An-Najah National University
Faculty of Graduate Studies

Rainfall – Runoff Analysis of Wadis Contributing to the Dead Sea: Wadi Og as a Case Study

By
Lina Omar Bahjat Lahlabat

Supervisor
Dr. Anan Jayyousi

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This Thesis was Defended Successfully on 8/7/2013, and Approved by:

Defense Committee Members	**Signature**
1. Dr. Anan Jayyousi / Supervisor	………………
2. Dr. Saed Al-khayyat / External Examiner	………………
3. Dr. Hafiz Shaheen / Internal Examiner	………………
4. Dr. Mohammad Al-masri / Internal Examiner	………………

DEDICATION

To my parents, without their love and support the completion of this work would have not been possible.

Papa and Mama, I love you.

ACKNOWLEDGEMNT

I would like to thank my God who gives me the strength to complete this work and make it possible. Praise be to Allah

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الإقرار

أنا الموقعة أدناه مقدمة الرسالة التي تحمل العنوان:

Rainfall – Runoff Analysis of Wadis Contributing to the Dead Sea: Wadi Og as a Case Study

تحليل الأمطار والجريان السطحي للأودية المساهمة في البحر الميت واد العوج كحالة دراسية

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة أو لقب 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 الطالبة:**

Signature: **التوقيع:**

Date: **التاريخ:**

List of Abbreviations

ARC	Antecedent Runoff Condition
C	Celsius
CN	Curve Number
CN_c	Composite Curve Number
D	Duration,
DEM	Digital Elevation Model
GIS	Geological Information System
HEC-HMS	Hydrological Modeling System-Hydrologic Modeling System
HSG	Hydrologic Soil Group
Km	Kilometer
KW-GIUH	Kinematic Wave based Geomorphological Instantaneous Unit Hydrograph
m	Meter
m^3/sec	Cubic Meter per Second
MCM	Million Cubic Meter
mm	Millimeter
PWA	Palestinian Water Authority
Q	Discharge
Q_p	Discharge of Peak
SCS	Soil Conservation Service
SPI	Standardized Precipitation Index
STD	Standard Deviation
SUMAR	Sustainable Management of Water Resources
T	Time
T_b	Base Time
T_c	Time of Concentration
T_{lag}	Lag Time
T_p	Time of Peak
UH	Unit Hydrograph
UNESCO	United Nations Educational, Scientific and Cultural Organisation
USDA	United States Department of Agriculture
V	Volt

Table of Contents

List of Tables

List of Figures

List of Annexes

Rainfall – Runoff Analysis of Wadis Contributing to the Dead Sea: Wadi Og as a Case Study

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Abstract

The distinctive features of arid and semi-arid areas affect rainfall-runoff modeling on both a discrete basis and continuous basis. Extreme events such as flash flood, severe storms, and droughts are the main features characterizing such environment. However, these features are prevailing in Jordan River Valley, in Palestine, where periodic fluctuations in rainfall affect runoff generation and cause rapid response to ephemeral streams of the wadis that contributes to the Dead Sea in winter season.

In this research; rainfall-runoff process for Og watershed that lies in the northwest shore of the Dead Sea was studied, the drainage watershed that contributes floods was characterized, and the surface runoff volume and flood peak was predicted.

The Hydrologic Engineering Center's –Hydrologic Modeling System (HEC-HMS) model was used to simulate single event and continuous hydrologic model for the watershed. Three scenarios were simulated for the continuous model (wet rainfall hydrological year 2002-2003, average rainfall hydrological year 2004-2005, and dry rainfall hydrological year 2003-2004) while flash flood from 8th January,2013 storm was simulated for event model.

The physical characteristics of the watershed was related to the model through developing the Digital Elevation Model, Watershed Delineation, and stream network using GIS capabilities. The dimensionless SCS unit hydrograph was used to transform the computed excess rainfall to direct runoff at the outlet of the watershed. The SCS-CN method was also used to simulate excess rainfall and losses. The Muskingum routing method was used to account for the transmission losses, while the meteorological model was developed for event and continuous basis.

Statistical rainfall analysis was performed for yearly, monthly and daily rainfall data for three rainfall stations surrounding the Og watershed. The consistency of rainfall data was checked and the areal rainfall was calculated using the Isohyetal map of the region. The results were used as an input to the meteorological model.

Surface runoff and peak discharges were predicted for each continuous scenario beside the event model. The model outputs reflect the aridity of the area where only 9 MCM of surface runoff was generated in average hydrological rainfall year, 19 MCM of surface runoff was generated in wet hydrological rainfall year and less than 1 MCM in dry hydrological rainfall year. Event model output depicts that only two to three peak discharges may take place through a rainy season with 73,000 m^3 volume.

Model calibration and validation is essential need for hydrological modeling developed for arid and semi-arid environment. However, as Og watershed is ungauged, a kind of verification was conducted to the event model output. Apparently, there is an urgent need to calibrate the model parameters in order to be applicable for other hydrological purposes.

The lack of high quality data to support the modeling, the difficulty of observing the generally high spatial variability of rainfall inputs and flow outputs, as well as the limited available tools for the Palestinian hydrologists to work on the field are the main obstacles facing this research.

Chapter One

Introduction

Chapter One
Introduction

1.1 Introduction

Water is a gift from God; it is the most essential and vital need for life. It is a main ingredient in most domestic, industrial and agricultural activities. Unfortunately, water resources in Palestine are scarce **(AlYaqoubi, 2007)**. This is due to the fact that, geographically, the West Bank is located in arid to semi-arid region, in addition, artificial constrains and restrictions are imposed by the Israelis on the Palestinians in utilizing their water resources **(Shadeed and Shaheen, 2008)**.

Surface water is considered as one of the significant water resources in the West Bank. It includes mainly the Jordan River along with its tributaries and Wadis flow from the central mountain towards the Jordan Valley. These Wadis are of importance for surface water streams, where floods from them coincide together to form major streams which rush unchecked fresh rainwater down to the Dead Sea in the high rainfall year **(Jayyousi & Srouji, 2009)**. **Figure 1-1** presents the major Wadis that contribute to the Dead Sea Basin.

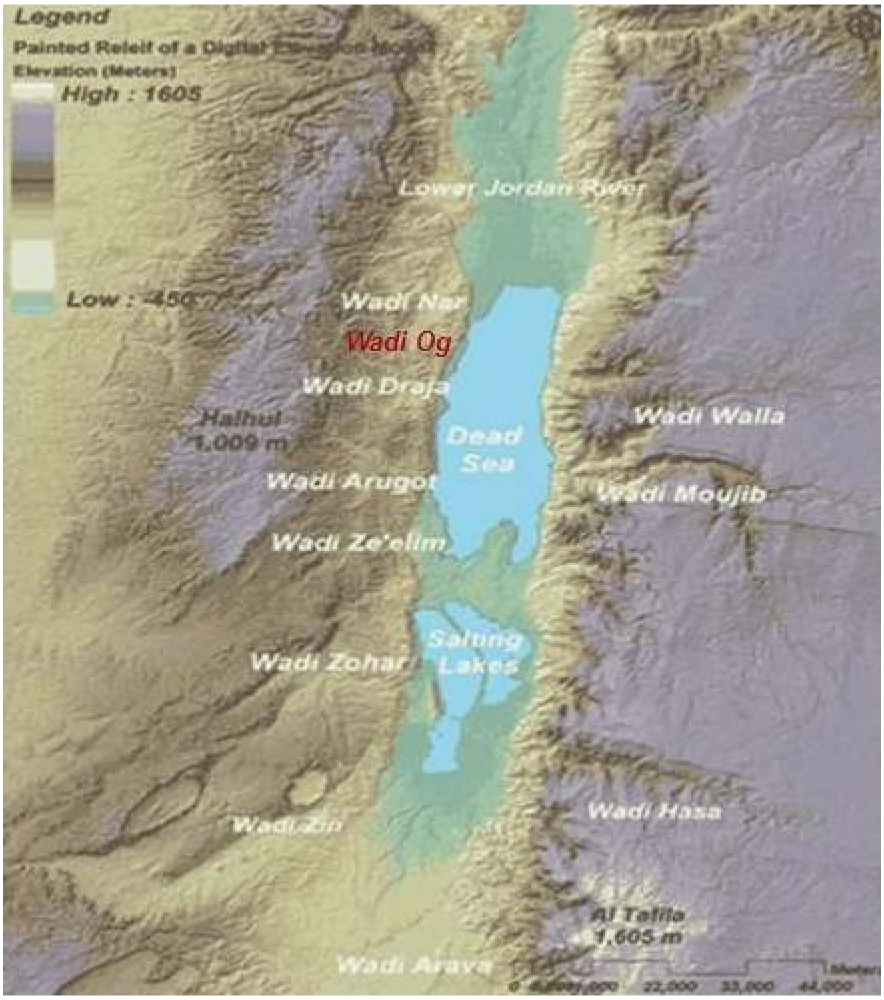

Figure (1-1): Major Wadis Contribute to the Dead Sea Basin. ***Source:*** **(deadseaproject.eu)**

On the other hand, the area surrounding the Dead Sea is classified as arid to semi-arid region where water is at its most scarcity. The hydrological regime in these areas is extreme and highly variable as it's greatly affected by the hydrological seasonal effects, notably rainfall. Periodic fluctuations in rainfall over the region influences runoff generation and causing severe hydrological problems, one of these is flash –flood that leads to short term of surface water availability **(Wheater et al., 2008)**.

Without proper management of this significant water resource, the excess rainfall can be quickly lost due to high evaporative environment and lost from the watershed via runoff without any proper benefit. This situation motivates the focusing on planning and implementation of an integrated water resources management plan in order to utilize all possible local surface water (ephemeral wadis flow) and groundwater resources.

The development of appropriate techniques for modeling runoff in arid and semi-arid region is presently regarded as one of the most challenging tasks in surface water hydrology, especially for ungauged watershed. One method can be used to achieve the goal; which is constructing synthetic unit hydrograph and simulate flow using modeling methods. Such techniques have been widely used for a variety of purposes, almost all modeling tools have been primarily developed for humid area applications compared to arid and semi-arid areas that have received little attention **(Wheater et al., 2008)**.

This research is intended to study the surface water at the Og watershed which lies at the northwest shore of the Dead Sea and drains eastwards to the Dead Sea through the Og Wadi. Predicting flood water volumes, estimating the peak flow, and the most important factors influencing it will be done using synthetic unit hydrograph and modeling tools which is commonly preferred for unguaged watersheds. Results will be compared and the developed model will be validated by using direct measurements that will be obtained from the newly installed flow measurement station.

1.2 Problem Description

The lower Jordan River and several Wadis along the Dead Sea shores in Jordan, Palestine, and Israel, are filled with fresh rainwater in winter and rush unchecked water down to the Dead Sea, in addition to the underground lateral water and spring discharges into it, where it salinizes upon contact. The major sides Wadis of the Dead Sea are Wadi Al-Hassa, Wadi Moujeb, Wadi Wala, Wadi Og, Wadi Nar, Wadi Daraja, Wadi Ghar (David), Wadi Ze'elim, Wadi Rahaf, Wadi Heimar, Wadi Zin and Wadi Northern Arava. Today, the major Wadis are dammed and their water is diverted to agricultural uses, to the Dead Sea works and to the Potash Companies, and several others are also filled with domestic and industrial wastewater.

Moreover, the Dead Sea is drying up causing water supply problems with severe negative consequences on the ecosystem, industry and wildlife in them. Long-term fluctuations of the Dead Sea water level are caused by periodic fluctuations in rainfall over the watershed, which cause severe hydrologic problems. One of these is that flash-flood in this setting of continuously and lowering base level cause incision of the channels at a formidable rate. Another critical issue is that surface water derived from springs in oases (such as Ein Feshka on the western side of the Dead Sea) is in danger of extinction, because the spring water flows into incised channels which, once incising into the oases lower the local ground water and may drain these world-unique ecological habitats.

1.3 Research Objectives

The main objective of this research is to contribute to a better understanding of the surface water discharges to the Dead Sea. In particular, the Og watershed. This research will try to meet the following objectives:

1. Develop relationship between rainfall-runoff processes.
2. Characterizing the drainage watershed that contributes floods.
3. Estimations of the surface runoff volume and flood peak for the study area.

1.4 Research Motivations

The following are the motivations for carrying out this research:

1. Throughout the world, the need for improved understanding of the hydrology of arid and semi- arid region is presently considered as one of the most important topics that have been highlighted in surface water hydrology, especially, nearly half the countries of the world face problems of aridity **(Pilgrim et al., 1989)**.
2. The area surrounding the Dead Sea is under arid and semi-arid condition, it’s extremely suffered from shortage of safe and reliable drinking water supplies. In these arid areas, Palestinian communities depend mainly on groundwater as their main source. The exploitation of the groundwater and springs in the alluvial aquifer in proximity to

the Dead Sea is strongly influenced by the recession of the Dead Sea, and the groundwater resources become suffering from serious problems represented by severe decline in water level and increasing salinity **(Abdel-Ghafour, 2005)**. The problems are further exacerbated as there is no guidance on the decision support tools that are needed to underpin flood and water resource management in these arid areas.

3. Challenges are present in studying the hydrology components of the Dead Sea basin, mainly resulted from inaccessibility, rugged and inhospitable terrain, and historical lack of foresight concerning the need to have these areas adequately gauged. Predictive tools for water resources, such as water quality, natural hazard mitigation and water availability assessment are generally data-driven; the lack of adequate hydrometric records poses difficult problems for studying the hydrology components in this region **(Ouarda, et al., 2003)**.

From the above points; it can be concluded that there is a need to develop appropriate techniques for studying surface water components and to model the rainfall-runoff process, and to support integrated water management in order to overcome water crisis in the Dead Sea basin.

1.5 Research Questions

This research tries to respond to the following questions:

1. What is the climatic pattern of the Og watershed and how does it change spatially and temporally?

2. How rainfall characteristics affect flash-flood events?

3. How do the characteristics of the drainage watershed affect the runoff in the catchment?

4. Does it necessary to take the transmission losses into account in this environment? What's the possible method that can be used to estimate it?

5. How much are the surface runoff volumes to the Dead Sea from the Og watershed?

1.6 Research Methodology

The methodology of the research is divided into four main steps summarized in the following flowchart:

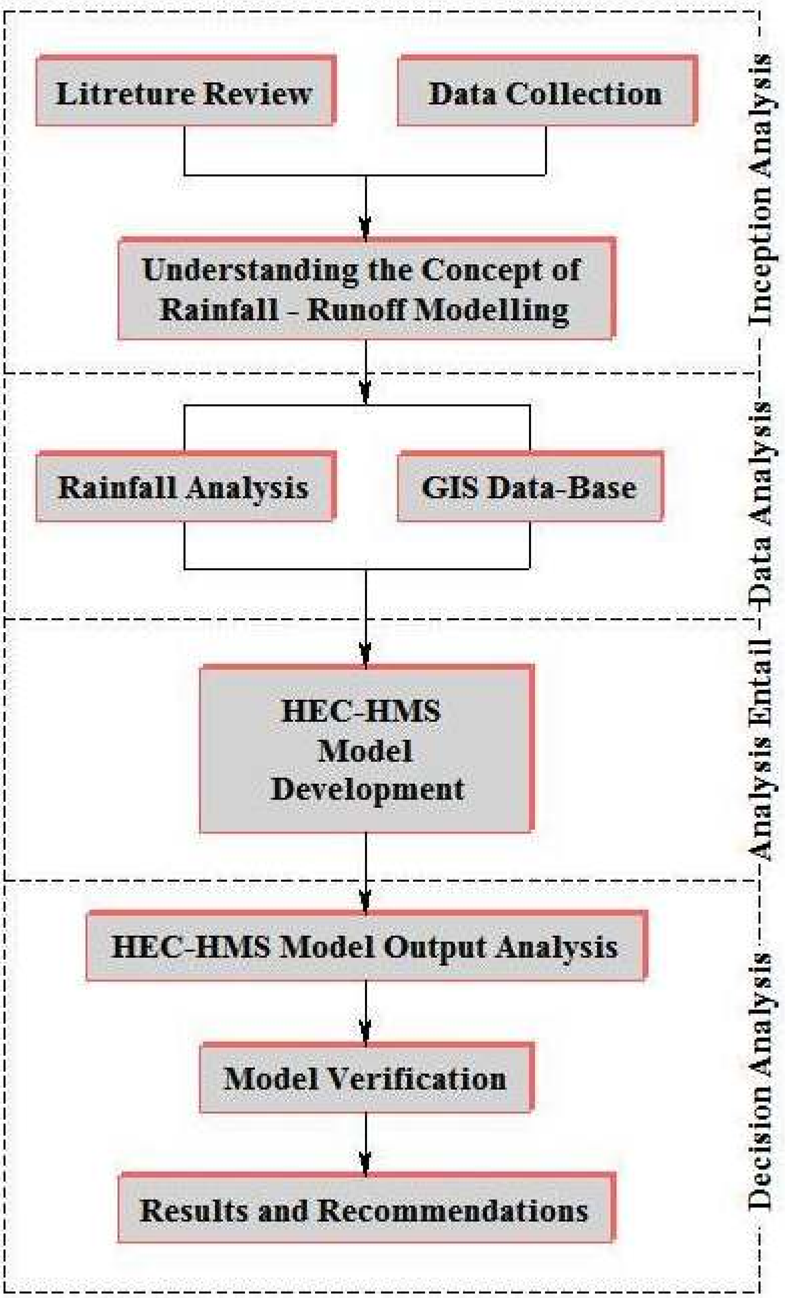

Figure (1-2): Research Methodology Flowchart

The first step of this research was an Inception Analysis; mainly consisted of data gathering from the Palestinian Water Authority (PWA) and Palestinian Meteorological Department. The collected data included: digitized relevant maps; metrological data; rainfall data; and soil data. Runoff data is not available except for some of the historic records of peak flood volumes in nearby sites. In addition, a literature review was carried out to outline the hydrological process in arid and semi-arid environment, and to develop understanding of the hydrological models.

The second step was Data Analysis and Processing. Rainfall analysis was carried out by analyzing and simulating the records from the rainfall stations surrounding the Og watershed. Simulated rainfall has great importance in applying such models to areas where rainfall gages are scarce or don't exist or where historical records are too short. However, yearly, monthly and daily rainfall data were analyzed, as well as the extreme events. The analysis was conducted with the aid of GIS and MS Excel. Also, this step included preparing the maps that describe the existing environment of the watershed; the topographic, geological, land use and meteorological maps were prepared using GIS 9.3 program.

The third step was building the HEC-HMS model. The characteristics of the watershed, the unit hydrograph, the rainfall events and the hydrological losses and routing were prepared as input parameters for the model; the Digital Elevation Model (DEM) for the watershed was generated as a first step to setup the GIS-based database, mainly the watershed delineation, the hydrological network, and the catchment response. The unit hydrograph was derived; SCS synthetic unit hydrograph was developed. The hydrological losses were computed including the evaporation and the estimation of curve number as well as Muskingum routing parameters. It is noteworthy, that this step included several visits to the watershed to assuring that the developed model simulated reality.

Finally, the fourth step was a decision analysis. This step consists of analyses the output of the model, the flood peak and volume. The performance of the model was assessed by conducting a kind of validation. The major recommendations also were included in this stage to enhance the hydrological researching in surface water components for the Dead Sea basin in general and Og watershed in particular as a new runoff station is installed.

1.7 Thesis Outline

The thesis consists of seven chapters in addition to this introductory chapter. Literature review is provided in chapter two. Description of study area is given in chapter three, while chapter four includes rainfall analysis. The development of HEC-HMS model for Og watershed is presented in chapter five. Chapter six discusses the analysis and results. The last chapter demonstrates the main conclusions and recommendations of this research.

Chapter Two

Literature Review

Chapter Two
Literature Review

2.1 Introduction

The distinctive features of arid and semi-arid regions affect rainfall – runoff modeling **(Pilgrim et al., 1989)**. Runoff generation in these areas is mainly controlled by rainfall characteristics and the surface's physical and chemical properties **(Ben-Zvi and Shentsis, 1999)**, Adding to that, flash-floods from a single large storm can exceed the total runoff from a sequence of years. The difficulty of predicting rainfall-runoff responses in arid watersheds using available data sets is well-known **(McIntyre et al., 2009)**.The lack of observed data in such regions accentuates the need for data synthesis by modeling, while at the same time, resulted in increasing the difficulty of the task. Comparatively, little is known about the hydrological modeling in the West Bank as it has not been given enough care or intensive studies **(Shadeed, 2008)**.

2.2 General Characteristics of Hydrological Process in Arid and Semi-arid Areas

There is a general agreement about the fact that large areas of the earth are considered arid to semi- arid region. According to UNESCO (1984) classification, nearly half the countries of the world face problems of aridity. The definition of aridity depends on the purpose of classification. However, the most formal definitions are in terms of the causes of aridity and are often based on comparison between precipitation and some measure of potential evaporation **(Pilgrim et al., 1989)**.

Semi-arid regions are associated with dry climate which are dominated by low annual rainfall, low soil moisture conditions, very high potential evapotranspiration levels and periodic droughts, in addition to different associations of vegetative cover and soils **(Shadeed, 2005)**. As well as, it's greatly affected by hydrological seasonal effects especially rainfall, which is the major factor controlling the hydrologic cycle of a region. In these areas, rainfall tends to be more variable in both space and time than in humid ones. Moreover, extreme spottiness of individual convective rain storms were demonstrated **(Renard et al., 1966 cited in Larrone et al., 1992)** and in a number of semiarid settings, the probability of receiving a similar longer-term pattern of rainfall diminishes dramatically over distances as small as a few kilometers has shown **(Sharon, 1972; 1974 cited in Larrone et al., 1992)**. This means that hydraulic conditions change rapidly.

Evaporatranspiration, infiltration and transmission losses play an important role in the hydrological regime of these areas, where there is high portion of incoming water that is returned to the atmosphere through evaporation mostly from the soil surface **(Shaheen, 2002)**, while transpiration from plants assumes less importance relative to evaporation. On the other hand, infiltration excess is the dominating runoff generation mechanism. In this process, rain intensities higher than the soil infiltration capacity generate runoff **(Morin et al., 2008)**. In addition to, transmission losses which vary from point to point along a channel and with the degree of saturation of the alluvium in the channel prior to the runoff event. Therefore, these loses must be taken into account in rainfall-runoff modeling especially it's the cause of the differences in runoff depth **(Sharma, 1998)**.

Water, which is not evaporating or infiltrating into the ground is running off at the surface. According to Khatib and Assaf (1994) surface runoff occurs only when rainfall exceeds 50 mm in one day or 70 mm in two consecutive days, otherwise all the rainfall is evaporating or infiltrating **(Sturm et al., 1996)**. In arid and semi-arid areas, stream flow tends to be dominated by rapid responses to intense rainfall events. Such events frequently have a high degree of spatial variability, coupled with poorly gauged rainfall data. This sets a fundamental limit on the capacity of any rainfall-runoff model to reproduce the observed flow **(Wheater et al., 2008)**.

Most of surface water in this environment is of the ephemeral kind that doesn't have any base-flow contribution **(www.nih.ernet.in)**. The characteristic of an ephemeral stream depend highly upon:

1. The rainfall characteristics, such as magnitude, intensity, distribution in time and space and its variability.

2. Catchment characteristics such as soil, vegetation, slope, geology, shape and drainage density.

3. Climatic factors which influence evapotranspiration.

Factors are important in assessing the annual runoff volume, they represent the system structure and act as an operator to convert a time sequence or naturally occurring rainfall into a time sequence of runoff. Consequently, a deeper knowledge of the hydrological response of arid and semi-arid watersheds would be useful for assessing flood volumes **(Ben-Zvi and Shentsis, 1999)**.

Many reasons attribute to consider almost all runoff events with little loss of accuracy as being independent of one another, this is due to the long intervals between runoff events, and the high rate of potential evapotranspiration, low values of soil moisture antecede, these may be necessary for simulating the rainfall-runoff process in these areas **(Ben-Zavi and Shentsis , 1999)**.

The characteristics of runoff hydrographs of the ephemeral wadis include flashy responses, very fast rises and fast recessions, with a frequency of occurrence of 1 -3 y-1 **(Reid et al., 1998)**. The rise-times varies with watershed area but may be merely a few minutes, often less than 1 hr **(Ben Zvi et al., 1991)** commonly much less than 30 minutes **(Reid et al., 1989)**. Recessions may last one day and in larger basins 2 days. Runoff volumes vary considerably between runoff events and between years.

The annual hydrograph of such watershed show series of short-duration spikes marking flash flows in response to storms **(Larrone et al., 1992)**. Peak flow rate and time to peak are the two important hydrograph characteristics that related to geomorphic parameters of the watershed, such as drainage area, channel gradient, and drainage density. These geometric characteristic of the watershed represent the constant factors that affect the storage and transmission of a volume of runoff generated by rainstorm event. Unfortunately, lack of observed data, and the short period of the available rainfall records provide major problems in estimating the hydraulic parameters.

2.3 Synthetic Unit Hydrograph Model

The need for new methodologies to make improved predictions in ungauged watersheds is well highlighted; specially most of watersheds in developing countries are totally ungauged. Therefore, all the efforts recently tend to focus on the planning problems at these watersheds **(Hunukumbura et al., 2007)**.

When no direct observations are available, or when suitable data to determine the unit hydrograph of a watershed are seldom adequate, Synthetic Unit Hydrograph procedures must be used **(Ramirez, 2000)**. The primary advantage of this method is that the complete unit hydrograph may be determined with the specification of one or two hydrograph parameters. Further, many studies have shown that synthetic unit hydrographs may be derived for ungauged watersheds utilizing the relations between hydrograph parameters, the watershed and storm characteristics as long as the ungauged watersheds are hydrologically similar to the gauged watersheds for which the relation was developed **(Melching and Marquardt ,1997)**.

Synthetic Unit Hydrograph procedures can be categorized to:

1) Those based on models of watershed storage (e.g., Nash, 1958, 1959; Dooge, 1959)

2) Those relating hydrograph characteristics such as (time to peak, peak flow, etc.) to watershed characteristics (e.g., Snyder, 1938; Geomorphologic Instantaneous Unit Hydrograph)

3) Those based on a dimensionless unit hydrograph (e.g., Soil Conservation Service, 1972) **(Ramirez, 2000)**.

In this research, SCS dimensionless unit hydrograph method is considered to develop UH for Og watershed.

2.3.1 The Dimensionless SCS Model

The SCS dimensionless unit hydrograph was developed by U.S. Soil Conservation Service (1972). It is based on dimensionless unit hydrograph which is obtained from a great number of unit hydrographs developed from basins ranging in size and from different geographic locations **(Nurünnisa, 1996)**. In this method; all the hydrograph ordinates are given by ratios between instantaneous discharge and peak discharge (q/qp) and between time and time to peak (t/tp) **(Melching and Marquardt, 1997)** as illustrated in **Figure 2-1**.

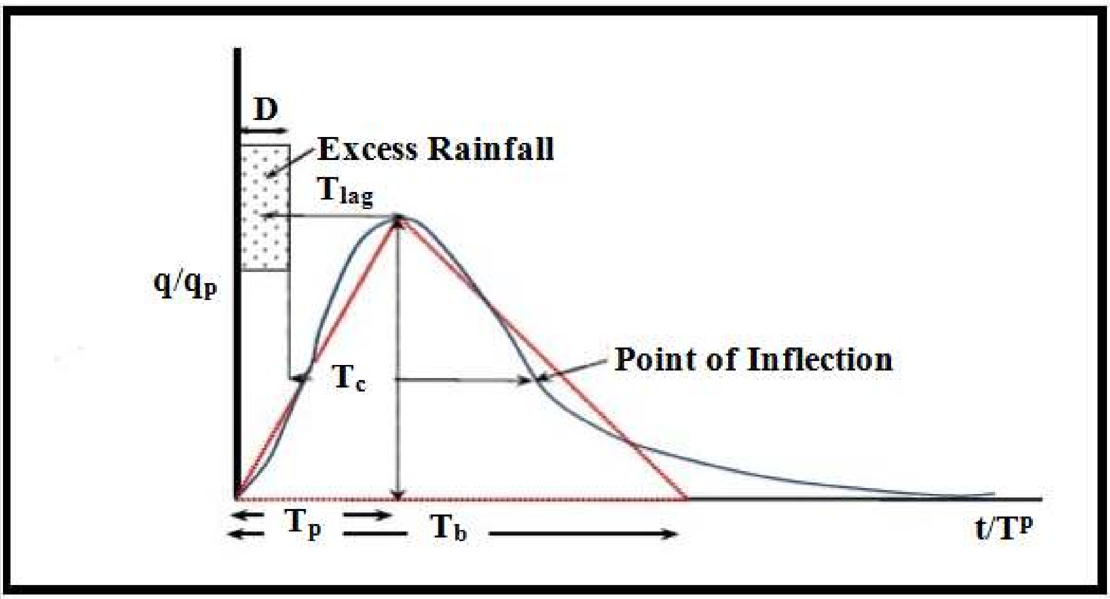

Figure (2-1): Curvilinear and Equivalent Triangle Dimensionless Unit Hydrograph. ***Source*****: (projects.juniata.edu)**

The SCS suggests that the dimensionless UH can be described in terms of an equivalent triangular hydrograph that having the same peak discharge q_p, time to peak T_p and the volume of direct runoff q as the original hydrograph by calculating the time base T_b of the triangle, the peak discharge q_p and the lag time $t_{lag.}$ Once the unit hydrograph is produced, it can be applied to estimate direct runoff via the convolution integral of the excess rainfall hyetograph and unit hydrograph **(Wang et al., 2008)**.

Determination of the curve number (CN), which is a function of hydrologic soil group (HSG), Cover type, Treatment, hydrologic condition and antecedent runoff condition (ARC) is essential for this method. Soils are classified into four HSG's (A, B, C, and D) according to their minimum infiltration rate, which is obtained for bare soil after prolonged wetting.

ARC is an attempt to account for the variation in CN at a site from storm to storm. CN for the average ARC at a site is the median value as taken from sample rainfall and runoff data **(Danill et al., 2005)**.

Time of concentration T_c is defined as (the time required for a particle of water to travel from the most remote point in the watershed to the point of collection) is the most critical parameter in determining the outflow from a drainage watershed, it reflects how the runoff is distributed over time. The T_c introduced by the SCS method as a time dependent factor. Normally rainfall duration equal to or greater than T_c is used **(Danill et al., 2005)**.

The SCS Dimensionless Unit Hydrograph is established using the following relations:

– **Lag Time**: the lag time (T_{lag}) is the key parameter needed to convert the regional dimensionless hydrograph into an ungauged watershed unit hydrograph. It is estimated by using the following equation:

$$T_{lag} = 2.587\,\frac{L^{0.8}\left(\frac{1000}{CN} - 9\right)^{0.7}}{1900\,S^{0.5}} \qquad (2.1)$$

Where:

- T_{lag}: Lag time (hr).
- L: Hydraulic watershed length m (length of longest watercourse).

- CN: Hydrologic area - weighted curve number.
- S: Average catchment land slope (%).

– **Curve Number:** For a watershed having more than one land use, treatment, or soil type; a composite curve number is estimated by weighting each curve number according to its area using the following equation **(USDA, 1986)**:

$$CN_c = \frac{CN_1 * A_1 + CN_2 * A_2 + \cdots + CN_i * A_i \ldots + CN_n * A_n}{\sum_{i=1}^{n} Ai} \ldots \ldots (2.2)$$

– **Time of Concentration:** the time of concentration (T_c) of the unit hydrograph is:

$$T_c = 1.76\ T_{lag} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.3)$$

– **Duration:** The duration (D) of excess unit rainfall is estimated using the following equation:

$$D = 0.133\ T_c \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.4)$$

– **Time to Peak:** the time to peak (Tp) is estimated using the following equation:

$$T_p = T_{lag} + \frac{D}{2} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.5)$$

– **Time Base:** the time base (Tb) of the unit hydrograph is :

$$T_b = 2.67\ T_p \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.6)$$

2.4 Flood Routing (Muskingum Method)

Transmission losses have been proven to be a significant hydrologic process in arid and semi-arid climates. The ability to estimate transmission losses is necessary for applications such as flood routing and forecasting, as well as when developing rainfall –runoff models in such environment. This type of losses is mainly includes the water that has been lost through channel infiltration prior to reaching some location downstream. This could lead to a significant reduction in flow volumes, velocities, and rates, depending on the magnitude of local inflow from the drainage area between the two locations and the infiltration characteristics of the channel **(Rew and Mccuen, 2010)**.

The Muskingum flow routing is one of the popular routing methods that are used to predict the downstream hydrograph along flow channel. This method is well established in the hydrological literature and its modest data requirements make it attractive for practical use. It utilizes the continuity equation and a storage relationship that depends on both inflow and outflow to simulate downstream hydrograph **(Chen and Yang, 2007)**.

To produce the Muskingum routing equation for a river reach, the following equation is used:

$$O_2 = C_0\, I_2 + C_1\, I_1 + C_2\, O_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.7)$$

Where:

- O: the out flow rate from the reach.

- I: the inflow rate to the reach.

- C_0, C_1 and C_2 are routing coefficients. In which:

$$C_0 = \frac{-K\,X + 0.5\,\Delta t}{K - K\,X + 0.5\,\Delta t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.8)$$

$$C_1 = \frac{K\,X + 0.5\,\Delta t}{K - K\,X + 0.5\,\Delta t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.9)$$

$$C_2 = \frac{\mathrm{K} - \ \mathrm{K\,X} - 0.5\,\Delta \mathrm{t}}{\mathrm{K} - \mathrm{K\,X} + 0.5\,\Delta \mathrm{t}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.10)$$

Where:

- K: the storage time constant for the reach, it is usually reasonably close to the wave travel time through the reach.

- X: dimensionless factor that weighs the relative influences of inflow and outflow upon the storage. It is varies (0.1 – 0.3)

- Δt: routing time interval.

The stability of Muskingum method is accomplished if these two conditions have been achieved:

1. $C_0 + C_1 + C_2 = 1 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.11)$

2. $KX < \Delta t \leq K \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.12)$

2.5 Rainfall – Runoff Model

Hydrological modeling is playing an increasingly important role in the management of watersheds with respect to floods, water resources, water quality, and environmental protection especially in arid and semi-arid areas **(Wheater et al., 2008)**. Most of conducting research recently, raising awareness of advanced technologies for greater clarity the unique features of arid zone hydrological systems and the nature of the dominant hydrological processes using modeling tool.

According to Wheater (2002), "model is a simplified representation of a real world system, and consists of a set of simultaneous equations or a logical set of operations contained within a computer program". Modeling approach, in general, depends on the required scale of the problem (space-scale and time-scale), the type of watershed, and the modeling task. The tasks for which rainfall-runoff models are used and the scale of applications ranges are diverse. Typical tasks for hydrological simulation models include:

1. Runoff estimation on ungauged watersheds.
2. Prediction of effects of catchment change (e.g., land use change, climate change).
3. Coupled hydrology and geochemistry (e.g., nutrients, acid rain).
4. Coupled hydrology and meteorology (e.g., Global Climate Models).

When selecting a rainfall–runoff model for application to an arid region, the literature dictates the need to consider the spatial features of rainfall, the variability and non-linearity of losses, and to match model complexity to the availability and quality of data (**McIntyre and Al-**

Qurashib, 2009). However, in the general absence of reliable long-term data and experimental research, adding to that, there is even limited available hydrological data in particular for small drainage area. Moreover, models require some degree of parameter calibration to achieve reliable predictions, this problem is accentuates further when it comes to prediction in ungauged watersheds, where sufficiently long stream flow time series for are typically not available, and all modeling tools have been primarily developed for humid area applications. All of these problems formed the major limitation of the development of arid zone hydrology models **(Ostrowski, 1990)**. Therefore, there has been a tendency to rely on humid zone experience and modeling tools, and data from other regions **(Wheater et al., 2008)**.

Flood prediction and modeling refer to the processes of transformation of rainfall into a flood hydrograph and to the translation of that hydrograph throughout a watershed or any other hydrologic system using routing methods. Flood prediction and modeling generally involve approximate descriptions of the rainfall-runoff transformation processes. These descriptions are based on either empirical, or physically-based, or combined conceptualphysically- based descriptions of the physical processes involved **(Ramirez, 2000)**.

In modeling single floods, the effects of evapotranspiration, as well as the interaction between the aquifer and the streams, are ignored. Evapotranspiration may be ignored because its magnitude during the time period in which the flood develops is negligible when compared to other fluxes such as infiltration. Likewise, the effect of the stream-aquifer interaction is generally ignored. In addition, effects of other hydrologic processes such as interception and depression storage are also neglected **(Ramirez, 2000)**.

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the rainfall-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation (**www.scisoftware.com**).

The program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model. In most cases, several model choices are available for representing each flux. Each mathematical model included in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgment.

A combination of event and continuous hydrologic modeling can be done using HEC-HMS model. Event hydrologic modeling for a watershed characterizes finer-scale hydrologic processes and reveals how the watershed responds to an individual rainfall event; (quantity of surface runoff, peak, timing of the peak, and detention) thus, event hydrological modeling is useful for better understanding the underlying hydrologic processes and identifying the relevant parameters. Also, data for certain rainfall events, which are essential to the calibration of the event hydrologic model, are easily obtained. In contrast, continuous hydrologic modeling synthesizes hydrologic processes and phenomena (Synthetic responses of the watershed to a number of rain events and their cumulative effects) over a longer time period that includes both wet and dry conditions. In addition, a continuous hydrologic model over a long time period often requires considerable monitoring data. For many small watersheds such as Og watershed, such long-term monitoring data may not be available, may not be "continuous," or may not have sufficient resolution small time-interval data. Thus, a combination of event and continuous hydrologic modeling takes advantage of the two modeling methods and data availability. In particular, the parameters that are well calibrated in event models will help improve the continuous hydrologic modeling **(Chu and Steinman, 2009)**.

The development of models has gone hand-in-hand with developments in computing power, Digital Elevation Models (DEM) and Geographic Information Systems (GIS) have had a tremendous impact on the ability to describe and understand the effects of highly heterogeneous boundary conditions on hydrologic response. GIS makes it possible to integrate efficiently not only the topography, but the geomorphology, soil type, vegetation and land use characteristics of the watershed, with physically-based hydrologic models of watersheds **(Ramirez, 2000)**.

2.6 Selected Rainfall-Runoff Studies

Although several attempts have been made to model rainfall-runoff processes in arid zones, as yet there is very limited knowledge about how best to approach arid zone modeling, and limited guidance about assessing and reducing model parameter prediction uncertainty, especially in ungauged watershed. The following is a description of prior related studies:

- GIS- Based Hydrological Modeling of Sem-iarid Catchments: In his Master thesis work Sameer Shadeed used GIS-based KW-GIUH hydrological model to simulate the rainfall- runoff process in the Faria catchment. GIUH unit hydrographs were derived for the three sub-catchments of Faria. The KW-GIUH model then was tested by comparing the simulated and observed hydrographs of Al-Badan sub-catchment for two rainstorms with good results. Sensitivity of the KW-GIUH model parameters was also investigated. The simulated runoff hydrographs proved that the GIS-based KW-GIUH model is applicable to semi-arid regions and can be used to estimate the unit hydrographs in the West Bank catchments **(Shadeed, 2005)**.

- Up To Date Hydrological Modeling in Arid and Semi-arid Catchment, the Case of Faria Catchment, West Bank, Palestine: By further work on the Faria catchment, Sameer Shadeed continued his previous work that was done at Master work and an up to date physically-based and spatially distributed hydrological model (the coupled TRAIN-ZIN model) was applied in his PhD thesis work. The coupled TRAIN-ZIN model was used for runoff simulation. TRAIN simulates long term vertical fluxes between soils, vegetation and atmosphere whereas ZIN simulates short term runoff generation processes. The coupling layer of both models is the soil storage. Rainfall data from four tipping bucket rain-gauges and runoff data from two Parshall Flumes for three consecutive rainy seasons (2004-2007) were collected for the purpose of this study. Four considerable single rainfall events with different rainfall and runoff characteristics were used for model calibration and validation. After the successful calibration and validation of the coupled TRAIN-ZIN model, continuous simulation of the entire rainy seasons 2004/05, 2005/06 and 2006/07 from October to April were achieved. Results of both events based and continuous simulations were optimistic to assume the applicability of the coupled TRAIN-ZIN model to the Faria catchment **(Shadeed, 2008)**.

- Schentsis and Larrone in their study demonstrated that the generative process of floods in the Desert depends on two alternative synoptic conditions, Mediterranean fronts and localized thunderstorms due to Red Sea lows, thus the relationship between flood volume and rainfall is unclear. However, the relationship between flood volume and flood peak is relatively well defined, enabling the prediction of flood volumes also for engaged basins where peak flood stage has been documented **(Ben Zvi et al., 1999, Shentsis et al., 2005)**.

