A HYDROLOGIC STUDY OF WADI SU'D IN DURA AREA USING GIS AND GPS TECHNIQUES

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A PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF
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SUPERVISED BY

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CIVIL & ARCHITECTURAL ENGNEERING DEPARTMENT
COLLGE OF ENGINEERING AND TECHNOLOGY
PALESTINE POLYTECHNIC UNIVERSITY

HEBRON- WEST BANK
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إهــــداء

إلى الأم الحنــونة والأب الغــالي

إلى روح المرحوم الأستاذ كمال غطاشة

إلى عشاق الوطن..الشهداء..الجرحى..الأسرى

إلى أحــبائنا الذين تتــوق أنفســهم للتفوق والنجاح

إلى أعــزائنا الذين تهفو قلــوبهم للــسمو وتشــرئب أعناقهم للمعــالي

إلى الذيــن يجعلــون الاجــتهاد هدفهم والجد دأبهم

إلى كل الراغبين بالاستزادة من العلم والمعرفة

إلى كل هؤلاء نهدي هذا الجهد المتواضع

أحمد النمورة

أشرف الزين

صفوت القواسمة

ABSTRACT

A HYDROLOGIC STUDY OF WADI SU'D IN DURA AREA USING GIS AND GPS TECHNIQUES

By:

AHMAD NAMOURA **ASHRAF ZABEN** **SAFWAT QAWASMEH**

Palestine Polytechnic University

SUPERVISORE

DR. MAJED ABU SHARKH

For many hydrological studies on an ungaged watershed, a methodology has to be select for the determination of runoff at its outlet. The Soil Conservation Services (SCS) curve number method is the most popular method used in estimating the direct runoff for small catchment. The method can be apply by specifying a single parameter called the curve number CN, the CN values for a wide variety of soil types and condition are available in tabulation form. At the same time, the possibility of rapidly combining data of different types in a Geographical Information System (GIS) has led to significant increase in its use in hydrological application.

In the present study, SCS method is to be used with GIS to estimate the runoff from Wadi Su'd watershed, which is located in the Dura area of the Hebron District- West Bank. The watershed having a geographical area of 1.87 square kilometer and the average annual rainfall is around 500 mm. The rainfall and land use data were used along with the experimental data of soil classification and infiltration rate for the estimation of the direct runoff for the study area.

The results of the present study show that the average annual runoff depth for the study area (Wadi Su'd watershed) is 68mm, and the average volume of runoff from the same watershed is 127,083.6 cubic meter per year. The amount of runoff represents 13.6% of the total annual rainfall.

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Finally, we extended our thank to members in the Civil Engineering Dept. Especially the part of Surveying Engineering, which help us in designing our project.

Work Team

CERTIFICATION

Palestine Polytechnic University

PPU

Hebron-Palestine

The Senior Project Entitled:

A HYDROLOGIC STUDY OF WADI SU'D IN DURA AREA USING GIS AND GPS TECHNIQUES

Prepared By:

AHMAD AL-NAMORA **ASHRAF AL-ZABEN**
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In accordance with the recommendations of the project supervisors, and the acceptance of all examining committee members, this project has been submitted to the Department of Civil and Architectural Engineering in the College of Engineering and Technology in partial fulfillment of the requirements of Department for the degree of Bachelor of Science in Engineering.

Project Supervisors **Department Chairman**

MAY - 2006

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CHAPTER

1

INTRODUCTION

1.1 General
1.2 Problem Definition
1.3 Objectives of the Project
1.4 Previous Studies
1.5 Study Area
١.6 Rationale
1.7 Project Methodology
1.8 Project Task-Plan
1.9 Structure of the Report

PREVIEW

The main concepts of the project are introduced in this chapter. The problem identification, the study area, objectives, and the methodology to solve the problem are presented in this chapter. In addition, this chapter shows the project task – plan.

CHAPTER ONE

INTRODUCTION

1.1 General

Watershed is the area covering all the land that contributes runoff water to a common point. In Palestine, the availability of accurate information on runoff is scarcely available in most sites. However, quickening of watershed management programmed for conservation and development of natural resources management has necessitated the runoff information. Advances in computational power and the growing availability of spatial data have made it possible to accurately predict the runoff. The possibility of rapidly combining data of different types in a Geographical Information system (GIS) has led to significant increase in its use in hydrological applications.

Many methods are used to estimate the runoff from a watershed. The curve number method, also known as the hydrological soil cover complex method, is a versatile and widely used procedure for runoff estimation. This method includes several important properties of the watershed namely soils permeability, land use and antecedent soil water conditions which are taken into consideration. In the present study, the runoff from SCS Curve Number model modified for Palestinian condition has been used by using conventional database and GIS for Wadi Sud watershed in Dura area of the Hebron district, West Bank.

1.2 Problem Definition

The problem most often encountered in hydrological studies is the need for estimating runoff from a watershed for which there is records of precipitation and no records of runoff. An approach to solution of this problem is to compare runoff characteristics with those of watershed characteristics. Watershed characteristics which may be mostly readily compared to estimating the volume of runoff that will result from a given amount of rainfall are soil type and cover, which includes land use.

In Palestine, availability of runoff records is very limited compared to rainfall records, especially for medium and small catchments. Since discharge values are necessary for such ungauged catchments for the design of various hydraulic structures such as small dam, some analytical methodologies have to be utilized to estimate the same. Many such methods are available ranging from simple empirical equations relating catchment characteristics to the runoff, to complicated physical models that flow the movement of water from the farthest point of the catchments.

Hydrologists of the Soil Conservation Services constantly encounter the problem of estimating direct runoff where no records are available for the specific watershed. Soil Conservation Service (USDA, SCS, 1964) curve number method is a well accepted tool in hydrology, which uses a land conditions factor called "the curve number". It is reliance an only one parameter and its responsiveness to four important catchment properties, i.e. soil type, land use, surface condition, and antecedent moisture condition, increased its popularity.

In this study an attempts is made to estimate the amount of runoff that will result from a given amount of precipitation for Wadi Su'd watershed, Dura city in the Hebron area using soil conservation service method and with the help of Geographical Information System (GIS).

1.3 Objectives of the Project

The main objective of this study is to estimate direct runoff for the study area watershed where the records of runoff are not available using SCS curve number method. Within the framework of this study, the following data and parameters should be obtained and determined:

1. The boundary of catchment, sub-catchment, and stream network of the watershed under study, which located at Wadi Su’d, Dura city using GPS and GIS.
2. The climate data include values of precipitation, temperature, relative humidity, and wind information.
3. The geographical characteristics and land use of the study watershed.
4. The soil type and properties of the watershed by carried out sieve analysis and moisture content experiments.
5. The infiltration rate of different soil with the help of double ring infiltrometer.

All the data obtained were used to calculate the direct runoff of the study watershed and were demonstrated in GIS. The results may be generalized for estimating for other watersheds with similar soil type and land use.

1.4 Previous Studies

In our country, the hydrological studies are limited some investigators have studies the hydrology of different wadis and watersheds in the West Bank and Gaza strip in order to develop additional usable water resources to help in solving future hydrological problems.

Applied Research Institute of Jerusalem (ARIJ) published six articles on environmental profiles of West Bank cities. The Hebron district environmental profile shows that Dura area is preventative example of semiarid climate. In such area, most land is sloppy (2%-20%) and the infiltration rate is low. Consequently, low cost water harvesting could be introduced in this area. This method depends on collecting runoff water using construction such as soil dam or concrete dam.

Lange, J. et al (2000) have studies the runoff on a steep 180 m^2 Mediterranean Karts environment. To provide quantitative information, measurements are under taking on experimental hill slope plot applying artificial rainfall of predefined intensities. The results show that on a dry plot about 16 mm of rainfall was needed before terrain other bar rock generated runoff. Overall 16% of rainfall turn into runoff, while in the following day 73% of the applied rainfall arrived at the outlet of the wet plot.

In the study of Mohammadin, A. et al (2003), the mount of runoff for east Bani Naim watershed in the Hebron area using soil conservation service method were calculated and estimated to be about 417,913 cubic meters per year.

The study of Palestinian Hydrology Group (PHG) (2004) on agricultural water harvesting shows that in the southern West Bank runoff occurs as rainfall exceeds 50 mm/day or the total rainfall in two successive days is more than 70 mm. Runoff in the area varies due to variations in many factors like topography, rainfall intensity and duration. Runoff was also estimated at (2%-3.2%) of the total rainfall. Some other studies indicated that runoff in the southern part of the West Bank is range from 7% to 14% of the total rainfall depend upon the dry and wet years.

1.5 Study Area

The study area, named Wadi Su'd, is located at north Dura city of the Hebron area which will known later as Wadi Su'd watershed. The watershed having a geographical area of 1.868 square kilometer, Figure (1.1) shows the study area and its location. Physiographically, the watershed is divided into hills, pediments. Elevation in the watershed ranges from 550 to 820 m above mean sea level. The average annual precipitation at Dura city for the last five years is approximately 500 mm. About 90% of this rainfall is received from November to April, and the major land use/land cover categories in the watershed are: pasture, agricultural area, and stony waste land.

