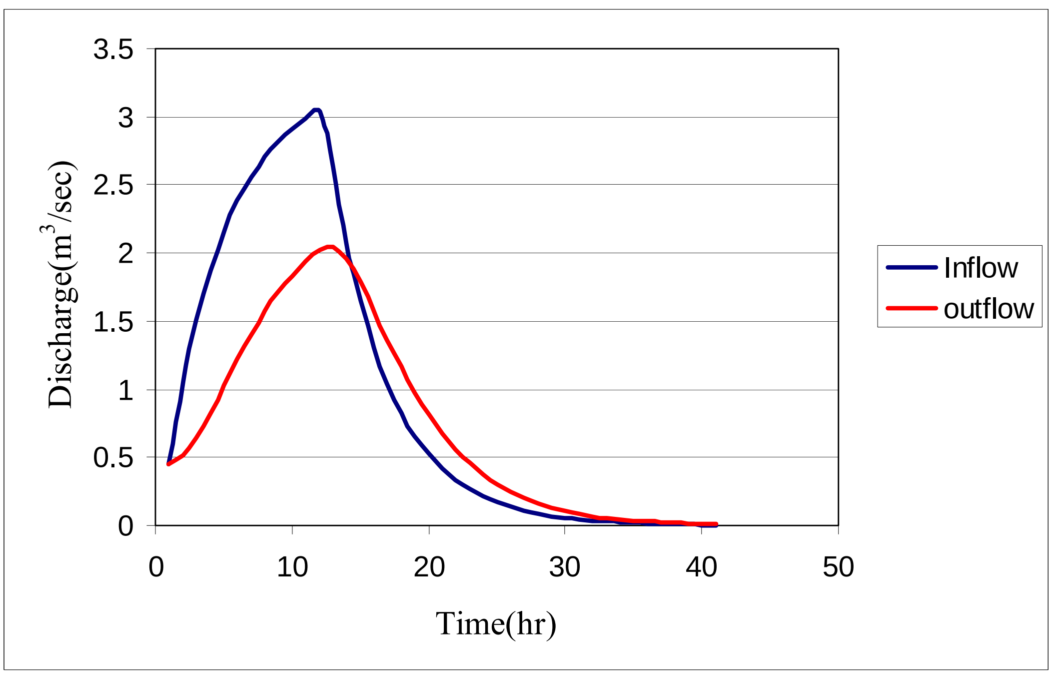

Figure 34: Routing of the Inflow Hydrograph into the Storage Reservoir.

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

Faria catchment is a small semi arid catchment that is divided into three sub catchments. This study is based on the Upper Faria catchment which area is 56 km^2 in order to establish infiltration systems. The analysis of the hydrology of the Upper Faria catchment is presented in this study. The following conclusions are meeting:

1. Double mass analysis shows internal consistency of all rainfall stations.

2. Gumbel distribution method fit extreme value analysis of the Faria rainfall.

3. Relationship between rainfall intensity and runoff coefficient is established.

4. The retention structure design return period is selected at 10-years.

5. The emergency spillway design return period is selected at 50-years.

6. An earth fill dam is enough to return water at outlet of Upper Faria catchment to allow for the artificial recharge of the groundwater aquifers.

7. The development of the suggested infiltration system to recharge the groundwater resources by constructing the earth retention dam at the

selected site in Upper Faria catchment is seen as an important requirement for the development of the water resources in the area.

5.2 Recommendations

Based on the outcome of this thesis, the following are recommended:

1. Studies are needed to investigate the infiltrated water quality at upper Faria catchment.

2. Badan sub-catchment wastewater flowing from Nablus East should be treated and allowed to be stored with the runoff water and infiltrated into the aquifer.

3. Further rainfall and runoff events should be recorded and analyzed to allow analysis and investigation of the surface runoff and its potential recharge into the aquifer system. This will enhance the proper management of the water resources of the Faria catchment.