Chapter Three

Description of the Study Area

Chapter Three
Description of the Study Area

3.1 Introduction

There are several Wadis along the Dead Sea Western shore in Palestine are filled with fresh rainwater in winter and rush down to the Dead Sea. One of them is Wadi Og which lies on the northwest shore of the Dead Sea and drains eastwards through al Og Wadi.

In this section; the characteristics of the drainage basins in the Jordan rift valley in general and the Og watershed in particular will be presented and described.

3.2 General Characteristics of Drainage Basins in the Jordan Rift Valley

The Dead Sea is a terminal lake of the Jordan Rift Valley. It is the lowest point on the surface of the earth about 418 m below mean sea level. The valley slopes gently upward to the north along the Jordan River and to the south along Wadi Araba. It extends from 35^{o}30’00 to 35^{o}34’05 East and 30^{o}58’01 to 31^{o}46’01 North. Its total area is 634 km^2, while its perimeter is approximately 148 km, and the total surface area of the Dead Sea basin is approximately 40,700 km^2 **(EXACT, 1998)**.

Major Wadis along the Jordan valley from Palestinian side are Wadi Og, Wadi Qumran, Wadi Nar, Wadi Daraja, Wadi Ghar and Wadi Abu El Hayyat. These Wadis rushed fresh rain water unchecked into the Dead Sea, and the majority of them are filled with domestic and industrial wastewater. **Table 3-1** below shows the wadis that contribute to the Dead Sea Basin from the West Bank.

Table (3-1): Palestinian Areas Flow Contribution to the Dead Sea Basin

Wadi Name	Flow (MCM/year)
Og	2
Qumran	3.9
Al Nar	2
Daraja	5.3
Al Gar	3.4
Abu El Hayyat	0.8
Total	17.4

***Source*: (Al Yaqoubi, 2007)**

3.3 Characteristics of Og Watershed

3.3.1 Geography and Topography

The Og watershed is a gravel – bed stream that drains a water catchment of 137 Km^2 which lies on the northwest shore of the Dead Sea and drains eastwards the Dead Sea through al Og Wadi. It extends from the Mountain plateau Eastern Jerusalem to Jordan River valley at the Dead Sea. **Figure 3-1** shows the location of Og watershed.

Topographic relief changes significantly through the watershed. It descends gently from an altitude of 800 to - 400 m in the west eastwards to sea level in the vicinity borders of the Dead Sea. **Figure 3-2** depicts the topographic map (DEM) of the Og watershed.

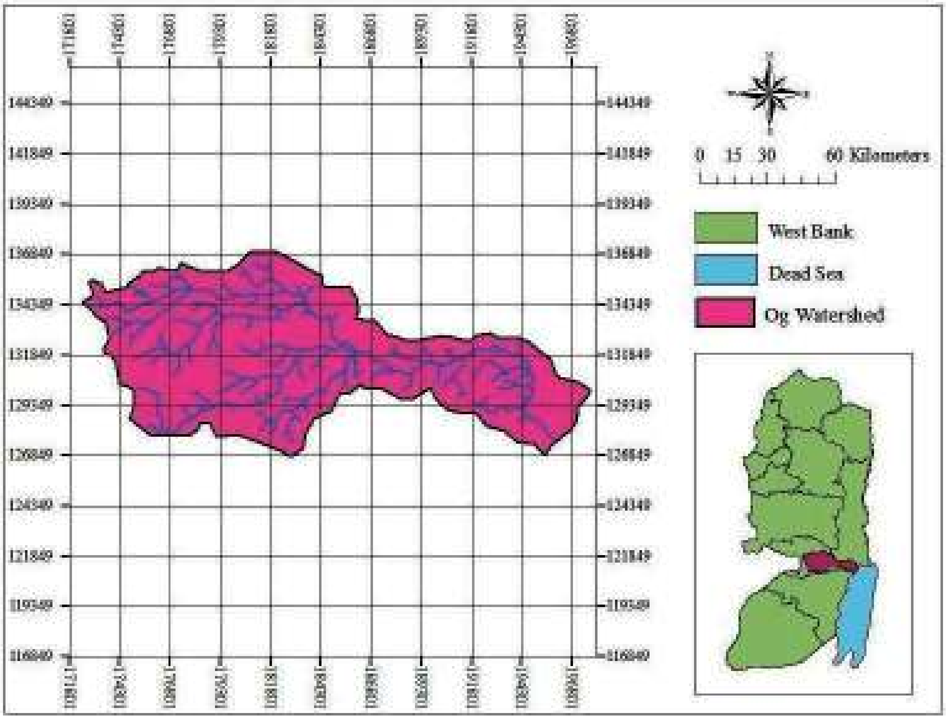

Figure (3-1): Og Watershed and its Location

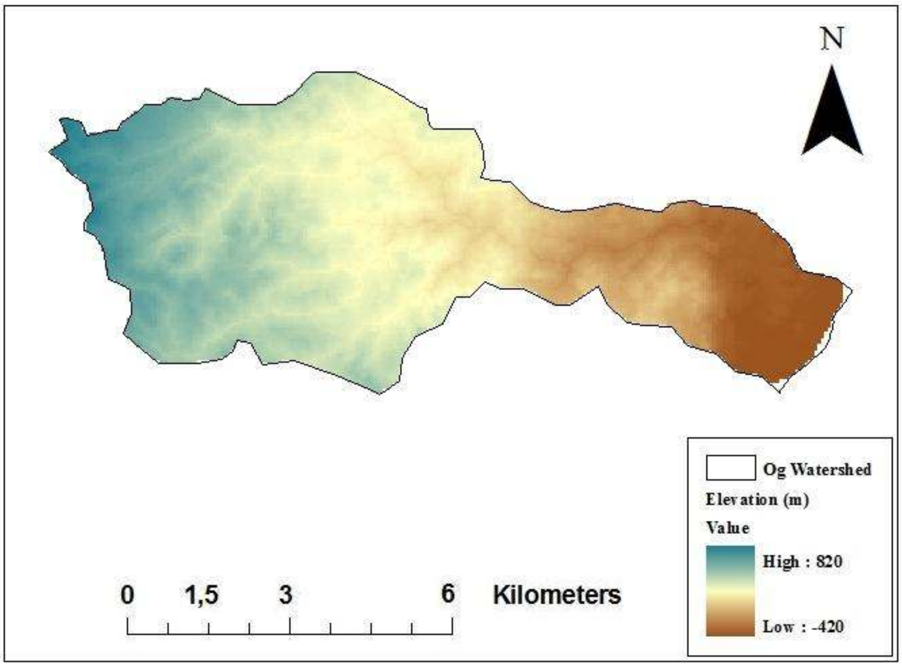

Figure (3-2): Topographic Map of Og Watershed

3.3.2 Climate

The climate in Dead Sea is highly variable. Average annual precipitation decreases along two geographical gradients; namely the latitudinal gradient as rainfall decreases from north to south and the altitudinal gradient as rainfall decreases along with the decrease in elevation. Rainfall is limited to winter months with annual precipitation in excess of 1,200 mm, to the arid regions of the southern Negev, where annual rainfall averages less than 50 mm. Over the Dead Sea itself, average annual rainfall is about 90 mm. **Figure 3-3** shows the rainfall contours in Og watershed which decreases eastwards with a high rainfall gradient changes from more than 500 mm to less than 100 mm in the vicinity of the Dead Sea.

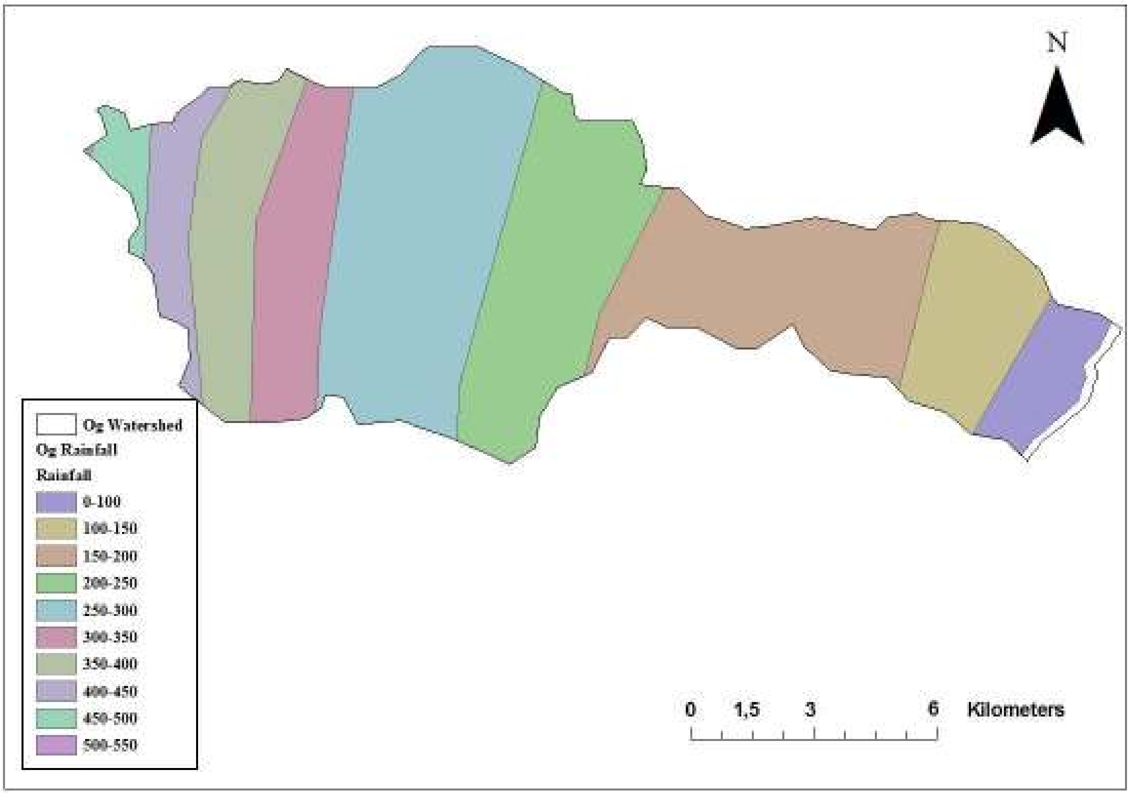

Figure (3-3): Rainfall Contour of Og Watershed

The annual potential evapotranspiration is about 2,000 mm, and the actual evaporation ranges from about 1,300 to 1,600 mm and varies with the salinity at the surface of the Dead Sea, which is affected by the annual volume of freshwater inflow. The average temperature is about 40 °C in summer and about 15 °C in winter. **Figure 3-4** shows the evapotranspiration in Og watershed.

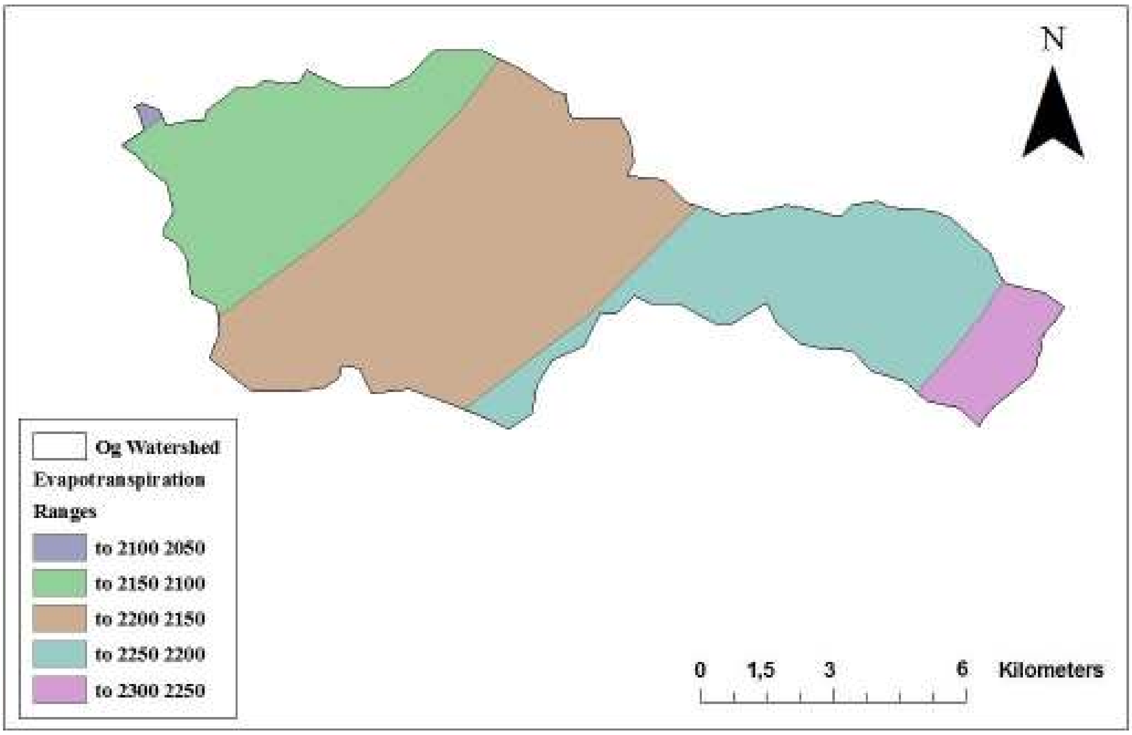

Figure (3-4): Evapotranspiration of Og Watershed

3.3.3 Land Cover and Land Use

The land cover types identified in the Dead Sea Basin were urban areas, road network, palm trees, banana trees, olive trees, vineyards, citrus plantations, other unclassified fruit trees, vegetables, wheat, natural trees (forest), shrubs land, Natural grass land, open space with little vegetation, open space with little or no vegetation.

The Land use map of the watershed was classified into: Palestinian built areas in the vicinity of Jerusalem, Israeli Settlements, arable lands supporting grain, small areas of Forests, and Rough Grazing / subsistence farming. **Figure 3-5** shows the land use in Og watershed.

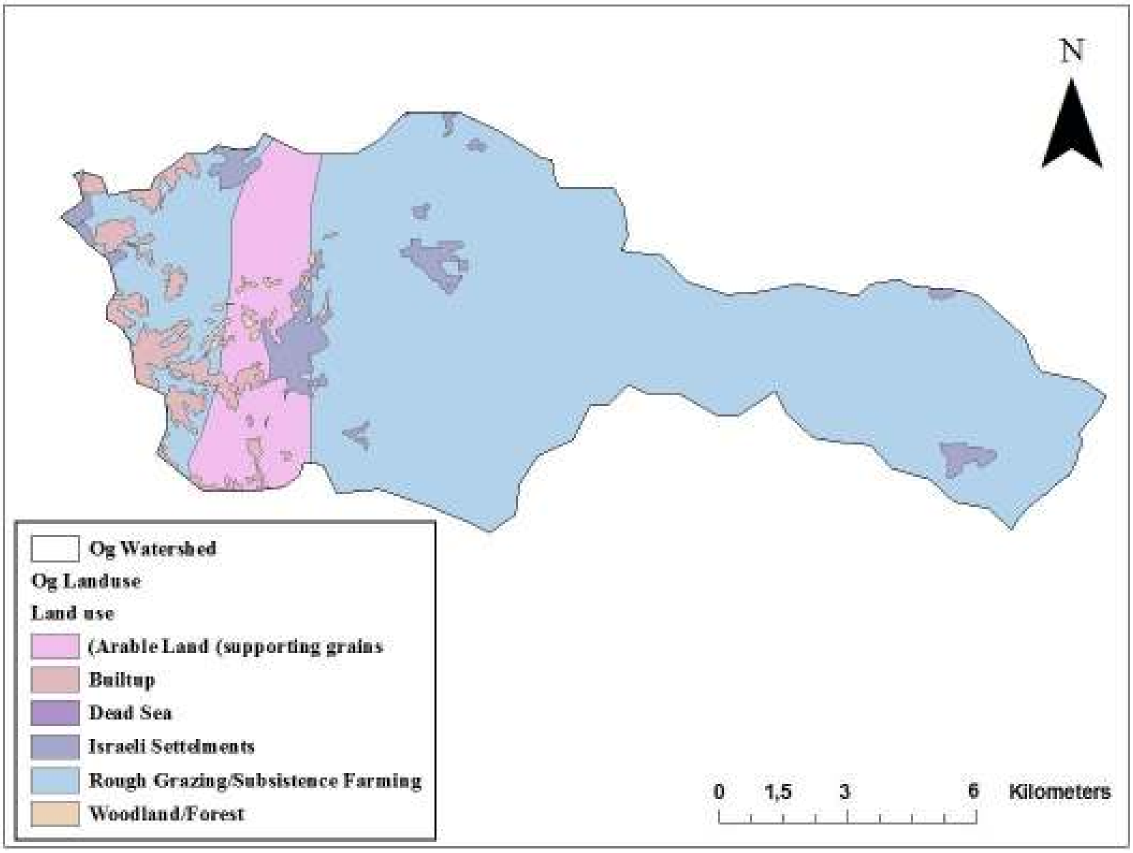

Figure (3-5): Land Use of Og Watershed

3.3.4 Geology and Soil

Approximately, 28% of the study area is composed of Coniacian-Camparian and Camparian Chalk and Chert formations, 27% is composed of Turonian and Cenomanian limestone, marl and dolostone formations while 16% is composed of Sandstone, siltstone, dolostone and limestone formations. Dolostone, clay, sand loess and gravel make up the remaining 29%. **Figure 3-6** shows the geology of Og watershed.

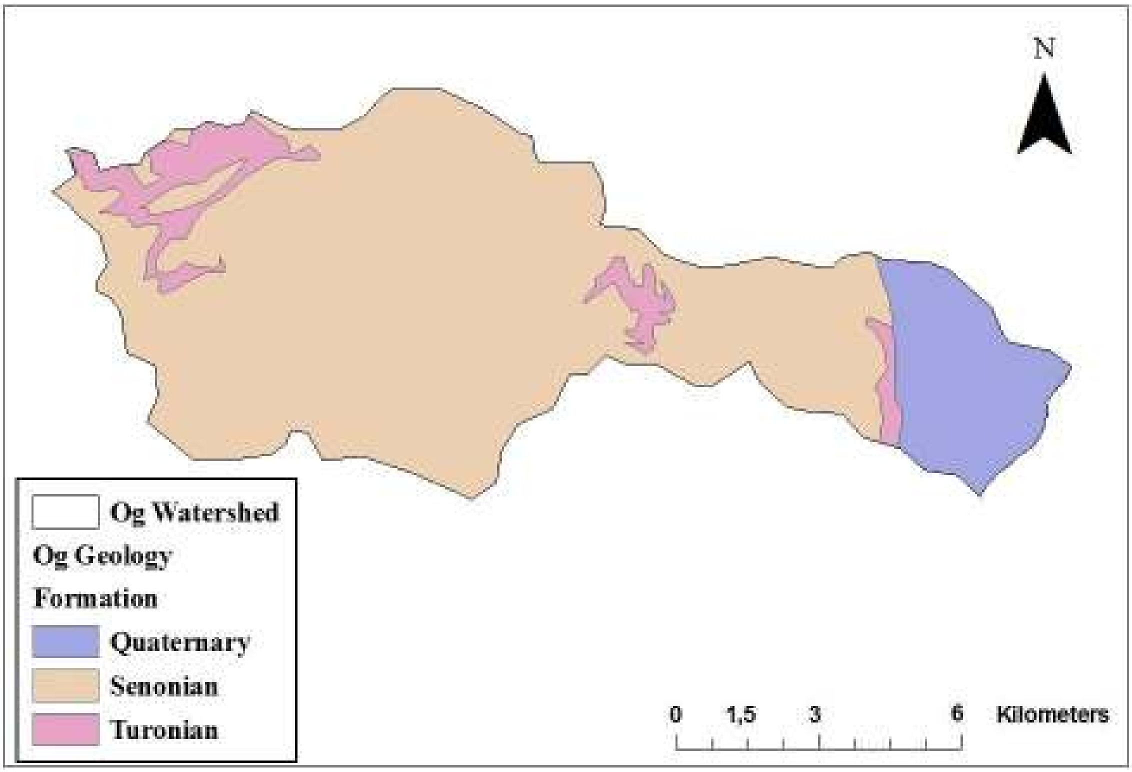

Figure (3-6): Geology of Og Watershed

USDA, 1968 defined the soil classes according to soil texture as shown in **Table 3-2** and **Figure 3-7** shows the Soil classifications and characteristics.

Table (3-2): Soil Classes According to Soil Texture

Soil Texture	Soil Type
Sandy Loam	Regosols
Clay	Grumusols
Clay	Terra Rosa
Sandy loam	Loessial Seozems
Clay loam	Brown Rindzianas and Pale Rendinas
Loamy	Brown lithosols and Loessial Arid Brown Soils

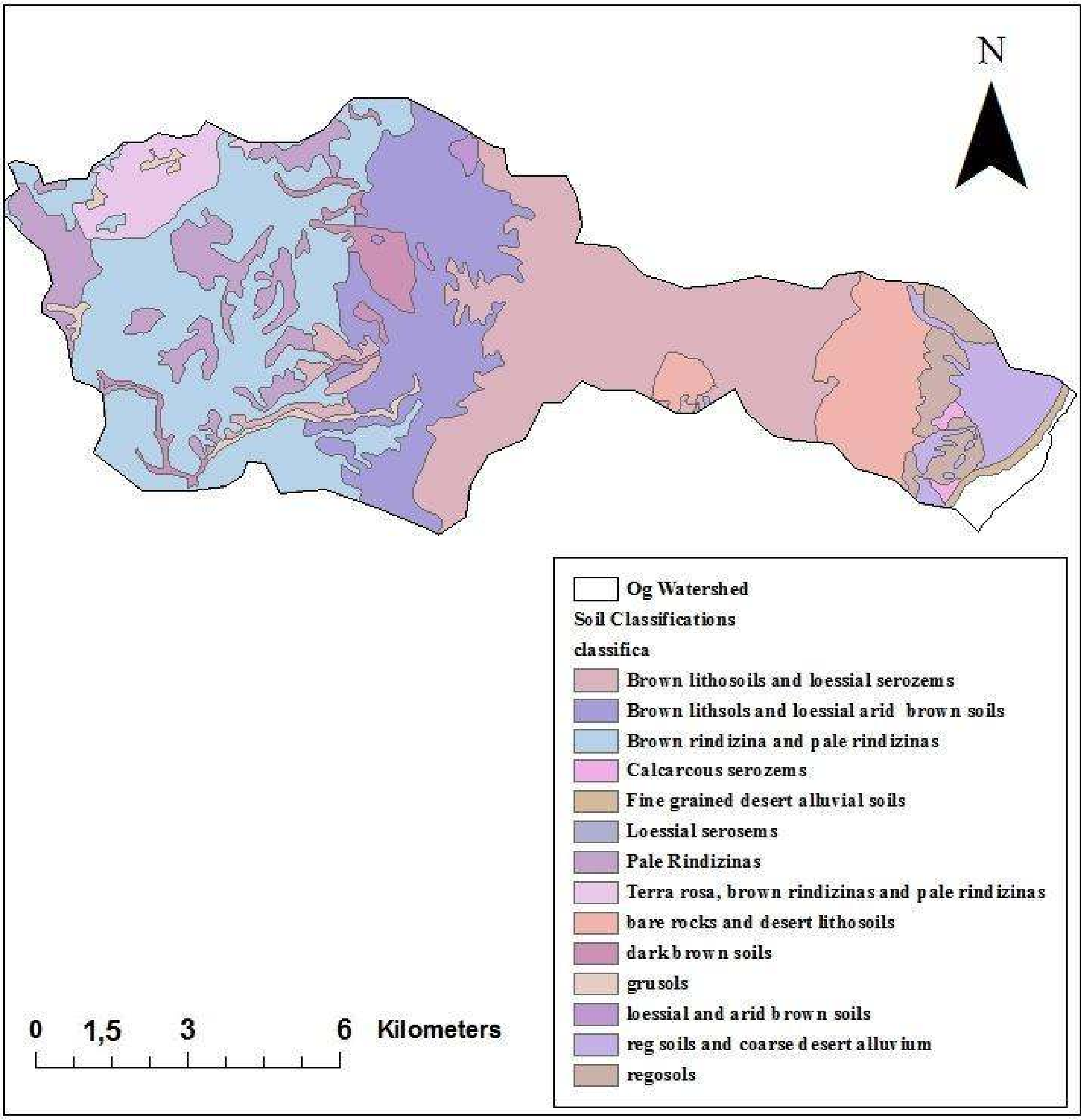

Figure (3-7): The Soil Classification of Og Watershed

3.4 Og Hydrometric Station Installation

Hydrologic studies to determine runoff and peak discharge should ideally be based on long- term stationary stream flow records for the area. Such records are not available for small drainage areas in the West Bank like the Og watershed. During Sustainable Management of Water Resources (SUMAR) Project, An-Najah National University with the help of project partners installed a new station at Og watershed in September

2012. The installed station will measure the depth of runoff generated at the watershed as well as it will collect water samples. The installed station consists mainly of two components which are:

1. A perforated pipe with sensors: the pipe is laid upstream of Og outlet. It has holes to allow water entrance to sensors and pipe that will carry water through cables to the hydrometric station and to the water to sampler (See **Figure 3-8**).

2. Hydrometric station: it contains water sampler and electrical system (hydrometric recorded). The water sampler containing 24 distributed sample containers in order to collect rain water during the flood for analysis purposes. The electrical system consists of data logger, data transmission units, conductivity unit, two 12V batteries, voltmeter, and antenna. The conductivity unit determines the conductivity and resistivity of the water, while the other components measured the pressure and the depth of water in the watershed stream and then transmit it by the antenna to web in order to announce when the flood is occurred (See **Figure 3-9** and **Figure 3-10**).

A visit was conducted to Hydro- geologist laboratory for the project partners in order to see how to deal with the hydrometric station when the flood takes place, how to clean the perforated pipe, to change the batteries, to take the samples and to prepare the station to receive the next flood.

Figure (3-8): Perforated Pipe and Hydraulic Station Installation

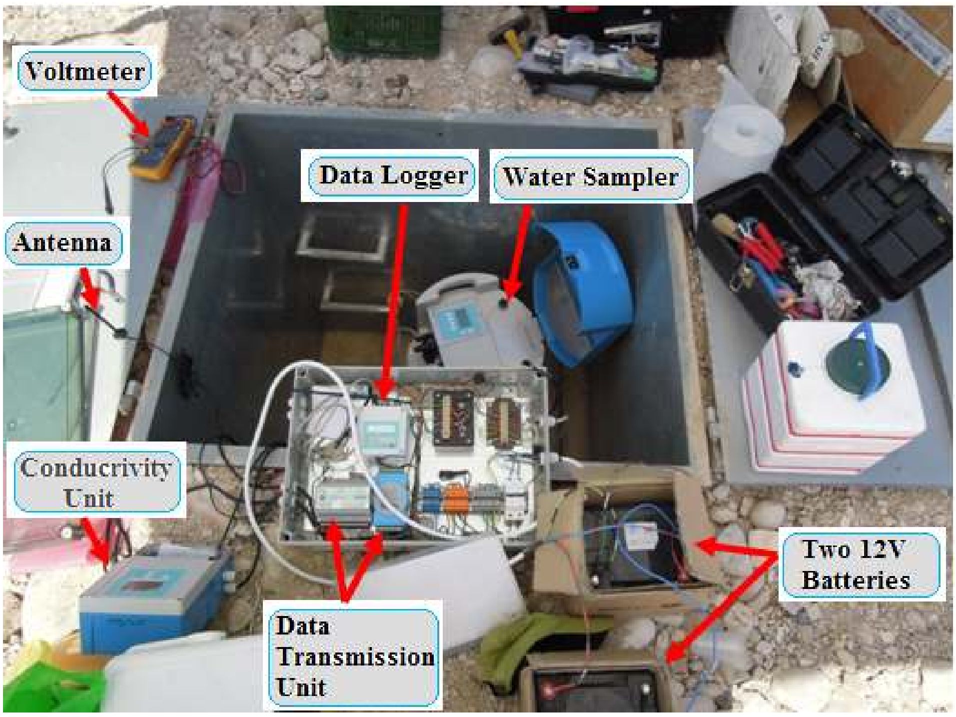

Figure (3-9): The Main Components of the Hydrometric Recorded System

Figure (3-10): Close up View of the System

Before the rainy season began, a visit was conducted to the watershed in order to check the station and to test the system by inserting electrodes and water pipes in a water bucket to check the readiness of the station to receive a flood (**See Figure 3-11**).

Figure (3-11): Testing the Og Hydrometric Station Prior Rainy Season

Chapter Four

Rainfall Analysis

Chapter Four
Rainfall Analysis

4.1 Introduction

In the view of watershed hydrology, the response of a watershed is driven mostly by rainfall, which is the major factor controlling the hydrologic cycle of a region notably in semi-arid areas where the rainfall tends to be more variable in both space and time.

In Og watershed; rainfall is concentrated only in rainy season, and approximately two thirds of the annual rainfall falls in three months of the year. The mean annual rainfall decreases from about 500 in the western part to less than 100 mm in the east. This decrease in rainfall is accompanied by an average increase in temperature. The northern and western parts of Og watershed approach the 538 mm isohyet while the southern and eastern borders come very close to the 70 mm. The rainfall gradient is very steep eastwards towards the Dead Sea valley. The fluctuations of the mean rainfall increase with increasing the aridity.

The first step in the hydrological analysis of Og watershed includes analysis of rainfall data. This encompasses statistical analysis of rainfall data on daily, monthly and annual bases as well as the estimation of areal rainfall of Og watershed.

4.2 Rainfall Stations

Rainfall analysis starts with collecting the available rainfall data from the surrounding stations of Og watershed. This step is considered one of the most challenges in this research; the available rainfall stations in the West Bank suffer from lack of experienced technicians for measuring the rainfall records as most of them are located in schools. As well as, the quality of the data is certainly affected with the period that had been collected; particularly at past when the Palestinians suffer from the curfews, some of the readings were for several days and sometime months. However, nowadays after the establishment of the Palestinian Water Authority (PWA) and the Meteorological Department, rainfall data for about 75 stations in the West Bank was gathered and compiled in one data base at the PWA.

In this study, huge efforts had been done in order to obtain long – term rainfall data from the surrounding rainfall stations. However, Three rainfall stations surrounding the watershed was selected; Jerusalem, Bethlehem, and Jericho as shown in **Figure 4-1**. The collected data from these stations covers monthly and yearly rainfall for 30 - 40 years. While, daily rainfall data is limited to 3 years. A summary of the selected stations, their elevations, coordinates, and the range of the available data is presented in **Table 4-1**.

Table (4-1): Available Rainfall Stations Surrounding Og Watershed

Rainfall Station	X (Km)	Y (Km)	Elev. (m)	Type of Data		
				Annual	Monthly	Daily
				Period		
Jericho Meteorological Station	194	140.2	-260	1971-2011	1976-2011	2002-2005
Bethlehem Primary School	169.8	123.7	750	1968-2011	1968-1987 & 1997-2011	2002-2005
Jerusalem station	175.5	138	600	1969-2011	1968-1990 &2001-2011	2002-2005

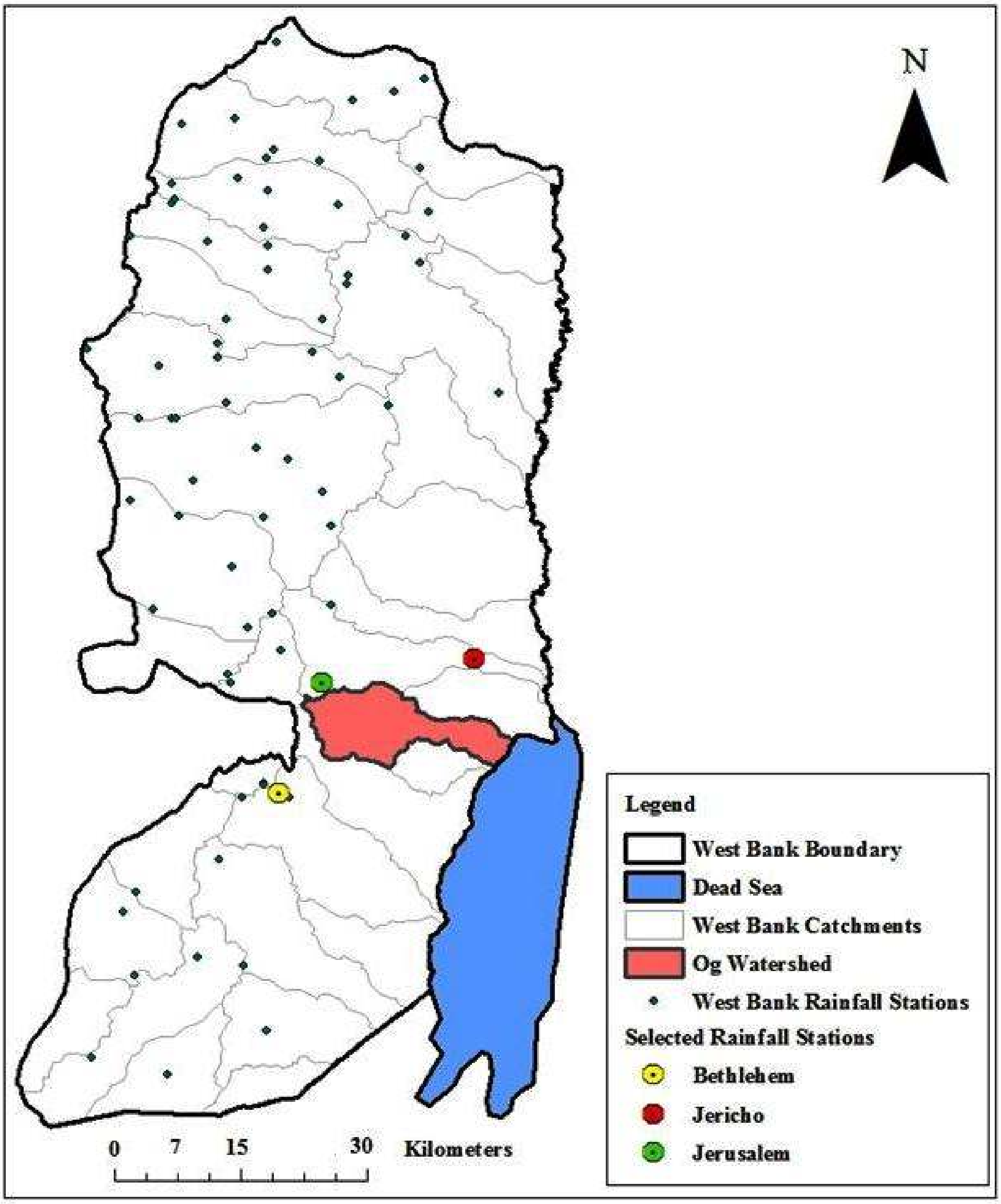

Figure (4-1): Deployed Rainfall Stations in the West Bank

4.3 Consistency of Rainfall Data

In order to obtain a reasonable results reflect the reality; attention must be paid to the quality of input data, in particular, the rainfall data that is considered the main input for the hydrological cycle. As mentioned above; it is not easy to get rainfall data for a long time with high quality.

Therefore, the collected rainfall data was checked by applying the consistency analysis. The missing data was estimated from the surrounding rainfall stations using **equation (4.1)**, and the consistency analysis was applied.

$$R_g = \frac{1}{n}\sum_{i=1}^{i=n}\left(\frac{\mathrm{AR_g}}{\mathrm{AR_i}}\ \mathrm{R_i}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (4.1)$$

Where:

AR: Annual average rainfall at the missing station g and at the n nearby stations.

Check for inconsistency of rainfall record was investigated using the double mass curve technique. The Accumulated rainfall at a specific station and the accumulated values of the average rainfall of the other stations were computed for the period 1971 – 2011. **Figure 4-2** presents the data for the selected rainfall stations.

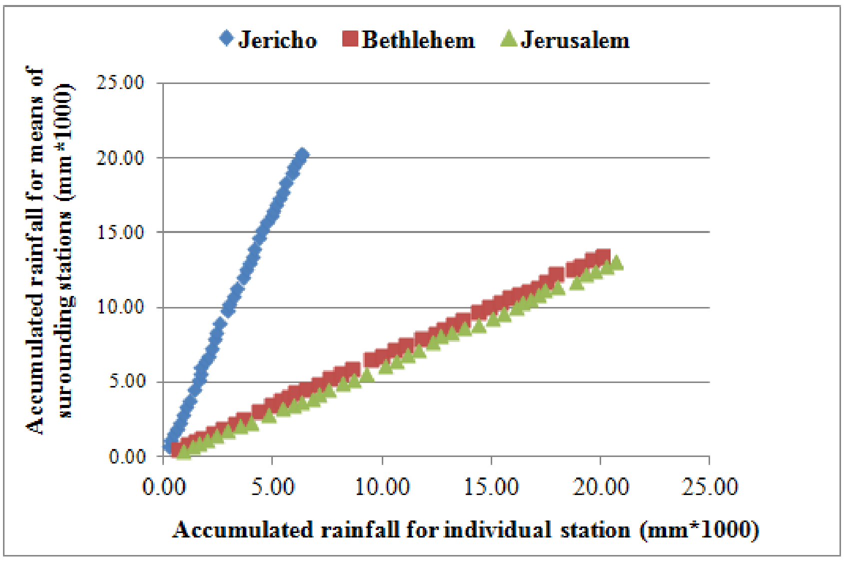

Figure (4-2): Double Mass Curve for the Stations Surrounding Og Watershed

4.4 Annual Rainfall Analysis

Annual rainfall data was analyzed for the selected stations surrounding the Og watershed for the hydrological years from 1971 to 2011 (See **Annex I**).

Since one of the main distinctive features of arid and semi-arid areas is the temporal variability of rainfall; a statistical analysis were conducted on the available data including the mean, median, standard deviation, skewness, kurtosis, as well as maximum and minimum rainfall records. The following **Table 4-2** summarizes the statistical analysis results of the annual rainfall data.

Table (4-2): Descriptive Statistical Analysis of Annual Rainfall Data for the Selected Stations

Station/ Parameter (mm)	Bethlehem Primary School	Jerusalem Meteorological Station	Jericho Meteorological Station
Mean	489.5	503.4	153.0
Median	475.0	480.0	148.0
STD	137.3	144.8	59.6
Skewenss	0.80	0.57	0.92
Kurtosis	0.48	0.38	1.44
Maximum	845.0	852.7	343.7
Minimum	238.2	223.0	39.2

From the above table, it can be noticed that the mean annual rainfall for the three stations is higher than the median. As well as, the value of the skewness is positive. This indicates that the annual rainfall skewed to the right. The values of the standard deviation is far away from the mean, this reflect the variability of the annual rainfall data during the long analysis period. There is a noticeable difference between the maximum and minimum rainfall records, the maximum values in the three stations were recorded in the wet year 1992, while the minimum values were recorded in the dry year 2010.

Kurtosis and skewness are two parameters that reflect the normal distribution of rainfall data. Kurtosis is a measure of data peakeness or flatness relative to a normal distribution, while the Skewness is a measure of symmetry. If the values of these two parameters are zero or near zero; the data set follows the normal distribution **(Masri and Shadeed, 2008)**. However, from the above table, the two parameters values for the three stations is positive, that indicates, the distribution is skewed to the right and have a peak distribution at each rainfall station.

The annual time series for the selected stations are depicted in **Figure 4-3**.There is a significant variation in the rainfall pattern for the three stations during the last 40 years. This indicates that the amount of rainfall oscillatory from period to another. The values of long term rainfall means for the Jerusalem, Bethlehem and Jericho stations are (503.4, 489.5, and 153.0 mm) respectively, Jericho rainfall mean is smaller compared with Bethlehem and Jerusalem, as well as, Bethlehem rainfall mean is smaller than Jerusalem. This reinforced that the amount of rainfall is changed spatially and decreased from west to east and from north to south. At the same time the aridity is increased eastward.

Figure 4-3 infers that in (17-19) out of 40 years for the three stations; the annual rainfall was above the average. This can be notice well in the wet year 1992 where more than twice of the annual average rainfall was recorded. In addition, the figure shows that there are more than 4maximum peaks for the three stations and more than 3 minimum peaks during the last 40 years.