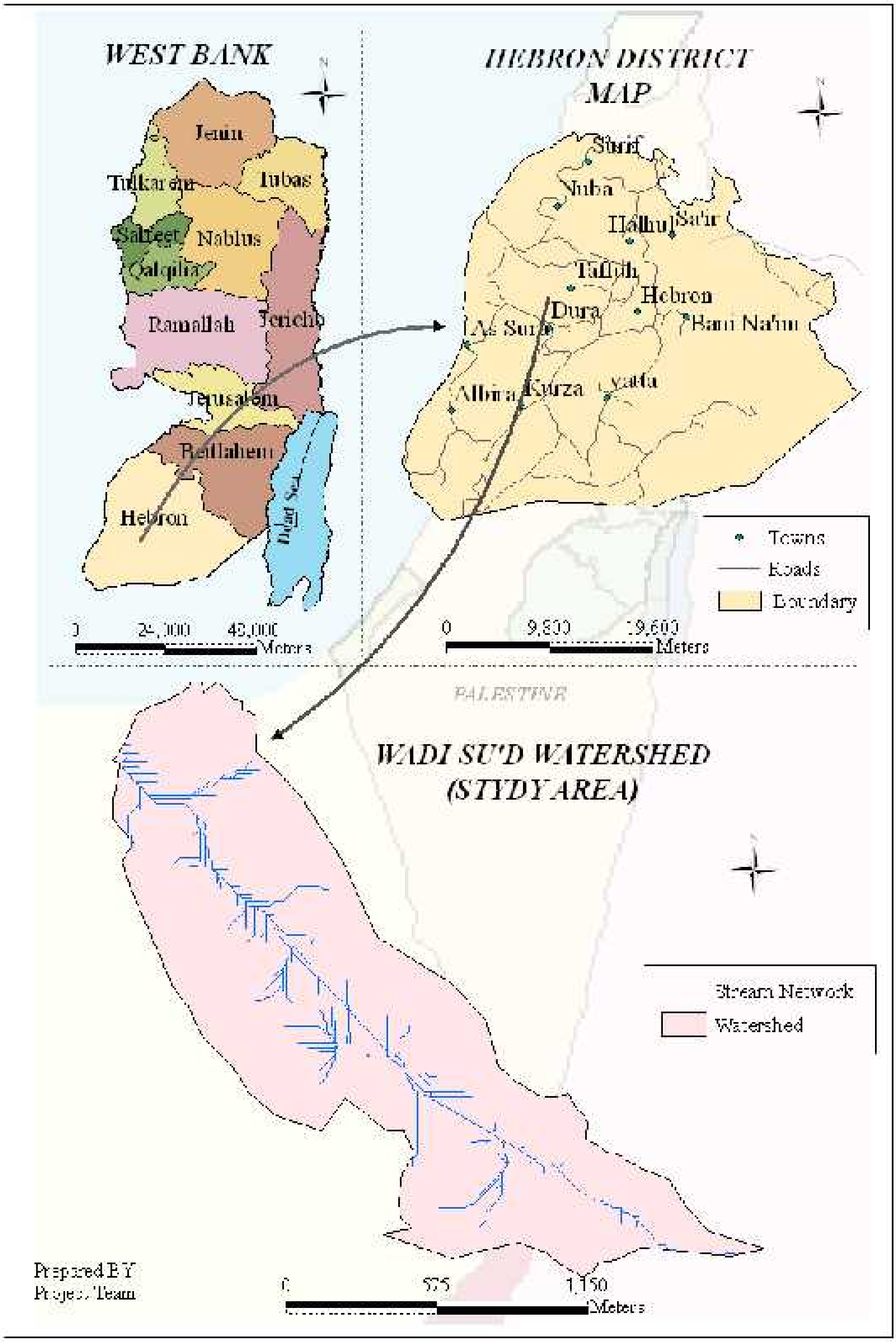


Figure (1.1): Location of the Study Area (Wadi Su'd Watershed)

1.6 Rationale

The justification for the proposed study is based on the scarcity of water resources in the West Bank and Gaza strip, which is threatening the life of humans, animals and plants. Therefore, having a reasonable estimate of rainfall and runoff of the selected watershed and promoting scientific researches related to rainwater harvesting is vital for the information of the problem.

This research will be unique in integrating essential component (rainfall, runoff, infiltration, etc.), related to water storage and use, specifically addressing the conditions in arid lands. The research will help in the planning and the operation of a watershed harvesting system.

The university will use the research in the evaluation and implementation of the results of related development projects. Since many of the finding will be based on field investigation.

1.7 Project Methodology

The project methodology includes the following:-

1. Many site visits to the study area and Dura city were done.
2. All needed maps and previous studies which, contains various information about the project were obtained.
3. The watersheds in the study area were delineated, and then Wadi Su'd catchment is divided into many sub catchments each of which having one or more combinations of soil and land cover. The delineation of the catchment and sub-catchment were prepared by using GIS (Arc Gis. 9) was done.

4. The data of rainfall and other meteorological data from the meteorological station were obtained and used as the input data for the estimating of direct runoff applying (SCS) curve number method.
5. The land use map for the watershed with the aid of land survey and aerial photo were prepared for the study area.
6. Soil characteristics such as type, moisture status, were determined from field survey and laboratory testing on different soil types.
7. Double ring Infiltrometer was fabricated and the infiltration rate was measured for different soil types. The experiments carried out in the field.
8. For application of SCS curve number method, the watershed was divided into four hydraulic soil groups (A, B, C, and D), based on the soil analyses of watershed.
9. By the land use, soil type and hydrological soil group values, runoff curve number were computed from the SCS tables. Then, the direct runoff was calculated using the SCS equations.
10. Finally, this report was issued upon the completion of the work. The report includes all collected data, results of the analysis, conclusions and recommendations.

1.8 Project Task–Plan

The following matrix explains the tasks have been under taken and the duration of each task.

Phase No.	Task	Duration(monthly)							
		2005			2006				
		10	11	12	1	2	3	4	5
One	Review of literature and other survey work	■	■	■	■	■			
Two	Delineation of the Watersheds		■						
Three	Preparation of land use map					■	■	■	
Four	Soil classification , and infiltration rate tests					■	■	■	
Five	Analysis and results							■	■
Six	Writing the report							■	■

1.9 Structure of the Report

The subject matter of the project is presented in eight chapters. The first chapter entitled "Introduction" outlines the problem, project objectives, literature review, study area, rationale, methodology, and structure of the report. The second chapter entitled "Hydrologic Principles" explains hydrologic circle, and water balance which includes precipitation, evaporation, infiltration and runoff. The third chapter entitled "Hydrological Models" explains geographical information system, global positioning system, models, and hydrological models.

The fourth chapter entitled" GIS and Spatial Hydrology "deals with water flow analysis, flow direction grids, watershed and stream delineation, and watersheds. Chapter five on "SCS Curve Number Method" displays the hydrologic soil group, land use, and estimation of direct runoff. The sixth chapter "Field Work and Experiments" explains watershed boundary and grid setup, soil tests and measurement of infiltration. Chapter seven "Analysis and Discussion of Results" presented land use and land cover, soil classification, infiltration rate, hydrological soil group, curve number and estimation of the surface runoff. The overall conclusions and recommendations are given in chapter eight.

CHAPTER

2 HYDROLOGIC PRINCIPLES

2.1 General
2.2 The Hydrologic Cycle
2.3 Precipitation
2.4 Evaporation
2.5 Infiltration
2.6 Runoff

PREVIEW

The main concept of this chapter is the hydrological parameters. It explains the hydrologic cycle, precipitation, evaporation, infiltration and runoff.

CHAPTER

3 *HYDROLOGICAL MODELS*

3.1 General
3.2 Hydrological Models in GIS
3.3 Geographic Information System
3.4 Global Positioning System

PREVIEW

Since it is important in the project to make synthesis of GIS and the hydrology, this chapter will discuss the hydrological models and how the models make the delineation of watersheds.

CHAPTER THREE

HYDROLOGICAL MODELS

3.1 General

The knowledge and understanding that the researcher and scientist have about the world is often represented in the form of models. The aim of the models is to simplify and explain the complexity and confusion of the world. The applied scientist and technologist then use the models of science to predict and control the world.

3.1.1 Definition of models

There is no specific definition for models. Modeling in general term, is a representation containing the essential structure of some objects or event in the real world. So, models are important constructs and architectures of more than one idea that directly or indirectly influence our state of mind and our lives.

3.1.2 Characteristics of the models

1. The models are necessarily incomplete: The model is a representation; no model includes every elements of real world. If it did, it would no longer be a model. To create a model, a researcher makes some assumptions about the essential structure and relationships of objects and events in the real world. These assumptions are important to explain the phenomena.

2. The models may be changed with relative ease: The technician changes the model and observes the results, rather than doing a similar operation in the real world. He or she does this because it is simpler and more convenient.

For example, design a model for car to test the behavior of it on the horizontal curve and studying the effect of changing the parameters of the physical model, the designer might vary the radius of the curve and notes the results. In this way, the model changes in simple way (Stock Burger, 2000).

3.1.3 Model classification

Models can be classified as follows:

1. Physical models, as in an airplane model or a vehicle model, such a models are constructed to appear similar prototype, but at different scale.
2. Symbolic models, as in the natural language, a computer program, or a set of mathematical equations.
3. Descriptive models, that are describe the prototype, as landscape panting.
4. Procedural models, these models consist of instructions on how to make something behave as it were the prototype.

But, in general the models can take two major forms, physical and symbolic; the latter is used much more often in science. Symbolic models are constructed using either a natural or formal language (kain, 1972). As an example of natural languages include Arabic, and English. Examples of formal languages include mathematics, logic, and computer languages.

Natural and formal languages share a number of commonalties. First, they are both composed of a set of symbols, called vocabulary of the language. Arabic forms of words, such as those that appear on the articles. Algebraic symbols such as: 2, 9.8, X, Y, =, +.

3.1.4 Model-building in science

There is a procedure for the model-building and verification. After a problem is formulated, the process consists of four stages.

1. Simplification \Idealization: As mentioned previously, a model contains the essential structure of objects or events.
2. Representation\Measurement: The symbols in a formal language are given meaning as objects, event, or relationships in the real world. This is the process used in translating "word problems" to algebraic expressions in high school algebra. (Stock Burger, 2002). This process is called representation of the real world.
3. Manipulation\Transformation: Researchers in the language are transformed into other statements in the language. In this manner implications of model are derived.
4. Verification\Calibration: Because of the idealization and simplification of the model-building process, no model can be in perfect agreement with the real world. In all cases, the important question is not whether the model is true or not, but how much does it match the real world. Powerful models replace less powerful models.

Models may be classified as distributed or lumped. Distributed models are those where their parameters depend upon spatial position, where lumped models do not have the spatial parameter, but may have time parameter.

In conclusion, the scientific method of model-building is very powerful tool in analyzing and dealing with the world.

3.2 Hydrological Models in GIS

An important method of the studying of hydrology is hydrological modeling as shown in Figure (3.1); which is an approximation of the actual hydrologic system.

Linking hydrology and GIS are very necessary due to ability of GIS to capture and manage a vast amount of data. In this project, the watershed delineation will mad by GPS and ArcGis.9 with a set of script and menus that automates the geographic data processing for in input files to the HEC-HMS model and other hydrology model.