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Appendices

Table A1: Annual rainfall of Faria rainfall stations

Years	Rainfall (mm)		
	Tubas	Tallouza	Tammun
65-66	Missing	473	Missing
66-67	Missing	926	483
67-68	274.1	533	358
68-69	467.6	770	267
69-70	321	575	279
70-71	351	664	419
71-72	504	704	378.7
72-73	288	565	219
73-74	583	881	529
74-75	378	456	307
75-76	459	594	233
76-77	391	634	270
77-78	285	508	236
78-79	219	372	214
79-80	638	872	414
80-81	345	608	285
81-82	459	480	207
82-83	614	815	397
83-84	460	561	295
84-85	296	386	258
85-86	307	508	287
86-87	309	707	218
87-88	522	1006	392.3
30	426	507	314.9
89-90	293	510	296.5
90-91	257	500	130
91-92	899.5	1303.1	616.1
92-93	485.5	734.4	330.13
93-94	336.5	498.8	276.8
94-95	450.5	678.8	398.5
95-96	378.5	633.7	337.2
96-97	500	775.3	360.3
97-98	546.1	790.8	460
98-99	201.5	292.2	124.2
99-00	365.4	492.8	317.6
00-01	243.1	324.8	225.4
01-02	494	522.3	303.8
02-03	599	704.8	487.8
03-04	317	347.6	Missing
04-05	434.6	434.6	Missing
05-06	514.8	690	425.8
06-07	488.4	715.4	420.4

TableA2: Tallouza Annual Max Daily Rainfall Gumbel Distribution

Data	Rank	Xext	p=(m-0.44)	Log T=1/P	Y=-Ln	Xgum
47	1	124.30	0.017	1.759	4.04	134.7
69.3	2	114.70	0.049	1.314	3.00	114.9
61.4	3	105.00	0.080	1.099	2.49	105.1
67.2	4	83.80	0.111	0.955	2.14	98.5
41.5	5	83.40	0.142	0.848	1.88	93.4
53.4	6	78.50	0.173	0.762	1.66	89.3
83.4	7	75.30	0.204	0.690	1.48	85.8
61.1	8	75.00	0.235	0.628	1.32	82.7
47.5	9	69.30	0.267	0.574	1.17	79.9
66.7	10	67.20	0.298	0.526	1.04	77.4
63.6	11	66.70	0.329	0.483	0.92	75.1
42.5	12	65.20	0.360	0.444	0.81	73.0
114.7	13	63.60	0.391	0.408	0.70	71.0
78.5	14	61.70	0.422	0.375	0.60	69.0
55.7	15	61.40	0.453	0.344	0.50	67.2
65.2	16	61.10	0.484	0.315	0.41	65.4
52.1	17	61.00	0.516	0.288	0.32	63.7
59.2	18	60.00	0.547	0.262	0.23	62.0
55	19	59.50	0.578	0.238	0.15	60.4
61	20	59.20	0.609	0.215	0.06	58.8
75	21	58.20	0.640	0.194	-0.02	57.2
59.5	22	57.30	0.671	0.173	-0.11	55.5
54.5	23	56.60	0.702	0.153	-0.19	53.9
61.7	24	55.70	0.733	0.135	-0.28	52.2
105	25	55.00	0.765	0.117	-0.37	50.5
124.3	26	54.50	0.796	0.099	-0.46	48.7
57.3	27	53.40	0.827	0.083	-0.56	46.8
60	28	52.10	0.858	0.066	-0.67	44.8
75.3	29	47.50	0.889	0.051	-0.79	42.5
83.8	30	47.00	0.920	0.036	-0.93	39.8
56.6	31	42.50	0.951	0.022	-1.11	36.4
58.2	32	41.50	0.983	0.008	-1.40	30.9

Table A3: Tammun Annual Max Daily Rainfall Gumbel Distribution

Data	Rank	Xext	p=(m-0.44)	Log T=1/P	Y=-Ln	Xgum
52	1	83.50	0.023	1.634	3.75	79.3
36.5	2	53.50	0.065	1.189	2.71	65.8
27	3	52.00	0.106	0.974	2.19	59.1
83.5	4	42.50	0.148	0.831	1.83	54.6
35	5	42.30	0.189	0.723	1.56	51.1
42.3	6	42.00	0.231	0.637	1.34	48.2
28	7	40.00	0.272	0.565	1.15	45.7
26	8	40.00	0.313	0.504	0.98	43.5
36	9	36.50	0.355	0.450	0.82	41.6
26.8	10	36.50	0.396	0.402	0.68	39.7
32	11	36.00	0.438	0.359	0.55	38.0
53.5	12	35.00	0.479	0.319	0.43	36.4
42	13	34.60	0.521	0.283	0.31	34.9
18.5	14	33.00	0.562	0.250	0.19	33.4
25.7	15	32.00	0.604	0.219	0.08	31.9
34.6	16	32.00	0.645	0.190	-0.04	30.5
30	17	30.00	0.687	0.163	-0.15	29.0
33	18	29.50	0.728	0.138	-0.26	27.5
40	19	28.00	0.769	0.114	-0.38	26.0
40	20	27.00	0.811	0.091	-0.51	24.3
42.5	21	26.80	0.852	0.069	-0.65	22.6
29.5	22	26.00	0.894	0.049	-0.81	20.5
32	23	25.70	0.935	0.029	-1.01	17.9
36.5	24	18.50	0.977	0.010	-1.33	13.8