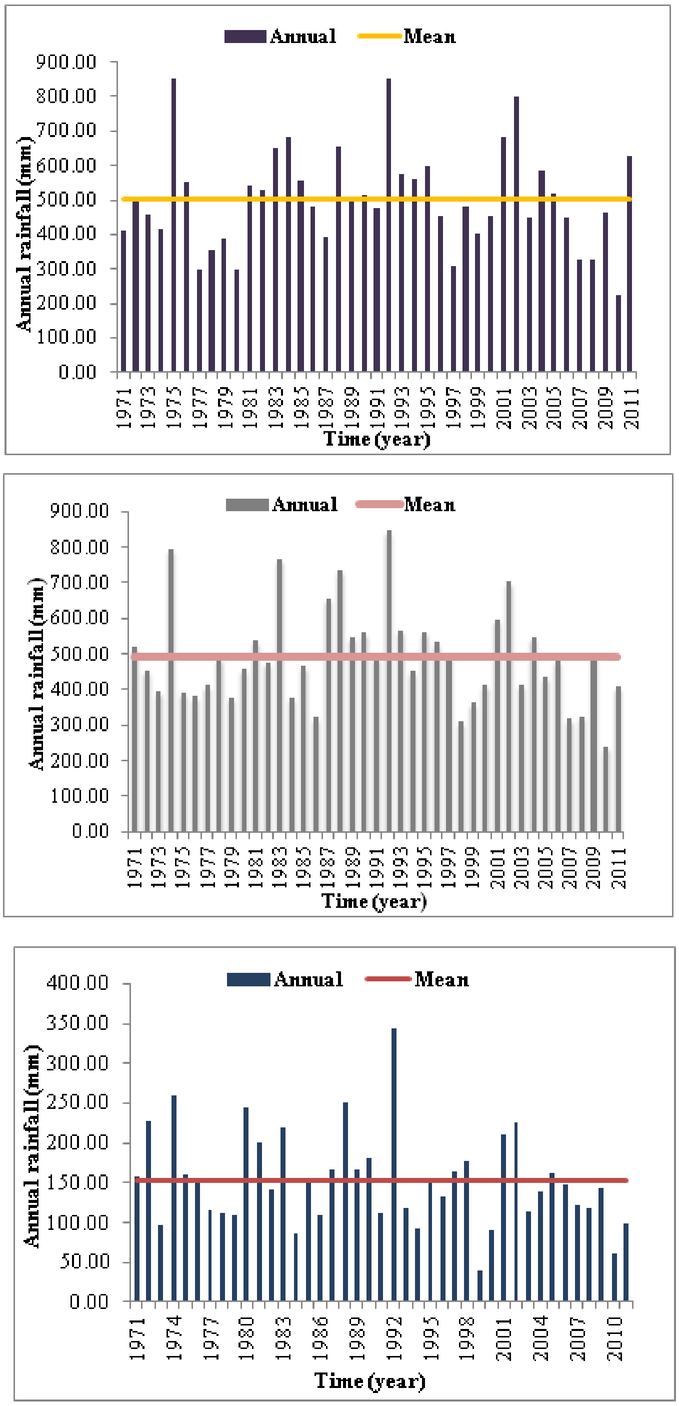

Figure (4-3): Annual Time Series for, (a): Jerusalem Station, (b) Bethlehem Station, and (c): Jericho Station

Since Og watershed is located in arid to semi-arid environment; it is essential to check the drought severity by estimating the Standardized Precipitation Index (SPI) for the available rainfall data. The SPI is considered an indicator of drought that recognizes the importance of time scales in rainfall analysis. It is a dimensionless index where negative values indicate drought and the positive values indicate wet conditions. It can be simply defined as the difference of rainfall from the mean for a specified time period divided by the standard deviation (**Tsakiris and Vangelis, 2004**). **Figure 4-4** presents the SPI values for the selected rainfall stations.

The drought severity can be classified to 4 categories as shown in **Table 4-3**:

Table (4-3): Drought Categories Defined for SPI Values

SPI values	Drought Category
0 to 0.99	Mild drought
-1 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
< -2	Extreme drought

***Source*: (Sonmez et al., 2005)**

According to this classification; it was found that the prevailing drought condition in the area is the mild during the last 40 years. It is worth mentioning that the probability of having severe drought has increased in the recent years, particularly in the Jordan Valley where the SPI values for Jericho rainfall records falls under the category “severe drought”. The following **Figure 4-5** depicts the frequency of occurrence for the SPI values for the selected stations in the last 40 years.

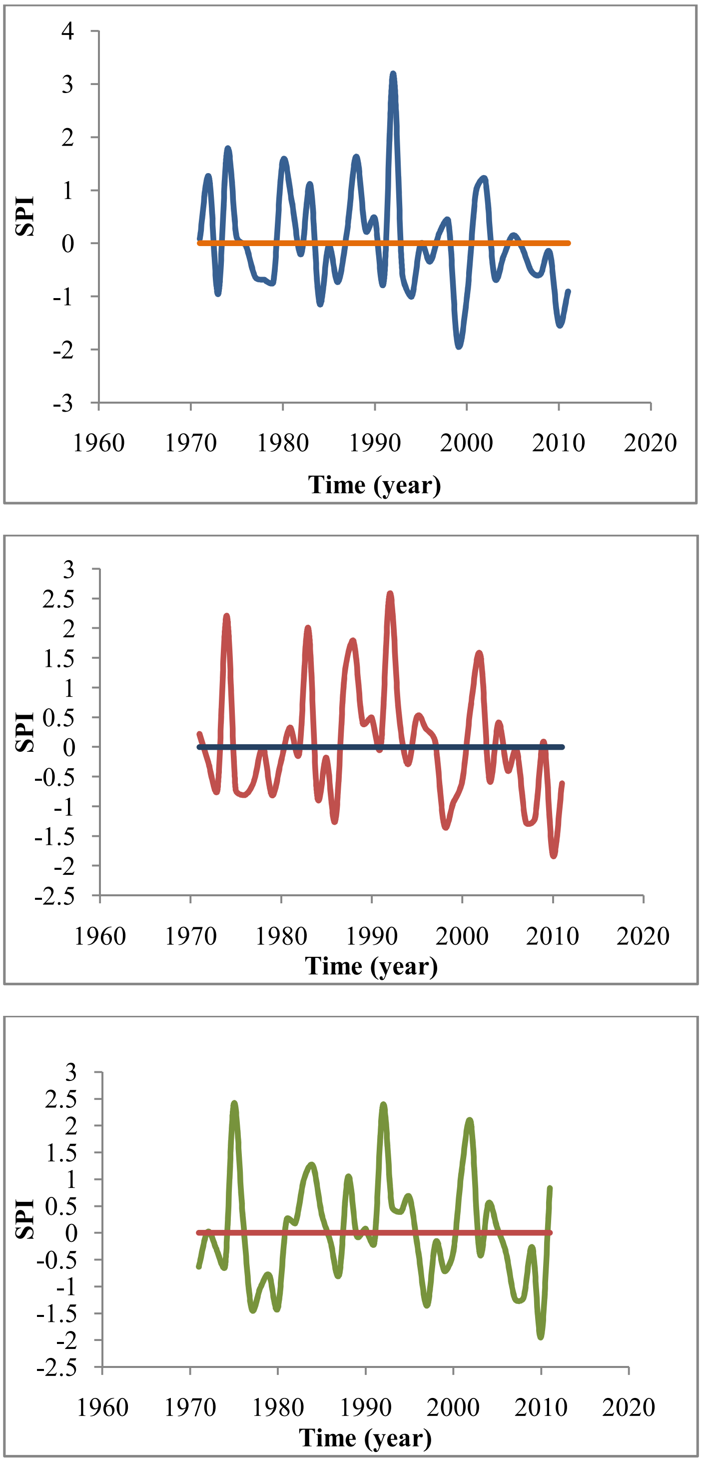

Figure (4-4): SPI values for, (a): Jericho Station. (b): Bethlehem Station and (c): Jerusalem Station

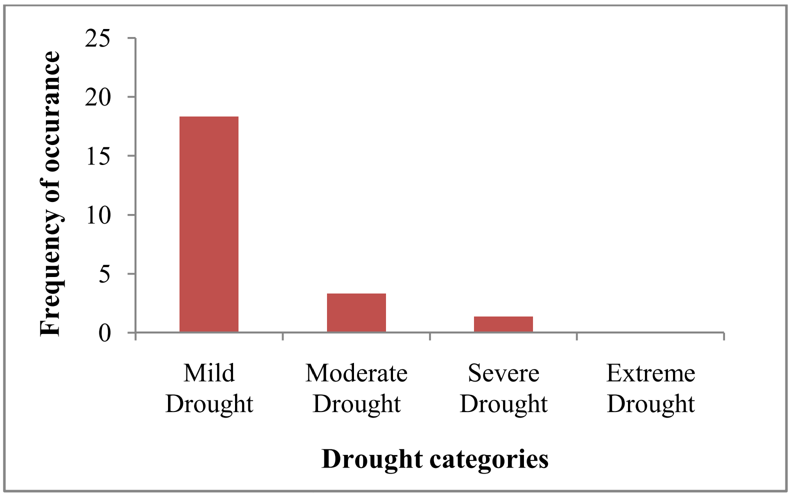

Figure (4-5): The Frequency of Occurrence for the Drought Categories

To have an idea about the trend of rainfall for the selected stations; the 5-year moving annual rainfall average was calculated for the selected stations over the period 1971 – 2007 as shown in **Figure 4-6**.

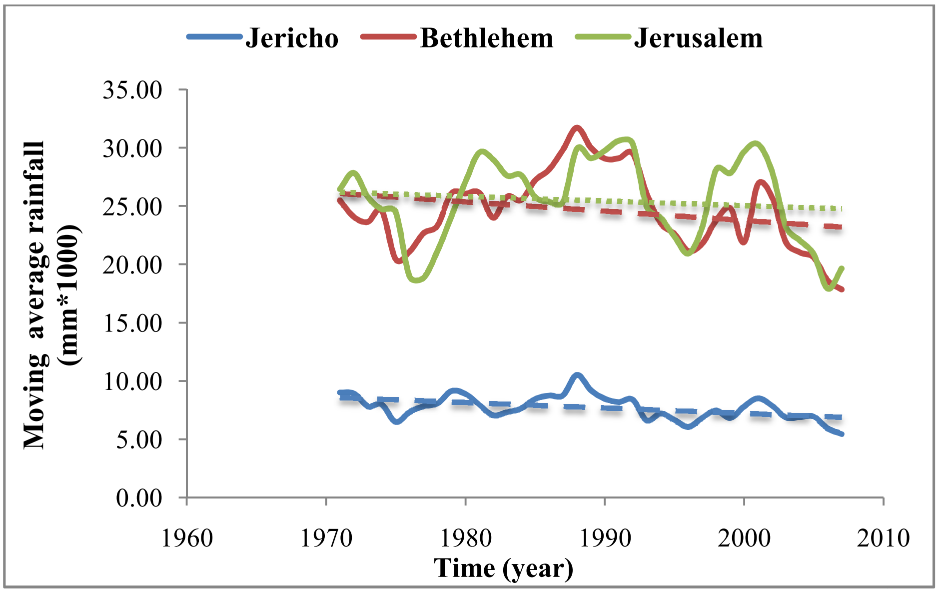

Figure (4-6): 5-Year Moving Average for the Annual Rainfall

From the above figure, it is clear that the trend of rainfall decreases over the period 1971-2007 for the three stations. This decrease in rainfall is accompanied by an average increase in temperature as well as in the aridity of area.

4.5 Monthly Rainfall Analysis

Monthly rainfall records were analyzed for Jericho, Jerusalem, and Bethlehem stations (See **Table 4-4**). The distribution of monthly rainfall is almost symmetry and has positive kurtosis and skewenss values. In addition, median values in all cases are lower than the mean. This is a result of that the majority of the months had only light rainfall punctuated with a few high values.

Figure 4-7 presents the average monthly rainfall for the three stations during the hydrological years 1970-2011. Rainfall is concentrated in rainy season, starting in October and ending in April or May. Whereas, the other seasons (spring and summer) are relatively dry and have zero rainfall.

Table (4-4): Statistical Summary of Monthly Rainfall Data

Month	Mean (mm)	Median (mm)	STD (mm)	Skewenss (mm)	Kurtosis (mm)
January	94.09	88.98	55.12	3.75	4.11
Febuary	86.03	68.42	56.62	0.97	1.16
March	55.60	45.87	35.06	0.22	0.87
April	19.86	7.22	30.42	2.81	9.93
May	2.12	0.00	6.18	5.85	16.74
October	4.42	3.17	12.12	1.45	2.04
November.	39.87	29.50	40.84	2.58	4.94
December	69.84	57.10	47.55	0.55	0.34

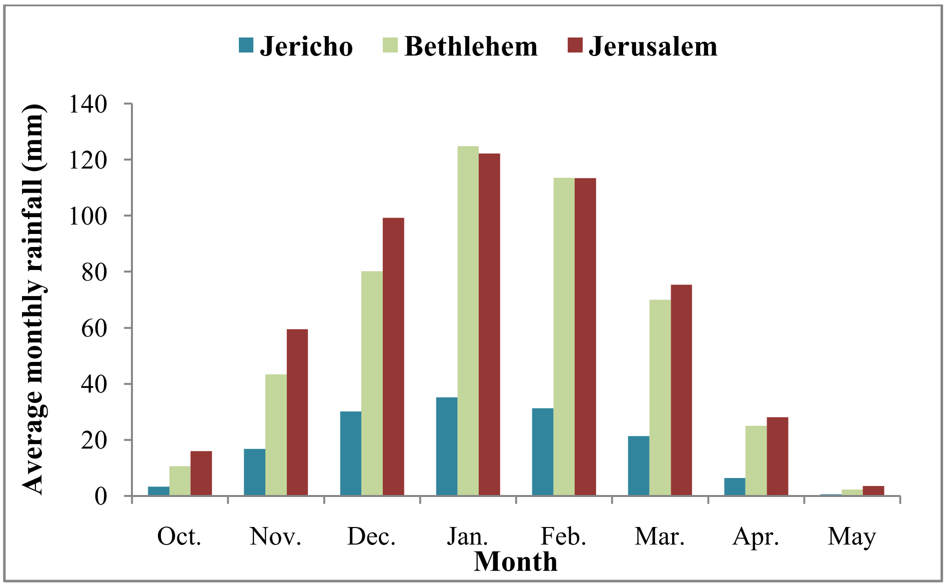

Figure (4-7): Monthly Rainfall Distribution

The frequency of total monthly rainfall was summarized in **Table 4-5**. It is apparent from the table that rainfall concentrated in three months (December, January, and February), where approximately two thirds of annual rainfall was fallen.

Table (4-5): Frequency of Total Monthly Rainfall Occurrence

Rainfall Interval (mm)	Frequency of Occurrence							
	October	November	December	January	February	March	April	May
0-25	34	29	19	11	18	20	35	35
25-50	1	2	8	15	10	15	0	0
50-75	0	3	6	8	6	0	0	0
75-100	0	1	1	1	0	0	0	0
100-125	0	0	1	0	1	0	0	0

4.6 Daily Rainfall Analysis

As mentioned earlier, collecting daily rainfall data is one of the most difficult tasks in this research. The available daily rainfall records in Jerusalem, Bethlehem and Jericho stations are limited and confined to the time period 2002 – 2005. **Figure 4-8** shows the time series of the daily rainfall for the selected stations. Apparently, there is an obvious fluctuation in the amount of daily rainfall during the analysis period, Jerusalem and Bethlehem stations had often received similar amount of rainfall compared with Jericho station which had a small share.

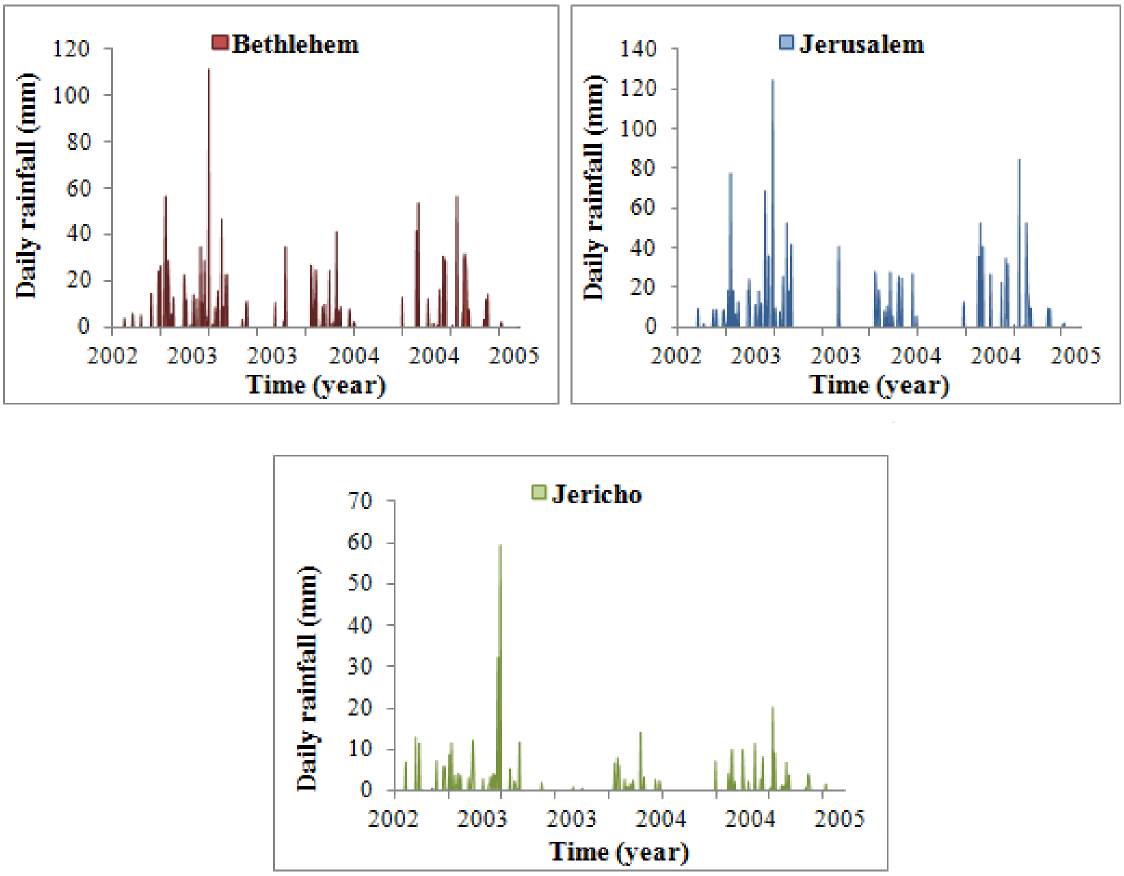

Figure (4-8): Time Series of Daily Rainfall

Statistical analysis for the daily rainfall data were carried out considering the zero and non-zero values of daily rainfall as summarized in **Table 4-6**. There is a great difference between mean values when considering the zero and non-zero cases. Kurtosis has high values when the zero case is considered. The maximum daily rainfall intensity is recorded in Jerusalem station 125 mm, while the minimum value is recorded in Bethlehem and Jericho stations 0.1 mm during the analysis period.

Table (4-6): Descriptive Statistics of Daily Rainfall Data

Parameter (mm)	With zeros			Without zeros		
	Bethlehem	Jerusalem	Jericho	Bethlehem	Jerusalem	Jericho
Mean	2.59	2.89	0.83	14.38	18.91	4.11
Median	0.00	0.00	0.00	9.00	11.25	1.90
Standard Deviation	8.86	10.51	3.49	16.37	20.54	6.87
skewenss	5.82	5.96	10.30	2.68	2.50	5.28
kurtosis	49.07	47.24	147.74	11.53	8.48	37.29
Maximum	112.00	125.00	59.40	112.00	125.00	59.40
Minimum	0.00	0.00	0.00	0.10	1.00	0.10

To characterize the frequency of rainy days occurrence for the hydrological years 2002 to 2005, different rainfall intervals were considered and the results were summarized in **Table 4-7**. It is clear from the table that the probability to have rainfall with intensty1-20 mm/day in the study area is considered high, this can be noticeable well for Jericho station where 98% of the rainfall falls within this interval. In such arid to semi-arid environment, the probability to have rainfall with high intensity (>100 mm/day) is considered very low. This is clearly shown in the table where Jerusalem and Bethlehem have the chance to receive more than 100 mm/day with probability 2% during the analysis period.

It is worth mentioning that a day was considered a rainy day when daily rainfall equals or exceeds 1 mm **(Masri and Shadeed, 2008)**. However, the average number of rainy days for Jerusalem and Bethlehem is equal 25. While for Jericho is 14 rainy day during the analysis period.

Table (4-7): Frequency of Rainy Days Rainfall Occurrence

	Frequency of occurrence		
Interval	**Bethlehem**	**Jerusalem**	**Jericho**
1 - 20	68	62	100
20 - 30	15	13	0
30 - 40	6	5	1
40 - 50	3	4	0
50 - 60	3	3	1
60 - 70	0	1	0
70 - 80	0	1	0
80 - 90	0	1	0
90 - 100	0	0	0
> 100	1	1	0

Studying the extreme hydrological events required selecting the largest or smallest extreme events. However, for rainfall-runoff hydrological modeling, the researcher is more interested with the largest extreme events that have a large probability to create runoff. The literature review indicated that the Surface runoff in the West Bank occurs when rainfall exceeds 50 mm in one day or 70 mm in two consecutive days **(Forward, 1998, cited by Takruri, 2003)**. According to this result, **Table 4-8** was conducted. It is summarized the number of these events and its values.

Table (4-8): Extreme Hydrological Events during 2002-2003 Years

Date	Bethlehem	Jerusalem	Jericho
21/12/2002	57	78	1.4
15/2/2003	35	69	3.4
26/2/2003	112	125	32.3
22/11/2004	54	53	10
23/11/2004	17	3	0
23/1/2005	57	85	0.8

Moreover, the extreme hydrological events were analyzed using frequency analysis. The main objective of the frequency analysis of hydrological data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distribution (**Masri and Shadeed, 2008**). Gumbel distribution was applied to the recorded daily rainfall data for the hydrological year 2002-2003. **Figure 4-9** presents the application of Gumbel distribution for the selected stations. Apparently, From the Figure, it can be noticed that a daily rainfall of up to 40 mm can be expected every year. The estimated return periods for daily rainfall events of over 70 and 100 mm exceed 3 and 12 years, respectively.

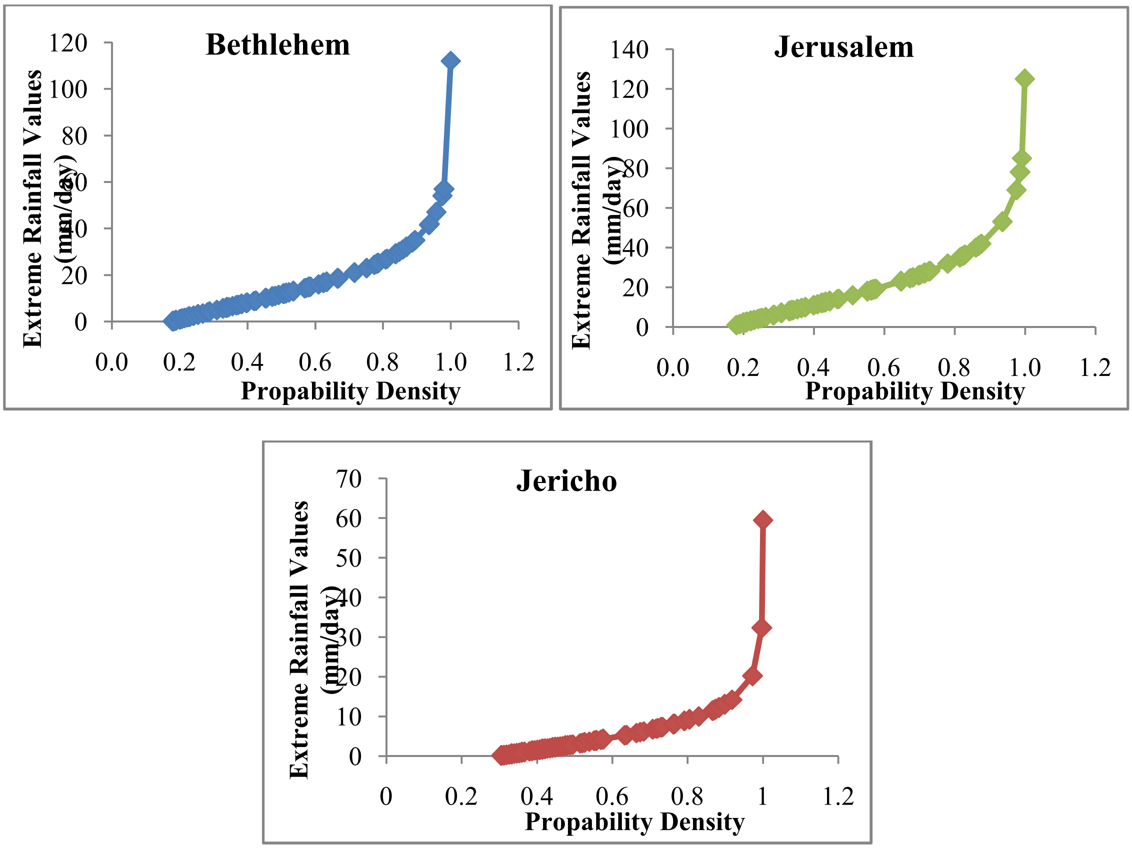

Figure (4-9): Gumball Distribution for Daily Rainfall Data

4.7 Areal Rainfall

Rainfall events recorded by gauges, are generally expressed in the form of point rainfall values which is the rainfall depth at a location. In order to obtain areal average values for an area; the hydrologists require techniques whereby point rainfall amounts can be transformed to average rainfall amounts over a specified area. This point-to-area rainfall conversion problem can be addressed using numerous methods such as: Arithmetic average, Thiessen polygon, Isohyetal, and Interpolation to a grid method **(Gill, 2005)**. In this research; the Isohyetal method was addressed to convert point rainfall to areal rainfall for Og watershed. The following section details the adopted method.

4.7.1 Isohyetal Rainfall

The Isohyetal method uses topographic and other data to yield reliable estimates for the areal rainfall. In this method; rainfall values are plotted at their respective stations on a suitable base map, and isohyets are drawn to create an Isohyetal map, then, the areal average rainfall is obtained using area-weighted average of the Isohyetal zones **(Jain and Singh, 2005**).

In this study, the GIS tools were used to create the Isohyetal map for Og watershed. A GIS shapefile includes the isohyets lines for the West Bank was obtained from the PWA. Using the analysis tools; a clip was done to the Og watershed to have its Isohyetal map as shown in **Figure 4-10**. Then, the data from the attribute table was export to Excel program to estimate the areal rainfall using the following formula:

$$\text{Average areal rainfall} = \frac{\sum_{i=1}^{n} A_i P_i}{\sum_{i=1}^{n} A_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

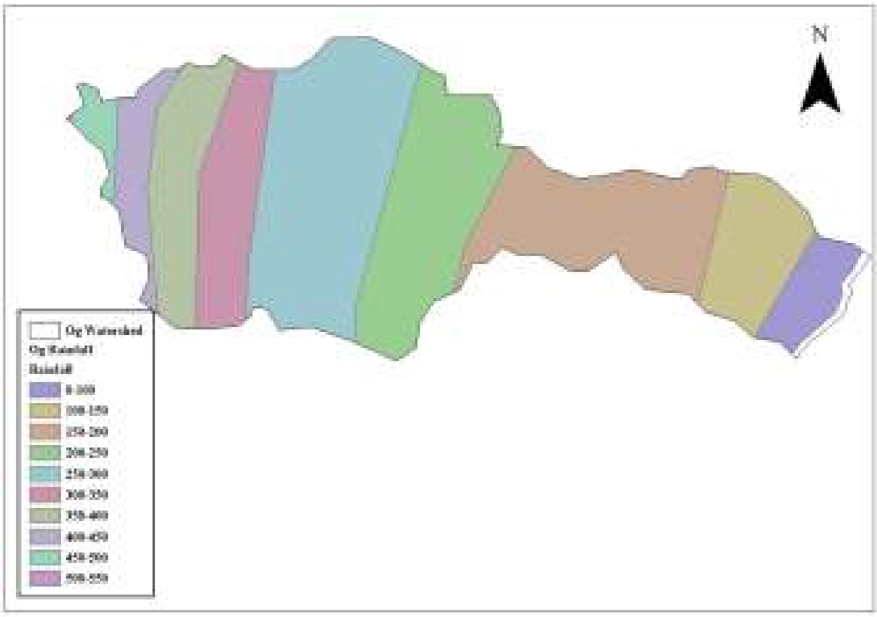

Figure (4-10): Isohyetal Map for Og Watershed

Table (4-9): Average Areal Rainfall of Og Watershed Using Isohyetal Method

Isohyetal zone	Area-Ai (Km^2)	Rainfall (P_i) (mm)	Ai * Pi
1	0.03	500	16.1507
2	2.49	450	1119.89
3	6.50	400	2599.75
4	13.15	350	4602.25
5	13.52	300	4056.64
6	35.30	250	8827.40
7	24.15	200	4829.55
8	23.91	150	3586.61
9	11.84	100	1184.6881
10	5.99	50	299.97
Total	**136.9061**	**-**	**31122.91**
Average areal rainfall (mm/year)		**227.33**	

Chapter Five

The Modeling Approach

Chapter Five
The Modeling Approach

5.1 Introduction

The development of hydrological models provides adequate tools to predict runoff volume and peak discharge. The best tool available for the hydrologist to face the challenge of prediction is usually a rainfall-runoff model. Rainfall-runoff model is a simplified system that is used to represent real life system. It relates something unknown (the output) to something known (the input). The known input is rainfall and unknown output is runoff (**Daniil et al., 2005**).

5.2 The Selected Rainfall-Runoff Model

HEC-HMS model was selected to predict runoff volume and peak discharge at Og watershed. The model is public domain and easily can be downloaded from the following site: (http://www.hec.usace.army.mil/software/hec-hms/download.html). HEC-HMS is a computer program that includes a variety of models which are used to simulate rainfall-runoff process.

In this chapter, HEC-HMS model was developed for Og watershed to estimate runoff volume and flash flood peak. GIS capabilities were added to this model in order to build the input data as described in the following sections.

5.3 The Description of HEC-HMS Model

The hydrologic modeling system (HEC-HMS) is one of the models that have been widely used for estimation of surface runoff and river/reservoir flow in a dendritic watershed system. It supersedes HEC-1 that was originally developed in 1967 by the staff of the Hydrologic Engineering Center at Sacramento, California. HEC-HMS provides a similar variety of options but presents a significant advancement in term of both computer science and hydrologic engineering. It's designed to be applicable in a wide range of geographic area by solving the widest possible range of problems. It has an extensive array of capabilities for conducting hydrological simulation (**HEC-HMS, 2010**).

The hydrologic simulation capabilities of HEC-HMS include several techniques to input and distribute the rainfall, treat the precipitation as rainfall or snowfall, compute rainfall and snowmelt losses and excess, and determine sub-catchment outflow hydrographs by various hydrologic routing techniques. The model may be used to simulate a simple single-basin watershed or a very complex basin with practically unlimited number of sub-catchment and river reaches. The HEC-HMS model can account for temporal and spatial variability of the rainfall-runoff process in a semi-distributed sense. That is, within a sub-catchment, HEC-HMS uses spatially and temporally lumped parameters to simulate the rainfall-runoff process. The rainfall hyetograph is input over the sub-catchment, and the losses are computed, leaving an excess rainfall hyetograph which in turn is transformed into surface runoff hydrograph through a specified unit hydrograph. The subsurface runoff hydrograph is computed separately and added to the surface runoff hydrograph to yield the total sub-catchment runoff hydrograph. In addition to being capable of hydrologic simulation, the HEC-HMS also has a provision for evaluating reservoir and channel development plans for flood control purposes by performing the economic analyses of flood damages for existing and post-development conditions. An additional application of the calibrated model is for impact assessment studies of watershed modifications and channel improvements **(HEC-HMS, 2010)**.

5.4 Model Approach

The following **Figure 5.1** presents the approach that is adopted to build HEC-HMS model.

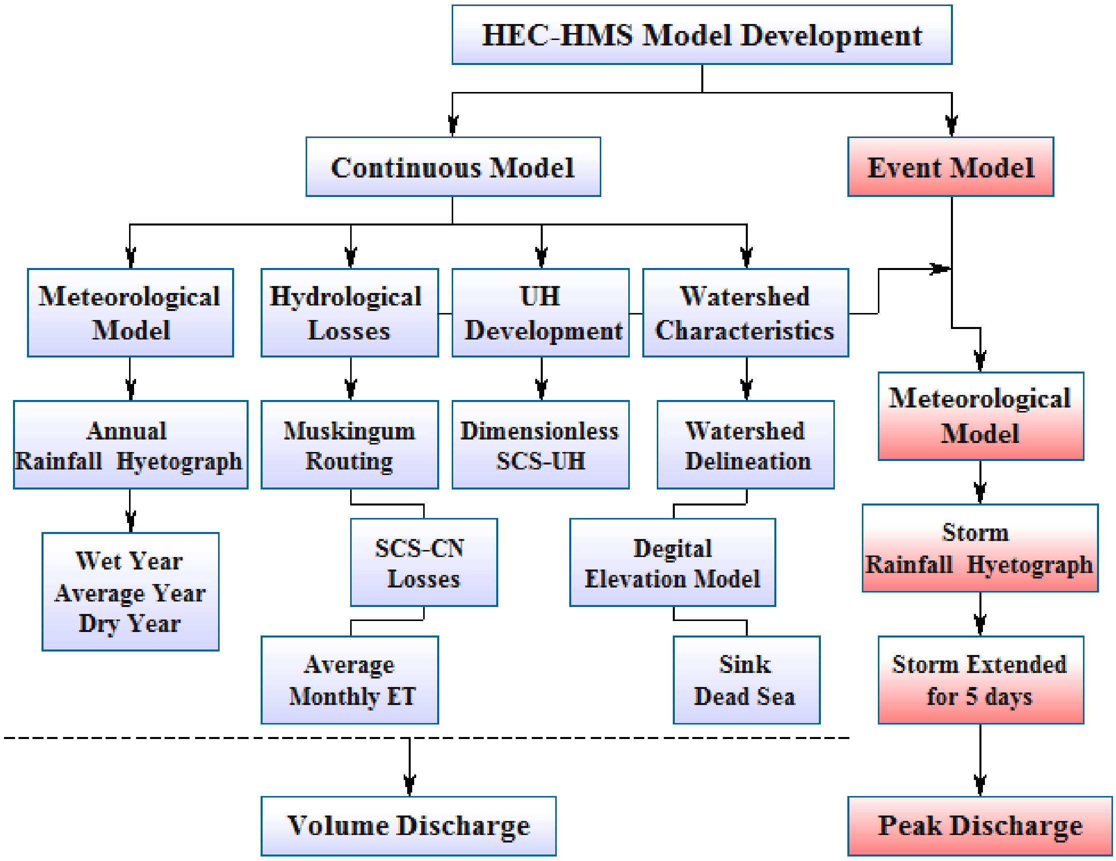

Figure (5-1): HEC-HMS Model Development

5.5 Characteristics of Og Watershed

When modeling the water flows, it is a requisite to relate the physical characteristics of the watershed to the model. Currently, the hydrology methodology utilized available geographic information system (GIS) tools to help model the movement of water across a surface and to identify the drainage systems.

In this section, the drainage system and the surface process include the watershed delineation; the flow direction, the flow accumulation, the stream order, and the stream network were extracted from the Digital Elevation Model (DEM) for Og Watershed in order to present the physical characteristics of the watershed.

5.5.1 Digital Elevation Model (DEM)

An understanding of the shape of Og watershed surface is useful to know how water flow across the watershed and how changes in this surface may affect the flow. To achieve this; the isoelevation lines (contours) from the topographic map of Og watershed was digitized using Arc-GIS 9.3 in order to built the Digital Elevation Model. “The DEM is a raster representation of a continuous surface terrain elevation in xyz coordinates, usually referencing the surface of the earth” **(Library of Arc-GIS9.3)**. To ensure we have a representative DEM with a proper drainage system; all sinks in the generated surface were identified and filled. **Figure 5-2** presents the Digital Elevation Model for Og watershed on which the hydrologic analysis will be performed.

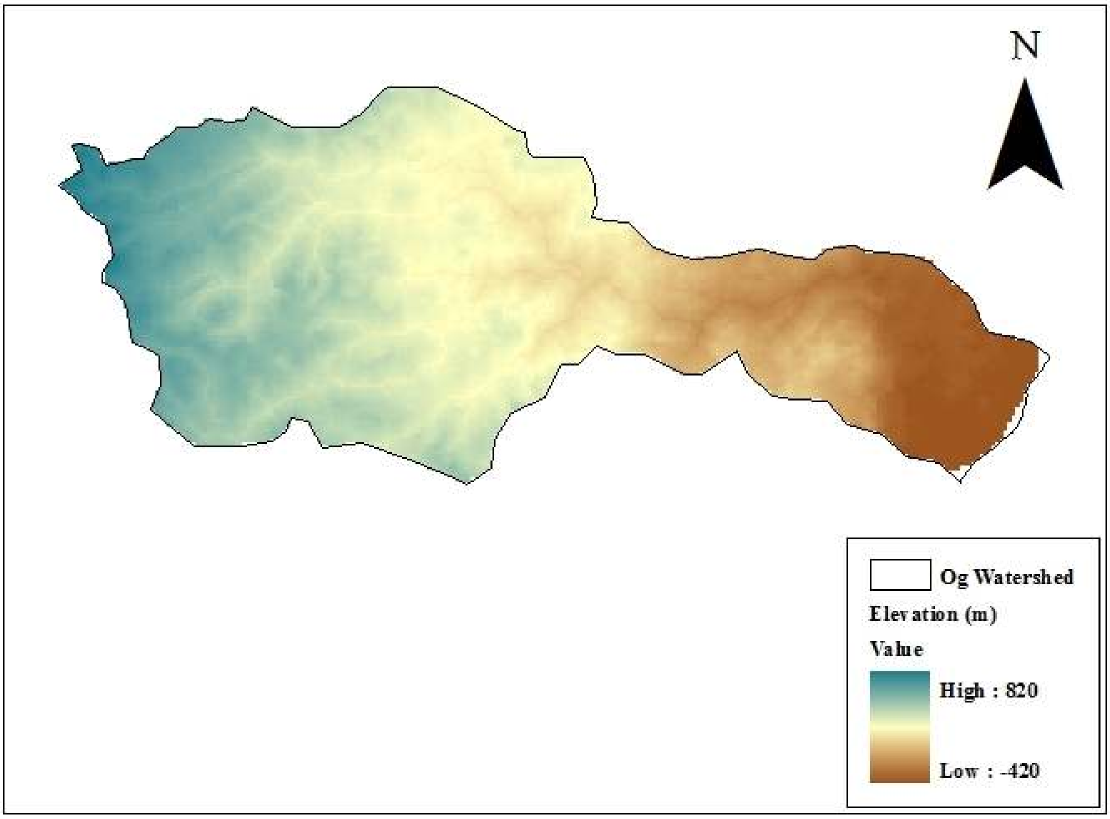

Figure (5-2): The Digital Elevation Model (DEM) for Og Watershed

5.5.2 Flow Direction

When the Digital Elevation Model was generated; the flow direction grid was derived directly depending on the D-8 drainage model which depicts the directions of drainage between the central cell and one of its eight neighbors. The direction is given in accordance to the principle of the maximum or steepest descent **(Library of Arc GIS9.3)**. **Figure 5-3** presents the flow direction map of Og watershed.