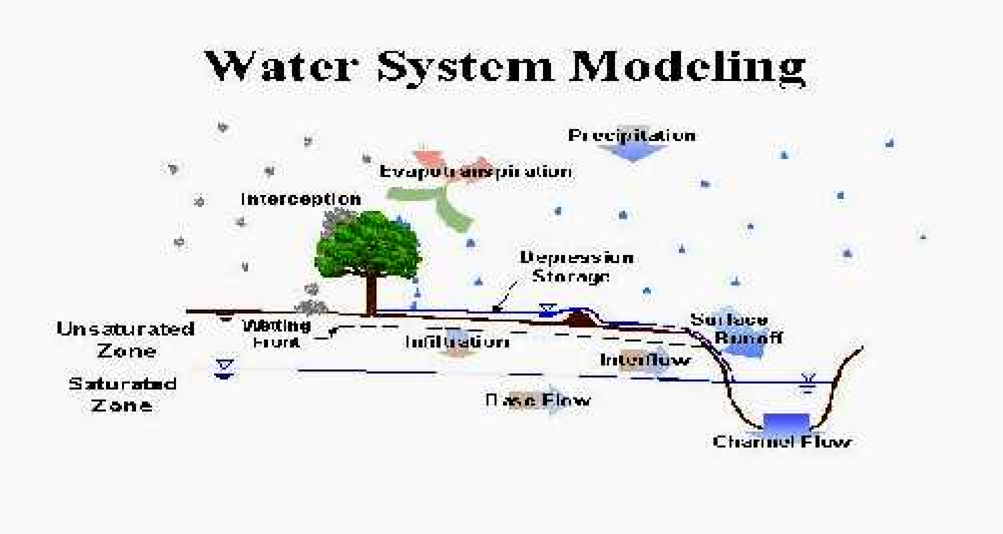


Figure (3.1): Hydrological Model Shows the Behavior of Water

3.3 Geographic Information System

Geographic Information System (GIS) is defined by ESRI (Environmental System Research Institute) as an organized collection of computer hardware, software, geographic data, and personal designed to efficiently capture, store, update, manipulate, analysis, and display all forms a geographically referenced information.

Many GIS databases consist of sets of information called layers. Each layer represents a particular type of geographic data. For example, one layer may include information on the streets in an area. Another layer may contain information on the soil in that area, while another records elevation.

The GIS can combine these layers into one image, showing how the streets, soil, and elevation relate to one another. Engineers might use this image to determine whether a particular part of a street is more likely to crumble. A GIS database can include as many as 100 layers (Maidment, 2002).

When looking at a map to know more about the features represented in it, than simply where they are. For example, when looking at a map of rivers and streams, it is helpful to know their names, and hydrologists want to know a good deal more about a river than its name. Such information as the slope of the river, the roughness of its bed and banks, and the shape of its cross-section, are important in being able to define the velocity of water flow in the river.

This type of descriptive information about a geographic feature is called its attributes. Attributes can be stored as numbers or character strings in a data record. A collection of data records makes up a data table. We thus have two descriptions available of each geographic feature: their spatial location and their descriptive attributes.

A key idea of GIS is that these two descriptions are connected by associating with each geographic feature a unique identifying number that is stored both with the spatial description and with the attribute description.

A GIS is designed to accept geographic data from a variety of sources, including maps, satellite photographs, and printed text and statistics. GIS sensors can scan some of this data directly—for example, a computer operator may feed a map or photograph into the scanner, and the computer “reads” the information it contains. The GIS converts all geographical data into a digital code, which it arranges in its database. Operators program the GIS to process the information and produce the images or information they need.

The applications of a GIS are vast and continue to grow. By using a GIS, scientists can research changes in the environment; engineers can design road systems; electrical companies can manage their complex networks of power lines; governments can track the uses of land; and fire and police departments can plan emergency routes. Many private businesses have begun to use a GIS to plan and improve their services. GIS technology attempts to precisely describe the spatial environment, while hydrology attempts to describe how water and pollutant move through the environment, then the synthesis of GIS and hydrology is spatial hydrology.

The purpose of spatial hydrology is to use spatial data and functions of GIS to help in solving the problems in water management. The spatial technology currently used in spatial hydrology is ArcGis.9 software and ArcGis.9 spatial Analysis Extension. ArcView GIS is readily available to the greatest number of users, although Arc/ Info software can be employed to solve spatial hydrology problems just as effectively. (Maidment, 2002)

The substance of current spatial hydrology is devoted to spatial data development for hydrology because GIS does not have explicit provisions for time-series data and much of hydrology is concerned with time-series measurement systems.

The ArcGis.9 Spatial Analysis has several built-in functions that enable simple watershed delineation using a Digital Elevation Model (DEM). These functions have been further developed by other organization, including the Center for Research in Water Resources (CRWR).

GIS has versions, and we will make our experiments (watershed delineation, runoff) by version "ArcGis.9 ".

3.4 Global Positioning System

The Global Positioning System (GPS) is the most significant recent advance in navigation and positioning technology. GPS is an aerospace technology that uses satellites and ground equipment to determine positions any where on earth. Anyone with a small receiver can use the system at no cost. GPS has drastically changed methods of navigation and is fast becoming important in everyday life.

3.4.1 Advantages of GPS surveying

For hundreds of years, surveyors have relied on optical instruments and physical measuring devices (such as tape measures or chains). Optical instruments (and newer electronic distance measuring (EDM) instruments) require direct line of site from the instrument to a target.

Measuring tapes or chains require that the survey crew physically pass through all the intervening terrain to measure the distance between two points. The big advantage of GPS is that line of site does not have to be established between two stations. Thus, surveying can be done in almost all weather conditions or on opposite sides of a mountain.

Because line of sight does not have to be established between GPS stations, major cost savings can be realized in large projects involving a large number of survey teams over a limited area (say, 100 sq miles). A single GPS receiver can be set up as a reference station which can be used by any number of surveyors, each of which can be working a job. This contrasts with conventional survey equipment in which at least two people must be working the same job (one for each end).

3.4.2 Accuracy requirements

Control surveys are used to establish the locations of arbitrary points. These points, called control points, may then be used as reference locations for performing additional survey work. Often, the reason for performing a control survey is to place control points in locations which are physically convenient for the intended survey work. Control surveys are generally performed to a higher standard of accuracy than other types of surveys. This is necessary because any follow-on survey work must be able to count on the accuracy of the control points, GPS smart in determine accurate location of points that’s needed in infiltration and land use process in this research in fast time and limited efforts.

CHAPTER

٤ GIS AND SPATIAL HYDROLOGY

4.1 General
4.2 Water Flow Analysis
4.3 Flow Direction Grids
4.4 Watershed and Stream Network
4.5 Watershed
4.6 Case Study: Wadi Sud Watershed-Dura Area

PREVIEW

Since it is important in the project to make synthesis of GIS and the hydrology, this chapter will discuss the spatially hydrology, and how the models make the delineation of watersheds.

CHAPTER FOUR

GIS AND SPATIAL HYDROLOGY

4.1 General

The study of the hydrology begins in describing the scientific principles governing hydrologic phenomena, studying the hydrologic system operation and predicts it's output, and applying the knowledge into water resources and environmental engineering project. As mentioned earlier, geographical information system (GIS) has lead to significant increase in its use in hydrological application. This chapter explains how to generate watershed and water stream for the project area using (GIS)

4.2 Water Flow Analysis

The model which used here follows the water from the farthest point until arriving the outlet, and analyses the movement of the point according to the elevations as describes below.

4.2.1 Triangulated irregular network

Triangulated Irregular Networks data (TIN) sets can be used to display and analyze surfaces. They contain irregularly spaced points that have x, y coordinates describing their location and a z-value that describes the surface at that point. The surface could represent elevation, precipitation, or temperature. A series of edges join the points to form triangles. The resulting triangular mosaic forms a continuous faceted surface, where each triangle face has a specific slope and aspect (Library of ArcGis.9).

4.2.2 Digital elevation model

A Digital Elevation Model (DEM) is a digital earth surface terrain elevations in xyz coordinates which built by converting the contour map of study area to Triangulated Irregular Network (TIN).

The terrain elevations for ground positions are sampled at regularly spaced horizontal intervals. In other countries DEMs are produced by some national institute, e.g. in the USA DEMs are produced by U.S Geological Survey (USGS) as apart of its national mapping program. Cell sizes for United States are available at (30m), (100m), (500m), and for the world at (1 km) cell size. (Maidment, 2002)

A Digital Elevation Model (DEM) consisting of a rectangular mesh of elevation points located over the landscape. Rectangular mesh has a number of cells represents the elevation of the center of the cell as the following Figure (4.1).

67	**56**	**55**	**40**	**50**
49	**44**	**37**	**38**	**48**
65	**55**	**23**	**32**	**24**
57	**47**	**21**	**17**	**20**
53	**34**	**30**	**11**	**13**

Figure (4.1): Surface Terrain Represented by a Mesh of Cells

The highest resolution DEM data is being produced by local mapping efforts with cell sizes of 10 m or smaller.

The USGS produces five different digital elevation products. Although all are identical in the manner the data are structured, each varies in sampling interval, geographic reference system, areas of coverage, and accuracy; with the primary differing characteristic being the spacing, or sampling interval, of the data.

4.2.3 The eight direction pour point model

The eight direction pour point model is the basis for cell-based drainage analysis using a DEM. Pour point is a location where the water flows out the cells. From Figure (4.2) each grid cell surrounding by eight cells (four on the principal axes and four on the diagonals) (Library of ArcGis.9).

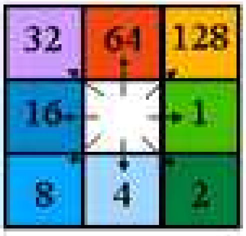
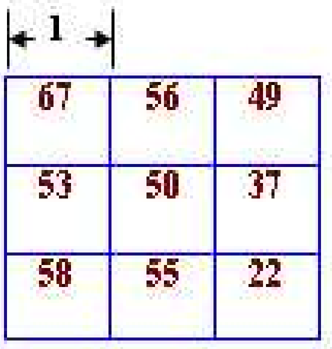


Figure (4.2): Pour Point Model

Water can flow in the cell to one and only one of its neighboring cells, in the direction of the steepest descent. The slope between the adjacent cells is defined as the ratio of the elevation difference to horizontal distance of the two cells centers. For example, Figure (4.3) illustrates a DEM grid with a cell size equal to one unit. (Maidment, 2002)



67	56	49
53	50	37
58	55	22

Figure (4.3): Direction of Steepest Descent

The distance between the cell centers is 1 on the principal axes and $\sqrt{2}$ = 1.414 along the diagonals. The water flow from cell 67 to:

The slope between cell 67 to cell 56: (67-56)/1 = 11

The slope between cell 67 to cell 53: (67-53)/1 = 14

The slope between cell 67 to cell 50: (67-50)/1.414 = 12

The flow direction of cell 67 to the steepest descent is from cell 67 to cell 53.The eight direction pour point models is a simplification of the true path of water flow in any direction, not just one of the eight prescribed directions.

4.3 Flow Direction Grids

Flow direction grids are the flow directions from cell center to cell center. When the DEM is filled the flow direction grid derived directly. It stores the flow direction number for each cell, which corresponding to the direction of steepest descent as determined by the eight direction pour point model. These directions can be represented schematically using arrows, as shown below in Figures (4.4), (4.5) and (4.6). (Maidment, 2002).