Table A4: Tubas Annual Max Daily Rainfall Gumbel Distribution

Data	Rank	Xext	p=(m-0.44)	Log T=1/P	Y=-Ln	Xgum
40	1	77.5	0.016	1.797	4.13	90.5
40.5	2	70	0.044	1.352	3.09	77.0
29.7	3	65	0.073	1.137	2.58	70.4
38.5	4	63	0.101	0.994	2.24	65.9
48.9	5	62	0.130	0.887	1.97	62.5
52	6	60	0.158	0.800	1.76	59.7
31.5	7	53	0.187	0.729	1.58	57.3
27.3	8	52	0.215	0.667	1.42	55.3
31.7	9	48.9	0.244	0.613	1.28	53.4
27	10	45	0.272	0.565	1.15	51.7
30	11	44	0.301	0.522	1.03	50.2
77.5	12	44	0.329	0.483	0.92	48.8
42	13	42.5	0.358	0.447	0.82	47.4
35	14	42	0.386	0.413	0.72	46.2
35	15	41.5	0.415	0.382	0.62	45.0
37	16	40.5	0.443	0.354	0.54	43.8
32	17	40	0.472	0.326	0.45	42.7
38	18	40	0.500	0.301	0.37	41.6
70	19	40	0.528	0.277	0.29	40.5
40	20	38.5	0.557	0.254	0.21	39.5
38.5	21	38.5	0.585	0.233	0.13	38.5
62	22	38	0.614	0.212	0.05	37.5
65	23	38	0.642	0.192	-0.03	36.5
44	24	37	0.671	0.173	-0.11	35.5
40	25	35	0.699	0.155	-0.18	34.4
44	26	35	0.728	0.138	-0.26	33.4
60	27	32	0.756	0.121	-0.34	32.3
41.5	28	31	0.785	0.105	-0.43	31.3
31	29	31.5	0.813	0.090	-0.52	30.1
53	30	31	0.842	0.075	-0.61	28.9
22	31	30	0.870	0.060	-0.71	27.6
63	32	29	0.899	0.046	-0.83	26.1
42.5	33	27	0.927	0.033	-0.96	24.3
38	34	27	0.956	0.020	-1.14	22.1
45.00	35	22	0.984	0.007	-1.42	18.4

Table A5: Upper Faria catchment Max.Daily Areal Rainfall

Tallouza (mm)	**Rainfall ($mm.km^2$)**	**Tammun (mm)**	**Rainfall ($mm.km^2$)**	**Tubas (mm)**	**Rainfall ($mm.km^2$)**	**Areal Rainfall (mm)**
124.3	3256.7	83.5	1052.1	77.5	1333.0	100.7
114.7	3005.1	53.5	674.1	70.0	1204.0	87.2
105.0	2751.0	52.0	655.2	65.0	1118.0	80.8
83.8	2195.6	42.5	535.5	63.0	1083.6	68.1
83.4	2185.1	42.3	533.0	62.0	1066.4	67.6
78.5	2056.7	42.0	529.2	60.0	1032.0	64.6
75.3	1972.9	40.0	504.0	53.0	911.6	60.5
75.0	1965.0	40.0	504.0	52.0	894.4	60.1
69.3	1815.7	36.5	459.9	48.9	841.1	55.7
67.2	1760.6	36.5	459.9	45.0	774.0	53.5
66.7	1747.5	36.0	453.6	44.0	756.8	52.8
65.2	1708.2	35.0	441.0	44.0	756.8	51.9
63.6	1666.3	34.6	436.0	42.5	731.0	50.6
61.7	1616.5	33.0	415.8	42.0	722.4	49.2
61.4	1608.7	32.0	403.2	41.5	713.8	48.7
61.1	1600.8	32.0	403.2	40.5	696.6	48.2
61.0	1598.2	30.0	378.0	40.0	688.0	47.6
60.0	1572.0	29.5	371.7	40.0	688.0	47.0
59.5	1558.9	28.0	352.8	40.0	688.0	46.4
59.2	1551.0	27.0	340.2	38.5	662.2	45.6
58.2	1524.8	26.8	337.7	38.5	662.2	45.1
57.3	1501.3	26.0	327.6	38.0	653.6	44.3
56.6	1482.9	25.7	323.8	38.0	653.6	43.9
55.7	1459.3	18.5	233.1	37.0	636.4	41.6