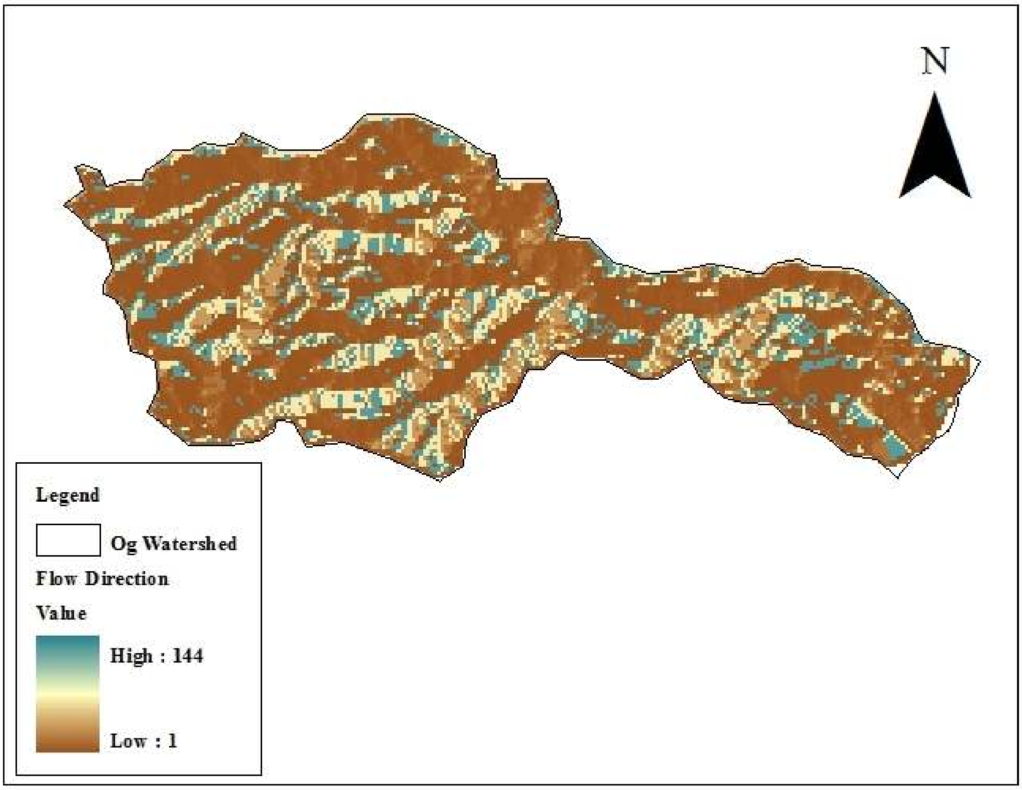

Figure (5-3): Flow Direction Map of Og Watershed

5.5.3 Watershed Delineation

Og Watershed was delineated using flow direction raster **(**See **Figure 5-4**). Depending on this delineation; the watershed had been divided into three sub-catchments: sub-catchment one, sub-catchment two and sub-catchment three (See **Figure 5-5**). The first sub-catchment encompasses 53.69 km^2**,** its elevation start with 800 m and decrease eastward to 150 m. It contributes with the largest amount of flow as its location down of the central mountains that divided the Palestinian wadis into two major groups: the eastern and western wadis. The second sub-catchment encompasses 43.89 km^{2,} its elevation start with 650 m and decrease eastward to 150 m. it appears that this sub-catchment probably contribute with less amount of flow comparing to the first one, while the third sub-catchment encompasses 40.23 km^2, it is located in arid area, downstream of the wadi, its elevation ranges 150 - -400m at the mouth of the wadi, this sub-catchment probably does not contribute with significant amount of flow.

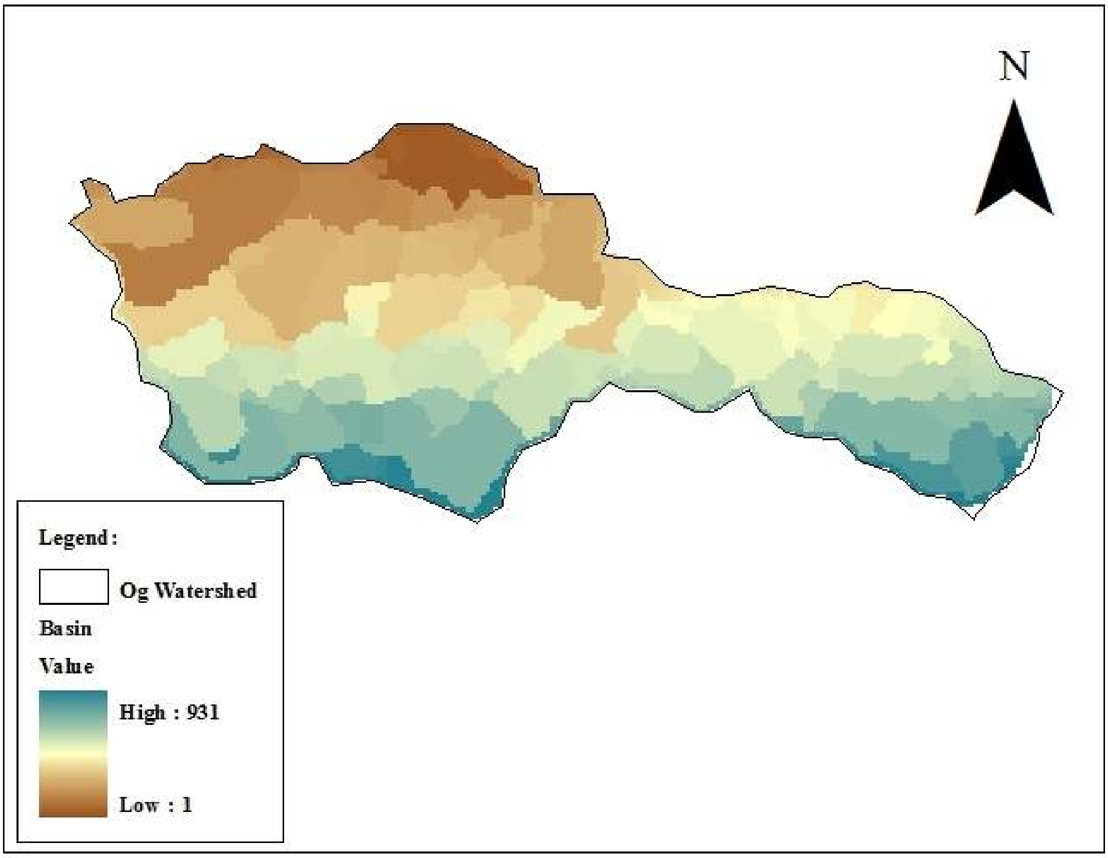

Figure (5-4): Og Watershed Delineation

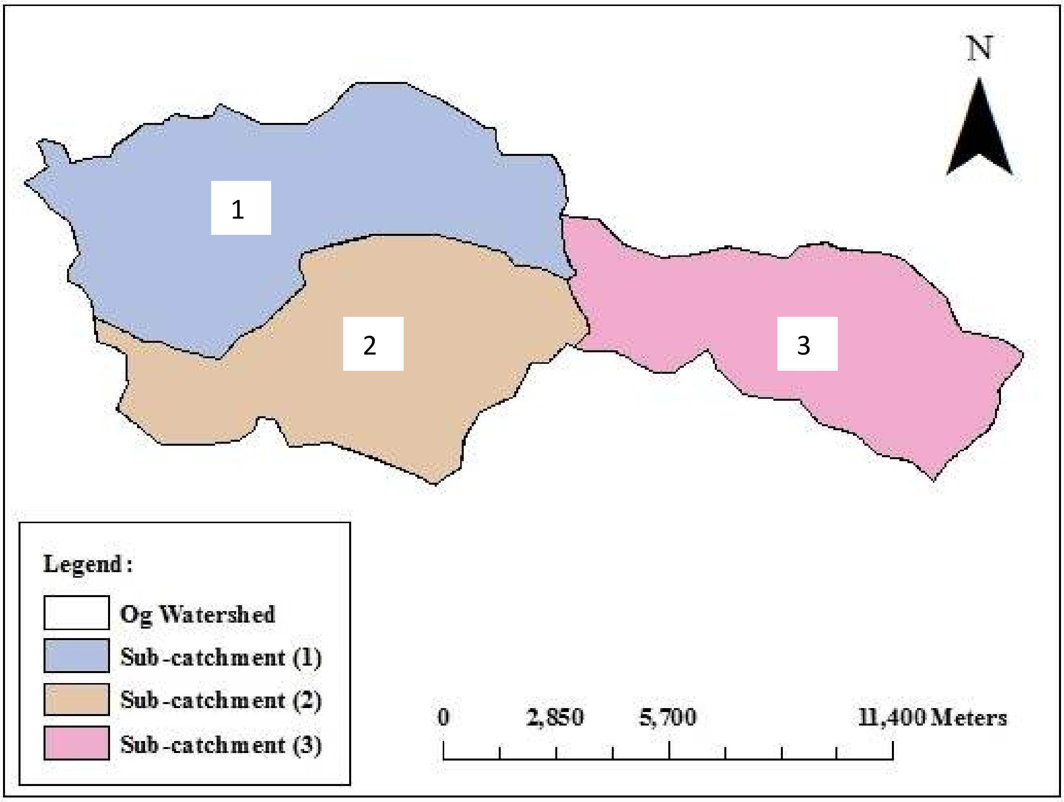

Figure (5-5): Sub-catchments of Og Watershed

5.5.4 Stream Network

The stream network of Og watershed was defined using the output from the flow accumulationgrid. Flow accumulation is one of the most important grids in identifying the stream network, the areas with high flow accumulation indicate concentrated flow and resulted with stream channel, while the areas with a flow accumulation of zero are local topographic highs and may be used to identify ridges. Once the stream network is delineated, it can be further analyzed to find the stream order and to study the movement of water through the Og landscape.

Figure 5-6 presents the flow accumulation map of Og watershed, while **Figure 5-7** shows the delineated stream network of Og watershed.

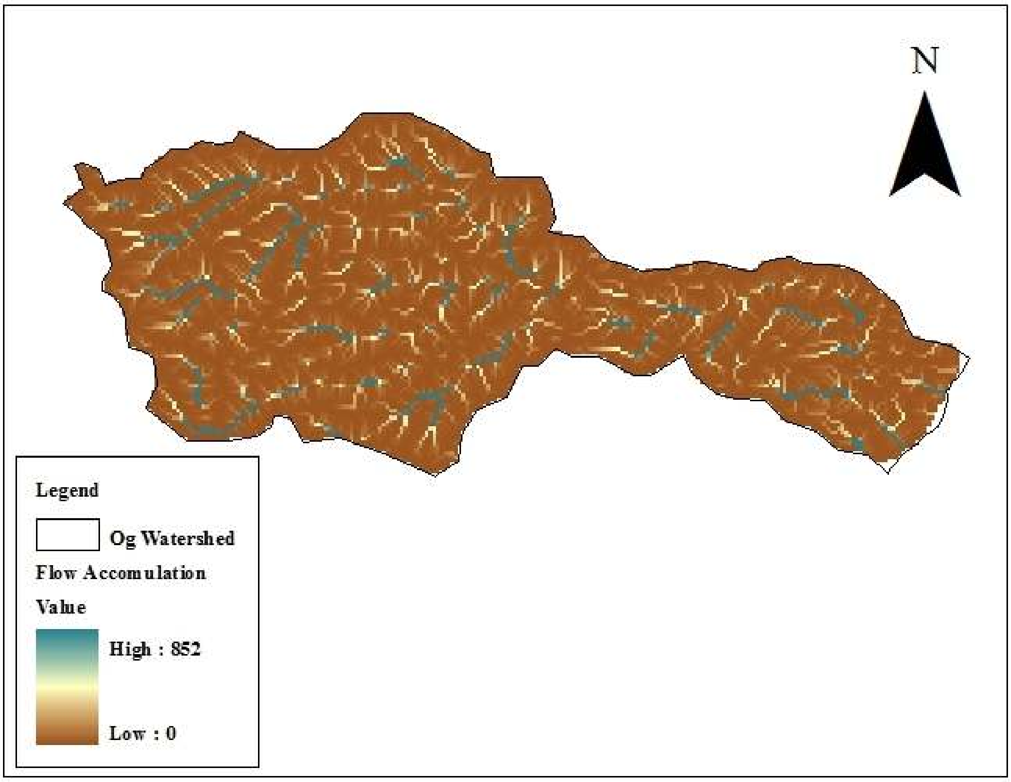

Figure (5-6): Flow Accumulation of Og Watershed

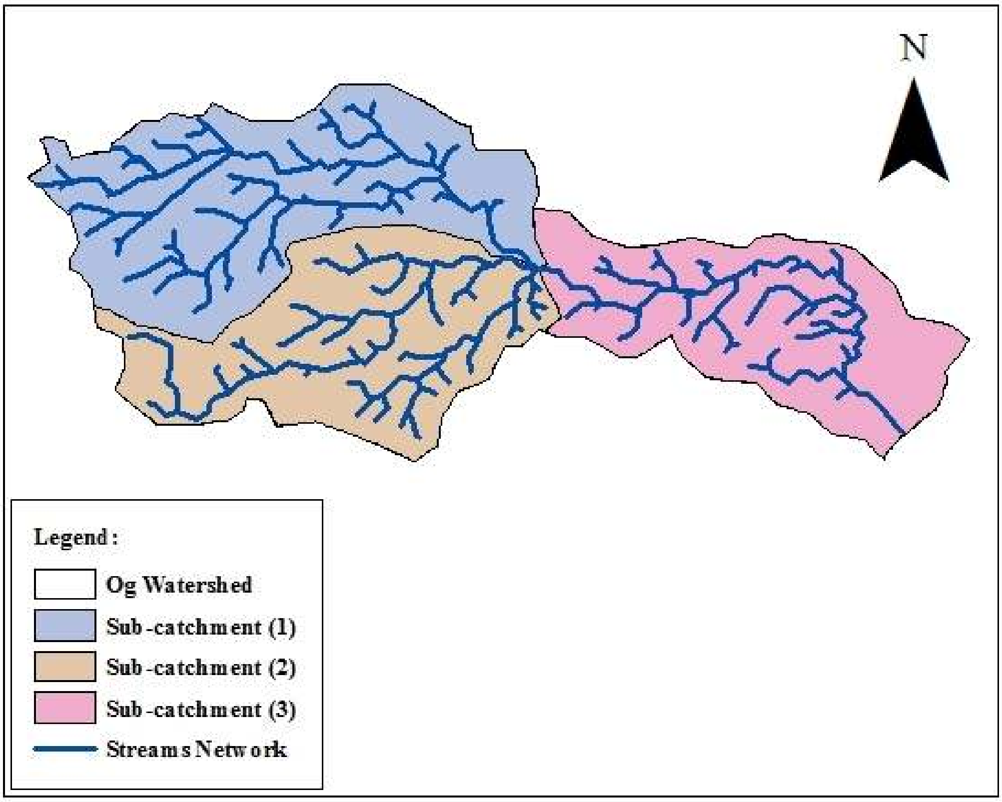

Figure (5-7): Stream Network of Og Watershed

5.5.5 Stream Order

The characteristics of the streams can be simply inferred by knowing the order of it. The size of the watershed, its channel dimensions, and the stream flow are proportional to the stream order. For this reason; the stream ordering of Og watershed was defined using the stream network and the flow directions grids.

For Og watershed; Strahler method was used to identify and classify the types of the streams based on their number of tributaries. The smallest tributaries were classified as order one, while the main stream channel that carries the flow from the entire tributaries areas upstream to the outlet of the watershed was classified as the highest order stream and has fourth order. **Figure 5-8** presents stream order for Og watershed.

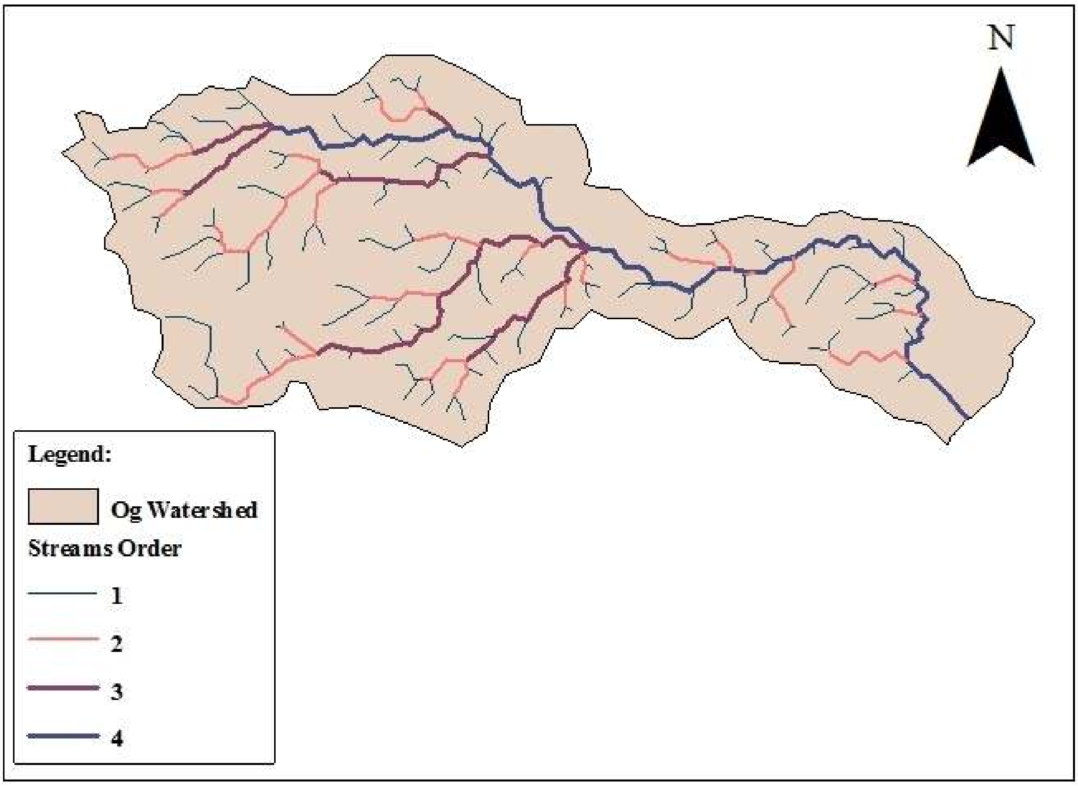

Figure (5-8): Streams Order for Og Watershed

5.6 Development of Unit Hydrograph (UH)

Unit hydrographs (UH) are either determined from gauged data or derived using empirically-based synthetic unit hydrograph procedures. In Og watershed, the absence of reliable long term data let the construction of a unit hydrograph one of the most difficult part of the work. Therefore the unit hydrograph is determined synthetically.

In this section; The Dimensionless SCS model is used in parallel with geographic information system capabilities (GIS) to construct a synthetic unit hydrograph for Og watershed.

5.6.1 The Dimensionless SCS Model

To construct the dimensionless SCS unit hydrograph, the following parameters (Time of concentration (T_c), time to peak (T_p), base time (T_b), tag time (T_{lag}) and peak discharge (q_p)) are estimated for each sub-catchment of the Og watershed.

The lag time is the key parameter needed to construct the unit hydrograph. The curve number and the slope for each sub-catchment of Og watershed were estimated to determine the lag time by applying **Equation (2.1)**. Estimation of a curve number requires mapping of the soil and land use within the watershed boundaries, and specification of unique soil types and unique land use categories. These requirement Shapefiles were first obtained and compiled in a GIS-based database. According to the soil texture map (**Figure 5-9**) and classifications, the hydrologic soil group map of Og watershed was developed (**Figure 5-10**).the soils were classified into the USDA Hydrologic Soil Groups (HSG's) which are A, B, C, and D for each sub-catchment area as shown in **Table 5-1**.

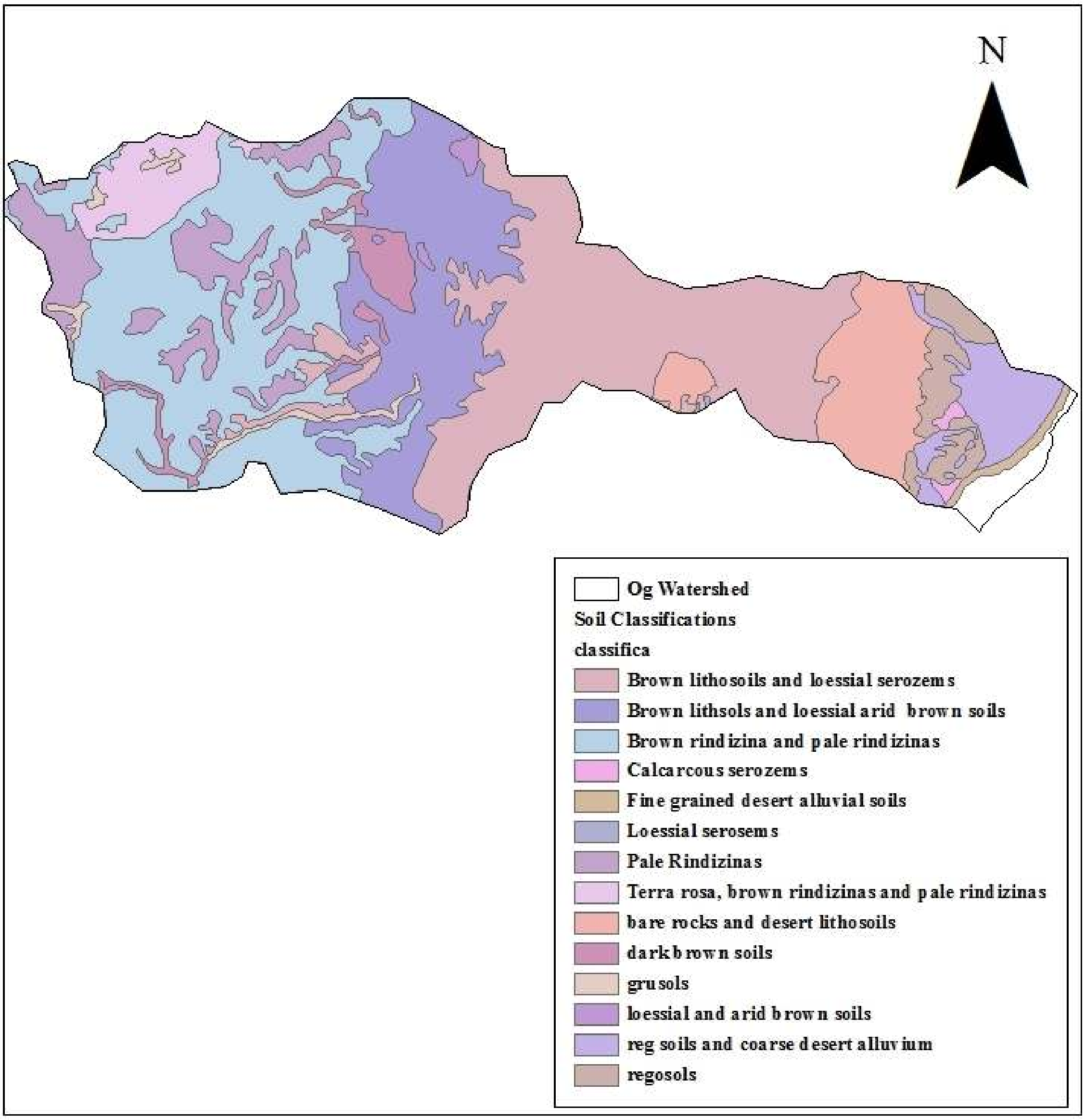

Figure (5-9): Soil Classifications of Og Watershed

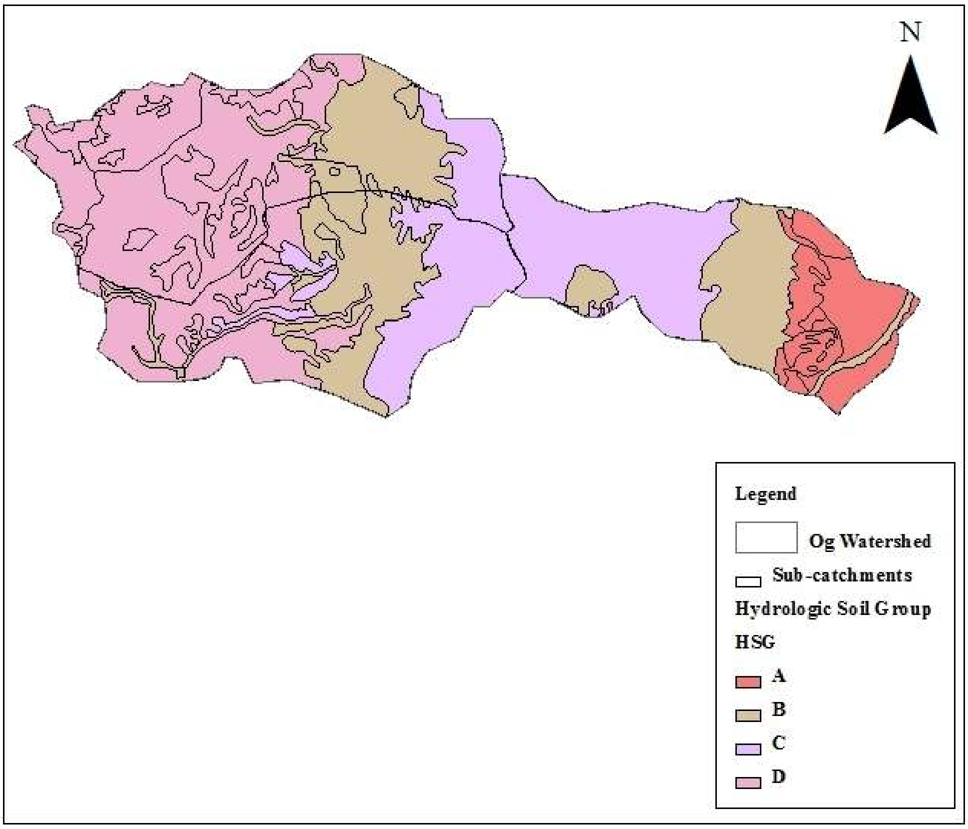

Figure (5-10): Hydrologic Soil Group of Og Watershed

Table (5-1): Sub-Catchments Area HSG of Og Watershed

	Unit	**A**	**B**	**C**	**D**
Sub-catchment (1)	Km^2	-	11.54	5.05	37.11
Sub-catchment (2)	Km^2	-	14.45	13.29	16.15
Sub-catchment (3)	Km^2	10.31	13.16	16.76	-
Total	Km^2	10.31	39.15	35.1	53.26

Soil group D which has high runoff potential, covers more than half the area of Og watershed in upstream part, while soil group A which has low runoff potential, concentrates in downstream area of the watershed. That means, the upper part of the watershed will contribute with the most amount of runoff.

Moreover, land use map of Og watershed was generated (See **Figure 5-11**) and the percentage area for each type of land use was estimated. (For more details regarding the calculations; see **Annex II**).

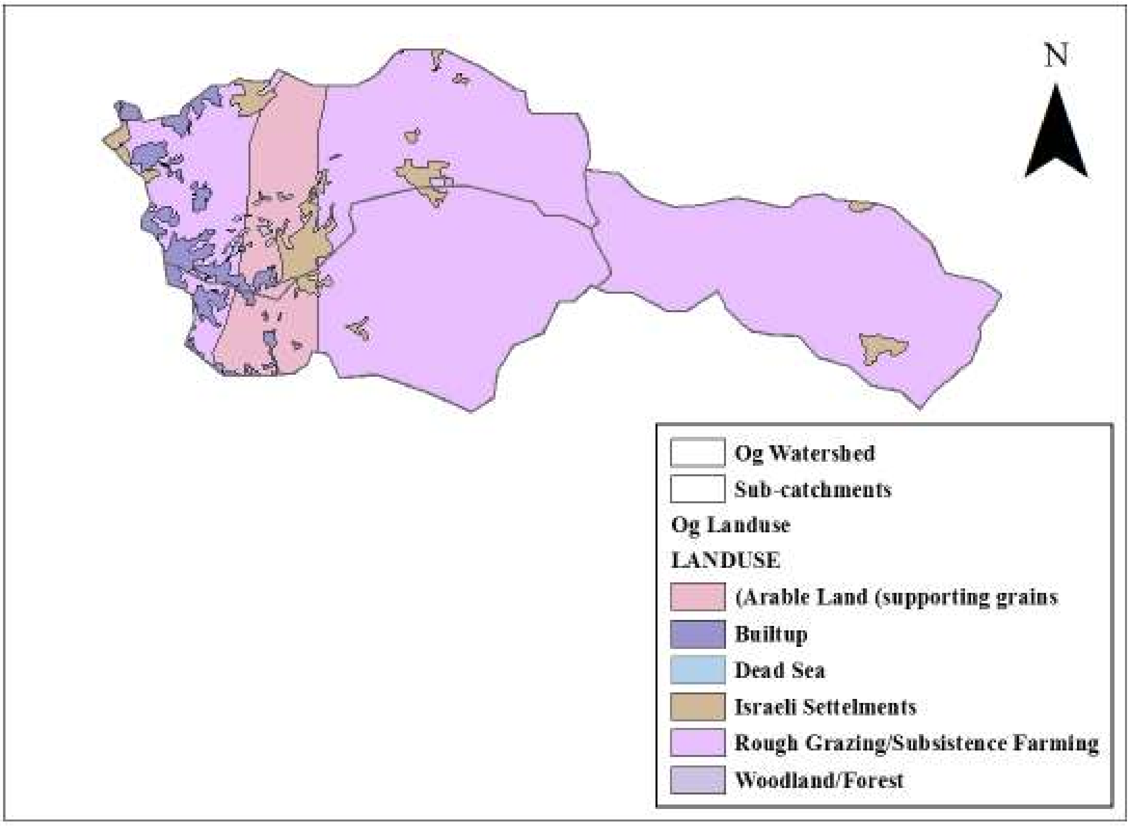

Figure (5-11): Land Use Map of Og Watershed

According to HSG's and land use maps which its spatial variations was kept by using the GIS capabilities; a composite curve number was founded by weighting each curve number according to its area using **Equation (2.2)**. **Table 5-2** represents curve number values for each sub-catchment of Og watershed for dry condition.

Table (5-2): Curve Number Values of Og Watershed

	Composite CN Value
Sub-Catchment (1)	72
Sub-Catchment (2)	70
Sub-Catchment (3)	60
Og watershed	67

The average land slope for Og watershed was estimated using the digital elevation map (DEM). **Figure 5-12** presents the slope as a percentage for the watershed. **Table 5-3** presents the average slope value for each sub-catchment of Og watershed.

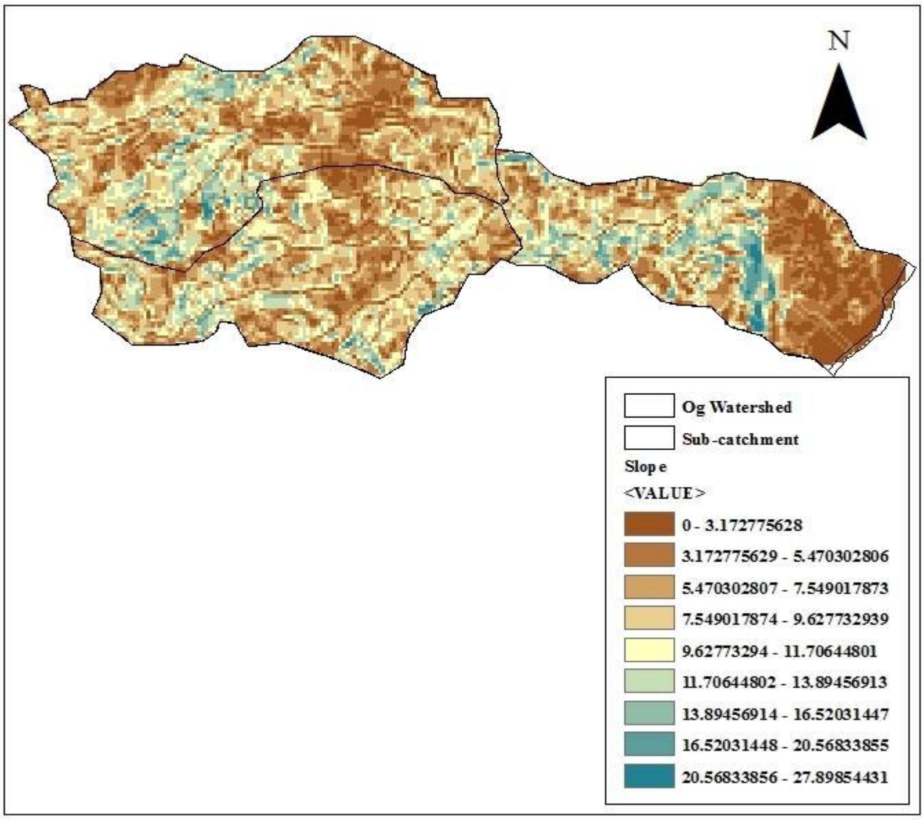

Figure (5-12): Average Land Slope of Og Watershed

Table (5-3): Average Land Slope Values of Og Watershed

	Average Slope (%)
Sub-Catchment (1)	14.20
Sub-Catchment (2)	14.00
Sub-Catchment (3)	13.12
Og watershed	13.77

The calculations were entails to construct the SCS unit hydrograph; the following parameters (time of concentration, duration of excess unit rainfall, time to peak, peak flow, and time base) were founded by applying equations in **Section (2.3.1)** (See **Table 5-4**). The SCS unit hydrograph was developed for each sub-catchment of Og watershed as shown in **Figure 5-13**.

Table (5-4): 1 cm Excess Rainfall SCS Dimensionless Unit Hydrograph Parameters

	Unit	Sub-Catchment (1)	Sub-Catchment (2)	Sub-Catchment (3)
Lag Time (T_{lag})	(hr)	2.62	2.65	3.43
Time of Concentration (T_c)	(hr)	4.37	4.43	5.74
Duration (D)	(hr)	0.58	0.59	0.76
Time to Peak (T_p)	(hr)	2.91	2.95	3.82
Time Base (T_b)	(hr)	7.77	7.88	10.19
Peak Flow (q_p)	(m^3/sec)	38.37	30.95	21.92

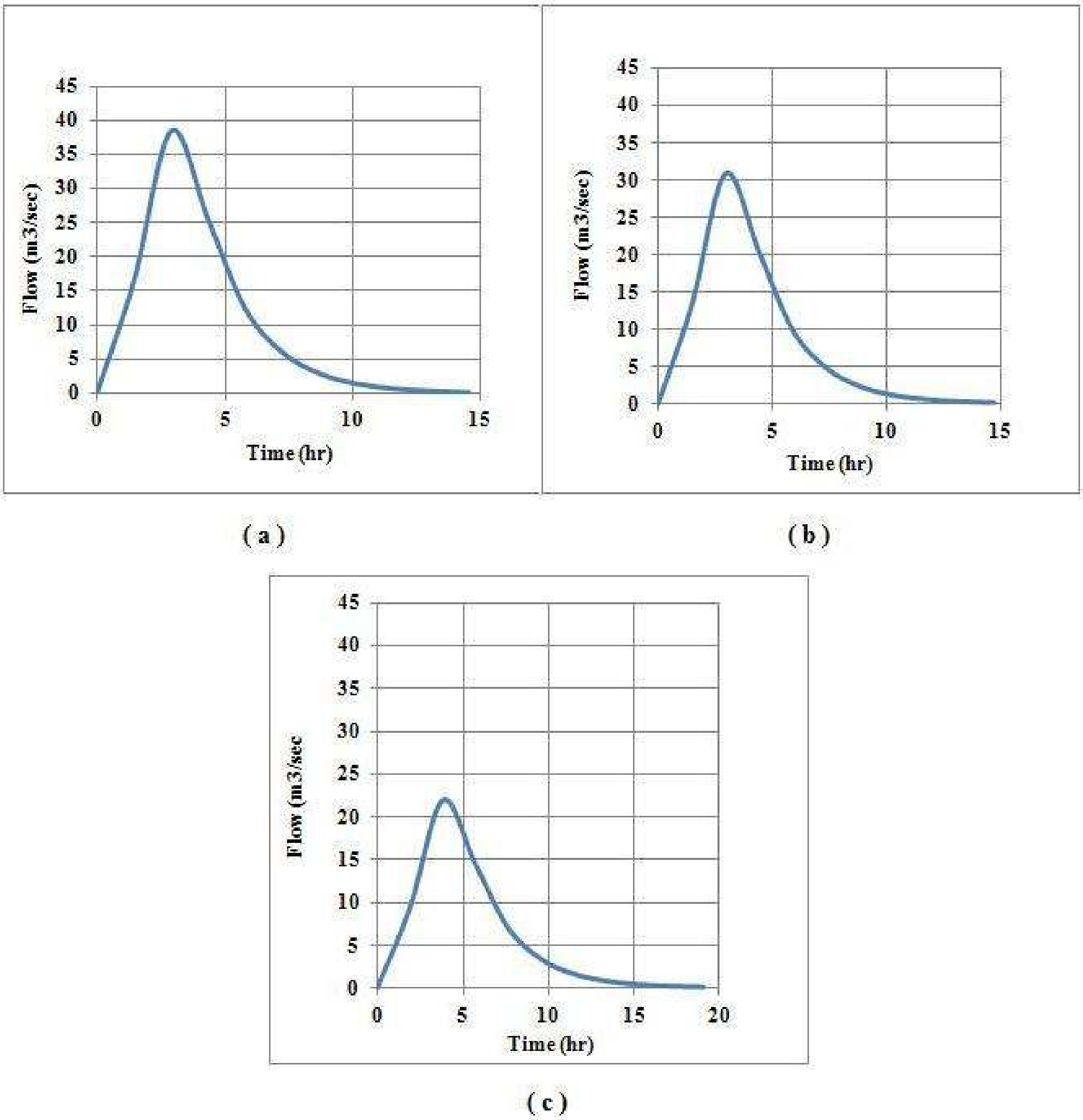

Figure (5-13): (a) UH for Jerusalem sub-catchment One, (b) UH for Bethlehem Sub-catchment Two, (c) UH for Jericho Sub-catchment Three

5.7 Hydrological Losses

Accounting for transmission losses properly is critical in developing rainfall - runoff modeling in arid and semi-arid regions, especially because the streams in such environment flow only in response to storm events (ephemeral) generally predominate, and mainly composed of coarse-textured alluvial materials that's could lead to a significant reduction in flow volume **(Sadeghi & Singh, 2010)**.

Up to date; most of the transmission losses researches, has involved reducing the total volume of flow by some appropriate factor and possibly evaluating the reduction of the peak flow. Few studies have attempted to account for transmission losses as the stream flow is routed along the channel **(Rew and Mccuen, 2010)**. However, two different approaches, the Soil Conservation Service (SCS) Curve Number (CN) method and routing techniques were developed in this section to account the spatial and temporal variations of transmission losses along Og watershed.

5.7.1 Soil Conservation Service (SCS) Curve Number (CN) Method

The SCS-CN is considered one of the alternative methods that included in HEC-HMS model to account for cumulative losses. It estimates excess rainfall as a function of cumulative rainfall, soil cover, land use, and antecedent moisture **(HEC-HMS, 2010)**.

Selecting this method to represent the cumulative losses requires only one input parameter, which is the curve number. **Table 5-5** shows composite curve number values for each of the three sub-catchment of Og watershed. For more details regarding estimating these values, see **Section 5.2.1**.

Table (5-5): Curve Number Values of Og Watershed

	Composite CN Value
Sub-Catchment (1)	72
Sub-Catchment (2)	70
Sub-Catchment (3)	60
Og watershed	67

Table 5-6 presents the initial abstraction and maximum retention values for the three sub-catchments.

Table (5-6): Initial Abstraction and Maximum Retention Values for the Og Sub-catchments

	Initial Abstraction (cm)	Potential max. Retention (cm)
Sub-Catchment (1)	2.0	9.8
Sub-Catchment (2)	2.2	11
Sub-Catchment (3)	3.3	16.5

5.7.2 Muskingum Routing

Routing rainfall-derived runoff through the model requires definition of channel reach. In Og watershed, there are three sub-catchments that are connected by a reach (See **Figure 5-14**), this channel reach is based on the location of sub-catchments inflow. It is routed the flow hydrographs from the upstream to the downstream end of the channel reach. (i.e., movement of flow from one concentration point to another).

In HEC-HMS model, there is more than one alternative to represent routing techniques. Muskingum method is one of the available choices that was established in this study. This method simulate conveyance of flow and outflow peak attenuation resulting from storage within the system for natural, undeveloped channels and is deemed appropriate for approximating channel routing in arid and semi-arid region **(Murphy, 2011)**.