67	56	52	44	50
49	44	37	38	48
65	55	23	32	24
57	47	21	17	20
53	34	30	11	13

Figure (4.4): DEM Grid

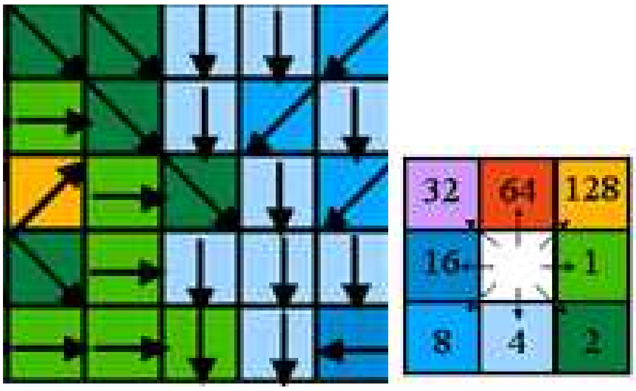


Figure (٤.٥): Flow directions and the Eight Directions

Pour Point Model

2	2	4	4	8
1	2	4	8	4
128	1	2	4	8
2	1	4	4	4
1	1	1	2	16

Figure (٤.٦): Flow Direction Grid

٤.٣.1 Grid networks

Flow network is a network of elementary flow paths that connected each cell in the grid, cell by cell downstream, to the eventual outlet point of the terrain surface. This network called network grid (defined with a grid).

DEMs useful in the hydrology if it can be able to describe a flow with a one-dimensional network over a two-dimensional surface. Because modeling two-dimensional flows is more complex, grid networks transform the problem of describing a two-dimensional flow over a surface into a problem of defining a one-dimensional flow through a network, (see Figure (4.7)).

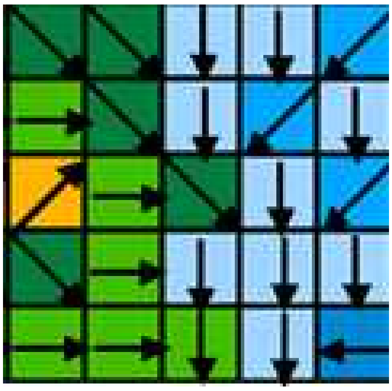


Figure (4.7): Flow Direction for Each Cell

4.3.2 Flow accumulation grids

Is one of the most important grids in hydrologic analysis, count the number of cells upstream from each individual cell? To illustrate how derived flow accumulation grid from a grid network look at the following Figures (4.8.a) and (4.8.b).

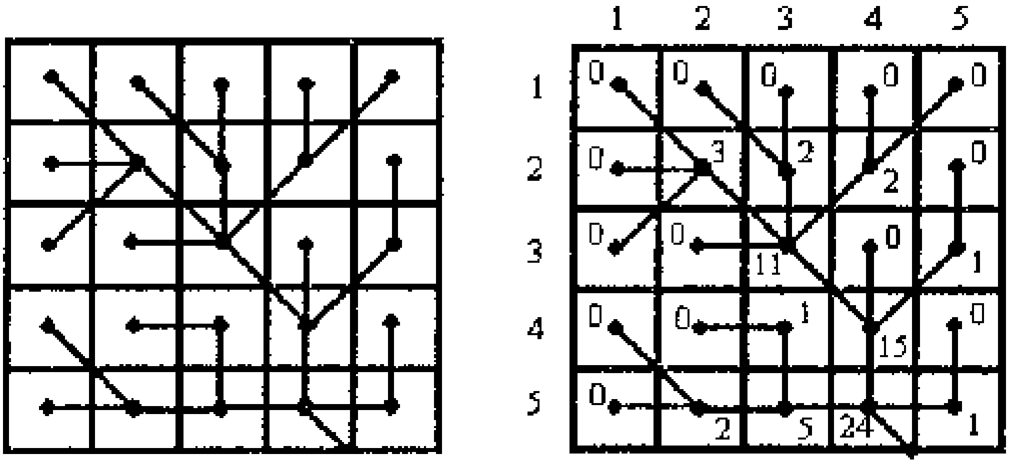
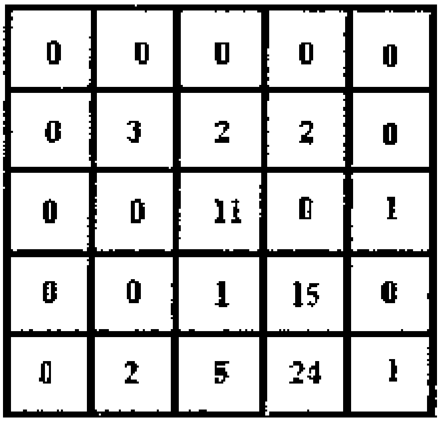


Figure (4.8): a) Grid Network **b) Flow Accmulation Grid**

(Mohammadin, 2003)

The entire cell in the first column and first row gave zero upstream cells, which are coded with a flow accumulation of 0. Cell (2, 2) has 3 cells upstream. Cell (2, 3) has two cells upstream ...etc. To determined the flow accumulation grid by similarly computing the values for all other cells as indicated in the Figure (4.٩).

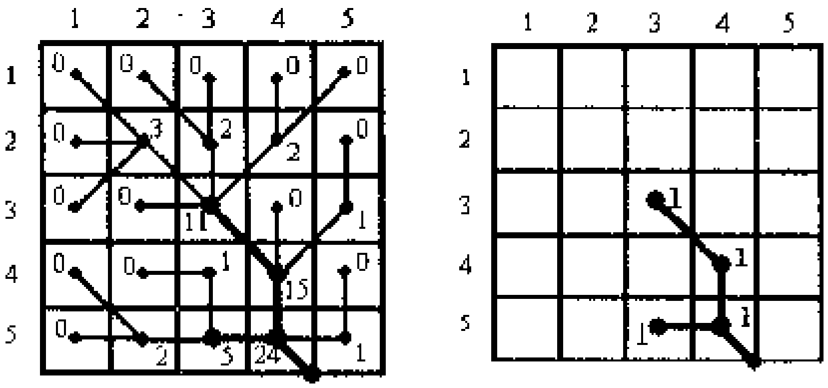


0	0	0	0	0
0	3	2	2	0
0	0	11	0	1
0	0	1	15	0
0	2	5	24	1

Figure (4.٩): Flow Accumulation Grid (Mohammadin, 2003)

4.4 Watershed and Stream Network

Stream Network and its watersheds is a fundamental to studying the movement of water through the landscape. Watershed and stream networks are defined using DEM. A stream cell is any cell with a flow accumulation value larger than the cell threshold. All stream cells are assigned a value of 1; all others are NO DATA cells. A stream network is the connection of all the stream cells (value = 1) in the direction of flow, which defined by the flow direction grid. From the following Figure (4.١٠.a), the cells are connected in the direction of flow. Figure (4.١٠.b) shows the stream grid from flow accumulation grid. Each cell with its flow accumulation value equal to or greater than **5** is defined as part of the stream grid and assigned a value of **1**. All arte assigned a NO DATA value. (Maidment, 2002)



	1	2	3	4	5
1	0	0	0	0	0
2	0	3	2	2	0
3	0	0	11	0	1
4	0	0	1	15	0
5	0	2	5	24	1

	1	2	3	4	5
1					
2					
3			1		
4				1	
5			1	1	

Figure (4.10): a) Flow Accumulation Grid b) Stream Grid

(Mohammadin, 2003)

Water flows downstream cell by cell. Flow accumulation grids count the number of cells upstream from any given cell. When the amount of water flow into the cell accumulation to a certain point, the cell considered part of the stream network.

4.4.1 Steam links

The Stream Link function allows you to assign unique values to each of the links in a raster linear network, as shown in Figure (4.11). This is most useful as input to the watershed function to quickly create watersheds based on stream junctions. It can also be useful for attaching related attribute information to individual segments of a stream.

A raster linear network can be accurately converted to features representing the linear network using the stream to feature function. The vectorization algorithm is designed primarily for vectorization of raster stream networks, or any other raster representing a raster linear network for which directionality is known. In the output feature dataset, all arcs will point downstream.

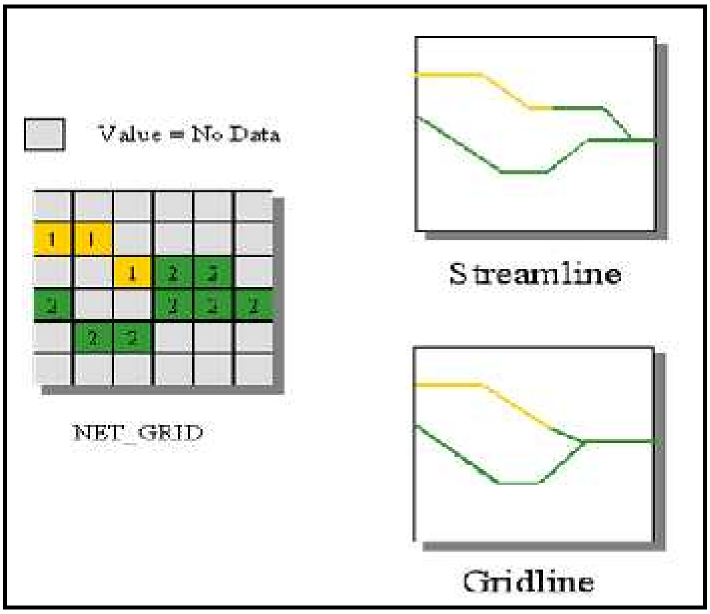


Figure (4.11): Stream Links

The stream to feature algorithm is optimized to use a direction raster to aid in vectorizing intersecting and adjacent cells. With stream to feature it is possible for two adjacent linear features of the same value to be vectorized as two parallel lines instead of being lumped into a single line as they would when using other vectorization methods.

Links are the sections of a stream channel connecting two successive junctions, a junction and the outlet, or a junction and the drainage divide, (Figure (4.12)).