Table A6: Upper Faria catchment Max.Daily Areal Rainfall Gumbel Distribution

Areal Rainfall (mm)	Rank	Xext	p(x)=(r-0.44) /(N+0.12)	Log T=1/P	Y=-Ln (-Ln(1-p))	Xgum
100.746	1	100.75	0.023	1.634	3.75	129.2
87.2007	2	87.20	0.065	1.189	2.71	109.2
80.7893	3	80.79	0.106	0.974	2.19	99.4
68.1189	4	68.12	0.148	0.831	1.83	92.6
67.5796	5	67.58	0.189	0.723	1.56	87.4
64.6054	6	64.61	0.231	0.637	1.34	83.2
60.5082	7	60.51	0.272	0.565	1.15	79.5
60.0607	8	60.06	0.313	0.504	0.98	76.3
55.6543	9	55.65	0.355	0.450	0.82	73.3
53.4739	10	53.47	0.396	0.402	0.68	70.6
52.8204	11	52.82	0.438	0.359	0.55	68.1
51.8936	12	51.89	0.479	0.319	0.43	65.7
50.5943	13	50.59	0.521	0.283	0.31	63.4
49.1918	14	49.19	0.562	0.250	0.19	61.2
48.6729	15	48.67	0.604	0.219	0.08	59.1
48.2254	16	48.23	0.645	0.190	-0.04	56.9
47.575	17	47.58	0.687	0.163	-0.15	54.7
46.9946	18	46.99	0.728	0.138	-0.26	52.5
46.4232	19	46.42	0.769	0.114	-0.38	50.2
45.5971	20	45.60	0.811	0.091	-0.51	47.8
45.0843	21	45.08	0.852	0.069	-0.65	45.2
44.3296	22	44.33	0.894	0.049	-0.81	42.1
43.9346	23	43.93	0.935	0.029	-1.01	38.3
41.5864	24	41.59	0.977	0.010	-1.33	32.3

Photo A7: The Flood Event at Upper Faria Flume, February 2006

جامعة النجاح الوطنية
كلية الدراسات العليا

الجريان الطبيعي وتطوير أنظمة ترشيح المياه في حوض الفارعة

إعداد
بهاء رشيد فايق صلاحات

إشراف
د.حافظ شاهين
د.عنان الجيوسي

قدمت هذه الأطروحة استكمالا لمتطلبات نيل درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس- فلسطين.

2008

الجريان الطبيعي وتطوير أنظمة ترشيح المياه في حوض الفارعة

إعداد

بهاء رشيد فايق صلاحات

إشراف

د. حافظ شاهين

د. عنان الجيوسي

الملخص

تهدف هذه الدراسة إلى إدارة مياه الجريان السطحي والناتجة عن مياه الأمطار الفائضة خلال موسم الشتاء في حوض وادي الفارعة خصوصا في الجزء العلوي الشمالي من الحوض وذلك من خلال تطوير أنظمة جمع و ترشيح لمياه الأمطار والينابيع وحقنها في المياه الجوفية.

كثير من الدراسات والبحوث المائية تم انجازها في منطقة وادي الفارعة وجاءت هذه الدراسة ضمن مشروع (EXACT) والذي من خلاله تم دراسة إمكانية تطوير نموذج لحصاد مياه الأمطار وحقنها في المياه الجوفية على أساس افتراض قوي بين المعطيات الهيدرولوجية والتي تمثلت بكميات الأمطار المتساقطة وربطها بقياسات الجريان السطحي عند مخارج وادي الفارعة. تم ذلك من خلال دراسة الأحداث المطرية التي سببت جريان في الوادي من خلال التحليل الإحصائي بتطبيق نظم المعلومات الجغرافية (GIS) وباستخدام برنامج (EXCEL), حيث تم التوصل للعلاقة التي تربط بين شده الأمطار ومقدار معامل تدفق الأمطار.

الجزء الأخير من هذه الأطروحة تناول اقتراح إنشاء سد مائي ترابي لحجز المياه عند مخرج حوض الدراسة خلال موسم الشتاء ليتاح لها الارتشاح في المياه الجوفية حيث تم وضع معايير التصميم اللازمة لإنشاء السد وتحديد الأماكن المقترحة لإقامة السد.