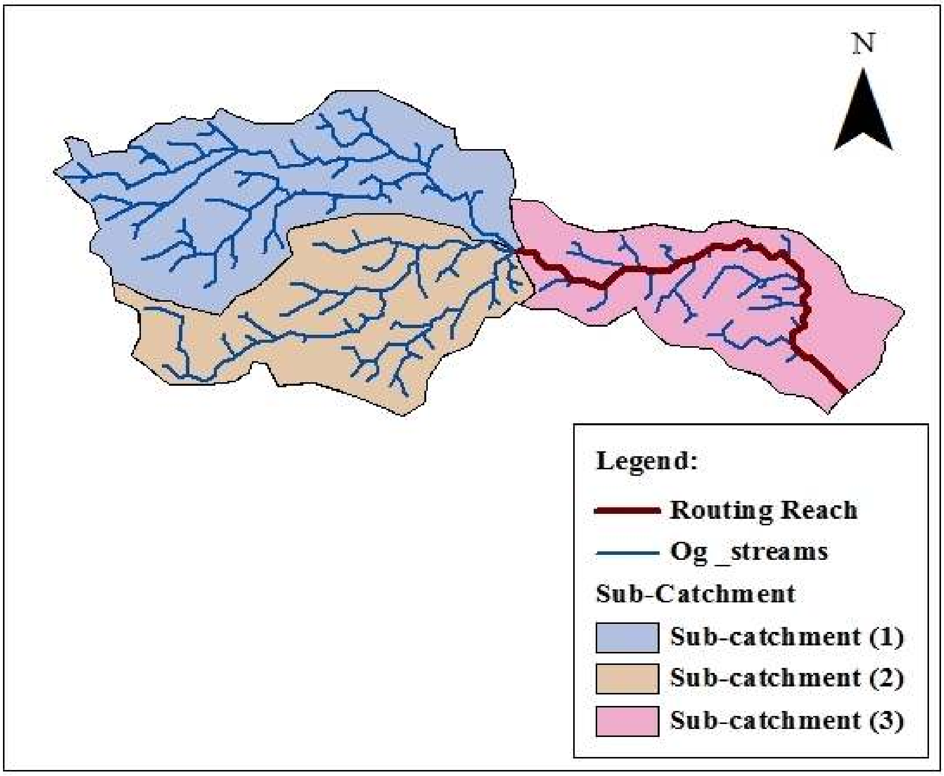

Figure (5-14): Reach through Og Watershed

In HEC-HMS model, simulating the downstream hydrograph at the end of the reach using Muskingum method required three input parameters which are:

1. K: is a travel time of the flood wave through routing reach.
2. X: dimensionless factor that weighs the relative influences of inflow and outflow upon the storage.
3. ΔX: number of steps into which a reach is divided for routing.

As with other routing models, an accurate solution requires selection of appropriate time step (Δt), distance step (ΔX), and the parameter (K) to ensure accuracy and stability of the solution. **Table 5-7** presents the calculated values for the Muskingum input parameters.

Table (5-7): Muskingum Routing Input Parameters for HEC-HMS Model

Parameter	Unit	Value
X	hr	0.2
K	-	2
ΔX	-	3

Behind the table:

1. The dimensionless factor X lies between (0.1 and 0.3), it indicating both attenuation and translation. In this study, the model value is about 0.2 **(Song et al. , 2011)**.

2. The value of K equals the total travel time along the reach (6 hr). However, as the reach is divided into three sub-reaches, the model value is 2 hr/sub-reach.

3. Distance step (ΔX) presents the number of sub-reaches. This value is properly obtained from the relation (K /**Δ**t), the total travel time along the reach is 6 hr while the time step is 2 hr, so the distance step is 3 sub-reaches.

It should be noted, that these input parameters were determined taking into account the sum of the routing coefficient (C_0, C_1, and C_2) to be equal to one -as shown in **Equations 2.8, 2.9, and 2.10** - while the value of the time step (**Δ**t = 2 hr) is located within the range, ($2KX < \Delta t \leq K$).

5.7.3 Evaporation and Transpiration

In common application, a detailed accounting of evaporation and transpiration are considered when a continuous hydrologic modeling is adopted. However, in arid and semi-arid climate, particularly in the case of shorter storm such as events, it may be appropriate to omit this accounting as the evaporation and transpiration are insignificant during a flash flood (**HEC-HMS, 2010**).

In this study, event and continuous hydrologic modeling were developed for Og watershed. The evaporation and transpiration losses are not accounting in event model. In continuous model, potential evaporation rate for the study area were considered. The average monthly potential evaporation rate was obtained from the Palestinian Meteorological Department. **Table 5-8** presents the average monthly potential evaporation rate for the study area.

Table (5-8): Average Monthly Potential Evaporation Rate

Month	Potential Evaporation Rate (mm)
January	52
February	56
March	85
April	121
May	163
June	181
July	194
August	188
September	166
October	140
November	91
December	58

5.8 Meteorological Model

The available daily rainfall data for Jerusalem, Bethlehem, and Jericho stations was used to build the meteorological model. A hyetograph rainfall data (Rainfall depth versus duration) was entered for each station. Jerusalem rainfall data was selected to represent the amount of rainfall falls over sub-catchment one, while Bethlehem and Jericho rainfall data was selected to represent sub-catchment two and three respectively.

The hyetograph rainfall data was multiplied with a factor to determine the actual amount of rainfall falls over the watershed. The factor is estimated for each sub-catchment depending on the long term average rainfall for each station and the Isohyetal map for Og watershed. **Table 5-9** presents the multiplied factor for each sub-catchment.

Table (5-9): Estimated Rainfall Factor for Og Watershed Sub-catchments

	Historical Average Rainfall of the Stations (mm/year)	Sub-catchments	Average Rainfall of the Catchments (mm)	Factor
Jerusalem Station	503.4	(1)	319.35	0.634
Bethlehem Station	489.5	(2)	266.45	0.544
Jericho Station	153	(3)	141.25	0.923

Two approaches were followed to construct the meteorological model as shown in the following **Figure 5-15**.

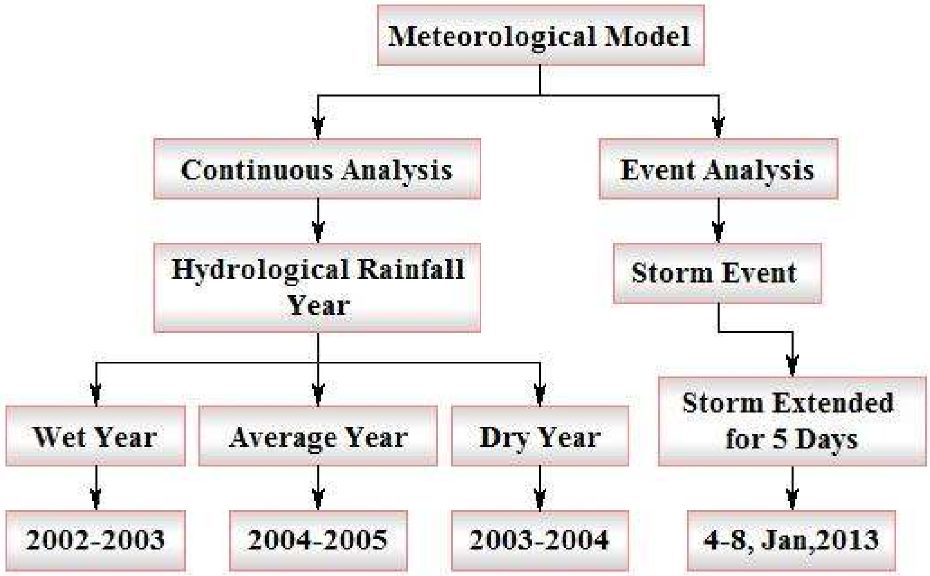

Figure (5-15): Meteorological Model Structure

Behind the Figure:

– **Continuous Analysis**: daily rainfall data for the selected stations was entered from 1st October to 30th April. The available daily rainfall data was classified to average, dry, and wet hydrological rainfall year. The data were multiplied with the calculated factor to present the actual amount of rainfall that had been fallen over Og watershed. **Table 5-10** summarizes the total amount of rainfall for the selected stations during the period 2002-2005. **Annex III** presents the available daily rainfall data for this period.

Table (5-10): Multiplied Daily Rainfall Data for the Selected Stations

	Long Term Average Rainfall (mm)	Hydrological Year		
		2002-2003	**2003-2004**	**2004-2005**
Bethlehem Station	475	719	287	511
Jerusalem Station	480	800	343	580
Jericho Station	148	284	106	134

– **Event Analysis:** During the 4th of January 2013, a deep storm extended for seven days was occurred. This storm resulted to fall large amount of rainfall with snow over Palestine. The meteorologists pointed out that this storm has a return period about 20 years. However, the amount of rainfall that was measured in Jerusalem, Bethlehem, and Jericho stations during this storm was obtained from the Palestinian Meteorological Department. (See **Table 5-11**).15 minutes rainfall records were obtained. However, the obtained rainfall data was multiplied with the calculated factor and used to represent the event storm.

Table (5-11): Daily Rainfall Data During 4th January Storm

	Rainfall Stations		
Date	**Jerusalem**	**Bethlehem**	**Jericho**
4th Jan 2013	1.4	3.2	1.4
5th Jan 2013	16.4	12.1	7.6
6th Jan 2013	0.8	0.2	0
7th Jan 2013	40	69.2	15.6
8th Jan 2013	68.2	42.5	10.6
9th Jan 2013	37.4	57	5.8
10th Jan 2013	28.4	22	4

5.9 Continuous Model

In the continuous hydrologic model, the simulation time period ranges from October 1st to April 30th, and an half hourly time step was used. The SCS-CN loss method, the Dimensionless SCS transforms method, The Digital Elevation Model (DEM) map, and the monthly average potential evaporation rates were selected for all sub-catchments. The SCS-CN method simulates rainfall excess and losses; the

Dimensionless SCS unit hydrograph method transforms the computed rainfall excess to direct runoff at the outlet of a sub-catchment; the DEM map represents the physical characteristics of the surface, and the average monthly potential evaporation rate computes the evaporation from the ground surface and transpiration by vegetation. To better accounting for transmission losses, reach routing method (Muskingum) was utilized in the modeling (See **Figure 5-16**).

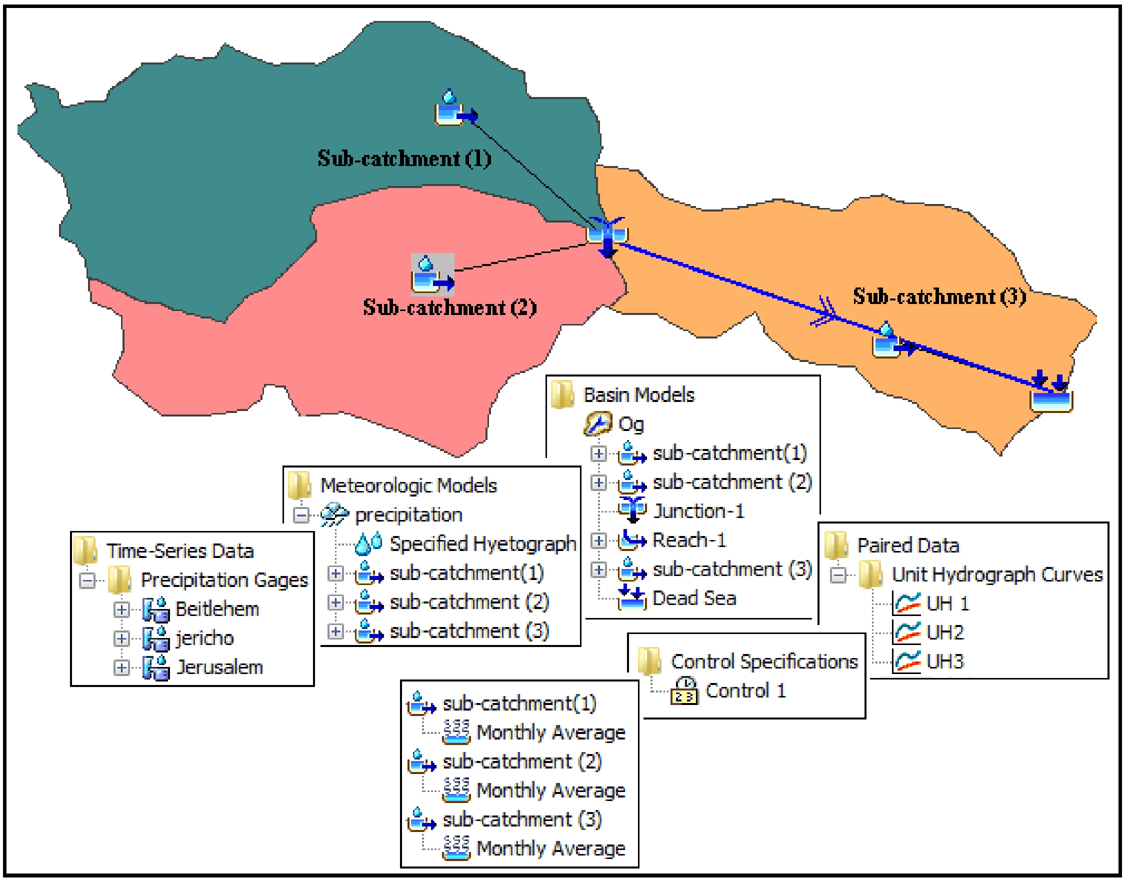

Figure (5-16): HEC-HMS Model Input Data

Three scenarios were developed to estimate the total runoff volume:

1. **Scenario One:** Runoff volume generated in average hydrological rainfall year (2004-2005),

2. **Scenario Two:** Runoff volume generated in dry hydrological rainfall year (2003-2004),
3. **Scenario Three:** Runoff volume generated in wet hydrological year (2002-2003).

The HEC-HMS model was applied for the three scenarios and the output for the three sub-catchments is presented in chapter six.

5.10 Event Model

A 30 min time step was selected in the event hydrologic modeling. The modeling starts in 4th of January, 2013 and extended for 5 days. As in the continuous model, The SCS-CN loss method, the Dimensionless SCS transforms method, and the Digital Elevation Model (DEM) map was selected for each sub-catchment. Muskingum routing method was utilized and the obtained rainfall hyetograph for this period is entered to the model. See **Figure 5-17**.

The HEC-HMS model was run and the peak discharge in addition to the total runoff volume of this event were predicted as will be discussed later in Chapter six of this thesis.

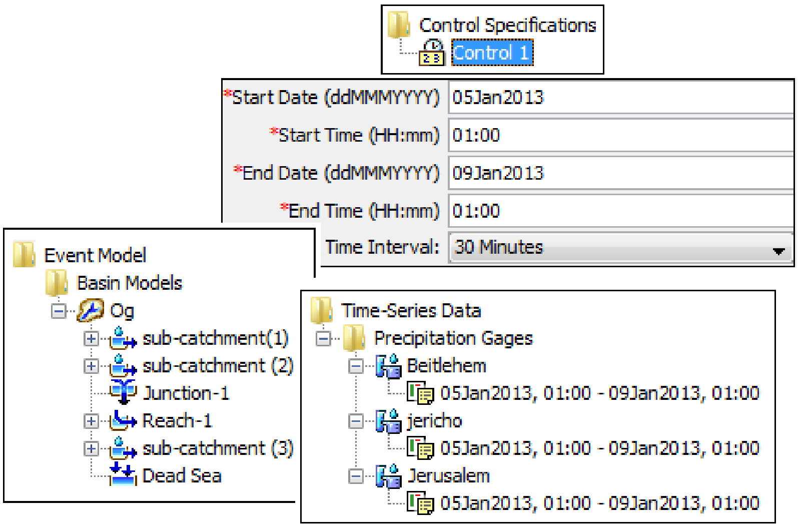

Figure (5-17): Event Model Input Data

5.11 Model Outputs

A number of different simulations were applied in order to predict the total runoff volume resulted from wet, average and dry rainfall season. As well as the total runoff volume and peak discharge generated from flash flood event will also be evaluated.

The results from applying the HEC-HMS model for the different scenarios are discussed in the following sections.

5.11.1 Continuous Model Output

The HEC-HMS model was applied for the three scenarios and the total runoff volume at the Dead Sea is predicted as shown in **Table 5-12**.

Table (5-12): Total Runoff Volume Generated from Og Watershed

Scenarios	Runoff Volume (MCM)
1. Average Hydrological Rainfall Year	9
2. Dry Hydrological Rainfall Year	0.93
3. Wet Hydrological Rainfall Year	14

The output of scenario one (Average hydrological rainfall year) is summarized and discussed in details below (For more details regarding dry and wet hydrological scenarios outputs, See **Annex IV**).

The total runoff volume generated from Og watershed during the hydrological rainfall year (2004-2005) for the three sub-catchments is presented in **Table 5-13** while the outflow hydrograph at the Dead Sea is shown in **Figure 5-18**.

Table (5-13): Runoff Volume Generated from the Og Sub-Catchments

	Runoff Volume (MCM)
Sub-Catchment (1)	6.36
Sub-Catchment (2)	2.59
Sub-Catchment (3)	.051
Dead Sea	9

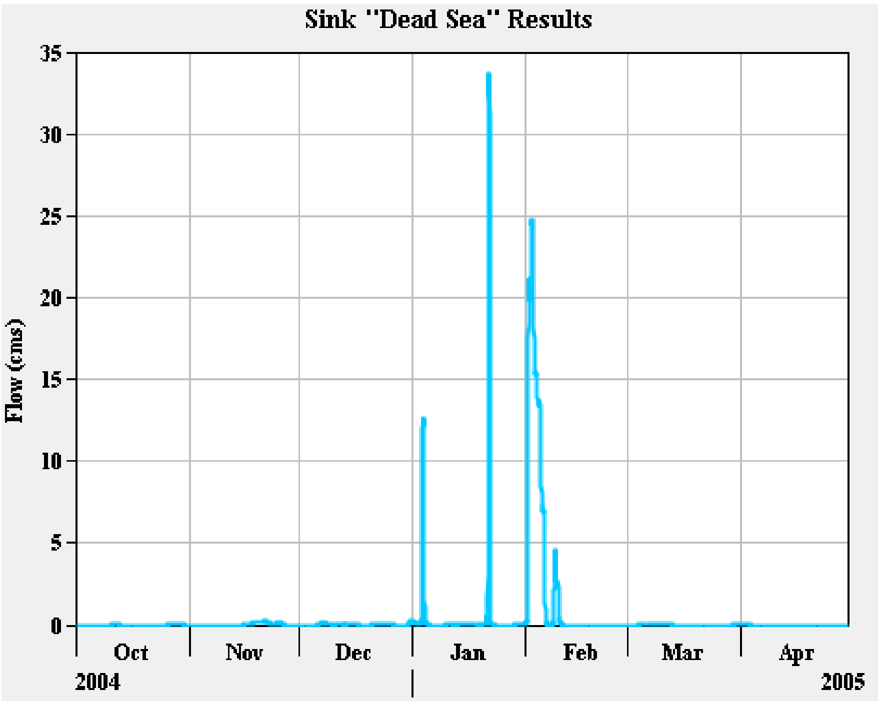

Figure 5-18: Outflow Hydrograph at the Dead Sea

Appearently, Sub-catchment one and two contributes with more than 99% of the total runoff volume generated from the watershed. While , sub-catchment three has the smallest share (less than 1% of the total runoff volume). This is due to many reasons including:

1. Sub-catchment one and two are located down of the central mountains that divided the Palestinian wadis into two major groups: the eastern and western wadis. This distinctive location provided the sub-catchments with an opportunity to receive large amount of runoff that drains eastward from the mountains during wet season.

2. The western part of the Og watershed (sub-catchment one and two) receives larger amount of rainfall compared with the eastern part (sub-catchment three). The mean annual rainfall decreases eastward from 500 to less than 100 mm.

3. The aridity rate changes spatially in the Og watershed. It changes from semi- arid in the western part to extremely arid in the eastern part. This can be clearly seen in sub-catchment three where most of rainfall lost as losses due to the high aridity of the area (See **Figure 5-19**).

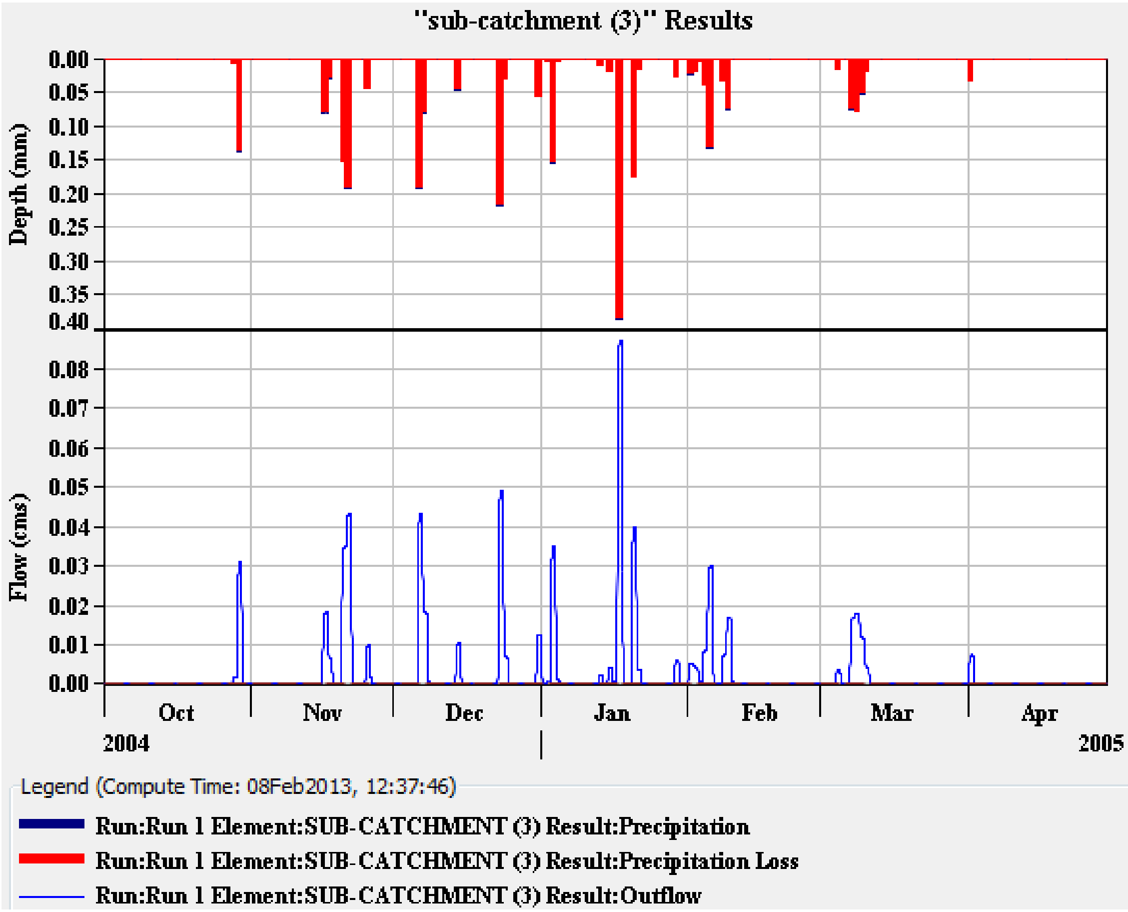

Figure (5-19): Outflow Generated from Sub-Catchment Three

In the early time of winter, most amount of rainfall is lost as losses. No runoff event is occurred. In the months of January and February, the soil becomes moves saturated and the probability to have runoff event is higher. This is clearly shown in **Figure 5-20** and **Figure 5-21**.

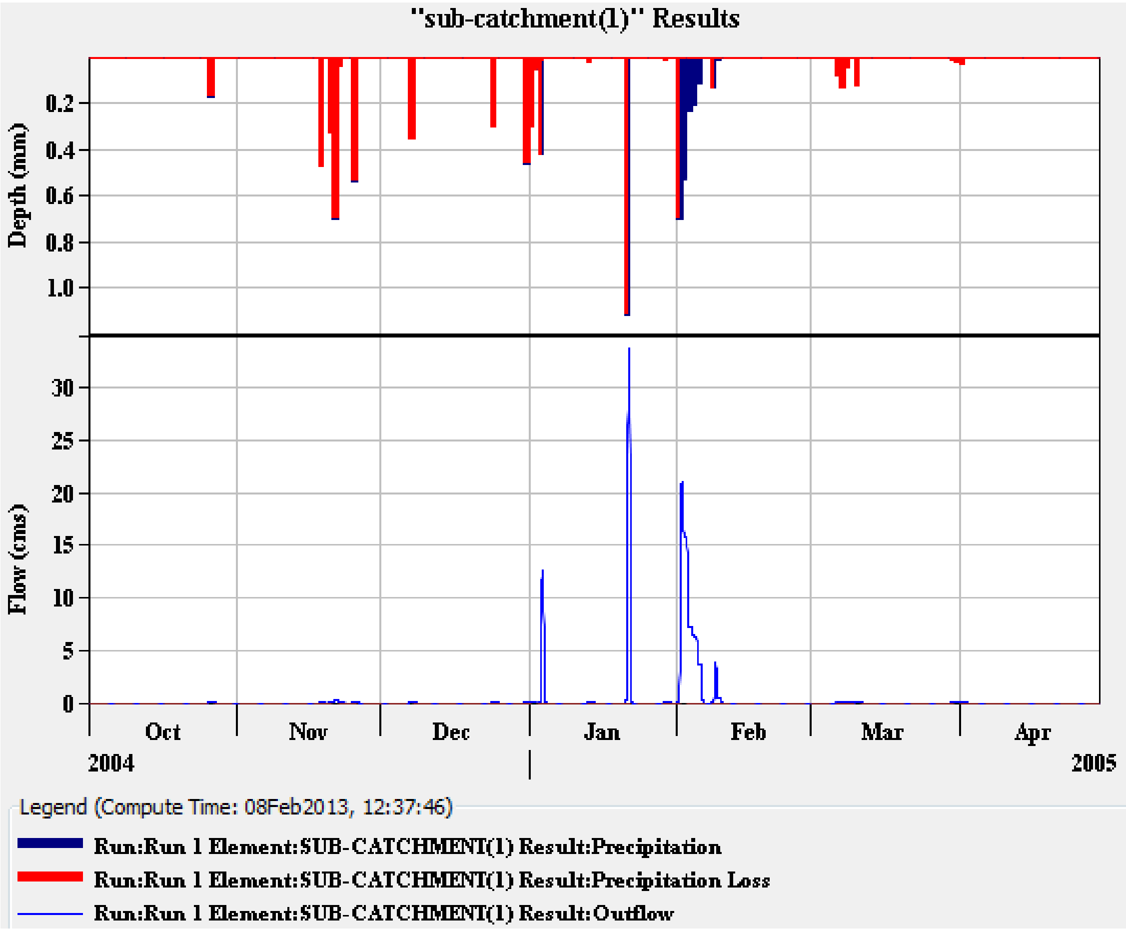

Figure (5-20): Outflow Generated from Sub-Catchment One

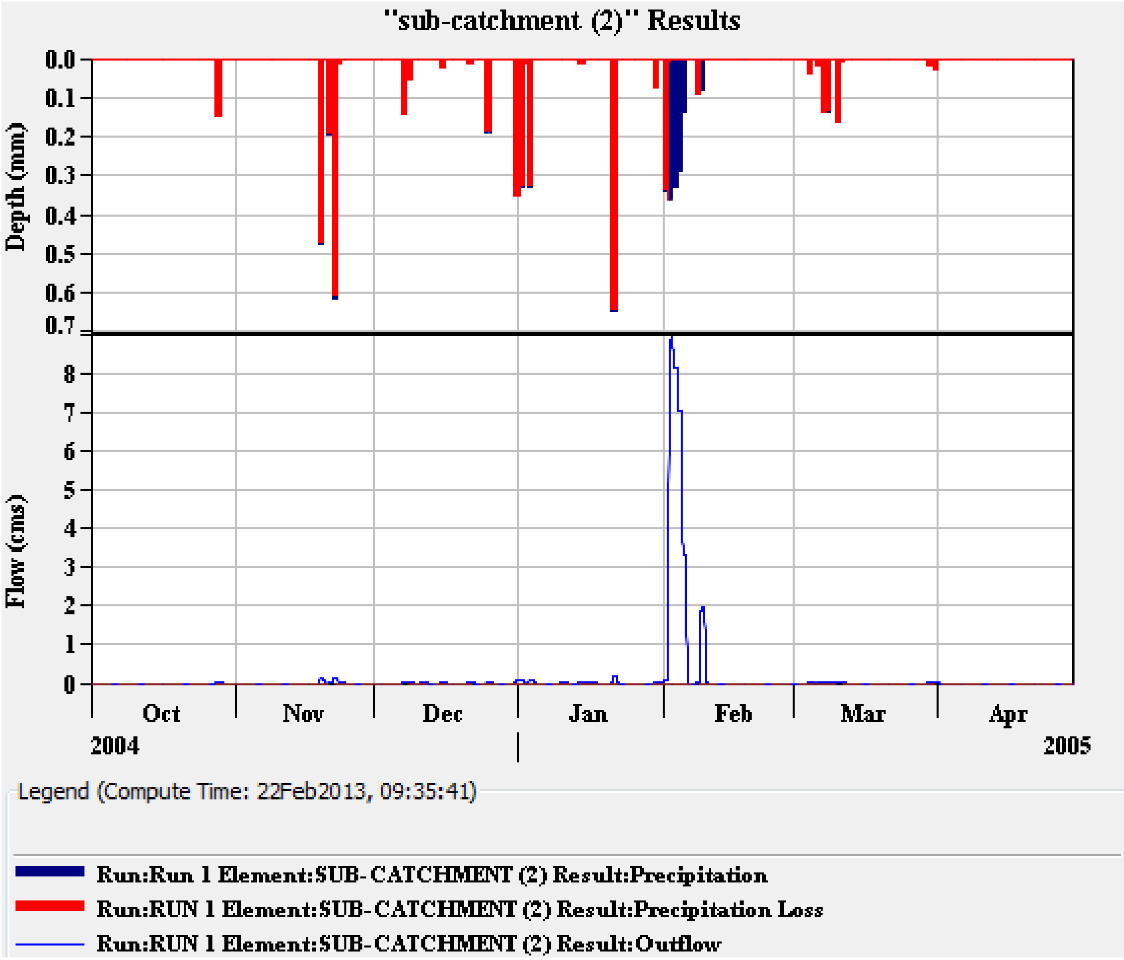

Figure (5-21): Outflow Generated from Sub-catchment Two

At the Dead Sea, the peak outflow is 33.74 m^3/sec. this was occurred on 22th of January when more than 84 mm/day fell over the Og watershed. On average hydrological year, one or two large storms may occur. The total volume of these single events may exceed the total runoff from one year.

For more details regarding continuous model output, see **Annex IV**.

5.11.2 Event Model Output

The total runoff volume generated from 5 consecutive rainy days at Dead Sea is predicted using HEC-HMS model. The computer outputs shows that 0.073 MCM runoff volume is resulted from this event. **Table 5-**

14 summarizes runoff volume generated from each sub-catchment of Og watershed, as well as, the total runoff volume after the routing technique is applied for sub-catchment one and two hydrograph is provided in the table.

Table (5-14): Total Runoff Volume Generated from Og Sub-catchments

Hydrologic Element	Runoff Volume (m^3)
Sub-catchment (1)	37,000.67
Sub-catchment (2)	28,000.24
Junction (1)	65,000.91
Reach (1)	63,000.23
Sub-catchment (3)	10,000.19
Dead Sea	73,000.42

Outflow hydrograph at the Dead Sea is presented in **Figure 5-22**. The hydrograph illustrates how runoff volume was varied within the event period (for more details regarding runoff variation with time, See **Table 5 in Annex IV**). Three peak discharges is presented in the figure, the first one was occurred one day after the event was started and extended for one hour. However, this peak was shy and didn't cause noticeable runoff in the wadi. The second peak was occurred two days after the event was started and extended for half hour, this peak discharge is considered as an introduction for the large one which was occurred after less than one day of it and has 0.954 m^3/sec peak outflow at the Dead Sea (See **Table 6-4**).

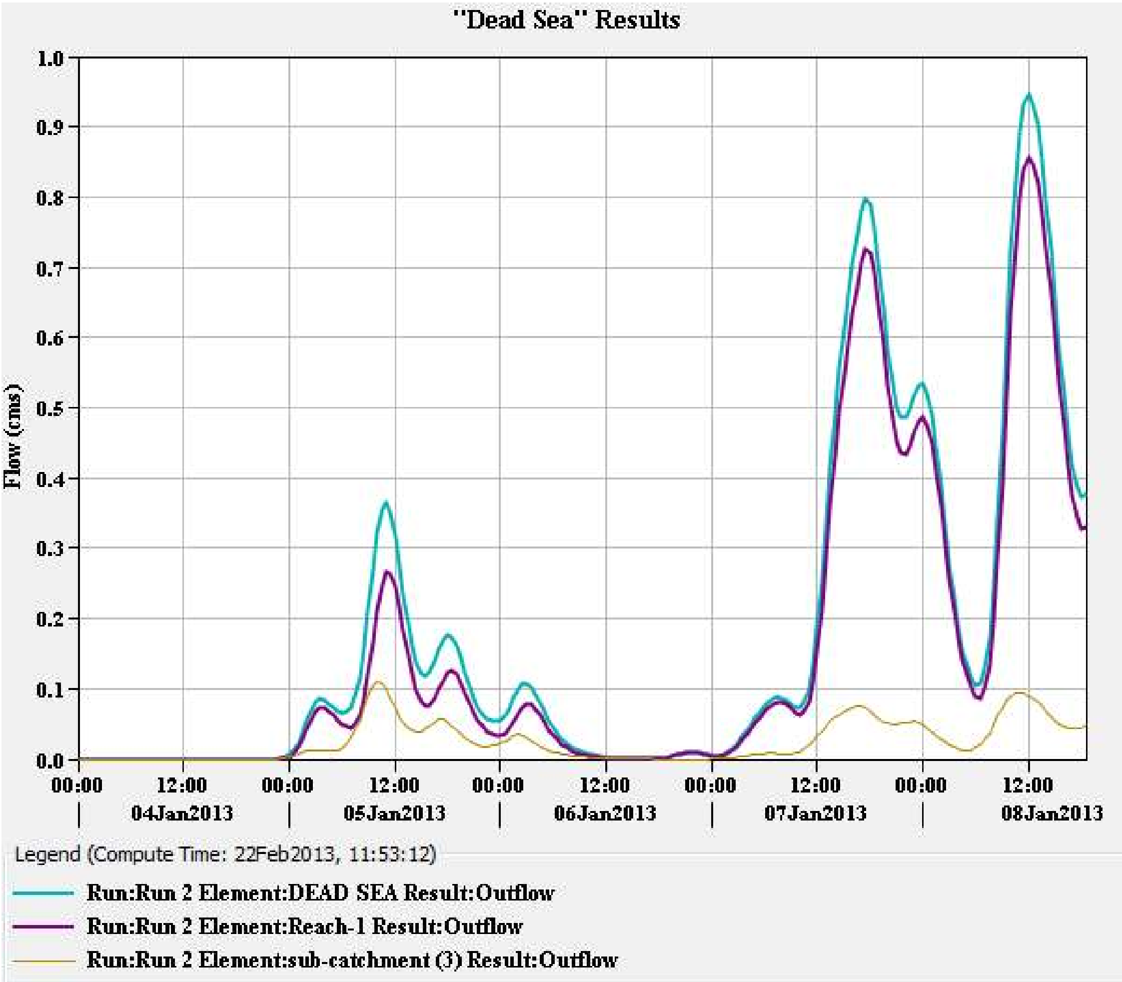

Figure (5-22): Outflow Hydrograph at the Dead Sea

Table (5-15): Peak Outflow Generated during the Event

No.	Date	Time	Out flow (m^3/sec)
(1)	5-Jan-13	10:30 am	0.364
(2)	7-Jan-13	17:00 am	0.797
(3)	8-Jan-13	12:00 am	**0.954**

Peak outflow generated on 8th of January was a result of 50 mm rainfall falls over the watershed for 12 hour. This result is in line with the fact that "surface runoff occurs only when rainfall exceeds 50 mm in one day or 70 mm in two consecutive days". However, this event caused flash flood at the watershed; it is recorded large amount of runoff in short time. It is worth mentioning that sub-catchment one has the largest share in this event, it contributes with more than 50% of it; this is due to the steep slope comparing to sub-catchment three that has large area with smooth slope.

The peak of the outflow hydrograph from the reach is usually attenuated and delayed compared with that inflow hydrograph. This attenuation and translation is clearly shown in **Figure 5-23**; peak discharge in sub-catchment one and two was occurred at 10:00 am, while it is recorded at the Dead Sea at 12:00pm. Moreover, for sub-catchment three, peak outflow is occurred at 11:00 am and recorded at the Dead Sea at 12:00pm, which means, one hour is required for the flood wave to move from upstream to downstream through sub-catchment three. If a comparison was conducted between the combined inflow and outflow volume; three (thousand m^3) attenuation is occurred in outflow hydrograph, this reflects the effects of storage and flow resistance within the reach during the movement of flood wave from upstream to downstream (See **Table 5-16**).

Table (5-16): Peak Outflow Generated from Og Sub-catchments with Attenuation and Translation Effects

Hydrologic Element	Date	Time	Peak Outflow (m^3/sec)
Sub-catchment (1)	**8-Jan-13**	**9:30**	0.615
		10:00	**0.620**
		10:30	0.618
Sub-catchment (2)	**8-Jan-13**	**9:30**	0.268
		10:00	**0.271**
		10:30	0.269
Sub-catchment (3)	**8-Jan-13**	**10:30**	0.093
		11:00	**0.094**
		11:30	0.093
Reach	**Unit**	**Total inflow**	**Total outflow**
	1000 m^3	66	63

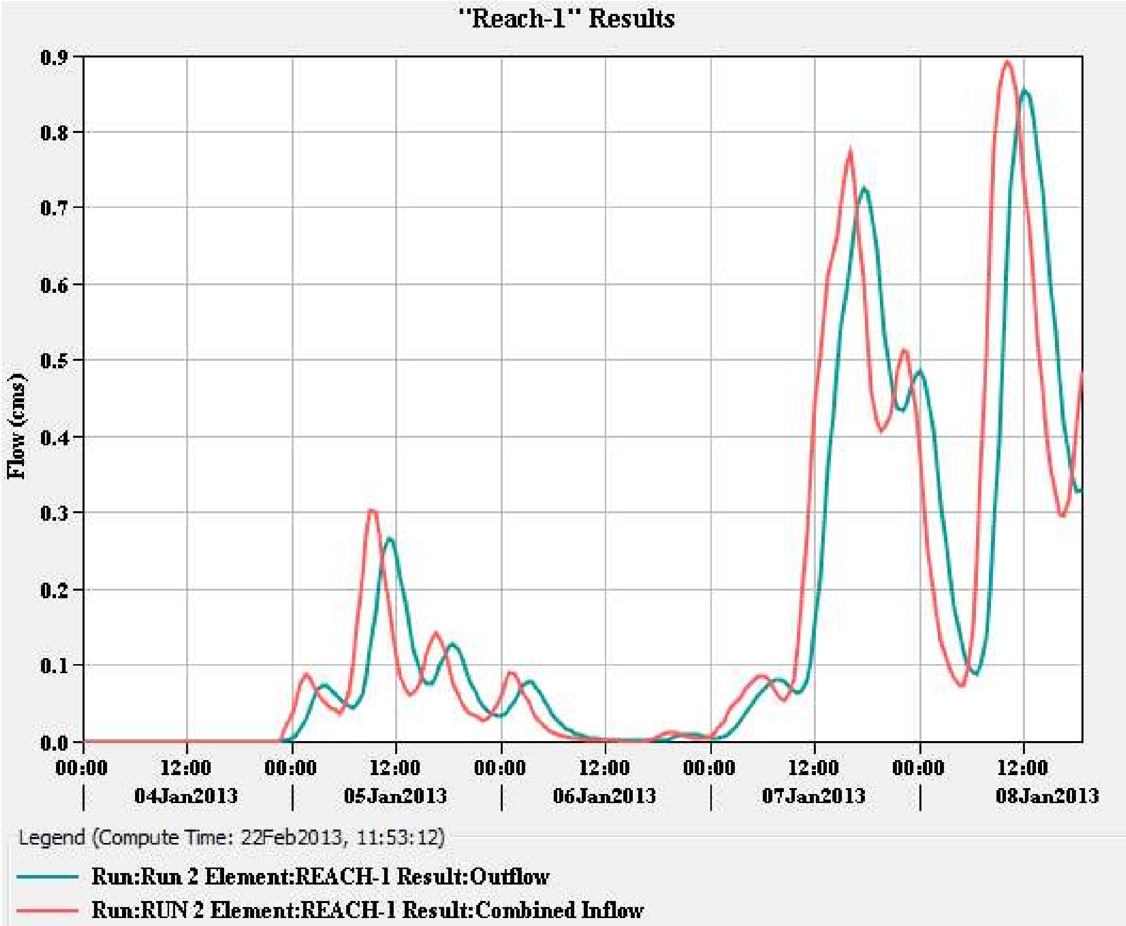

Figure (5-23): Combined Inflow and Outflow Hydrograph at the Reach

Og streams don't contain flow most of the time, it is considered an ephemeral stream, this caused an initial delay in the start of flow followed by a very rapid rise to peak flow and a receding limb of short duration due in part to transmission losses. These hydrograph characteristics are apparently shown in outflow hydrograph for each sub-catchment of Og watershed (see **Figure 5-24**, also **Annex IV**).