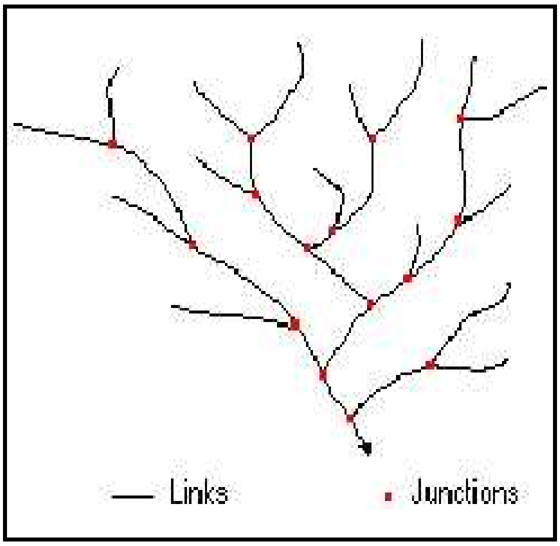


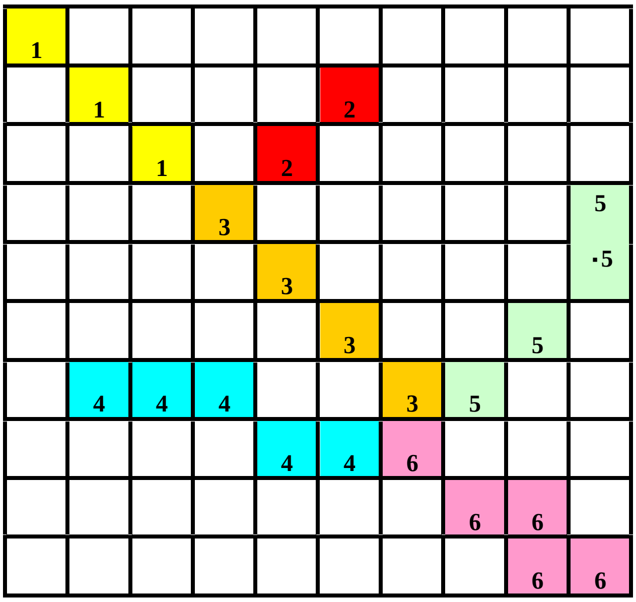
Figure (4.12): links and Junctions

4.4.2 Stream outlets

Stream outlets are the most downstream cell of a watershed. The water within the watershed flow through the outlet (which has the maximum flow accumulation value) to another watershed downstream.

The watershed delineated by outlet cells. The number of outlet cells determines how many sub-watersheds will be delineated. Each of the sub-watersheds is the drainage area to its outlet.

To determined the drainage area for a certain location (as a stream gauging station or water right location), should be define those locations as the outlet cells by converting the point theme of those locations to a grid theme, then delineate the watershed or drainage area from those locations (see Figure (4.13)). It is important that the location points fall exactly on the streams; otherwise the delineation will not be accurate.



1									
	1				2				
		1		2					
			3						5
				3					·5
					3			5	
	4	4	4			3	5		
				4	4	6			
							6	6	
								6	6

Figure (4.13): Stream Outlet

4.5 Watershed

A watershed is an area that drains water and other substances to a common outlet as concentrated drainage. Other common terms for a watershed are basin, catchment, or contributing area. This area is normally defined as the total area flowing to a given outlet, or pour point. These areas are the output of the watershed function. The boundary between two watersheds is referred to as a watershed boundary or drainage divide .

An outlet, or pour point, is the point at which water flows out of an area. This is the lowest point along the boundary of the watershed. The cells in the source raster are used as pour points above which the contributing area is determined. Source cells may be features such as dams or stream gauges, for which you want to determine characteristics of the contributing area, (Figure (4.14)).

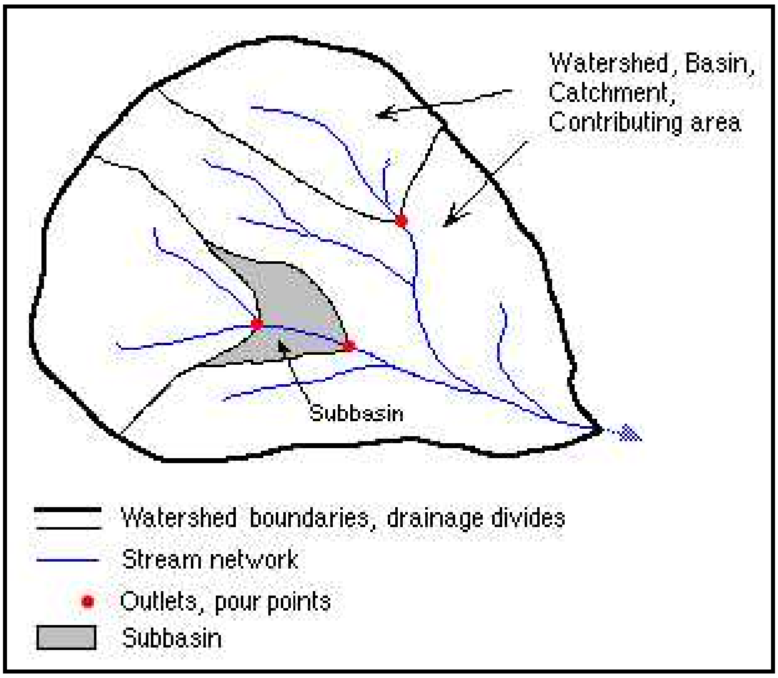


Figure (4.14): Watershed and Sub Watershed Boundaries

In the ArcGis.9 Spatial Analysis Extension watershed built as a function. The input grids for the watershed function are a flow direction grid and an outlet grid. The output grid is a watershed grid.

4.6 Case Study: Wadi Su'd Watershed-Dura area

An ArcGis.9 was used to process the DEM and generate the hydrologic parameters required to develop the spatially distributed travel time distribution and direct runoff hydrographs by routing the runoff down to the outlets. The original procedure was created the DEM in ArcGis.9 project; to identify and fill sinks; to generate flow direction, flow accumulation, and stream network. The procedures are as follow:

1- Triangulated Irregular Networks (TIN) was fined as appear in Figure (4.15).

2- The Digital Elevation Model (DEM) derived from (TIN) as shown Figure (4.16).

3- The Flow Direction was computed as shown in Figure (4.17).

4- The Flow Accumulation derived from flow direction as shown in Figure (4.18).

5- The Stream Network was constructed as shown in Figure (4.19).

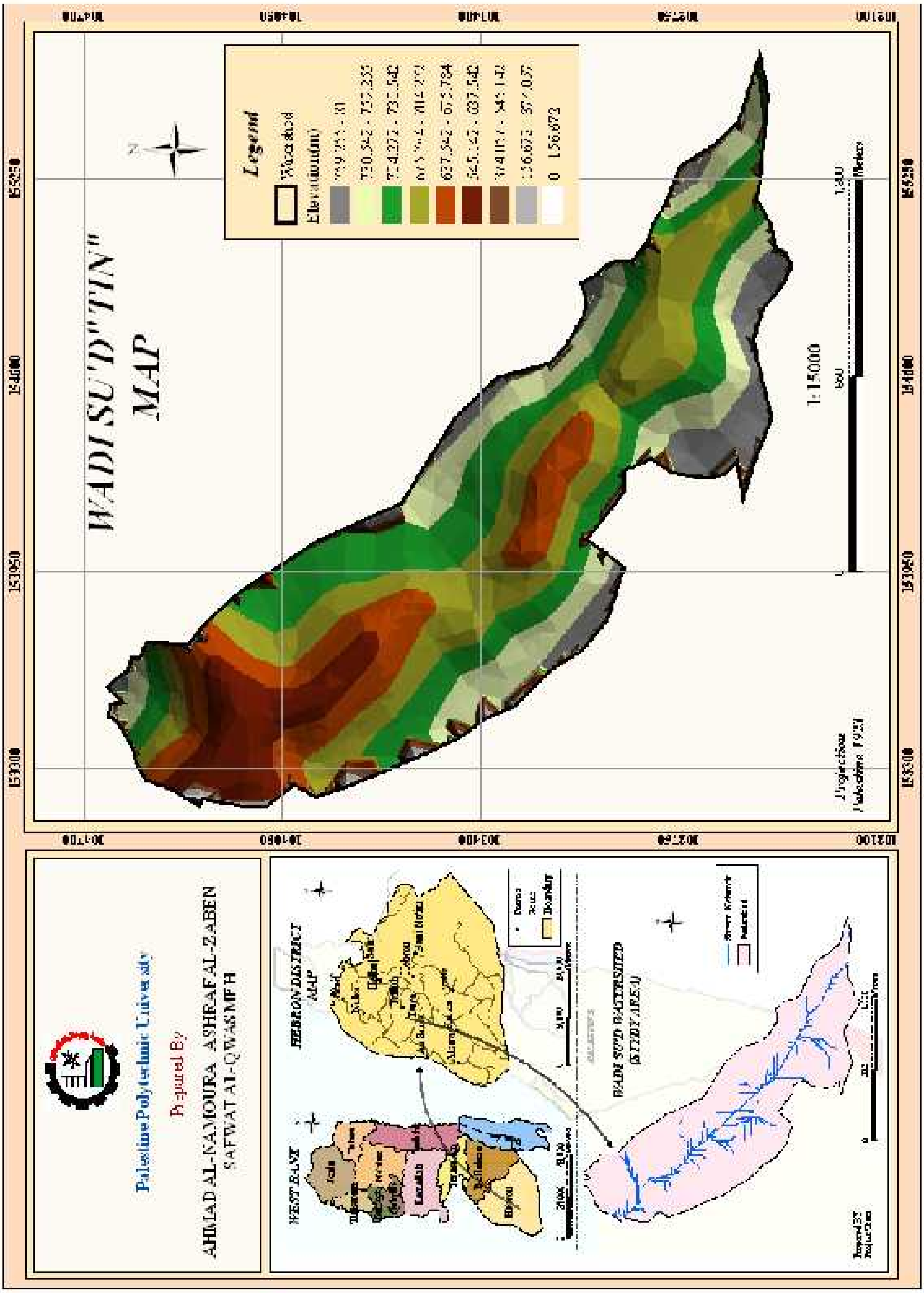


Figure (4.15): Triangulated Irregular Networks (TIN)

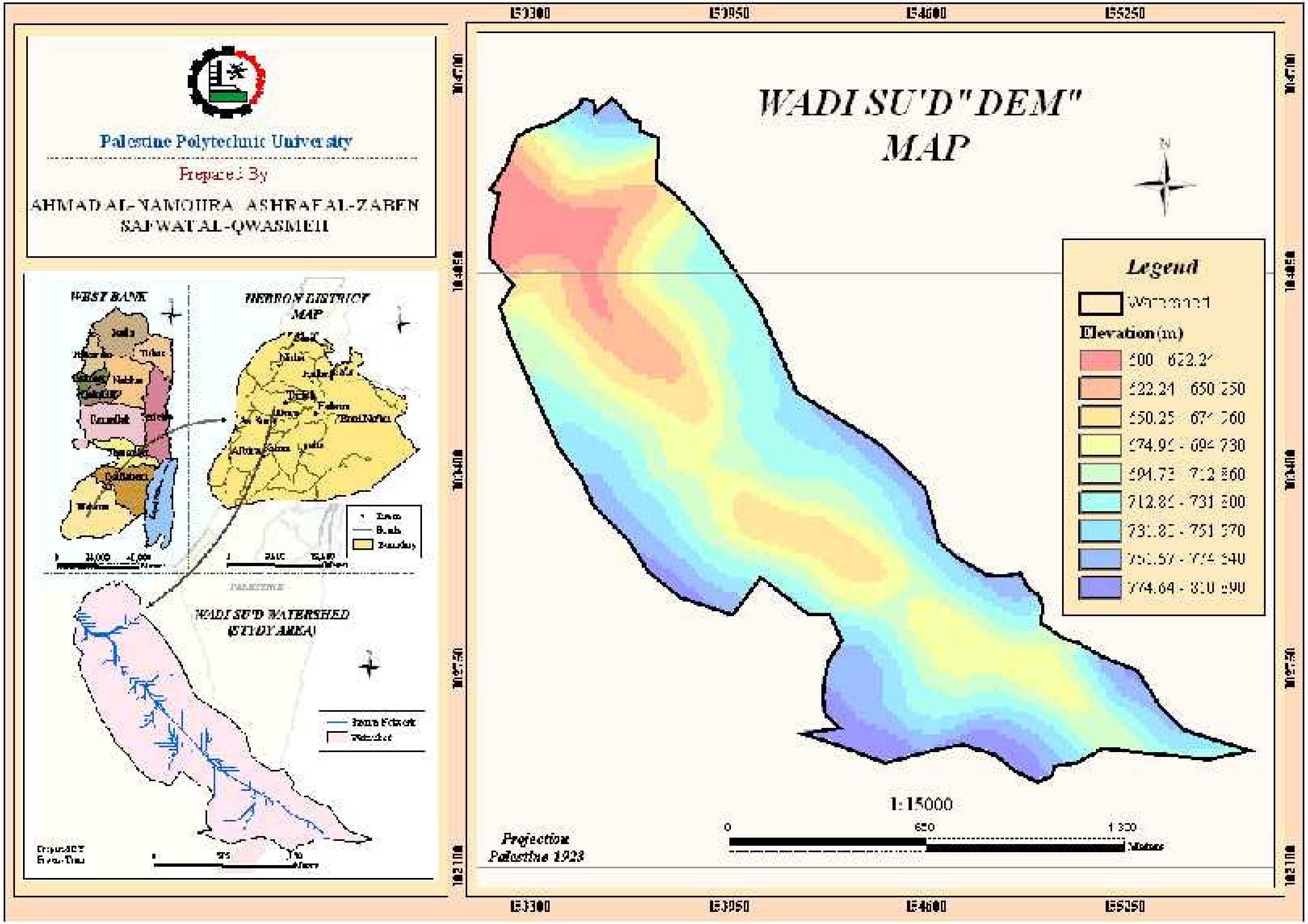


Figure (4.16): The Digital Elevation Model (DEM)