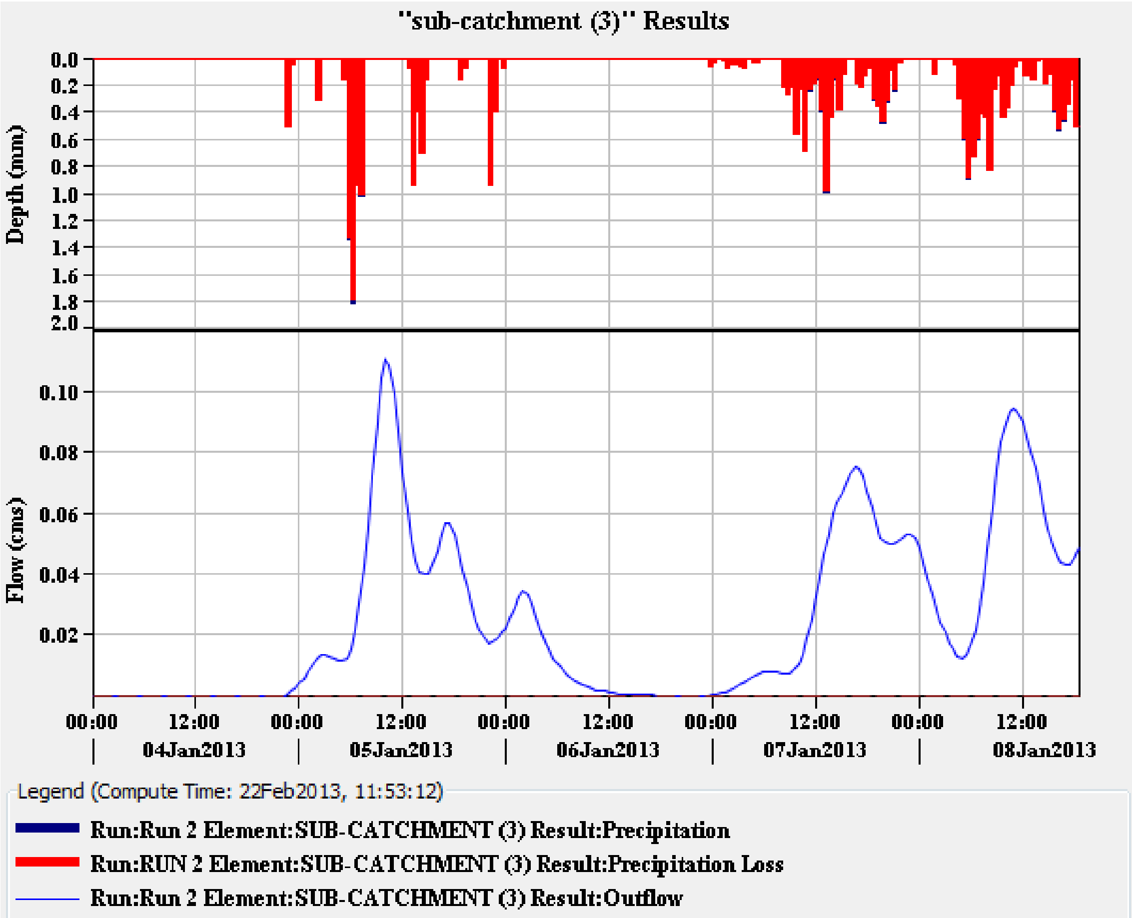

Figure (5-24): Outflow Hydrograph and Precipitation Losses for Sub-catchment Three

Chapter Six

Model Calibration And Validation

Chapter Six
Model Calibration And Validation

6.1 Introduction

In order to obtain realistic model that best reflect an understanding of the physical system and its simulation outputs are closest to the observed data; model calibration and validation should be performed. In the absence of long term observed data and the uncertainty of data available, the hydrological expert try to find another alternatives to check the model applicability and to achieve results that could be used as a base data for other hydrological researches.

The Og is still ungauged watershed, this fact create big challenge to check the developed model applicability. The efforts that had been exerted toward this, is highlighted in this section.

6.2 8th January Event

During the rainy season of 2012-2013, only one flash flood was recorded by Og hydrometric station on the 8th of January (See **Figure 6-1**). Based on data received from the installed station; at 9:02 am the hydrometric station start to record water depth in the Og stream (See **Appendix V**). Therefore, a visit was conducted to the wadi in order to collect water samples, to measure the cross section of the stream if it is possible, and to catch some pictures to the flash flood (See **Figure 6-2** and **Figure 6-3**).

Figure (6-1): Flash Flood at Og Watershed on 8th of January

Figure (6-2): Collecting Water Samples at Og Watershed

Figure (6-3): Og Watershed on 8th of January

The event was simulated using the HEC-HMS model. The point rainfall recorded by Jerusalem, Bethlehem, and Jericho rainfall stations was obtained and the model output hydrograph was predicted at the watershed outlet.

In order to calibrate the hydrological model, cross section for the Og stream at the station should be measured. For this purpose, another visit was conducted to the watershed. unfortunately, we were surprised that the hydrometric station was destroyed and dragged by the storm proceeded the 8th of January storm, the height of erosion at the edge of the stream was more than one and half meter, the installed pipe which includes the sensors and the pipe for the sampler at the mid of the stream was disappear and the stream cross section was completely changed .This had impeded the conversion of water level measured by the station to discharge values, as well as it was the main reason for data cutting that were obtained by internet server at 18:40 pm of 8th of January (See **Figure 6-4**, **Figure 6-5**, and **Figure 6-6**).

Figure (6-4): Location of the Dragged Hydrometric Station and the Remains of the Pipe after 8th January flood at Og Watershed

Figure 6-5: The High Bank and Its Erosion at Og Watershed, and the Perforated Pipe which Contains the Sensors and the Pipe for the Sampler

Figure (6-6): Og Watershed Stream with Width One Third Larger After 8th January Flash Flood

As mentioned above and due to the damage that occurred in the station, real calibration cannot be performed since only one event is measured by the station. The event will be used as a kind of model validation. **Figure 6-7** shows the computer output hydrograph predicted at

Watershed outlet while **Figure 6-8** shows the observed hydrograph at watershed outlet measured by the hydrometric station.

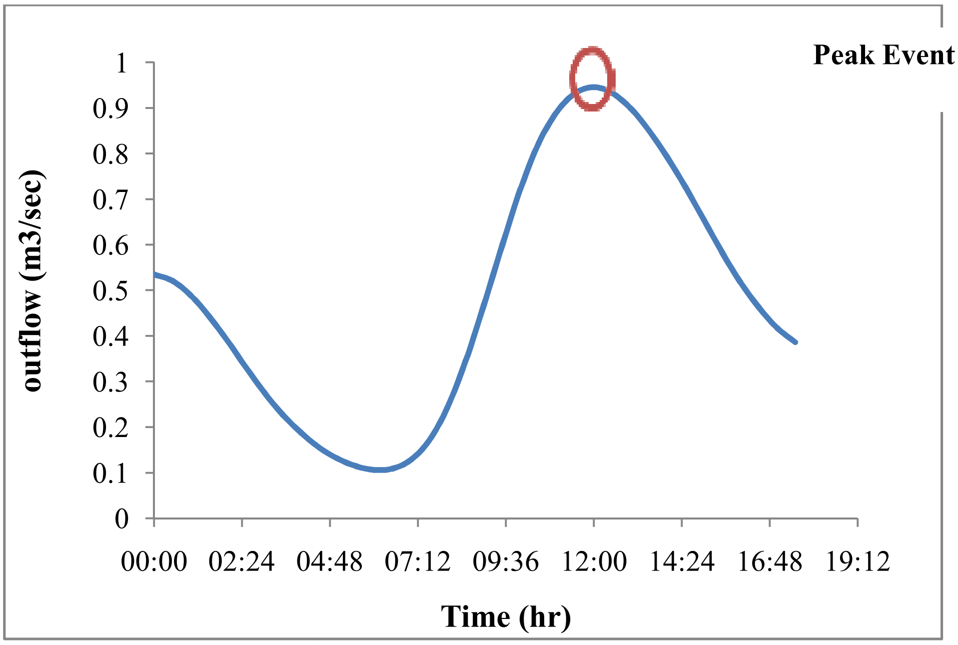

Figure (6-7): Predicted Output Hydrograph at Watershed Outlet

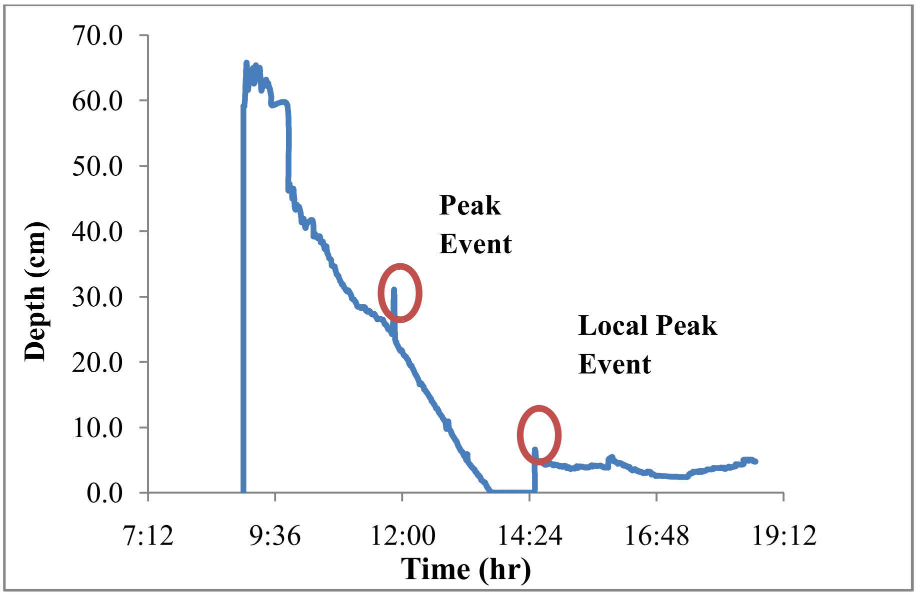

Figure (6-8): Observed Output Hydrograph at Watershed Outlet

It is worth mentioning that, the initial rise in the observed hydrograph is not included as the sensors were raised by 50 cm above the thalweg. However, the hydrograph shows two peak flow event, the first one was recorded at 11:49 am with 31.07 cm depth, while the second was local peak flow event with 6.59 cm depth at 14:30 pm. However, the predicted hydrograph includes one peak flow event that was recorded at 12:00 pm, with flow 0.945 m^3/sec.

It is worth to mention that, the predicted data agreed poorly with observation. Unfortunately, due to lack of measured data; model parameters couldn't be calibrated. The model parameters should be calibrated in order to be applicable for hydrological purposes.

Chapter Seven

Conclusions and Recommendations

Chapter Seven
Conclusions and Recommendations

7.1 Conclusions

In light of the previous analyses and discussions, the following are the research conclusions:

1. The climatological factors of Og watershed affected runoff generation. Flash flood from single rainfall event exceeds runoff volume from a year.

2. Rainfall is variable in both space and time. Its gradient is very steep eastward towards the Dead Sea Valley. The average annual areal rainfall over Og watershed is about 227 mm estimated using Isohyetal map for the region.

3. Yearly, monthly, and daily rainfall data for three stations surrounding Og (Jerusalem, Bethlehem, and Jericho) were studied and analyzed well. The analysis resulted with high consistency for the selected rainfall data; high standard deviation reflects the aridity of the area, rainfall trends decreases over the analysis period, the mean annual rainfall for the three stations is higher than the median. Jerusalem station has the highest mean annual rainfall with 503.4 mm while Jericho station has the lowest mean annual rainfall with 153 mm.

4. Mild drought condition is prevailing for the last 40 year in the area. The probability of having severe drought has increased in the recent

years, particularly in the Jordan Valley where the SPI values falls under the category “severe drought”.

5. The winter season has the highest amount of rainfall, it starts in October and end in April or May. Rainfall is concentrated in three months (December, January, and February), where approximately two thirds of annual rainfall was fallen. Spring and summer seasons are relatively dry and have zero rainfall.

6. There is an obvious fluctuation in the amount of daily rainfall during the analysis period. There is a great difference between mean values when considering the zero and non-zero rainfall data. The maximum daily rainfall intensity is recorded in Jerusalem station 125 mm, while the minimum value is recorded in Bethlehem and Jericho stations 0.1 mm.

7. The frequency of rainy days occurrence indicated that the probability to have rainfall with intensty1-20 mm/day in the study area is considered high, while the probability to have rainfall with high intensity (>100 mm/day) is considered very low.

8. Continuous HEC-HMS simulation were applied for three scenarios, Average hydrological year (2004-2005) generated 9 MCM runoff volume per year. Wet hydrological year (2002-2003) generated 19 MCM runoff volume per year, while dry hydrological year (2003-2004) generated 0.93 MCM runoff volume per year.

9. Event HEC-HMS simulation were applied for 8th January storm. The total runoff volume generated from Og watershed is about 73,000.42 m^3.

10. The western part of the watershed contributes with more than 99% of the total runoff volume . While , sub-catchment three has small share (less than 1% of total runoff volume generated from the watershed).

11. Og watershed is poorly gauged or ungauged, a kind of validation was conducted and resulted that the model parameters needs to be calibrated.

12. GIS capabilities are considered a great tool to relate the physical characteristics of the surface to the model through conducting DEM and streams network characterizing the watershed topography.

7.2 Recommendations

Based on research output, the following points are recommended to be considered in the future hydrological researches related to rainfall-runoff modeling:

1. Rainfall uncertainty is the major factor contributing to the uncertainty in the predicted flows; good quality rainfall data with appropriate distribution is required. However, the available rainfall data in the meteorological stations should be verified and checked against the consistency, applicability, and reliability.

2. Meteorological stations should be installed in the Og watershed and the surrounding area in order to have spatial and temporal rainfall data that could be used for hydrological modeling.

3. The model output could be analyzed and understands well in order to translate the results to proper management plan served the water crisis in the region.

4. Rainwater harvesting should be considered in order to utilize the amount of runoff rushed in the wadi for example, irrigation purposes for agriculture activities in the Jordan Valley.

5. The HEC-HMS model should be calibrated and validated to be applicable for other catchments. Rainfall-runoff process in such arid and semi-arid environment could be investigated and understanding well.

6. The hydrometric station that was installed to measure runoff depth at the Og outlet in the context of SUMER project should be followed. Flow measurement devices could be installed to have reliable runoff data for modeling purposes.

7. The available GIS data base in the Palestinian Authorities needs more developing and incorporating with hydrological researches. This development has high importance for presenting the physical characteristics of watershed.

8. More hydrological researches related to surface water in Palestine are required. Jordan River valley with its tributaries needs more studying and understanding the hydrological regime in it.

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Annexes

Annex (I): Annual Rainfall Data for Jerusalem, Bethlehem, and Jericho Meteorological Stations (1971 – 2011)

Table (1): Average Annual Rainfall Data for Jerusalem, Bethlehem, and Jericho Stations

Year	Average Annual Rainfall (mm)		
	Jericho	Bethlehem	Jerusalem
1971	158.00	520.00	411.90
1972	227.40	452.40	506.30
1973	96.00	392.10	460.35
1974	258.90	793.40	414.40
1975	160.20	391.10	852.70
1976	150.70	378.20	551.70
1977	115.50	409.50	300.00
1978	112.20	488.60	355.00
1979	109.60	377.90	390.00
1980	244.90	456.45	300.00
1981	199.70	535.00	540.00
1982	140.70	475.00	530.00
1983	219.00	765.00	650.00
1984	85.40	375.00	685.00
1985	150.50	465.00	555.00
1986	109.50	320.00	480.00
1987	167.20	655.00	392.00
1988	250.40	735.00	655.00
1989	167.20	545.00	495.00
1990	181.30	558.00	515.00
1991	110.90	490.00	476.00
1992	343.70	845.00	850.00
1993	119.00	565.00	575.00
1994	93.10	450.00	560.00
1995	152.60	560.00	600.00
1996	132.40	531.50	453.5
1997	164.00	503.00	307.00
1998	177.80	308.50	480
1999	39.20	360.40	400
2000	91.60	412.30	453

2001	211.60	595.50	682.3
2002	224.70	701.40	800
2003	114.80	411.70	447.5
2004	138.90	546.50	584
2005	162.00	435.00	517
2006	148.00	482.00	450
2007	122.00	316.00	326
2008	118.30	324.10	328.5
2009	142.80	501.40	464
2010	61.60	238.20	223
2011	99.00	405.70	624.6

Annex (II): Curve Number (CN) Calculations

Table (1): Land- Use Area Calculations for Sub-Catchment (1)

FID	Shape *	Land-Use	Area (Km^2)	Sum (Km^2)	% of Total Area
0	Polygon	Arable Land (supporting grains)	0.02		
1	Polygon	Arable Land (supporting grains)	0.01		
2	Polygon	Arable Land (supporting grains)	8.77		
3	Polygon	Arable Land (supporting grains)	0.02		
4	Polygon	Arable Land (supporting grains)	0.01		
	Polygon	**Arable Land (supporting grains)**		**8.83**	**16.44**
5	Polygon	Built-up	0.03		
6	Polygon	Built-up	0.23		
7	Polygon	Built-up	0.68		
9	Polygon	Built-up	0.54		
10	Polygon	Built-up	0.11		
11	Polygon	Built-up	0.04		
12	Polygon	Built-up	0.03		
13	Polygon	Built-up	0.24		
14	Polygon	Built-up	0.01		
15	Polygon	Built-up	0.00		
16	Polygon	Built-up	0.28		
17	Polygon	Built-up	0.02		
18	Polygon	Built-up	0.01		
19	Polygon	Built-up	0.57		
20	Polygon	Built-up	1.41		
	Polygon	**Built-up**		**4.20**	**7.83**
21	Polygon	Israeli Settlements	0.00		
22	Polygon	Israeli Settlements	0.70		
23	Polygon	Israeli Settlements	0.09		
24	Polygon	Israeli Settlements	1.86		
25	Polygon	Israeli Settlements	0.06		
26	Polygon	Israeli Settlements	0.01		
27	Polygon	Israeli Settlements	0.10		

28	Polygon	Israeli Settlements	0.76		
29	Polygon	Israeli Settlements	0.13		
30	Polygon	Israeli Settlements	0.56		
	Polygon	**Israeli Settlements**		**4.28**	**7.96**
31	Polygon	Rough Grazing/ Subsistence Farming	0.18		
32	Polygon	Rough Grazing/ Subsistence Farming	0.00		
33	Polygon	Rough Grazing/ Subsistence Farming	0.01		
36	Polygon	Rough Grazing/ Subsistence Farming	0.06		
37	Polygon	Rough Grazing/ Subsistence Farming	35.33		
38	Polygon	Rough Grazing/ Subsistence Farming	0.13		
	Polygon	**Rough Grazing/ Subsistence Farming**		**35.71**	**66.50**
40	Polygon	Woodland/Forest	0.03		
42	Polygon	Woodland/Forest	0.02		
43	Polygon	Woodland/Forest	0.01		
44	Polygon	Woodland/Forest	0.07		
45	Polygon	Woodland/Forest	0.03		
46	Polygon	Woodland/Forest	0.01		
47	Polygon	Woodland/Forest	0.03		
48	Polygon	Woodland/Forest	0.01		
49	Polygon	Woodland/Forest	0.05		
50	Polygon	Woodland/Forest	0.04		
51	Polygon	Woodland/Forest	0.02		
52	Polygon	Woodland/Forest	0.03		
53	Polygon	Woodland/Forest	0.05		
54	Polygon	Woodland/Forest	0.05		
55	Polygon	Woodland/Forest	0.03		
56	Polygon	Woodland/Forest	0.02		
57	Polygon	Woodland/Forest	0.06		
58	Polygon	Woodland/Forest	0.04		
59	Polygon	Woodland/Forest	0.06		
60	Polygon	Woodland/Forest	0.01		
61	Polygon	Woodland/Forest	0.01		
	Polygon	**Woodland/Forest**		**0.68**	**1.26**
Total area				**53.69**	

Table (2): Land- Use Area Calculations for Sub-Catchment (2)

FID	Shape *	Land-Use	Area (Km^2)	Sum (Km^2)	% of Total Area
1	Polygon	Arable Land (supporting grains)	0.01		
2	Polygon	Arable Land (supporting grains)	5.43		
3	Polygon	Arable Land (supporting grains)	0.03		
	Polygon	**Arable Land (supporting grains)**	**0.03**	**5.47**	**12.46**
5	Polygon	Built-up	0.01		
6	Polygon	Built-up	0.02		
7	Polygon	Built-up	0.01		
8	Polygon	Built-up	0.36		
9	Polygon	Built-up	0.14		
10	Polygon	Built-up	0.03		
11	Polygon	Built-up	0.11		
12	Polygon	Built-up	0.86		
	Polygon	**Built-up**		**1.53**	**3.48**
13	Polygon	Israeli Settlements	0.12		
14	Polygon	Israeli Settlements	0.23		
15	Polygon	Israeli Settlements	0.35		
	Polygon	**Israeli Settlements**		**0.70**	**1.61**
16	Polygon	Rough Grazing/ Subsistence Farming	34.72		
17	Polygon	Rough Grazing/ Subsistence Farming	1.47		
	Polygon	**Rough Grazing/ Subsistence Farming**		**36.19**	**82.45**
Total Area				**43.89**	

Table (3): Land- Use Area Calculations for Sub-Catchment (3)

FID	Shape *	Land-Use	Area (Km^2)	Sum (Km^2)	% of Total Area
0	**Polygon**	**Dead Sea**	**0.0000 36**	**0.0000 36**	**0.00**
1	Polygon	Israeli Settlements	0.60	0.60	0.01
2	Polygon	Israeli Settlements	0.13		
	Polygon	**Israeli Settlements**		**0.73**	**1.83**
3	**Polygon**	**Rough Grazing/ Subsistence Farming**	**39.49**	**39.49**	**98.17**
Total area				**40.23**	

Table (4): Summary of Land-Use area Calculations for Og Watershed

Land Use	**Sub-Catchment (1)**		**Sub-Catchment (2)**		**Sub-Catchment (3)**	
	Area (km^2)	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**
Arable Land (supporting grains)	**8.83**	**16.44**	**5.47**	**12.46**	**-**	**-**
Built up	**4.20**	**7.83**	**1.53**	**3.48**	**-**	**-**
Israeli Settlements	**4.28**	**7.96**	**0.70**	**1.61**	**0.73**	**1.83**
Rough Grazing/Subsistence Farming	**35.71**	**66.50**	**36.19**	**82.45**	**39.49**	**98.17**

In order to calculate the composite curve number for each sub-catchment of Og watershed, the following tables were conducted.

Using hydrological soil group map that conducted using GIS capabilities, the area for each soil group is determined for each sub-catchment as shown in the following table.

Table (5): Soil Group Area for Og sub-catchment One

Using HSG Map	Area (Km^2)			
	A	B	C	D
	-	9.18	5.05	22.00
	-	1.85	-	9.05
	-	0. 51	-	5.39
	-	-	-	0.67
Total area	**-**	**11.54**	**5.05**	**37.11**
% Soil Condition		**21.49**	**9.40**	**69.11**

Table (6): Soil Group Area for Og sub-catchment Two

Using HSG Map	Area (Km^2)			
	A	B	C	D
	-	12.32	13.29	13.82
	-	2.09	-	1.60
	-	0.28	-	0.73
Total area	-	14.45	13.29	16.15
% Soil Condition		**32.93**	**30.27**	**36.80**

Table (7): Soil Group Area for Og sub-catchment Three

Using HSG Map	Area (Km^2)			
	A	B	C	D
	0.42	2.67	16.76	-
	0.054	10.48	-	-
	5.53	-	-	-
	4.30	-	-	-
Total area	10.31	13.15	16.76	-
% Soil Condition		**25.63**	**32.71**	**41.66**

Runoff curve number for hydrologic soil curve was determined from literature review tables related to SCS-CN tables. The following tables present the calculated CN values for each soil group depending on land use classifications.

Table (8): Calculated CN for Each Soil Group

	Calculated CN			
	A	B	C	D
Sub-catchment (1)	-	78.10	84.71	88.34
Sub-catchment (2)	-	78.25	85.20	89.10
Sub-catchment (3)	67.18	78.13	85.09	-

Then a composite curve number was founded by weighting each curve number according to its area. The composite curve number for each sub-catchment is presented in the following table.

Table (9): Composite Curve Number (II) for Og Sub-catchments

	Composite CN (II-Average Case)
Sub-catchment (1)	85.8
Sub-catchment (2)	84.34
Sub-catchment (3)	78.2

Curve number (I) for dry condition was calculated for each sub-catchment of Og watershed as shown in the following table:

Table (10): Composite Curve Number (I) for Og Sub-catchments

	Composite CN (II-dry Case)
Sub-catchment (1)	72
Sub-catchment (2)	70
Sub-catchment (3)	60.6

Annex (III): Daily Rainfall Data for Jerusalem, Bethlehem, and Jericho Rainfall Stations (2002-2005)

Table (1): Daily Rainfall Data for Jerusalem, Bethlehem, and Jericho stations (2002-2005)

Date	Bethlehem	Jerusalem	Jericho
(2002-2003)			
1/10/2002	0	0	0
2/10/2002	0	0	0
3/10/2002	0	0	0
4/10/2002	0	0	0
5/10/2002	0	0	0
6/10/2002	0	0	0
7/10/2002	0	0	0
8/10/2002	0	0	0
9/10/2002	0	0	0
10/10/2002	0	0	0
11/10/2002	0	0	0
12/10/2002	0	0	0
13/10/2002	0	0	0
14/10/2002	0	0	0
15/10/2002	0	0	0.2
16/10/2002	0	0	7
17/10/2002	4	0	0
18/10/2002	0	0	0
19/10/2005	0	0	0
20/10/2005	0	0	0
21/10/2002	0	0	0
22/10/2002	0	0	0
23/10/2002	0	0	0
24/10/2002	0	0	0
25/10/2002	0	0	0
26/10/2002	0	0	0

27/10/2002	0	0	0
28/10/2002	0	0	0
29/10/2002	0	0	0
30/10/2002	6.2	9.5	13
1/11/2002	0	0	0
2/11/2002	0	0	0
3/11/2002	0	0	0
4/11/2002	0	0	0
5/11/2002	0	0	11.5
6/11/2002	0	0	0
7/11/2002	0	0	0
8/11/2002	0	0	0.2
9/11/2002	0	2	0.2
10/11/2002	0	0	0
11/11/2002	0	0	0
12/11/2002	0	0	0
13/11/2002	5.6	0	0
14/11/2002	0	0	0
15/11/2002	0	0	0
16/11/2002	0	0	0
17/11/2002	0	0	0
18/11/2002	0	0	0
19/11/2005	0	0	0
20/11/2005	0	0	0
21/11/2002	0	0	0
22/11/2002	0	0	0
23/11/2002	0	3.5	0.7
24/11/2002	0	9	0
25/11/2002	0	0	0
26/11/2002	0	0	0
27/11/2002	0	0	0
28/11/2002	0	0	1.5
29/11/2002	14.8	9	7.3
30/11/2002	0	0	0
1/12/2002	0	0	0

2/12/2002	0	0	0
3/12/2002	0	0	0
4/12/2002	0	0	0
5/12/2002	0	0	0
6/12/2002	0	0	0
7/12/2002	0	0	0
8/12/2002	0	0	0
9/12/2002	0	8	5.8
10/12/2002	24.4	9	6
11/12/2002	0	7	5.2
12/12/2002	0	0	0
13/12/2002	26.7	0	0
14/12/2002	0	0	0
15/12/2002	0	2	0
16/12/2002	0	0	0.8
17/12/2002	0	19	8.8
18/12/2002	0	0	0.2
19/12/2005	0	0	0
20/12/2005	34	0	11.6
21/12/2002	57	78	1.4
22/12/2002	6	5	0
23/12/2002	0	0	0.5
24/12/2002	0	2	0
25/12/2002	29.1	18.8	3.8
26/12/2002	18.5	4	0.7
27/12/2002	0	0	1.3
28/12/2002	0	0	0
29/12/2002	0	7	0
30/12/2002	5.9	0	4.2
1/1/2003	0	0	0
2/1/2003	0	0	0
3/1/2003	13	13	3.6
4/1/2003	0	0	0
5/1/2003	0	0	0
6/1/2003	0	0	0

7/1/2003	0	0	0
8/1/2003	0	0	0
9/1/2003	0	0	0
10/1/2003	0	0	0
11/1/2003	0	0	0
12/1/2003	0	0	0
13/1/2003	0	0	0
14/1/2003	0.5	0	3.2
15/1/2003	0	0	0.5
16/1/2003	0	0	0
17/1/2003	0	0	0.5
18/1/2003	0	19	2.2
19/1/2003	0	12	6
20/1/2003	23	24.5	12.2
21/1/2003	15	14	7
22/1/2003	0	0	0
23/1/2003	12	0	0
24/1/2003	0	0	0
25/1/2003	0	0	0
26/1/2003	0	0	0
27/1/2003	0	0	0
28/1/2003	0	0	0
29/1/2003	0	0	0
30/1/2003	1	11.5	0
1/2/2003	0	0	0
2/2/2003	0	0	0
3/2/2003	0	0	0
4/2/2003	14.3	18.5	2.9
5/2/2003	0	0	0
6/2/2003	0	0	0
7/2/2003	0	0	0
8/2/2003	0	3.1	0.1
9/2/2003	12.5	12.5	0
10/2/2003	0	0	0
11/2/2003	0	0	0

12/2/2003	0	0	1
13/2/2003	0	0	1.7
14/2/2003	0	0	1.9
15/2/2003	35	69	3.4
16/2/2003	6	11	0
17/2/2003	0	0	0.6
18/2/2003	8.1	0	4.1
19/2/2003	10.7	8.5	3.9
20/2/2003	0	36.5	0.5
21/2/2003	29.1	35.5	3.9
22/2/2003	4.2	0	0.9
23/2/2003	5	0	0.3
24/2/2003	0	0	11.6
25/2/2003	0	0	0.3
26/2/2003	0	0	1
27/2/2003	112	125	32.3
28/2/2003	7.5	0	59.4
29/2/2003	0	0	0
30/2/2003	0	0	0
1/3/2003	0	10	0
2/3/2003	0	0	0
3/3/2003	0	0	0
4/3/2003	1.5	0	0
5/3/2003	0	0	0
6/3/2003	0	0	0.2
7/3/2003	0	0	0
8/3/2003	8.8	8	0
9/3/2003	0	0	0
10/3/2003	0	0	0
11/3/2003	1	0	0.5
12/3/2003	16	0	5.3
13/3/2003	0	26	0
14/3/2003	0	0	0
15/3/2003	0	0	0
16/3/2003	0	0	0

17/3/2003	0	0	0
18/3/2003	47	53	2.4
19/3/2003	7	0	2
20/3/2003	0	9	0.8
21/3/2003	9	0	0.3
22/3/2003	1	18.6	0.2
23/3/2003	0	0	0
24/3/2003	15	0	0.9
25/3/2003	23	27	11.8
26/3/2003	23	42	0
27/3/2003	0	0	0
28/3/2003	0	0	0
29/3/2003	0	0	0
30/3/2003	0	0	0
1/4/2003	0	0	0
2/4/2003	0	0	0
3/4/2003	0	0	0
4/4/2003	0	0	0
5/4/2003	0	0	0
6/4/2003	0	0	0
7/4/2003	0	0	0
8/4/2003	0	0	0
9/4/2003	0	0	0
10/4/2003	0	0	0
11/4/2003	0	0	0
12/4/2003	0	0	0
13/4/2003	0	0	0
14/4/2003	0	0	0
15/4/2003	0	0	0
16/4/2003	0	0	0
17/4/2003	0	0	0
18/4/2003	0	0	0
19/4/2003	0	0	0
20/4/2003	3.5	0	0
21/4/2003	1	0	0

22/4/2003	0	0	0
23/4/2003	0	0	0
24/4/2003	0	0	0
25/4/2003	0	0	0
26/4/2003	10.1	0	2.1
27/4/2003	11.4	0	0.7
28/4/2003	0	0	0
29/4/2003	0	0	0
30/4/2003	0	0	0
(2003-2004)			
1/10/2003	0	0	0
2/10/2003	0	0	0
3/10/2003	0	0	0
4/10/2003	0	0	0
5/10/2003	0	0	0
6/10/2003	0	0	0
7/10/2003	0	0	0
8/10/2003	0	0	0
9/10/2003	0	0	0
10/10/2003	0	0	0
11/10/2003	0	0	0
12/10/2003	0	0	0
13/10/2003	0	0	0
14/10/2003	0	0	0
15/10/2003	0	0	0
16/10/2003	0	0	0
17/10/2003	0	0	0
18/10/2003	0	0	0
19/10/2003	0	0	0
20/10/2003	0	0	0
21/10/2003	0	0	0
22/10/2003	0	0	0
23/10/2003	0	0	0
24/10/2003	0	0	0
25/10/2003	0	0	0

26/10/2003	0	0	0
27/10/2003	0	0	0
28/10/2003	0	0	0
29/10/2003	0	0	0
30/10/2003	0	0	0
1/11/2003	0	0	0
2/11/2003	0	0	0
3/11/2003	0	0	0
4/11/2003	0	0	0
5/11/2003	0	0	0
6/11/2003	0	0	0
7/11/2003	0	0	0
8/11/2003	0	0	0
9/11/2003	0	0	0
10/11/2003	0	41	0.9
11/11/2003	11	4.3	0
12/11/2003	0	0	0
13/11/2003	0	0	0
14/11/2003	0	0	0
15/11/2003	0	0	0
16/11/2003	0	0	0
17/11/2003	0	0	0
18/11/2003	0	0	0
19/11/2003	0	0	0
20/11/2003	0	0	0
21/11/2003	0	0	0
22/11/2003	0	0	0
23/11/2003	0	0	0.7
24/11/2003	32	25	40
25/11/2003	0	0	0
26/11/2003	0	0	0
27/11/2003	0	0	0
28/11/2003	0	0	0
29/11/2003	0	0	0
30/11/2003	0	0	0

1/12/2003	0	0	0
2/12/2003	0	0	0
3/12/2003	0	0	0
4/12/2003	0	0	0
5/12/2003	0	0	0
6/12/2003	0	0	0
7/12/2003	0	0	0
8/12/2003	0	0	0
9/12/2003	0	0	0
10/12/2003	0	0	0
11/12/2003	0	0	0
12/12/2003	0	0	0
13/12/2003	0	0	0
14/12/2003	0	0	0
15/12/2003	0	0	0
16/12/2003	0	0	0
17/12/2003	0	0	0
18/12/2003	0	0	0
19/12/2003	0	0	0
20/12/2003	0	0	0
21/12/2003	0	0	0
22/12/2003	0	0	0
23/12/2003	0	0	0
24/12/2003	0	0	0
25/12/2003	0	0	0
26/12/2003	0	0	0
27/12/2003	0	0	0
28/12/2003	0	0	0
29/12/2003	0	0	0
30/12/2003	0	0	0
1/1/2004	0	0	0
2/1/2004	0	0	0
3/1/2004	0	0	0
4/1/2004	0	0	0
5/1/2004	0	0	0

6/1/2004	0	0	0
7/1/2004	27	28.2	1.5
8/1/2004	21	26.3	6.7
9/1/2004	0	6.1	0
10/1/2004	0	0	0
11/1/2004	2	0	0
12/1/2004	12	10	8
13/1/2004	0	19.2	3.3
14/1/2004	25	14.2	6.2
15/1/2004	18.6	0	0
16/1/2004	0	0	0
17/1/2004	0	0	0
18/1/2004	0	0	0
19/1/2004	0	0	0
20/1/2004	0	0	0
21/1/2004	0	0	0.2
22/1/2004	1	8.3	2.8
23/1/2004	0	0	0
24/1/2004	9	0	0
25/1/2004	2	0	1
26/1/2004	0	11	0.6
27/1/2004	3	2.3	0.9
28/1/2004	10	0	0
29/1/2004	0	0	0
30/1/2004	0	0	1.8
1/2/2004	0	28	0.6
2/2/2004	0	5	0
3/2/2004	0	0	0
4/2/2004	0	6	2.6
5/2/2004	24.8	2.3	0
6/2/2004	0	0	0
7/2/2004	2	0	0
8/2/2004	0	0	0
9/2/2004	0	0	0
10/2/2004	0	0	0

11/2/2004	0	0	0
12/2/2004	2.5	0	0
13/2/2004	0	12.3	0
14/2/2004	8.1	26	14.2
15/2/2004	0	6	0.8
16/2/2004	41.5	0	0
17/2/2004	0	0	0
18/2/2004	0	3	1.6
19/2/2004	7.2	25	3.3
20/2/2004	0	0	0
21/2/2004	0	0	0
22/2/2004	9	0	0
23/2/2004	0	0	0
24/2/2004	0	0	0
25/2/2004	0	0	0
26/2/2004	0	0	0
27/2/2004	0	0	0
28/2/2004	0	0	0
29/2/2004	0	0	0
30/2/2004	0	0	0
1/3/2004	0	0	0
2/3/2004	0	0	0
3/3/2004	0	0	0
4/3/2004	0	0	0
5/3/2004	0	0	2.8
6/3/2004	8	27.2	1.6
7/3/2004	6	0	0
8/3/2004	0	0	0
9/3/2004	0	0	0
10/3/2004	0	0	0
11/3/2004	0	0	2.5
12/3/2004	0	6	1.7
13/3/2004	2.5	0	0
14/3/2004	2.1	0	0
15/3/2004	0	0	0

16/3/2004	0	0	0
17/3/2004	0	0	0
18/3/2004	0.1	0	0
19/3/2004	0	0	0
20/3/2004	0	0	0
21/3/2004	0	0	0
22/3/2004	0	0	0
23/3/2004	0	0	0
24/3/2004	0	0	0
25/3/2004	0	0	0
26/3/2004	0	0	0
27/3/2004	0	0	0
28/3/2004	0	0	0
29/3/2004	0	0	0
30/3/2004	0	0	0
1/4/2004	0	0	0
2/4/2004	0	0	0
3/4/2004	0	0	0
4/4/2004	0	0	0
5/4/2004	0	0	0
6/4/2004	0	0	0
7/4/2004	0	0	0
8/4/2004	0	0	0
9/4/2004	0	0	0
10/4/2004	0	0	0
11/4/2004	0	0	0
12/4/2004	0	0	0
13/4/2004	0	0	0
14/4/2004	0	0	0
15/4/2004	0	0	0
16/4/2004	0	0	0
17/4/2004	0	0	0
18/4/2004	0	0	0
19/4/2004	0	0	0
20/4/2004	0	0	0

21/4/2004	0	0	0
22/4/2004	0	0	0
23/4/2004	0	0	0
24/4/2004	0	0	0
25/4/2004	0	0	0
26/4/2004	0	0	0
27/4/2004	0	0	0
28/4/2004	0	0	0
29/4/2004	0	0	0
30/4/2004	0	0	0
(2004-2005)			
1/10/2004	0	0	0
2/10/2004	0	0	0
3/10/2004	0	0	0
4/10/2004	0	0	0
5/10/2004	0	0	0
6/10/2004	0	0	0
7/10/2004	0	0	0
8/10/2004	0	0	0
9/10/2004	0	0	0
10/10/2004	0	0	0
11/10/2004	0	0	0.1
12/10/2004	0	0	0
13/10/2004	0	0	0
14/10/2004	0	0	0
15/10/2004	0	0	0
16/10/2004	0	0	0
17/10/2004	0	0	0
18/10/2004	0	0	0
19/10/2004	0	0	0
20/10/2004	0	0	0
21/10/2004	0	0	0
22/10/2004	0	0	0
23/10/2004	0	0	0
24/10/2004	0	0	0

25/10/2004	0	0	0
26/10/2004	0	13	0
27/10/2004	0	0	0
28/10/2004	13	0	0.4
29/10/2004	0	0	7.2
30/10/2004	0	0	0
1/11/2004	0	0	0
2/11/2004	0	0	0
3/11/2004	0	0	0
4/11/2004	0	0	0
5/11/2004	0	0	0
6/11/2004	0	0	0
7/11/2004	0	0	0
8/11/2004	0	0	0
9/11/2004	0	0	0
10/11/2004	0	0	0
11/11/2004	0	0	0
12/11/2004	0	0	0
13/11/2004	0	0	0
14/11/2004	0	0	0
15/11/2004	0	0	0
16/11/2004	0	0	0
17/11/2004	0	0	4.2
18/11/2004	0	0	1.5
19/11/2004	0	36	0
20/11/2004	42	0	0
21/11/2004	0	25	8
22/11/2004	17	53	10
23/11/2004	54	3	0
24/11/2004	1	0	0
25/11/2004	0	0	0
26/11/2004	0	41	2.3
27/11/2004	0	0	0
28/11/2004	0	0	0
29/11/2004	0	0	0

30/11/2004	0	0	0
1/12/2004	0	0	0
2/12/2004	0	0	0
3/12/2004	0	0	0
4/12/2004	0	0	0
5/12/2004	0	0	0
6/12/2004	0	0	0
7/12/2004	0	0	10
8/12/2004	12.5	27	4.2
9/12/2004	5	0	0
10/12/2004	0	0	0
11/12/2004	0	0	0
12/12/2004	0.2	0	0
13/12/2004	0	0	0
14/12/2004	0	0	0
15/12/2004	0	0	2.4
16/12/2004	2	0	0
17/12/2004	0	0	0
18/12/2004	0	0	0
19/12/2004	0	0	0
20/12/2004	0	0	0
21/12/2004	0	0	0
22/12/2004	1	0	0
23/12/2004	0	0	0
24/12/2004	0	0	11.4
25/12/2004	0	23	1.6
26/12/2004	16.6	0	0
27/12/2004	0	0	0
28/12/2004	0	0	0
29/12/2004	0	0	0
30/12/2004	0	0	0
1/1/2005	0	0	0
2/1/2005	31	35	2.9
3/1/2005	29	23	0
4/1/2005	1.2	4.5	0.2

5/1/2005	29	32	8.1
6/1/2005	0	0	0.2
7/1/2005	0	0	0
8/1/2005	0	0	0
9/1/2005	0	0	0
10/1/2005	0	0	0
11/1/2005	0	0	0
12/1/2005	0.3	0	0
13/1/2005	0	0	0
14/1/2005	0	0	0
15/1/2005	0	1.5	0.5
16/1/2005	1	0	0
17/1/2005	0	0	1
18/1/2005	0.3	0	0
19/1/2005	0	0	20.2
20/1/2005	0	0	0
21/1/2005	0	0	0
22/1/2005	0	0	9.2
23/1/2005	57	85	0.8
24/1/2005	0	0	0
25/1/2005	0	0	0
26/1/2005	0	0	0
27/1/2005	0	0	0
28/1/2005	0	0	0
29/1/2005	0	0	0
30/1/2005	0	0	0
1/2/2005	0	1	1.4
2/2/2005	6.6	0	0
3/2/2005	0.1	0	0
4/2/2005	30	53	1.2
5/2/2005	32	40	1
6/2/2005	29.2	18	0.2
7/2/2005	25.2	16	2
8/2/2005	11.9	9	6.9
9/2/2005	0	0	0

10/2/2005	0	0	0
11/2/2005	8	10	1.7
12/2/2005	7	1	3.9
13/2/2005	0	0	0
14/2/2005	0	0	0
15/2/2005	0	0	0
16/2/2005	0	0	0
17/2/2005	0	0	0
18/2/2005	0	0	0
19/2/2005	0	0	0
20/2/2005	0	0	0
21/2/2005	0	0	0
22/2/2005	0	0	0
23/2/2005	0	0	0
24/2/2005	0	0	0
25/2/2005	0	0	0
26/2/2005	0	0	0
27/2/2005	0	0	0
28/2/2005	0	0	0
29/2/2005	0	0	0
30/2/2005	0	0	0
1/3/2005	0	0	0
2/3/2005	0	0	0
3/3/2005	0	0	0
4/3/2005	0	0	0
5/3/2005	3.5	0	0.8
6/3/2005	0	0	0
7/3/2005	1.5	6	0
8/3/2005	12.2	10	3.9
9/3/2005	11.9	3.5	4.1
10/3/2005	0	0	2.7
11/3/2005	14.5	9.5	1
12/3/2005	0.5	0	0
13/3/2005	0	0	0
14/3/2005	0	0	0

15/3/2005	0	0	0
16/3/2005	0	0	0
17/3/2005	0	0	0
18/3/2005	0	0	0
19/3/2005	0	0	0
20/3/2005	0	0	0
21/3/2005	0	0	0
22/3/2005	0	0	0
23/3/2005	0	0	0
24/3/2005	0	0	0
25/3/2005	0	0	0
26/3/2005	0	0	0
27/3/2005	0	0	0
28/3/2005	0	0	0
29/3/2005	0	0	0
30/3/2005	0	0	0
1/4/2005	1.8	1	0
2/4/2005	2.5	1.5	0
3/4/2005	0	2.5	1.7
4/4/2005	0	0	0
5/4/2005	0	0	0
6/4/2005	0	0	0
7/4/2005	0	0	0
8/4/2005	0	0	0
9/4/2005	0	0	0
10/4/2005	0	0	0
11/4/2005	0	0	0
12/4/2005	0	0	0
13/4/2005	0	0	0
14/4/2005	0	0	0
15/4/2005	0	0	0
16/4/2005	0	0	0
17/4/2005	0	0	0
18/4/2005	0	0	0
19/4/2005	0	0	0

20/4/2005	0	0	0
21/4/2005	0	0	0
22/4/2005	0	0	0
23/4/2005	0	0	0
24/4/2005	0	0	0
25/4/2005	0	0	0
26/4/2005	0	0	0
27/4/2005	0	0	0
28/4/2005	0	0	0
29/4/2005	0	0	0
30/4/2005	0	0	0

Annex (IV): HEC-HMS Model Results

1. Continuous Model Outputs

1.1. Dry Hydrological Scenario

The HEC_HMS model output resulted from this dry season are described below. The following table presents total runoff volume generated from each sub-catchment.