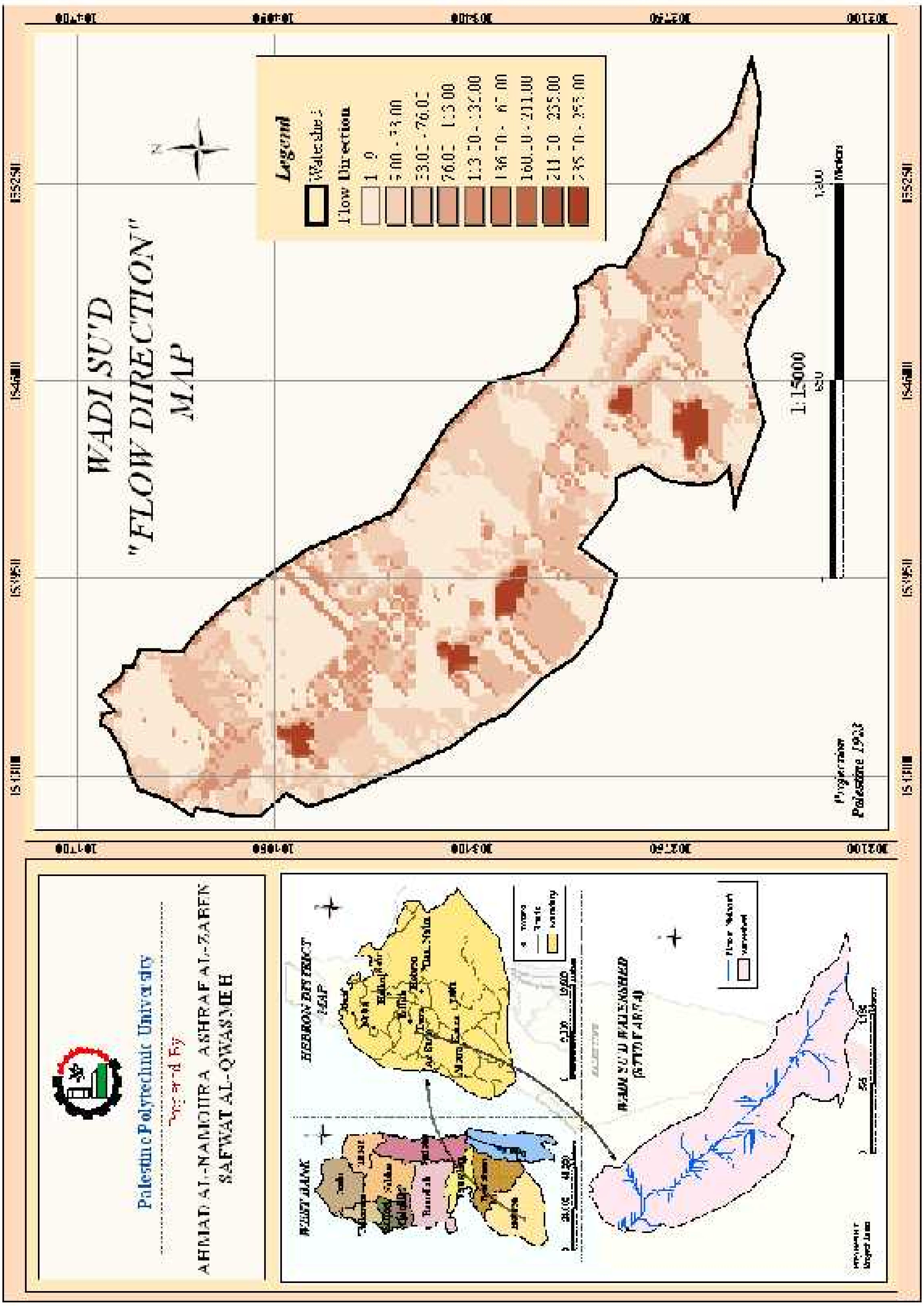


Figure (4.17): The Flow Direction

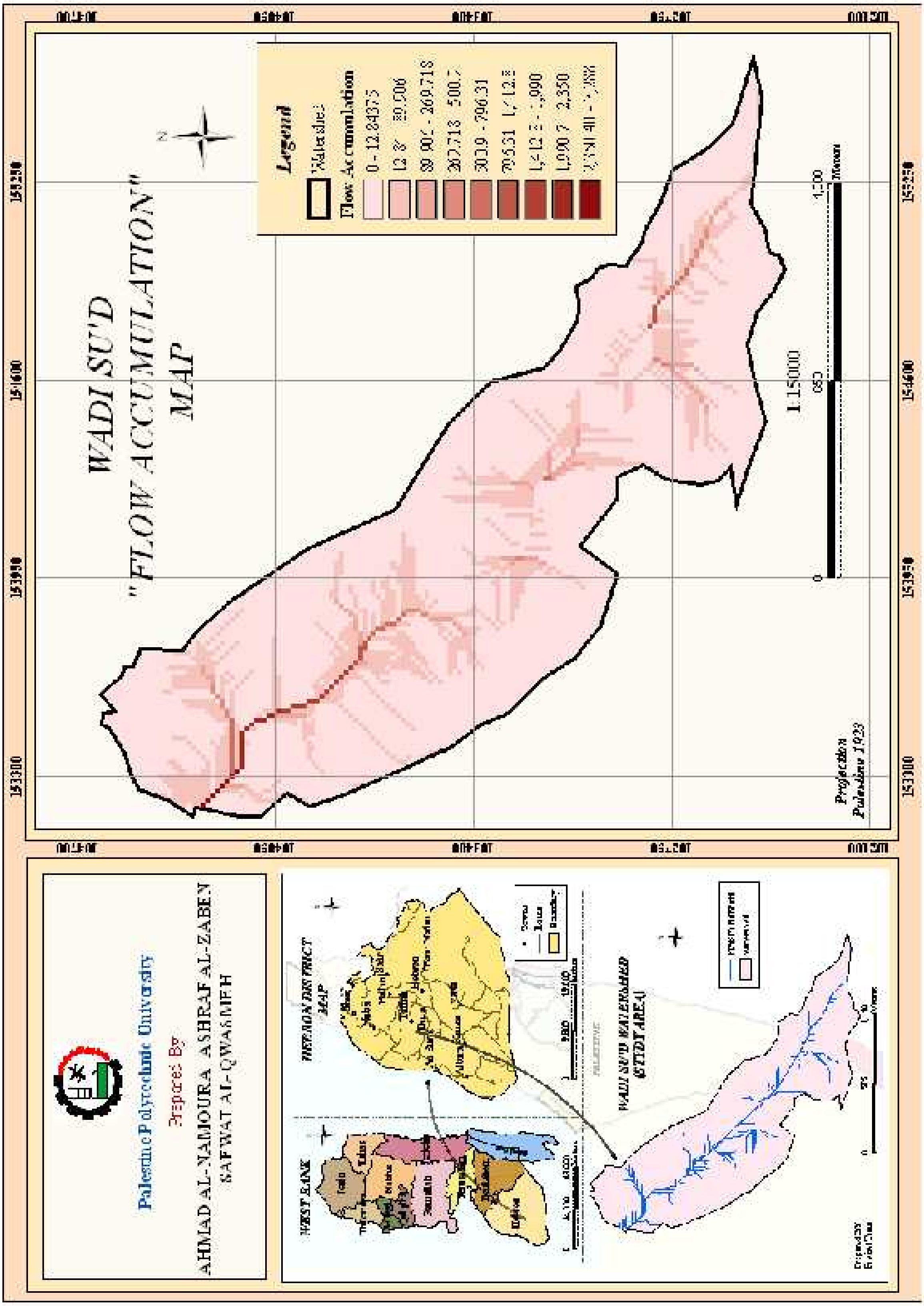


Figure (4.18): The Flow Accumulation

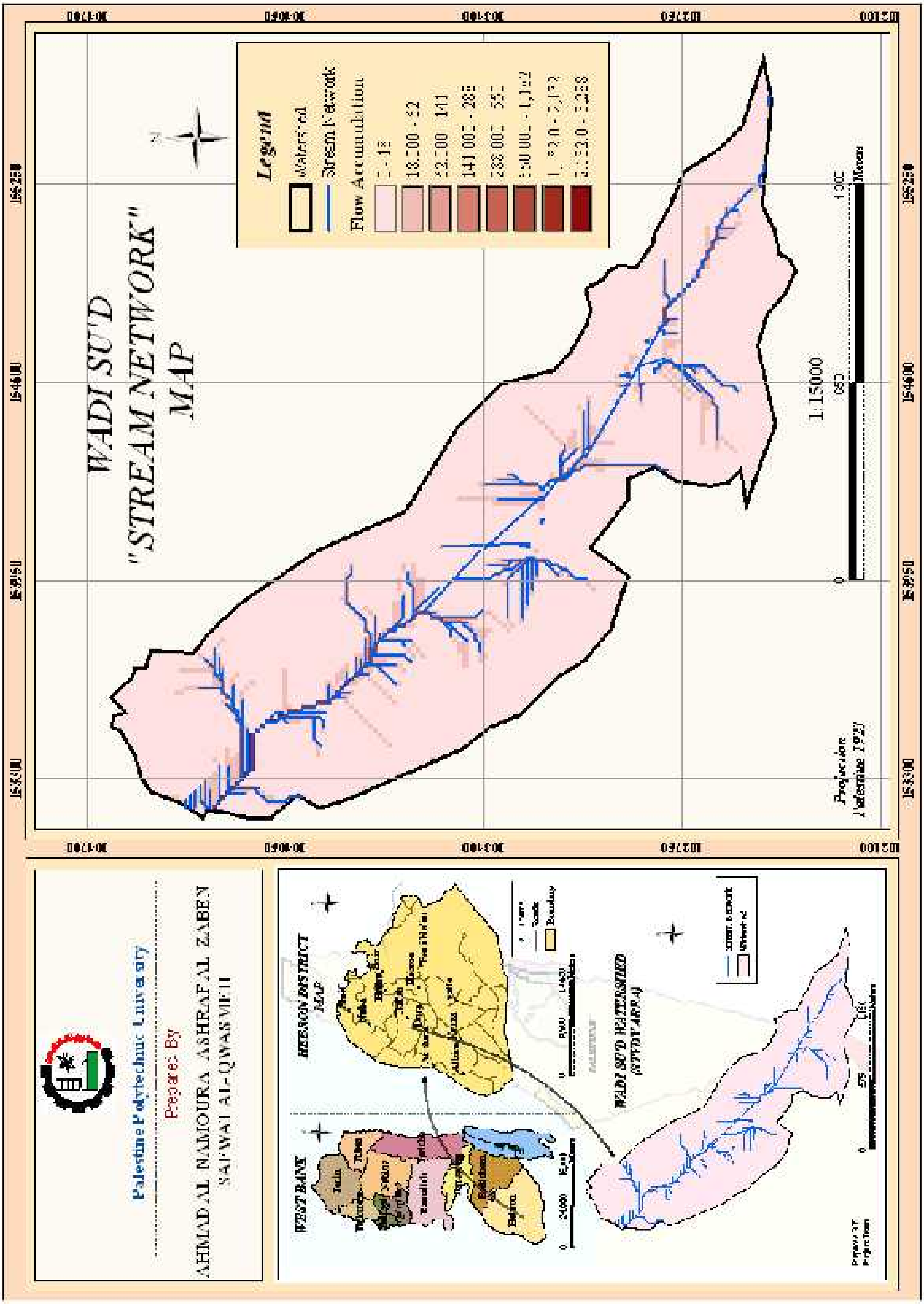


Figure (4.19): The Stream Network

CHAPTER

5 *SCS CURVE NUMBER METHOD*

5.1 General
5.2 Hydrologic Soil Groups
5.3 Land Use
5.4 Antecedent Soil Moisture Condition
5.5 Estimation of Direct Runoff

PREVIEW

The main concept of this chapter is the hydrologic soil groups, land use, and antecedent soil moisture condition to estimate direct runoff.

CHAPTER FIVE

SCS CURVE NUMBER METHOD

5.1 General

The SCS curve number method was developed by the soil conservation service (SCS) of the U.S. department of agriculture for use in rural areas. The procedure has been modified to permit its application to urban areas and has been further adapted to a computerized simulation technique which become routing of hydrographs. The SCS curve number method is a simple, widely used and efficient method for determining the approximate amount of runoff from a rainfall even in a particular area. Although the method is designed for a single storm event, it can be scaled to find average annual runoff values. The requirements for this method are very low, rainfall amount and curve number. The curve number is based on the areas hydrologic soil group, land use, treatment and hydrologic condition. The two former being of greatest importance. (Randkivi, 1978)

5.2 Hydrologic Soil Groups

Study of hydrologic soil classification is done with a view to study overland flow characteristics of runoff. Hydrologic soil classes are of great use in estimating the runoff for any given watershed as soil properties influence the process of generation of runoff from rainfall. Soils may be classified into four hydrologic groups (A, B, C and D), depend on infiltration, soil classification and other criteria. The hydrologic soil groups, as defined by SCS soil scientists, are as follows:

Group A (lowest runoff potential): Soils having high infiltration rates even if it wetted, and consisting deep sands with very little silt and clay, also deep, rapidly permeable loess.

Group B (moderately low runoff potential): Soils having moderate infiltration rates, mostly sandy soils less deep than A, less aggregated than A, and consisting chiefly of moderately well to well – drained soils with moderately fine to moderately coarse textures.

Group C (moderately high runoff potential): Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soil with moderately fine to fine texture. Comprise shallow soils and soils containing considerable clay and colloids, though less than group those of D.

Group D (high runoff potential): Soils having very slow infiltration rates when thoroughly wetted includes mostly clays of high swelling percent, soils with a permanent high water table, and soils with clay layer at or near the surface and shallow soils. (Randkivi, 1978)

Soils are also classified into four soil groups (A, B, C and D) according to their minimum infiltration rate, which is obtained for a bare soil after prolonged wetting. A description of these groups is shown in Table (5.1).

Table (5.1): Hydrologic Soil Group Descriptions (USDA, 1985)

Soil Group	Description	Final Infiltration Rate (mm/hr)
A	Lowest runoff potential. Includes deep sands with very little silt and clays, also deep, rapidly permeable loess.	8 - 12
B	Moderately low runoff potential. Mostly sandy soils less deep than A, and less deep or less aggregated than A, but the group as a whole has above average infiltration thorough wetting.	4 - 8
C	Moderately high runoff potential. Comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below-average infiltration after presaturation.	1 - 4
D	Highest runoff potential. Includes mostly clays of high swelling percent, but the group also includes some shallow soils with nearly impermeable sub horizons near the surface.	0 - 1

5.3 Land Use

Land use and treatment classes are used in the preparation of hydrological soil-cover complex, which in turn are used in estimating direct runoff. Types of land use and treatment are classified on a flood runoff producing basis. Below are a few extracts of the land use classification (Karanth, 1988):

a- Crop rotations: The sequence of crops on a watershed must be evaluated on the basis of its hydrologic effects. Rotations range from poor to good largely in proportion to the amount of dense vegetation in the rotation. Poor rotations are those in which a row crop or small gain is planted in the same field year after year. Good rotations will contain alfalfa or other close seeded legumes or grasses, to improve tilth and increase infiltration.

b- Farm woodlots: Poor woodlots are heavily grazed and regularly burned in a manner that destroys litter, small trees, and brush. Fair woodlots are grazed but not burned and may have some litter, but usually these woods are not protected. Good woodlots are protected from grazing so that litter and shrubs cover the soil.

c- Native pasture or range: Poor pasture or range is heavily grazed, has no much or has plant cover on less than about 50% of the area. Fair pasture or range has between 50% and 75% of the area with plant cover and is not heavily grazed. Good pasture or range has more about 75% of the area with plant cover. And is lightly grazed.

d- Commercial forest: The hydrologic condition classes are determined on the basis of depth and quality of litter, humus, and compactness of humus.

e- Miscellaneous: Usually only very small parts of a watershed are farmsteads, roads, and urban areas. When this is so, the areas may be included with one of the other land use cover types (such as fallow or small grain) in the computation of runoff.

f- Straight row farming: This class includes up and down and cross slope farming in straight rows.

g- Contouring: Contour furrows used with small grains and legumes are made while planting, are generally small and disappear due to climatic action.

5.4 Antecedent Soil Moisture Condition (AMC)

Antecedent moisture condition is an indicator of watershed wetness and availability of soil moisture storage prior to a storm, and can have a significant effect on runoff volume. Recognizing its significance, SCS developed a guide for adjusting CN according to AMC based on the total rainfall in the 5-day period preceding a storm (USDA-SCS, 1985).

Three levels of AMC are used in the CN method: AMC-I for dry, AMC-II for normal, and AMC-III for wet conditions. Table (5.2) gives seasonal rainfall limits for these three antecedent moisture conditions.

Table (5.2): Classification of Antecedent Moisture Conditions (SFWMD, 1997).

AMC	**Total 5-days Antecedent Rainfall (mm)**	
	Dormant Season	**Growing Season**
I	<12.7	< 35.6
II	12.7 – 27.9	35.6 – 53.3
III	> 27.9	> 53.3

The CN values documented for the case of AMC-II (USDA, 1985). To adjust the CN for the cases of AMC-I and AMC-III, the following equations are used (Chow, 1988):

$$CN_{(I)} = \frac{4.2 * CN_{(II)}}{10 - (0.058 * CN_{(II)})} \quad \text{...(5.1)}$$

$$CN_{(III)} = \frac{23 * CN_{(II)}}{10 + (0.13 * CN_{(II)})} \quad \text{...(5.2)}$$

Where:

$CN_{(II)}$: curve number for normal condition.

$CN_{(I)}$: curve number for dry condition.

$CN_{(III)}$: curve number for wet condition.

5.5 Estimation of Direct Runoff

Analysis of storm event rainfall and runoff records indicates that there is a threshold which must be exceeded before runoff occurs. The storm must satisfy interception, depression storage, and infiltration volume before the onset of runoff. The rainfall required to satisfy the above volumes is termed initial abstraction. Additional losses as infiltration will occur after runoff begins. After runoff begins, accumulated infiltration increases with increasing rainfall up to some maximum retention. Runoff also increases as rainfall increases. The ratio of actual retention to maximum retention is assumed to be equal to the ratio of direct runoff to rainfall minus initial abstraction. This can be expressed mathematically as (USDA, 1985).

$$\frac{F}{S} = \frac{Q}{P-I} \qquad \text{...(5.3)}$$

where F is actual retention after runoff begins, mm; S is watershed storage mm; ($S = F$); Q is actual direct runoff mm; P is total rainfall mm; ($P = Q$); I is initial abstraction mm.