Table (1.1): Runoff Volume Generated from Og Sub-catchments

Hydrological Element	Total Volume (MCM)
Sub-catchment (1)	0.819
Sub-catchment (2)	0.069
Sub-catchment (3)	0.039
Dead Sea	**0.928**

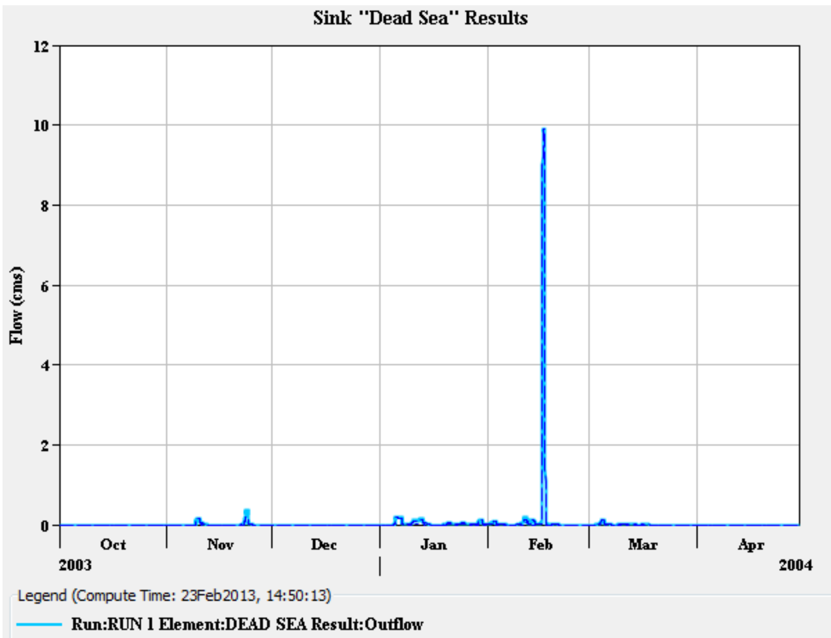

Figure (1.1): Outflow Hydrograph at the Dead Sea

Outflow hydrograph, the amount of rainfall, and rainfall losses are presented in the following figures for each sub-catchment.

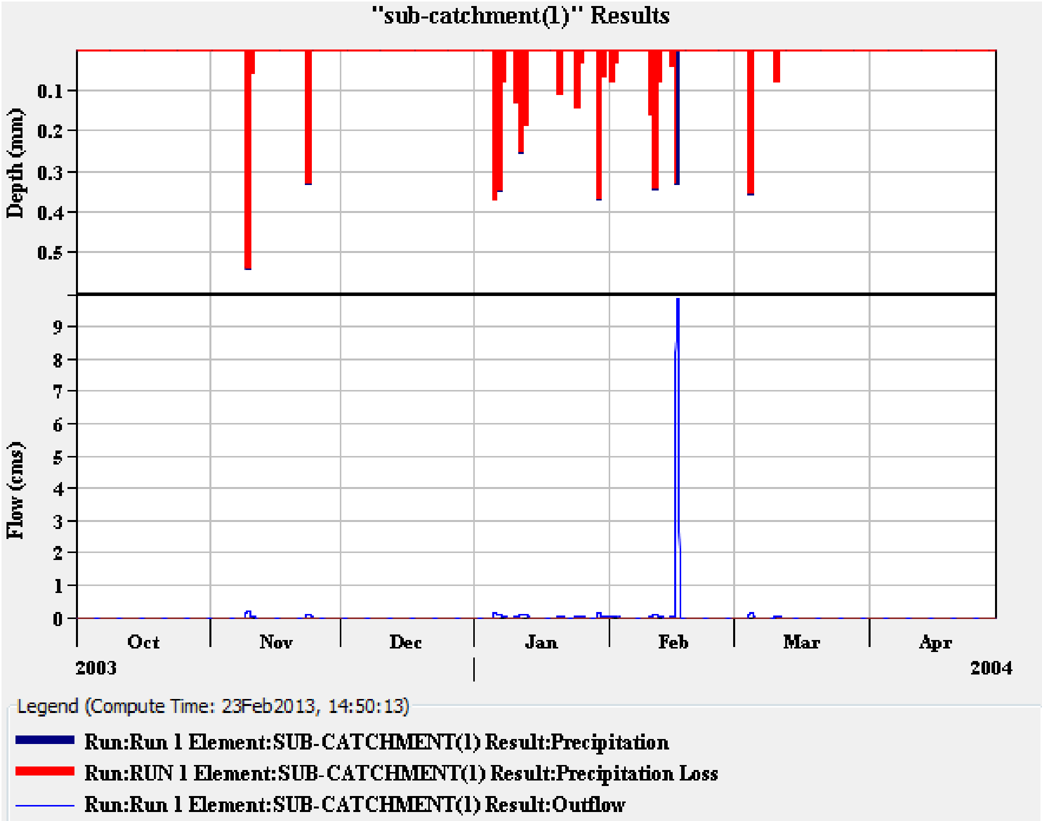

Figure (1.2): Outflow Hydrograph, Rainfall, and Rainfall Losses for Sub-catchment One

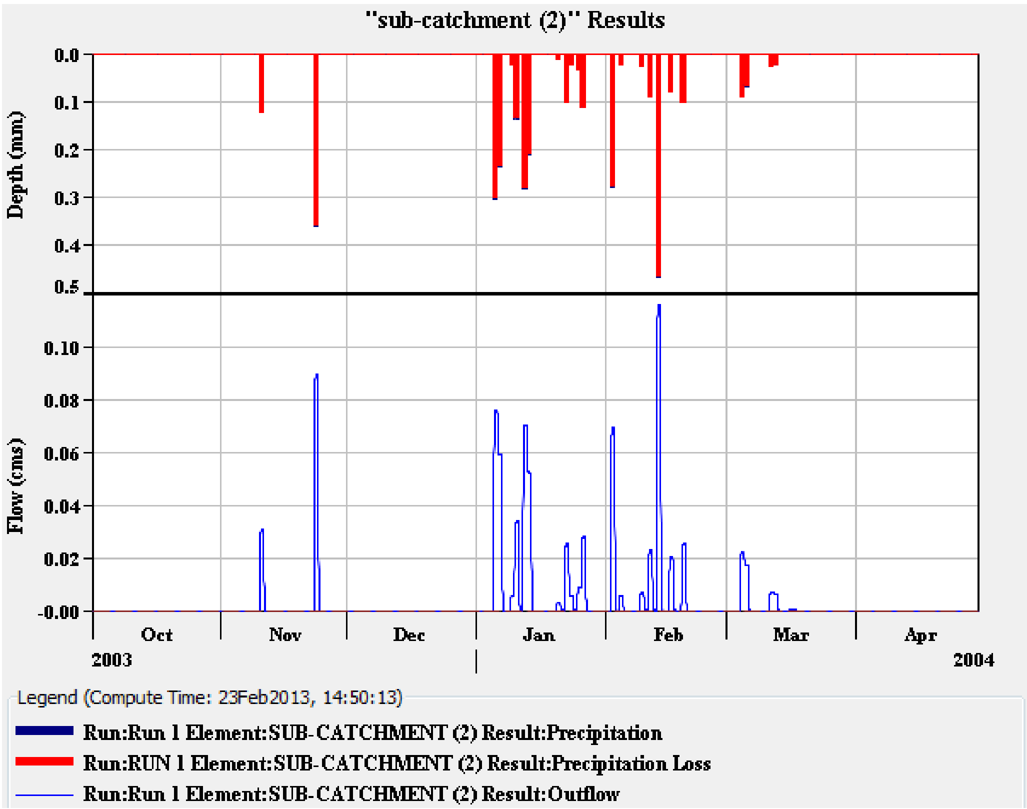

Figure (1.3): Outflow Hydrograph, Rainfall, and Rainfall Losses for Sub-catchment Two

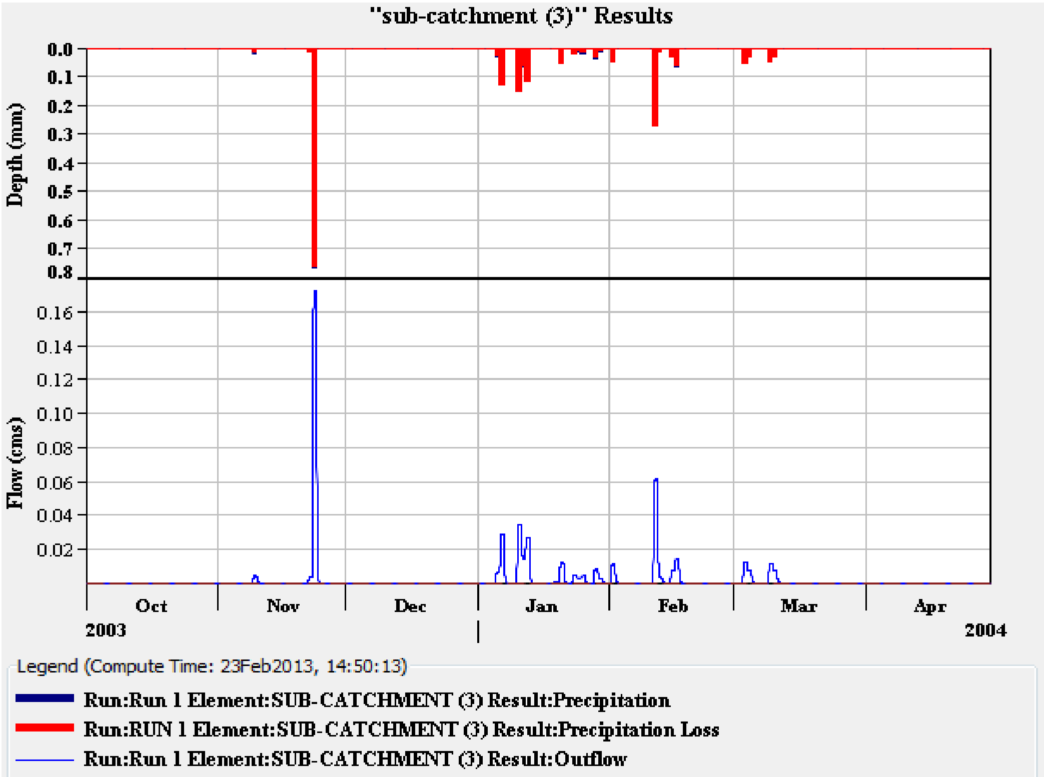

Figure (1.4): Outflow Hydrograph, Rainfall, and Rainfall Losses for Sub-catchment Three

The following Table presents peak discharge value for each sub-catchment of Og watershed, as well as at the outlet (Dead Sea).

Table (1.2): Peak Discharge and time of Peak for Og Sub-catchments

Hydrologic Element	Peak Discharge (m^3/sec)	Time of Peak
Sub-catchment (1)	9.88	17-Feb-2004
Sub-catchment (2)	0.116	13-Feb-2004
Junction	9.909	17-Feb-2004
Reach	9.901	17-Feb-2004
Sub-catchment (3)	0.173	23-Nov-2004
Dead Sea	9.916	17-Feb-2004

1.2. Wet Hydrological Scenario

The HEC_HMS model output resulted from wet season are described below. Table (2.1) presents total runoff volume generated from each sub-catchment.

Table (1.3): Runoff Volume Generated from Og Sub-catchments

Hydrological Element	Total Volume (MCM)
Sub-catchment (1)	10.31
Sub-catchment (2)	3.44
Sub-catchment (3)	0.305
Dead Sea	14.05

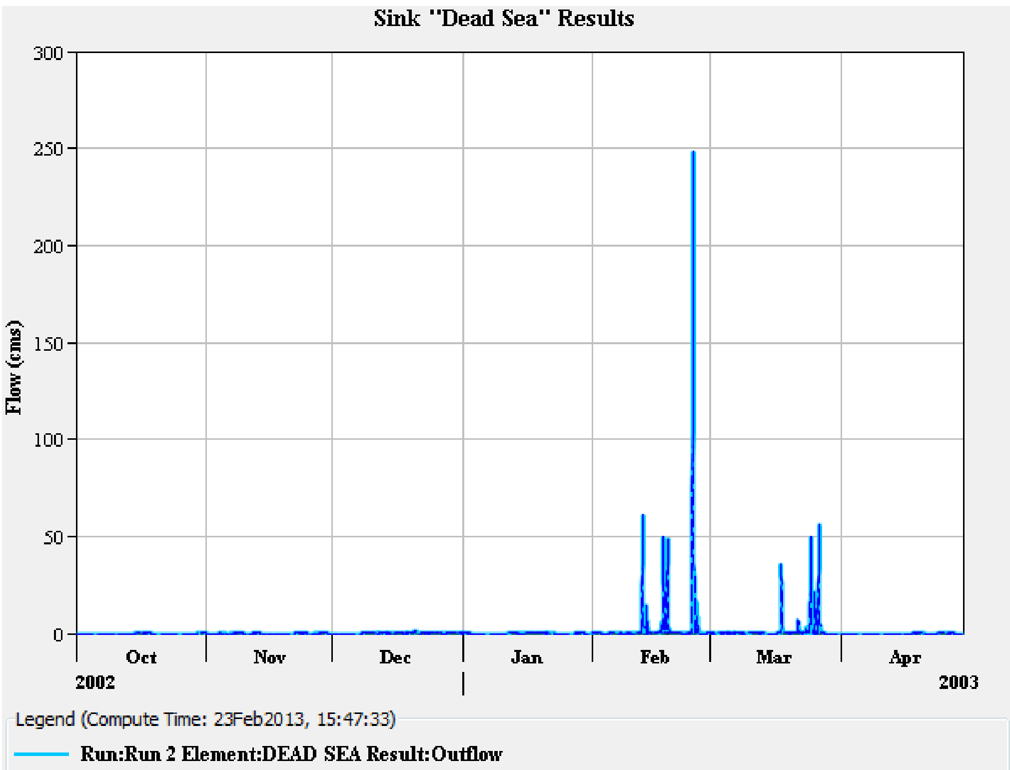

Figure (1.5): Outflow Hydrograph at the Dead Sea

Outflow hydrograph, the amount of rainfall, and rainfall losses are presented in the following figures for each sub-catchment.

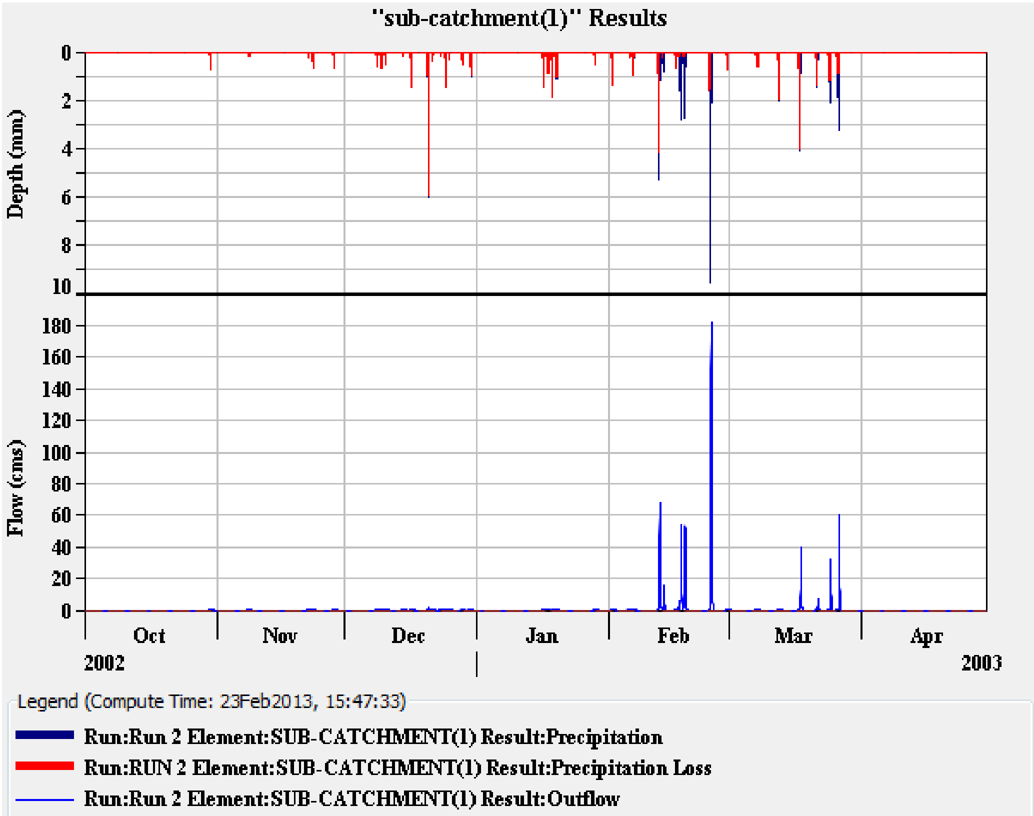

Figure (1.6): Outflow Hydrograph, Rainfall, and Rainfall Losses for Sub-catchment One

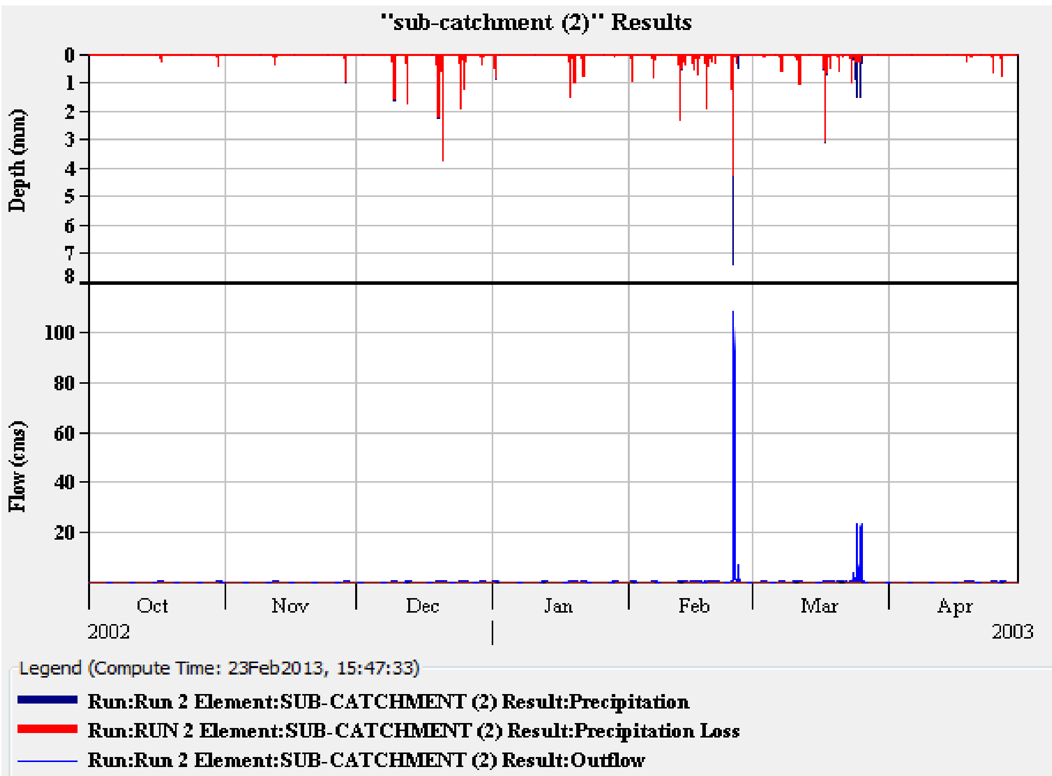

Figure (1.7): Outflow Hydrograph, Rainfall, and Rainfall Losses for Sub-catchment Two

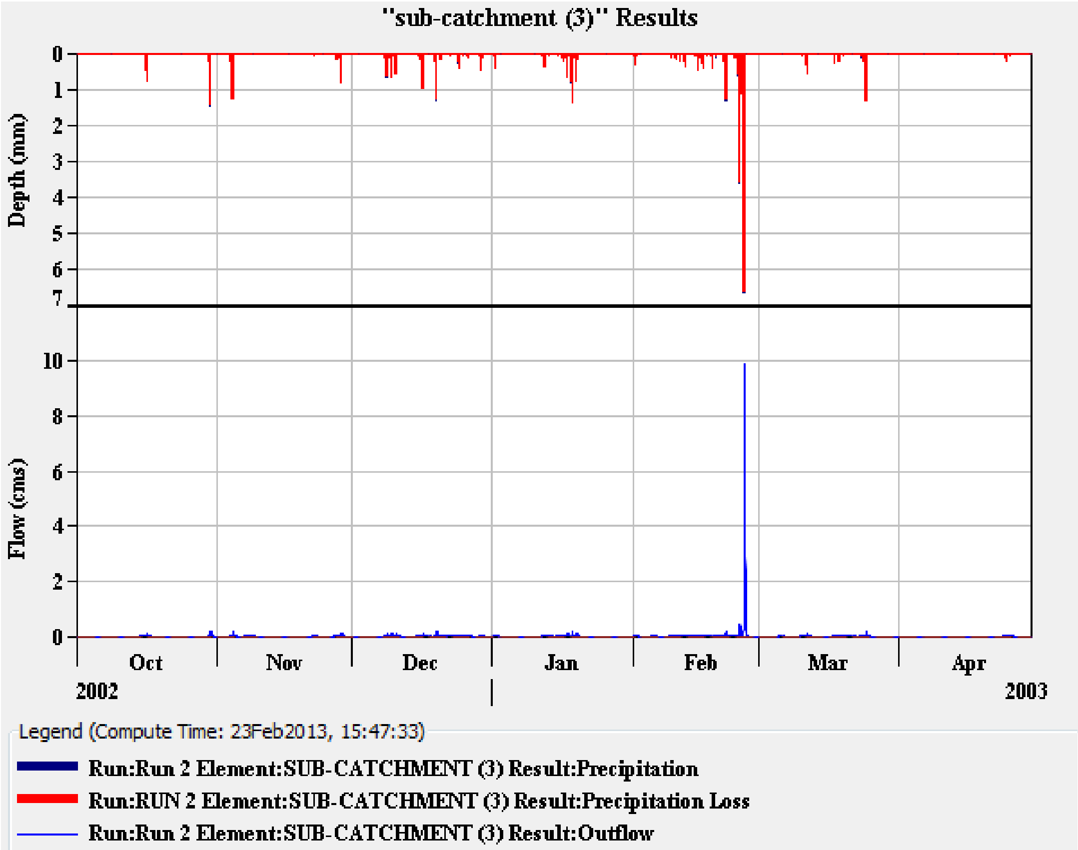

Figure (1.8): Outflow Hydrograph, Rainfall, and Rainfall Losses for Sub-catchment Three

The following Table presents peak discharge value for each sub-catchment of Og watershed, as well as at the outlet (Dead Sea).

Table (1.4): Peak Discharge and time of Peak for Og Sub-catchments

Hydrologic element	Peak Discharge (m^3/sec)	Time of Peak
Sub-catchment (1)	10.31	24-Feb-2003
Sub-catchment (2)	3.44	24-Feb-2003
Junction	13.75	24-Feb-2003
Reach	13.75	24-Feb-2003
Sub-catchment (3)	0.30	24-Feb-2003
Dead Sea	14.05	24-Feb-2003

2. Event Model Outputs

Outflow hydrograph at the Dead Sea resulted from 5 days event is presented in **Table (2.1)**.

Table (2.1): Outflow versus Time Resulted from 8th January Event

Date	Time	Out flow (thousand m^3)
4-Jan-13	0:00	0
4-Jan-13	0:30	0
4-Jan-13	1:00	0
4-Jan-13	1:30	0
4-Jan-13	2:00	0
4-Jan-13	2:30	0
4-Jan-13	3:00	0
4-Jan-13	3:30	0
4-Jan-13	4:00	0
4-Jan-13	4:30	0
4-Jan-13	5:00	0
4-Jan-13	5:30	0
4-Jan-13	6:00	0
4-Jan-13	6:30	0
4-Jan-13	7:00	0
4-Jan-13	7:30	0
4-Jan-13	8:00	0
4-Jan-13	8:30	0
4-Jan-13	9:00	0
4-Jan-13	9:30	0
4-Jan-13	10:00	0
4-Jan-13	10:30	0
4-Jan-13	11:00	0
4-Jan-13	11:30	0
4-Jan-13	12:00	0
4-Jan-13	12:30	0
4-Jan-13	13:00	0
4-Jan-13	13:30	0
4-Jan-13	14:00	0
4-Jan-13	14:30	0

4-Jan-13	**15:00**	0
4-Jan-13	**15:30**	0
4-Jan-13	**16:00**	0
4-Jan-13	**16:30**	0
4-Jan-13	**17:00**	0
4-Jan-13	**17:30**	0
4-Jan-13	**18:00**	0
4-Jan-13	**18:30**	0
4-Jan-13	**19:00**	0
4-Jan-13	**19:30**	0
4-Jan-13	**20:00**	0
4-Jan-13	**20:30**	0
4-Jan-13	**21:00**	0
4-Jan-13	**21:30**	0
4-Jan-13	**22:00**	0
4-Jan-13	**22:30**	0
4-Jan-13	**23:00**	0.0013
4-Jan-13	**23:30**	0.0028
5-Jan-13	**0:00**	0.0066
5-Jan-13	**0:30**	0.013
5-Jan-13	**1:00**	0.0235
5-Jan-13	**1:30**	0.0371
5-Jan-13	**2:00**	0.0533
5-Jan-13	**2:30**	0.0694
5-Jan-13	**3:00**	0.0808
5-Jan-13	**3:30**	0.0855
5-Jan-13	**4:00**	0.0841
5-Jan-13	**4:30**	0.0795
5-Jan-13	**5:00**	0.073
5-Jan-13	**5:30**	0.0676
5-Jan-13	**6:00**	0.0652
5-Jan-13	**6:30**	0.0672
5-Jan-13	**7:00**	0.0741
5-Jan-13	**7:30**	0.0901
5-Jan-13	**8:00**	0.1164
5-Jan-13	**8:30**	0.1577
5-Jan-13	**9:00**	0.211
5-Jan-13	**9:30**	0.2704
5-Jan-13	**10:00**	0.3224
5-Jan-13	**10:30**	0.3561
5-Jan-13	**11:00**	0.3648

5-Jan-13	**11:30**	0.3503
5-Jan-13	**12:00**	0.3175
5-Jan-13	**12:30**	0.2759
5-Jan-13	**13:00**	0.2322
5-Jan-13	**13:30**	0.1927
5-Jan-13	**14:00**	0.1598
5-Jan-13	**14:30**	0.1363
5-Jan-13	**15:00**	0.1212
5-Jan-13	**15:30**	0.1177
5-Jan-13	**16:00**	0.1235
5-Jan-13	**16:30**	0.138
5-Jan-13	**17:00**	0.1554
5-Jan-13	**17:30**	0.1703
5-Jan-13	**18:00**	0.1766
5-Jan-13	**18:30**	0.1735
5-Jan-13	**19:00**	0.1615
5-Jan-13	**19:30**	0.1434
5-Jan-13	**20:00**	0.1233
5-Jan-13	**20:30**	0.1032
5-Jan-13	**21:00**	0.0864
5-Jan-13	**21:30**	0.0729
5-Jan-13	**22:00**	0.0625
5-Jan-13	**22:30**	0.057
5-Jan-13	**23:00**	0.0538
5-Jan-13	**23:30**	0.0531
6-Jan-13	**0:00**	0.0544
6-Jan-13	**0:30**	0.0612
6-Jan-13	**1:00**	0.0712
6-Jan-13	**1:30**	0.0854
6-Jan-13	**2:00**	0.0987
6-Jan-13	**2:30**	0.1072
6-Jan-13	**3:00**	0.1082
6-Jan-13	**3:30**	0.1028
6-Jan-13	**4:00**	0.0925
6-Jan-13	**4:30**	0.0795
6-Jan-13	**5:00**	0.0667
6-Jan-13	**5:30**	0.0545
6-Jan-13	**6:00**	0.0438
6-Jan-13	**6:30**	0.0354
6-Jan-13	**7:00**	0.0278
6-Jan-13	**7:30**	0.0221

6-Jan-13	**8:00**	0.0173
6-Jan-13	**8:30**	0.0137
6-Jan-13	**9:00**	0.0108
6-Jan-13	**9:30**	0.0087
6-Jan-13	**10:00**	0.0068
6-Jan-13	**10:30**	0.0054
6-Jan-13	**11:00**	0.0044
6-Jan-13	**11:30**	0.0035
6-Jan-13	**12:00**	0.0026
6-Jan-13	**12:30**	0.0019
6-Jan-13	**13:00**	0.0014
6-Jan-13	**13:30**	0.001
6-Jan-13	**14:00**	0.0007
6-Jan-13	**14:30**	0.0004
6-Jan-13	**15:00**	0.0003
6-Jan-13	**15:30**	0.0006
6-Jan-13	**16:00**	0.0002
6-Jan-13	**16:30**	0
6-Jan-13	**17:00**	0.0001
6-Jan-13	**17:30**	0.0001
6-Jan-13	**18:00**	0.0004
6-Jan-13	**18:30**	0.0011
6-Jan-13	**19:00**	0.0022
6-Jan-13	**19:30**	0.0037
6-Jan-13	**20:00**	0.0056
6-Jan-13	**20:30**	0.0075
6-Jan-13	**21:00**	0.0089
6-Jan-13	**21:30**	0.0094
6-Jan-13	**22:00**	0.0091
6-Jan-13	**22:30**	0.0082
6-Jan-13	**23:00**	0.007
6-Jan-13	**23:30**	0.0058
7-Jan-13	**0:00**	0.0048
7-Jan-13	**0:30**	0.0045
7-Jan-13	**1:00**	0.0051
7-Jan-13	**1:30**	0.0072
7-Jan-13	**2:00**	0.011
7-Jan-13	**2:30**	0.0166
7-Jan-13	**3:00**	0.0241
7-Jan-13	**3:30**	0.0327
7-Jan-13	**4:00**	0.0417

7-Jan-13	**4:30**	0.0504
7-Jan-13	**5:00**	0.0589
7-Jan-13	**5:30**	0.0673
7-Jan-13	**6:00**	0.0751
7-Jan-13	**6:30**	0.0817
7-Jan-13	**7:00**	0.0864
7-Jan-13	**7:30**	0.0885
7-Jan-13	**8:00**	0.0875
7-Jan-13	**8:30**	0.0841
7-Jan-13	**9:00**	0.079
7-Jan-13	**9:30**	0.0742
7-Jan-13	**10:00**	0.0736
7-Jan-13	**10:30**	0.0799
7-Jan-13	**11:00**	0.0992
7-Jan-13	**11:30**	0.1334
7-Jan-13	**12:00**	0.1859
7-Jan-13	**12:30**	0.2533
7-Jan-13	**13:00**	0.3317
7-Jan-13	**13:30**	0.4129
7-Jan-13	**14:00**	0.4896
7-Jan-13	**14:30**	0.557
7-Jan-13	**15:00**	0.6146
7-Jan-13	**15:30**	0.6626
7-Jan-13	**16:00**	0.7053
7-Jan-13	**16:30**	0.7462
7-Jan-13	**17:00**	0.7804
7-Jan-13	**17:30**	0.7972
7-Jan-13	**18:00**	0.7884
7-Jan-13	**18:30**	0.755
7-Jan-13	**19:00**	0.7037
7-Jan-13	**19:30**	0.6423
7-Jan-13	**20:00**	0.5829
7-Jan-13	**20:30**	0.5338
7-Jan-13	**21:00**	0.5012
7-Jan-13	**21:30**	0.486
7-Jan-13	**22:00**	0.4858
7-Jan-13	**22:30**	0.498
7-Jan-13	**23:00**	0.5165
7-Jan-13	**23:30**	0.5319
8-Jan-13	**0:00**	0.535
8-Jan-13	**0:30**	0.5206

8-Jan-13	**1:00**	0.4887
8-Jan-13	**1:30**	0.443
8-Jan-13	**2:00**	0.3885
8-Jan-13	**2:30**	0.3311
8-Jan-13	**3:00**	0.2767
8-Jan-13	**3:30**	0.2283
8-Jan-13	**4:00**	0.1882
8-Jan-13	**4:30**	0.1553
8-Jan-13	**5:00**	0.131
8-Jan-13	**5:30**	0.1143
8-Jan-13	**6:00**	0.106
8-Jan-13	**6:30**	0.1086
8-Jan-13	**7:00**	0.1278
8-Jan-13	**7:30**	0.1707
8-Jan-13	**8:00**	0.2428
8-Jan-13	**8:30**	0.3444
8-Jan-13	**9:00**	0.4675
8-Jan-13	**9:30**	0.5995
8-Jan-13	**10:00**	0.7232
8-Jan-13	**10:30**	0.8235
8-Jan-13	**11:00**	0.8929
8-Jan-13	**11:30**	0.9327
8-Jan-13	**12:00**	0.9453
8-Jan-13	**12:30**	0.9328
8-Jan-13	**13:00**	0.8992
8-Jan-13	**13:30**	0.851
8-Jan-13	**14:00**	0.7923
8-Jan-13	**14:30**	0.7258
8-Jan-13	**15:00**	0.6548
8-Jan-13	**15:30**	0.5835
8-Jan-13	**16:00**	0.5183
8-Jan-13	**16:30**	0.4624
8-Jan-13	**17:00**	0.4175
8-Jan-13	**17:30**	0.3861
8-Jan-13	**18:00**	0.3718
8-Jan-13	**18:30**	0.3778

The following figures present outflow hydrograph, rainfall amount, and rainfall losses for sub-catchment two.

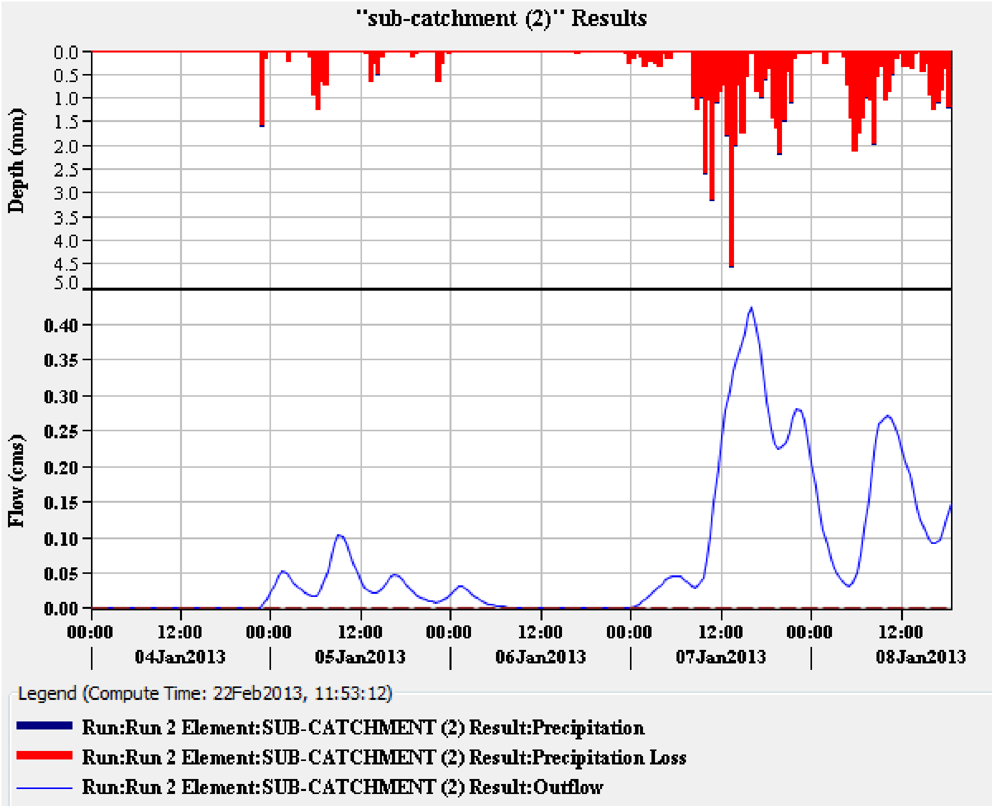

Figure (2.2): Outflow Hydrograph, Rainfall, and Rainfall Losses for Sub-catchment Two

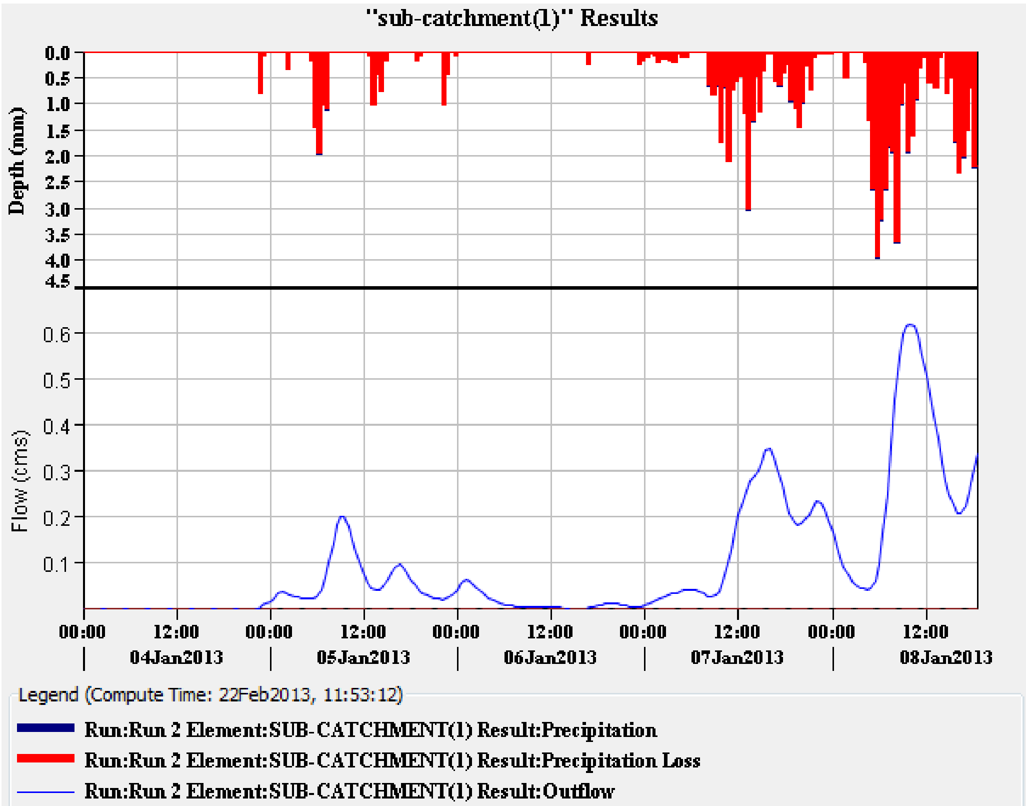

Figure (2.3): Outflow Hydrograph, Rainfall, and Rainfall Losses for Sub-catchment One

Appendix (V): Water Depth and Conductivity values measured by Og station on 8th of January

Table (1): Runoff Depth Measured by Og Station resulted from 8th January Storm

Date	Time	Level (cm)
8/1/2013	**8:59**	59.16
8/1/2013	**8:59**	59.16
8/1/2013	**9:01**	62.66
8/1/2013	**9:02**	65.78
8/1/2013	**9:03**	61.66
8/1/2013	**9:04**	63.24
8/1/2013	**9:06**	64.48
8/1/2013	**9:07**	63.79
8/1/2013	**9:08**	62.77
8/1/2013	**9:09**	64.94
8/1/2013	**9:10**	62.60
8/1/2013	**9:12**	62.99
8/1/2013	**9:13**	65.37
8/1/2013	**9:14**	64.24
8/1/2013	**9:15**	63.51
8/1/2013	**9:16**	64.95
8/1/2013	**9:17**	64.97
8/1/2013	**9:18**	63.12
8/1/2013	**9:19**	61.52
8/1/2013	**9:20**	62.01
8/1/2013	**9:21**	62.16
8/1/2013	**9:22**	62.44
8/1/2013	**9:23**	62.32
8/1/2013	**9:24**	63.17
8/1/2013	**9:25**	62.21
8/1/2013	**9:26**	62.65
8/1/2013	**9:28**	62.13
8/1/2013	**9:29**	61.66
8/1/2013	**9:30**	60.56
8/1/2013	**9:31**	59.23
8/1/2013	**9:32**	59.31
8/1/2013	**9:49**	46.26
8/1/2013	**9:51**	47.24

8/1/2013	**9:52**	46.42
8/1/2013	**9:53**	46.58
8/1/2013	**9:54**	44.98
8/1/2013	**9:55**	46.49
8/1/2013	**9:56**	44.83
8/1/2013	**9:57**	43.55
8/1/2013	**9:58**	43.29
8/1/2013	**9:59**	44.05
8/1/2013	**10:00**	43.50
8/1/2013	**10:01**	43.76
8/1/2013	**10:02**	43.35
8/1/2013	**10:03**	42.76
8/1/2013	**10:04**	41.36
8/1/2013	**10:06**	41.56
8/1/2013	**10:07**	41.93
8/1/2013	**10:08**	41.23
8/1/2013	**10:09**	40.51
8/1/2013	**10:10**	41.20
8/1/2013	**10:12**	41.63
8/1/2013	**10:18**	39.22
8/1/2013	**10:19**	39.64
8/1/2013	**10:20**	39.44
8/1/2013	**10:21**	39.07
8/1/2013	**10:22**	39.29
8/1/2013	**10:23**	38.89
8/1/2013	**10:24**	39.04
8/1/2013	**10:25**	39.20
8/1/2013	**10:26**	38.31
8/1/2013	**10:27**	38.28
8/1/2013	**10:28**	38.39
8/1/2013	**10:29**	37.84
8/1/2013	**10:31**	37.29
8/1/2013	**10:32**	37.37
8/1/2013	**10:33**	37.69
8/1/2013	**10:34**	36.68
8/1/2013	**10:35**	36.39
8/1/2013	**10:36**	35.90
8/1/2013	**10:37**	35.74
8/1/2013	**10:38**	35.60
8/1/2013	**10:39**	34.76

8/1/2013	**10:40**	34.70
8/1/2013	**10:41**	34.56
8/1/2013	**10:42**	34.62
8/1/2013	**10:43**	34.06
8/1/2013	**10:44**	33.51
8/1/2013	**10:45**	33.33
8/1/2013	**10:46**	33.20
8/1/2013	**10:47**	32.88
8/1/2013	**10:48**	32.42
8/1/2013	**10:49**	32.21
8/1/2013	**10:50**	31.83
8/1/2013	**10:51**	31.84
8/1/2013	**10:52**	31.43
8/1/2013	**10:53**	31.34
8/1/2013	**10:54**	31.10
8/1/2013	**10:55**	30.91
8/1/2013	**10:56**	30.76
8/1/2013	**10:57**	30.94
8/1/2013	**10:59**	30.68
8/1/2013	**11:00**	30.49
8/1/2013	**11:01**	30.12
8/1/2013	**11:02**	29.74
8/1/2013	**11:03**	29.58
8/1/2013	**11:04**	29.52
8/1/2013	**11:05**	29.33
8/1/2013	**11:06**	29.14
8/1/2013	**11:07**	28.78
8/1/2013	**11:08**	28.47
8/1/2013	**11:09**	28.42
8/1/2013	**11:10**	28.42
8/1/2013	**11:11**	28.38
8/1/2013	**11:12**	28.23
8/1/2013	**11:13**	28.38
8/1/2013	**11:14**	28.42
8/1/2013	**11:15**	28.39
8/1/2013	**11:16**	28.30
8/1/2013	**11:17**	27.94
8/1/2013	**11:18**	27.83
8/1/2013	**11:19**	27.68
8/1/2013	**11:20**	27.86

8/1/2013	**11:20**	27.77
8/1/2013	**11:22**	27.62
8/1/2013	**11:23**	27.45
8/1/2013	**11:24**	27.28
8/1/2013	**11:25**	27.28
8/1/2013	**11:26**	27.40
8/1/2013	**11:28**	27.17
8/1/2013	**11:29**	26.92
8/1/2013	**11:30**	26.76
8/1/2013	**11:31**	26.52
8/1/2013	**11:32**	26.65
8/1/2013	**11:33**	26.59
8/1/2013	**11:34**	26.58
8/1/2013	**11:35**	26.50
8/1/2013	**11:36**	26.40
8/1/2013	**11:37**	26.46
8/1/2013	**11:38**	26.10
8/1/2013	**11:39**	25.77
8/1/2013	**11:40**	25.73
8/1/2013	**11:41**	25.52
8/1/2013	**11:42**	25.13
8/1/2013	**11:43**	24.96
8/1/2013	**11:44**	24.90
8/1/2013	**11:45**	24.98
8/1/2013	**11:46**	24.57
8/1/2013	**11:47**	24.27
8/1/2013	**11:48**	26.49
8/1/2013	**11:49**	31.07
8/1/2013	**11:50**	23.48
8/1/2013	**11:51**	23.08
8/1/2013	**11:52**	22.77
8/1/2013	**11:53**	22.47
8/1/2013	**11:54**	22.22
8/1/2013	**11:55**	21.91
8/1/2013	**11:55**	21.70
8/1/2013	**11:58**	21.80
8/1/2013	**11:59**	21.53
8/1/2013	**12:00**	21.28
8/1/2013	**12:01**	21.03
8/1/2013	**12:02**	20.87

8/1/2013	**12:03**	20.76
8/1/2013	**12:04**	20.49
8/1/2013	**12:05**	20.34
8/1/2013	**12:06**	20.02
8/1/2013	**12:07**	19.70
8/1/2013	**12:08**	19.44
8/1/2013	**12:09**	19.44
8/1/2013	**12:10**	19.06
8/1/2013	**12:11**	18.81
8/1/2013	**12:12**	18.48
8/1/2013	**12:13**	18.14
8/1/2013	**12:14**	17.94
8/1/2013	**12:15**	17.73
8/1/2013	**12:16**	17.46
8/1/2013	**12:17**	17.13
8/1/2013	**12:18**	16.60
8/1/2013	**12:19**	16.78
8/1/2013	**12:20**	16.63
8/1/2013	**12:21**	16.39
8/1/2013	**12:22**	16.17
8/1/2013	**12:24**	15.78
8/1/2013	**12:25**	15.72
8/1/2013	**12:26**	15.44
8/1/2013	**12:27**	15.27
8/1/2013	**12:28**	15.08
8/1/2013	**12:29**	14.78
8/1/2013	**12:30**	14.59
8/1/2013	**12:31**	14.37
8/1/2013	**12:32**	14.04
8/1/2013	**12:33**	13.89
8/1/2013	**12:34**	13.64
8/1/2013	**12:35**	13.47
8/1/2013	**12:36**	13.17
8/1/2013	**12:37**	12.88
8/1/2013 1	**2:38**	12.85
8/1/2013	**12:39**	12.54
8/1/2013	**12:40**	12.28
8/1/2013	**12:41**	12.05
8/1/2013	**12:42**	11.88
8/1/2013	**12:43**	11.70

8/1/2013	**12:44**	11.41
8/1/2013	**12:45**	11.18
8/1/2013	**12:46**	11.06
8/1/2013	**12:47**	10.86
8/1/2013	**12:48**	9.81
8/1/2013	**12:50**	10.14
8/1/2013	**12:51**	10.91
8/1/2013	**12:52**	9.67
8/1/2013	**12:53**	9.56
8/1/2013	**12:54**	9.31
8/1/2013	**12:55**	9.00
8/1/2013	**12:56**	8.70
8/1/2013	**12:57**	8.53
8/1/2013	**12:58**	8.25
8/1/2013	**12:59**	8.00
8/1/2013	**13:00**	7.86
8/1/2013	**13:01**	7.48
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8/1/2013	**13:04**	6.54
8/1/2013	**13:05**	6.38
8/1/2013	**13:07**	6.27
8/1/2013	**13:08**	5.87
8/1/2013	**13:09**	5.62
8/1/2013	**13:10**	5.40
8/1/2013	**13:11**	5.32
8/1/2013	**13:12**	5.05
8/1/2013	**13:12**	4.99
8/1/2013	**13:13**	5.90
8/1/2013	**13:13**	5.87
8/1/2013	**13:13**	4.85
8/1/2013	**13:14**	4.55
8/1/2013	**13:15**	4.36
8/1/2013	**13:16**	4.21
8/1/2013	**13:17**	3.97
8/1/2013	**13:18**	3.88
8/1/2013	**13:19**	3.61
8/1/2013	**13:20**	3.55
8/1/2013	**13:21**	3.22
8/1/2013	**13:22**	3.02

8/1/2013	**13:24**	2.75
8/1/2013	**13:25**	2.70
8/1/2013	**13:26**	2.47
8/1/2013	**13:27**	2.38
8/1/2013	**13:28**	1.97
8/1/2013	**13:29**	1.84
8/1/2013	**13:30**	1.74
8/1/2013	**13:31**	1.57
8/1/2013	**13:32**	1.56
8/1/2013	**13:33**	1.20
8/1/2013	**13:34**	0.92
8/1/2013	**13:35**	0.74
8/1/2013	**13:36**	0.58
8/1/2013	**13:37**	0.35
8/1/2013	**13:38**	0.16
8/1/2013	**13:39**	0.07
8/1/2013	**13:41**	0.00
8/1/2013	**13:42**	0.00
8/1/2013	**13:43**	0.00
8/1/2013	**13:44**	0.00
8/1/2013	**13:45**	0.00
8/1/2013	**13:46**	0.00
8/1/2013	**13:47**	0.00
8/1/2013	**13:48**	0.00
8/1/2013	**13:49**	0.00
8/1/2013	**13:50**	0.00
8/1/2013	**13:51**	0.00
8/1/2013	**13:52**	0.00
8/1/2013	**13:53**	0.00
8/1/2013	**13:54**	0.00
8/1/2013	**13:55**	0.00
8/1/2013	**13:56**	0.00
8/1/2013	**13:57**	0.00
8/1/2013	**13:58**	0.00
8/1/2013	**13:59**	0.00
8/1/2013	**14:00**	0.00
8/1/2013	**14:01**	0.00
8/1/2013	**14:02**	0.00
8/1/2013	**14:03**	0.00
8/1/2013	**14:04**	0.00

8/1/2013	**14:06**	0.00
8/1/2013	**14:07**	0.00
8/1/2013	**14:08**	0.00
8/1/2013	**14:09**	0.00
8/1/2013	**14:10**	0.00
8/1/2013	**14:11**	0.00
8/1/2013	**14:12**	0.00
8/1/2013	**14:13**	0.00
8/1/2013	**14:14**	0.00
8/1/2013	**14:15**	0.00
8/1/2013	**14:16**	0.00
8/1/2013	**14:17**	0.00
8/1/2013	**14:18**	0.00
8/1/2013	**14:19**	0.00
8/1/2013	**14:20**	0.00
8/1/2013	**14:21**	0.00
8/1/2013	**14:22**	0.00
8/1/2013	**14:23**	0.00
8/1/2013	**14:24**	0.00
8/1/2013	**14:25**	0.00
8/1/2013	**14:26**	0.00
8/1/2013	**14:28**	0.00
8/1/2013	**14:29**	0.00
8/1/2013	**14:30**	6.59
8/1/2013	**14:30**	6.18
8/1/2013	**14:31**	5.23
8/1/2013	**14:31**	4.96
8/1/2013	**14:31**	5.00
8/1/2013	**14:31**	4.88
8/1/2013	**14:32**	4.83
8/1/2013	**14:33**	4.77
8/1/2013	**14:34**	4.73
8/1/2013	**14:35**	4.83
8/1/2013	**14:36**	4.67
8/1/2013	**14:37**	4.58
8/1/2013	**14:38**	4.49
8/1/2013	**14:39**	4.56
8/1/2013	**14:40**	4.28
8/1/2013	**14:41**	4.38
8/1/2013	**14:42**	4.32

8/1/2013	**14:43**	4.35
8/1/2013	**14:44**	4.41
8/1/2013	**14:45**	4.46
8/1/2013	**14:46**	4.49
8/1/2013	**14:47**	4.41
8/1/2013	**14:48**	4.36
8/1/2013	**14:49**	4.18
8/1/2013	**14:50**	4.32
8/1/2013	**14:52**	4.24
8/1/2013	**14:53**	4.22
8/1/2013	**14:54**	4.27
8/1/2013	**14:55**	4.22
8/1/2013	**14:56**	4.09
8/1/2013	**14:57**	4.03
8/1/2013	**14:58**	4.10
8/1/2013	**14:59**	4.06
8/1/2013	**14:59**	3.95
8/1/2013	**14:59**	3.97
8/1/2013	**15:02**	4.09
8/1/2013	**15:03**	4.01
8/1/2013	**15:04**	4.06
8/1/2013	**15:05**	3.77
8/1/2013	**15:06**	3.80
8/1/2013	**15:07**	3.89
8/1/2013	**15:08**	3.77
8/1/2013	**15:09**	3.63
8/1/2013	**15:10**	3.70
8/1/2013	**15:11**	3.72
8/1/2013	**15:12**	3.75
8/1/2013	**15:13**	3.69
8/1/2013	**15:14**	3.74
8/1/2013	**15:15**	3.89
8/1/2013	**15:16**	4.04
8/1/2013	**15:17**	3.80
8/1/2013	**15:18**	3.97
8/1/2013	**15:19**	4.03
8/1/2013	**15:21**	4.03
8/1/2013	**15:22**	3.97
8/1/2013	**15:23**	3.95
8/1/2013	**15:24**	3.95

8/1/2013	**15:25**	3.86
8/1/2013	**15:26**	3.88
8/1/2013	**15:27**	3.91
8/1/2013	**15:28**	3.85
8/1/2013	**15:29**	3.91
8/1/2013	**15:30**	3.89
8/1/2013	**15:31**	4.07
8/1/2013	**15:32**	4.12
8/1/2013	**15:33**	4.18
8/1/2013	**15:34**	4.01
8/1/2013	**15:36**	4.09
8/1/2013	**15:37**	4.16
8/1/2013	**15:38**	4.10
8/1/2013	**15:39**	4.07
8/1/2013	**15:40**	4.10
8/1/2013	**15:41**	4.09
8/1/2013	**15:42**	4.12
8/1/2013	**15:44**	4.03
8/1/2013	**15:47**	3.94
8/1/2013	**15:47**	3.94
8/1/2013	**15:47**	3.88
8/1/2013	**15:48**	3.85
8/1/2013	**15:49**	3.88
8/1/2013	**15:50**	3.97
8/1/2013	**15:51**	4.00
8/1/2013	**15:52**	3.86
8/1/2013	**15:53**	5.02
8/1/2013	**15:53**	5.22
8/1/2013	**15:54**	5.32
8/1/2013	**15:55**	5.35
8/1/2013	**15:57**	5.44
8/1/2013	**15:58**	4.96
8/1/2013	**15:58**	5.04
8/1/2013	**15:58**	4.90
8/1/2013	**15:58**	5.02
8/1/2013	**15:58**	4.86
8/1/2013	**15:58**	5.04
8/1/2013	**15:59**	4.91
8/1/2013	**16:00**	4.74
8/1/2013	**16:01**	4.67

8/1/2013	**16:02**	4.61
8/1/2013	**16:03**	4.43
8/1/2013	**16:04**	4.55
8/1/2013	**16:05**	4.53
8/1/2013	**16:06**	4.52
8/1/2013	**16:07**	4.43
8/1/2013	**16:08**	4.33
8/1/2013	**16:09**	4.16
8/1/2013	**16:10**	4.27
8/1/2013	**16:11**	4.16
8/1/2013	**16:12**	4.06
8/1/2013	**16:13**	4.07
8/1/2013	**16:14**	3.92
8/1/2013	**16:15**	3.88
8/1/2013	**16:16**	3.92
8/1/2013	**16:17**	3.61
8/1/2013	**16:18**	3.51
8/1/2013	**16:19**	3.42
8/1/2013	**16:20**	3.49
8/1/2013	**16:21**	3.58
8/1/2013	**16:21**	3.57
8/1/2013	**16:24**	3.46
8/1/2013	**16:25**	3.33
8/1/2013	**16:26**	3.37
8/1/2013	**16:27**	3.22
8/1/2013	**16:28**	3.22
8/1/2013	**16:29**	3.17
8/1/2013	**16:30**	3.11
8/1/2013	**16:31**	3.02
8/1/2013	**16:32**	2.96
8/1/2013	**16:33**	3.02
8/1/2013	**16:34**	3.02
8/1/2013	**16:35**	3.05
8/1/2013	**16:36**	3.20
8/1/2013	**16:37**	3.16
8/1/2013	**16:41**	2.78
8/1/2013	**16:42**	2.87
8/1/2013	**16:43**	2.64
8/1/2013	**16:47**	2.56
8/1/2013	**16:47**	2.56

8/1/2013	**16:49**	2.39
8/1/2013	**17:22**	2.79
8/1/2013	**17:24**	2.90
8/1/2013	**17:26**	2.91
8/1/2013	**17:26**	2.91
8/1/2013	**17:27**	3.06
8/1/2013	**17:29**	3.19
8/1/2013	**17:29**	3.19
8/1/2013	**17:31**	3.23
8/1/2013	**17:33**	3.23
8/1/2013	**17:34**	3.16
8/1/2013	**17:35**	3.34
8/1/2013	**17:36**	3.19
8/1/2013	**17:37**	3.17
8/1/2013	**17:39**	3.33
8/1/2013	**17:39**	3.33
8/1/2013	**17:42**	3.33
8/1/2013	**17:42**	3.33
8/1/2013	**17:42**	3.54
8/1/2013	**17:45**	3.55
8/1/2013	**17:45**	3.55
8/1/2013	**17:49**	3.61
8/1/2013	**17:52**	3.77
8/1/2013	**17:52**	3.77
8/1/2013	**17:53**	3.77
8/1/2013	**18:00**	3.85
8/1/2013	**18:01**	3.78
8/1/2013	**18:02**	3.70
8/1/2013	**18:03**	3.83
8/1/2013	**18:04**	3.63
8/1/2013	**18:05**	3.70
8/1/2013	**18:06**	3.80
8/1/2013	**18:07**	3.88
8/1/2013	**18:08**	4.01
8/1/2013	**18:09**	3.80
8/1/2013	**18:10**	3.85
8/1/2013	**18:12**	3.91
8/1/2013	**18:13**	4.07
8/1/2013	**18:18**	4.33
8/1/2013	**18:18**	4.33

8/1/2013	**18:26**	5.00
8/1/2013	**18:26**	4.99
8/1/2013	**18:26**	5.00
8/1/2013	**18:27**	4.91
8/1/2013	**18:27**	5.00
8/1/2013	**18:27**	4.94
8/1/2013	**18:27**	5.02
8/1/2013	**18:27**	4.91
8/1/2013	**18:28**	5.00
8/1/2013	**18:28**	4.99
8/1/2013	**18:28**	5.02
8/1/2013	**18:28**	4.93
8/1/2013	**18:28**	4.91
8/1/2013	**18:29**	5.00
8/1/2013	**18:29**	4.99
8/1/2013	**18:29**	4.99
8/1/2013	**18:30**	5.02
8/1/2013	**18:30**	4.99
8/1/2013	**18:30**	5.00
8/1/2013	**18:31**	5.00
8/1/2013	**18:31**	5.07
8/1/2013	**18:31**	4.99
8/1/2013	**18:31**	5.00
8/1/2013	**18:32**	4.99
8/1/2013	**18:32**	4.90
8/1/2013	**18:32**	5.05
8/1/2013	**18:33**	5.05
8/1/2013	**18:36**	4.99
8/1/2013	**18:36**	4.99
8/1/2013	**18:37**	4.79
8/1/2013	**18:38**	4.79
8/1/2013	**18:40**	4.76
8/1/2013	**18:40**	4.76

Table (2): Runoff Conductivity Measured by Og Station resulted from 8th January Storm

Date	Time	Conductivity Milisiemens
8/1/2013	**8:59**	0.60
8/1/2013	**8:59**	0.60
8/1/2013	**9:01**	0.60
8/1/2013	**9:02**	0.61
8/1/2013	**9:03**	0.62
8/1/2013	**9:04**	0.63
8/1/2013	**9:06**	0.63
8/1/2013	**9:07**	0.64
8/1/2013	**9:08**	0.64
8/1/2013	**9:09**	0.63
8/1/2013	**9:10**	0.63
8/1/2013	**9:12**	0.63
8/1/2013	**9:13**	0.63
8/1/2013	**9:14**	0.64
8/1/2013	**9:15**	0.64
8/1/2013	**9:16**	0.65
8/1/2013	**9:17**	0.64
8/1/2013	**9:18**	0.64
8/1/2013	**9:19**	0.65
8/1/2013	**9:20**	0.65
8/1/2013	**9:21**	0.65
8/1/2013	**9:22**	0.66
8/1/2013	**9:23**	0.66
8/1/2013	**9:24**	0.66
8/1/2013	**9:25**	0.66
8/1/2013	**9:26**	0.66
8/1/2013	**9:28**	0.67
8/1/2013	**9:29**	0.67
8/1/2013	**9:30**	0.67
8/1/2013	**9:31**	0.67
8/1/2013	**9:32**	0.67
8/1/2013	**9:49**	0.65
8/1/2013	**9:51**	0.65
8/1/2013	**9:52**	0.65
8/1/2013	**9:53**	0.65
8/1/2013	**9:54**	0.65

8/1/2013	**9:55**	0.66
8/1/2013	**9:56**	0.65
8/1/2013	**9:57**	0.66
8/1/2013	**9:58**	0.66
8/1/2013	**9:59**	0.66
8/1/2013	**10:00**	0.66
8/1/2013	**10:01**	0.67
8/1/2013	**10:02**	0.67
8/1/2013	**10:03**	0.67
8/1/2013	**10:04**	0.68
8/1/2013	**10:06**	0.67
8/1/2013	**10:07**	0.67
8/1/2013	**10:08**	0.68
8/1/2013	**10:09**	0.68
8/1/2013	**10:10**	0.68
8/1/2013	**10:12**	0.68
8/1/2013	**10:18**	0.70
8/1/2013	**10:19**	0.69
8/1/2013	**10:20**	0.70
8/1/2013	**10:21**	0.69
8/1/2013	**10:22**	0.70
8/1/2013	**10:23**	0.70
8/1/2013	**10:24**	0.70
8/1/2013	**10:25**	0.71
8/1/2013	**10:26**	0.70
8/1/2013	**10:27**	0.70
8/1/2013	**10:28**	0.70
8/1/2013	**10:29**	0.70
8/1/2013	**10:31**	0.71
8/1/2013	**10:32**	0.70
8/1/2013	**10:33**	0.71
8/1/2013	**10:34**	0.71
8/1/2013	**10:35**	0.71
8/1/2013	**10:36**	0.71
8/1/2013	**10:37**	0.71
8/1/2013	**10:38**	0.71
8/1/2013	**10:39**	0.71
8/1/2013	**10:40**	0.71
8/1/2013	**10:41**	0.71
8/1/2013	**10:42**	0.71

8/1/2013	**10:43**	0.71
8/1/2013	**10:44**	0.71
8/1/2013	**10:45**	0.71
8/1/2013	**10:46**	0.71
8/1/2013	**10:47**	0.71
8/1/2013	**10:48**	0.71
8/1/2013	**10:49**	0.71
8/1/2013	**10:50**	0.71
8/1/2013	**10:51**	0.72
8/1/2013	**10:52**	0.71
8/1/2013	**10:53**	0.71
8/1/2013	**10:54**	0.72
8/1/2013	**10:55**	0.72
8/1/2013	**10:56**	0.71
8/1/2013	**10:57**	0.72
8/1/2013	**10:59**	0.72
8/1/2013	**11:00**	0.72
8/1/2013	**11:01**	0.72
8/1/2013	**11:02**	0.72
8/1/2013	**11:03**	0.72
8/1/2013	**11:04**	0.72
8/1/2013	**11:05**	0.72
8/1/2013	**11:06**	0.72
8/1/2013	**11:07**	0.72
8/1/2013	**11:08**	0.72
8/1/2013	**11:09**	0.72
8/1/2013	**11:10**	0.72
8/1/2013	**11:11**	0.72
8/1/2013	**11:12**	0.72
8/1/2013	**11:13**	0.72
8/1/2013	**11:14**	0.73
8/1/2013	**11:15**	0.72
8/1/2013	**11:16**	0.72
8/1/2013	**11:17**	0.73
8/1/2013	**11:18**	0.72
8/1/2013	**11:19**	0.72
8/1/2013	**11:20**	0.72
8/1/2013	**11:21**	0.72
8/1/2013	**11:22**	0.72
8/1/2013	**11:23**	0.73

8/1/2013	**11:24**	0.72
8/1/2013	**11:25**	0.73
8/1/2013	**11:26**	0.73
8/1/2013	**11:28**	0.73
8/1/2013	**11:29**	0.72
8/1/2013	**11:30**	0.73
8/1/2013	**11:31**	0.73
8/1/2013	**11:32**	0.73
8/1/2013	**11:33**	0.72
8/1/2013	**11:34**	0.73
8/1/2013	**11:35**	0.73
8/1/2013	**11:36**	0.73
8/1/2013	**11:37**	0.73
8/1/2013	**11:38**	0.73
8/1/2013	**11:39**	0.73
8/1/2013	**11:40**	0.73
8/1/2013	**11:41**	0.72
8/1/2013	**11:42**	0.73
8/1/2013	**11:43**	0.73
8/1/2013	**11:44**	0.73
8/1/2013	**11:45**	0.73
8/1/2013	**11:46**	0.73
8/1/2013	**11:47**	0.73
8/1/2013	**11:48**	0.73
8/1/2013	**11:49**	0.73
8/1/2013	**11:50**	0.73
8/1/2013	**11:51**	0.73
8/1/2013	**11:52**	0.73
8/1/2013	**11:53**	0.73
8/1/2013	**11:54**	0.73
8/1/2013	**11:55**	0.73
8/1/2013	**11:56**	0.73
8/1/2013	**11:58**	0.73
8/1/2013	**11:59**	0.73
8/1/2013	**12:00**	0.73
8/1/2013	**12:01**	0.73
8/1/2013	**12:02**	0.73
8/1/2013	**12:03**	0.73
8/1/2013	**12:04**	0.73
8/1/2013	**12:05**	0.73

8/1/2013	**12:06**	0.73
8/1/2013	**12:07**	0.73
8/1/2013	**12:08**	0.73
8/1/2013	**12:09**	0.73
8/1/2013	**12:10**	0.74
8/1/2013	**12:11**	0.73
8/1/2013	**12:12**	0.73
8/1/2013	**12:13**	0.73
8/1/2013	**12:14**	0.73
8/1/2013	**12:15**	0.73
8/1/2013	**12:16**	0.74
8/1/2013	**12:17**	0.73
8/1/2013	**12:18**	0.73
8/1/2013	**12:19**	0.73
8/1/2013	**12:20**	0.74
8/1/2013	**12:21**	0.74
8/1/2013	**12:22**	0.74
8/1/2013	**12:24**	0.73
8/1/2013	**12:25**	0.74
8/1/2013	**12:26**	0.74
8/1/2013	**12:27**	0.73
8/1/2013	**12:28**	0.74
8/1/2013	**12:29**	0.74
8/1/2013	**12:30**	0.73
8/1/2013	**12:31**	0.73
8/1/2013	**12:32**	0.73
8/1/2013	**12:33**	0.73
8/1/2013	**12:34**	0.74
8/1/2013	**12:35**	0.74
8/1/2013	**12:36**	0.73
8/1/2013	**12:37**	0.74
8/1/2013	**12:38**	0.74
8/1/2013	**12:39**	0.74
8/1/2013	**12:40**	0.74
8/1/2013	**12:41**	0.74
8/1/2013	**12:42**	0.74
8/1/2013	**12:43**	0.74
8/1/2013	**12:44**	0.73
8/1/2013	**12:45**	0.74
8/1/2013	**12:46**	0.73

8/1/2013	**12:47**	0.74
8/1/2013	**12:48**	0.74
8/1/2013	**12:50**	0.73
8/1/2013	**12:51**	0.74
8/1/2013	**12:52**	0.74
8/1/2013	**12:53**	0.74
8/1/2013	**12:54**	0.73
8/1/2013	**12:55**	0.74
8/1/2013	**12:56**	0.74
8/1/2013	**12:57**	0.74
8/1/2013	**12:58**	0.74
8/1/2013	**12:59**	0.74
8/1/2013	**13:00**	0.74
8/1/2013	**13:01**	0.74
8/1/2013	**13:02**	0.74
8/1/2013	**13:03**	0.74
8/1/2013	**13:04**	0.74
8/1/2013	**13:05**	0.74
8/1/2013	**13:06**	0.74
8/1/2013	**13:07**	0.74
8/1/2013	**13:08**	0.74
8/1/2013	**13:09**	0.74
8/1/2013	**13:10**	0.74
8/1/2013	**13:11**	0.74
8/1/2013	**13:12**	0.74
8/1/2013	**13:14**	0.74
8/1/2013	**13:15**	0.74
8/1/2013	**13:16**	0.74
8/1/2013	**13:17**	0.74
8/1/2013	**13:18**	0.74
8/1/2013	**13:19**	0.74
8/1/2013	**13:20**	0.74
8/1/2013	**13:21**	0.74
8/1/2013	**13:22**	0.74
8/1/2013	**13:24**	0.74
8/1/2013	**13:24**	0.74
8/1/2013	**13:25**	0.74
8/1/2013	**13:26**	0.74
8/1/2013	**13:27**	0.74
8/1/2013	**13:28**	0.74

8/1/2013	**13:29**	0.74
8/1/2013	**13:30**	0.74
8/1/2013	**13:31**	0.74
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8/1/2013	**14:06**	0.09
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جامعة النجاح الوطنية
كلية الدراسات العليا

تحليل الأمطار والجريان السطحي للأودية المساهمة في البحر الميت – واد العوج كحالة دراسية

إعداد
لينا عمر بهجت لهلبت

إشراف
د. عنان جيوسي

قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2013م

تحليل الأمطار والجريان السطحي للأودية المساهمة في البحر الميت

واد العوج كحالة دراسية

إعداد

لينا عمر بهجت لهلبت

إشراف

د. عنان جيوسي

الملخص

تؤثر الخصائص المميزة للمناطق الجافة وشبه الجافة على نمذجة العلاقة ما بين المطر والجريان السطحي الناتج من عاصفة مطرية أو موسم مطري بأكملة. حيث تعتبر الفيضانات والعواصف المطرية الشديدة والجفاف من السمات الرئيسية التي تميز البيئة الجافة وشبه الجافة. تسود هذه الخصائص المناخية في منطقة وادي نهر الأردن في فلسطين، حيث يؤثر تذبذب كميات الأمطار المتساقطة على تشكل الجريان السطحي في مجرى الأودية التي تصب في البحر الميت في فصل الشتاء.

في هذا البحث، سيتم دراسة العلاقة ما بين الأمطار والجريان السطحي لوادي العوج الذي يقع في الشمال الغربي للبحر الميت. حيث سيتم التنبؤ بكمية الجريان السطحي المتدفق في الواد والناتج عن عاصفة مطرية شديدة وأيضا عن موسم مطري كامل. كما وسيتم دراسة طبوغرافية الواد وتأثيرة على الجريان السطحي.

لقد تم استخدام النموذج الهيدرولوجي HEC-HMS لبناء نموذج يحاكي الجريان السطحي المتدفق في الواد والناتج من موسم مطري وعاصفة مطرية. حيث تم نمذجة ثلاث سيناريو لموسم مطري جاف (2004–2003) ومعتدل (2005–2004) ووفير (2003–2002). كما وتم نمذجة العاصفة المطرية قي شهر كانون ثاني لعام 2013.

لقد تم عكس الخصائص الفيزيائية لسطح الواد في النمذجة، من خلال بناء نموذج الأرتفاع الرقمي (DEM)، وتحديد المستجمعات المائية، ورسم المجاري التي تتدفق بها مياه الأمطار في الشتاء (Stream Network) باستخدام نظم المعلومات الجغرافية (GIS). كما وتم

حساب منحنى التدفق عند مخرج المستجمعات المائية لواد العوج من خلال استخدام SCS-UH. تم استخدام SCS-CN لحساب كميات الأمطار التي تعود الى الدورة الهيدرولوجية من خلال عملية التبخر والنتح اضافة الى المياه المتسربة الى باطن الأرض. وللأخذ بعين الاعتبار كميات المياه التي يتم فقدها خلال جريان المياه في مجرى الواد، تم تطبيق Muskingum routing في عملية النمذجة. اضافة الى ذلك، تم اختيار العاصفة المطرية والموسم المطري الذي سيتم استخدامه في عملية نمذجة الأمطار والجريان السطحي للواد.

كما وشملت الدراسة تحليل احصائي لقراءات الأمطار المتوفرة في ثلاثة محطات في منطقة واد العوج، حيث تضمن التحليل المعدل السنوي والشهري واليومي للأمطار. كما وتم دراسة مدى توافق قراءات الأمطار المتوفرة في المحطات وتم حساب كميات الأمطار المتساقطة على الواد باستخدام خارطة خطوط تساوي الأمطار(Isohyetal Map) مع الأخذ بعين الأعتبار التوزيع المكاني للأمطار المتساقطة. تم استخدام نتائج تحليل الأمطار في المنطقة لتحديد الطريقة التي سيتم اتباعها لادخال الأمطار في عملية النمذجة.

تم التنبؤ بحجم الجريان السطحي الناتج من ثلاث سيناريوهات لموسم مطري كامل بالإضافة الى الحجم الناتجة عن عاصفة مطرية شديدة. كما وشملت النتائج حجم الجريان الناتج عند الذروة. أظهرت النتائج أن حجم المياه المتدفقة في وادي العوج والناتجة عن سقوط كميات من الأمطار في موسم مطري معتدل يساوي 9 مليون متر مكعب، وموسم مطري وفير 19 مليون متر مكعب، بينما حجم المياه الجارية والناتجة من موسم مطري يتصف بالجفاف لا يتعدى 1 مليون متر مكعب وهذا يعكس مدى جفاف المنطقة . كما وأظهرت النتائج أن حجم المياه المتدفقة والناتجة عن عاصفة مطرية شديدة يساوي 37 ألف متر مكعب

تعتبر عملية المعايرة والتحقق من النموذج الهيدرولوجي متطلب ضروري في دراسة العلاقة ما بين الأمطار والجريان السطحي في البيئة الجافة وشبه الجافة. وبسبب عدم توفر قراءات تحدد كميات المياه الجارية في وادي العوج، تم القيام بالتحقق من عملية النمذجة للأمطار والجريان السطحي الناتج عن عاصفة مطرية شديدة من خلال مقارنة قراءات الجريان

التي تم قياسها بواسطة المحطة الموجودة عند مخرج الواد والنتائج التي تم الحصول عليها من النموذج الهيدرولوجي . حيث أظهرت النتائج أن هناك حاجة ملحة لمعايرة مدخلات النموذج الهيدرولوجي الذي تم بناؤه وذلك من أجل استخدامه في تطبيقات هيدرولوجية أخرى.

تعتبر قلة جودة المعلومات المستخدمة في بناء النموذج الهيدرولوجي ، والصعوبات التي يتم مواجهتها في الحصول على قراءات أمطار تعكس تغير المطر مكانيا، إضاقة الى قراءات تحدد كميات الجريان الناتجة من الواد من أهم الصعوبات التي يواجهها الباحث الهيدرولوجي في فلسطين فضلا عن قلة الإمكانيات المتوفرة لديه للعمل في الموقع. هذا يتطلب دعم الأبحاث الهيدرولوجية ليتم مواجهة نقص المياه في المنطقة.