The amount of actual retention can be expressed as

$$F = (P-I) - Q \text{ ....(5.4)}$$

The initial abstraction defined by the SCS mainly consists of interception, depression storage, and infiltration occurring prior to runoff. To eliminate the necessity of estimating both parameters I and S in the above equation, the relation between I and S was estimated by analyzing rainfall-runoff data for many small watersheds. The empirical relationship is

$$I = 0.2S \quad \text{...} (5.5)$$

Substituting Eq. (5.5) into Eq. (5.3) and (5.4) yields

$$Q = \frac{(P - I)^2}{(p - I + S)} \quad \text{...} (5.6)$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (p > 0.2S) \text{.........................} (5.7)$$

Which is the rainfall-runoff equation used by the SCS for estimating depth of direct runoff from storm rainfall. The equation has one variable P and one parameter S.

S is related to curve number (CN) by

$$S = \frac{25400}{CN} - 254 \text{...} (5.8)$$

Where CN is a dimensionless parameter and its value range from 1 (minimum runoff) to 100 (maximum runoff). It is determined based on the following factors: hydrologic soil group, land use, land treatment, and hydrologic conditions. The soil type classification and curve number as a function of land use and hydrologic soil group are shown in Table (5.3).

Table (5.3): Description and Curve Numbers. (Mohmmadin.2003)

Land Use Description on Input Screen	**Description and Curve Numbers**					
	Cover Description		**Curve Number for Hydrologic Soil Group**			
	Cover Type and Hydrologic Condition	% Impervious Areas	A	B	C	D
Agricultural	Row Crops - Straight Rows + Crop Residue Cover- Good Condition (1)		64	75	82	85
Commercial	Urban Districts: Commercial and Business	85	89	92	94	95
Forest	Woods(2) - Good Condition		30	55	70	77
Grass/Pasture	Pasture, Grassland, or Range(3) - Good Condition		39	61	74	80
High Density Residential	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Industrial	Urban district: Industrial	72	81	88	91	93
Low Density Residential	Residential districts by average lot size: 1/2 acre lot	25	54	70	80	85
Open Spaces	Open Space (lawns, parks, golf courses, cemeteries, etc.)(4) Fair Condition (grass cover 50% to 70%)		49	69	79	84
Parking and Paved Spaces	Impervious areas: Paved parking lots, roofs, drives ways, etc.	100	98	98	98	98
Residential 1/8 acre	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92

Residential 1/4 acre	Residential districts by average lot size: 1/4 acre	38	61	75	83	87
Residential 1/3 acre	Residential districts by average lot size: 1/3 acre	30	57	72	81	86
Residential 1/2 acre	Residential districts by average lot size: 1/2 acre	25	54	70	80	85
Residential 1 acre	Residential districts by average lot size: 1 acre	20	51	68	79	84

The SCS runoff equation is widely used in estimating direct runoff because of its simplicity and flexibility.

CHAPTER

6

FIELD WORK AND EXPERIMENTS

٦.1 General
6.2 Watershed Boundary and Grid Setup
٦.3 Soil Tests
٦.4 Measurement of Infiltration

PREVIEW

One of the most important of catchment characteristics is the infiltration rate that helps to classify the soil; there are many soils classification systems which discussed in this chapter.

CHAPTER SIX

FIELD WORK AND EXPERIMENTS

٦.1 General

Response of a watershed (catchment) to specified rainfall input is shaped by the catchment characteristics such as soil classification, infiltration rate, land use and land cover (LULC); this input data is used to determined the SCS curve number (CN) for the watershed area, and then to estimate the amount of direct runoff for the given precipitation.

This chapter deals with the procedure of experimental and fieldwork, which were carried out in order to classify the soil, measure the infiltration rate and prepare the land use and land cover map. The results were used to classify the soil, find out the curve number, and then estimate the surface direct runoff for the watershed that is studies in the next chapter.

٦.2 Watershed Boundary and Grid Setup

6.2.1 Watershed boundary

The watershed boundary was restricted by land surveying using (GPS) techniques especially navigation instrument (Magellan). The (GPS) techniques is more suitable than (GIS) for delineation watershed boundary because the study area is not large. The points of the boundary were taken from the field prepared into ArcGis.9 as shown in Table (6.1), and the boundary of the watershed appeared in Figure (6.1).

Table (6.1) : Coordinates of Wadi Su'd Watershed Boundary

NO	X-coordinate(m)	Y-coordinate(m)	NO	X-coordinate(m)	Y-coordinate(m)
0	153321	104112	29	155481	102807
1	153450	103786	30	155411	102916
2	153515	103646	31	155297	102960
3	153585	103552	32	155216	103008
4	153624	103459	33	155170	103020
5	153745	103338	34	155096	103072
6	153807	103239	35	155098	103130
7	153910	103154	36	155025	103238
8	154083	103101	37	154917	103232
9	154174	103222	38	154823	103288
10	154333	103100	39	154759	103342
11	154400	103101	40	154713	103518
12	154441	103014	41	154580	103653
13	154392	102940	42	154294	103830
14	154378	102828	43	154165	104367
15	154432	102731	44	153995	104367
16	154313	102712	45	153894	104477
17	154581	102615	46	153830	104527
18	154750	102657	47	153835	104664
19	154838	102676	48	153781	104687
20	154941	102643	49	153781	104716
21	154941	102643	50	153687	104795
22	155082	102550	51	153635	104749
23	155140	102603	52	153627	104789
24	155212	102614	53	153577	104768
25	155299	102661	54	153493	104718
26	155645	102628	55	153375	104669
27	155780	102654	56	153341	104574
28	155565	102722	57	153289	104495

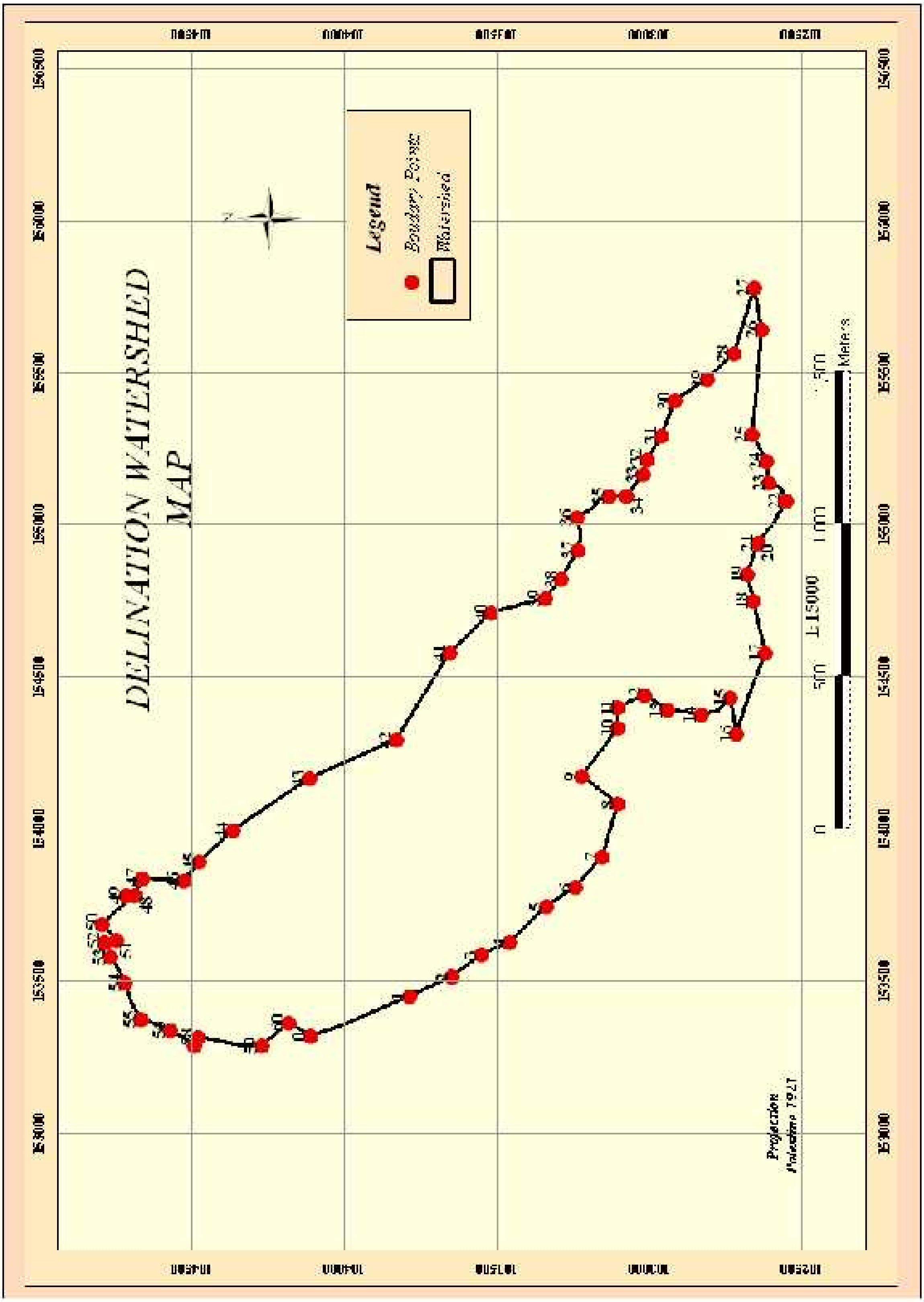


Figure (6.1): Boundary of Wadi Su'd Watershed

6.2.2 Grid setup

After the watershed delineation into the GIS, it is necessary to setup the grid of the field to conduct the experiments in suitable sites, and to choose the techniques for the infiltration test and to classify the soil.

The grid covers the watershed as shown in Figure (6.2) in order to:

1- Get some practical ideas concerning the infiltration rate, and its variation relative to the variation in spatial position.

2- Understand the influence of soil type variation on the infiltration rates, which were measured using a double ring infiltrometer, at total of (23) sites, representing different soil type, and land use types.

Navigation GPS used land surveying to setup the grid in the field. The grid was designed using ArcGis.9 and the coordinates of grid points in the Table (6.2).

Table (6.2): Coordinates of Grid Points

NO	X-coordinate(m)	Y-coordinate(m)	NO	X-coordinate(m)	Y-coordinate(m)
1	153562	104565	13	154764	103065
2	153562	104265	14	155064	103065
3	153862	104265	15	153862	103665
4	153562	103965	16	154162	103665
5	153862	103965	17	154461	103665
6	154162	103965	18	154861	103365
7	154461	102765	19	154162	103365
8	154764	102765	20	154462	103365
9	153562	103665	21	154752	103365
10	155064	102765	22	153254	104860
11	155364	102765	23	1555954	102467
12	154461	103065			

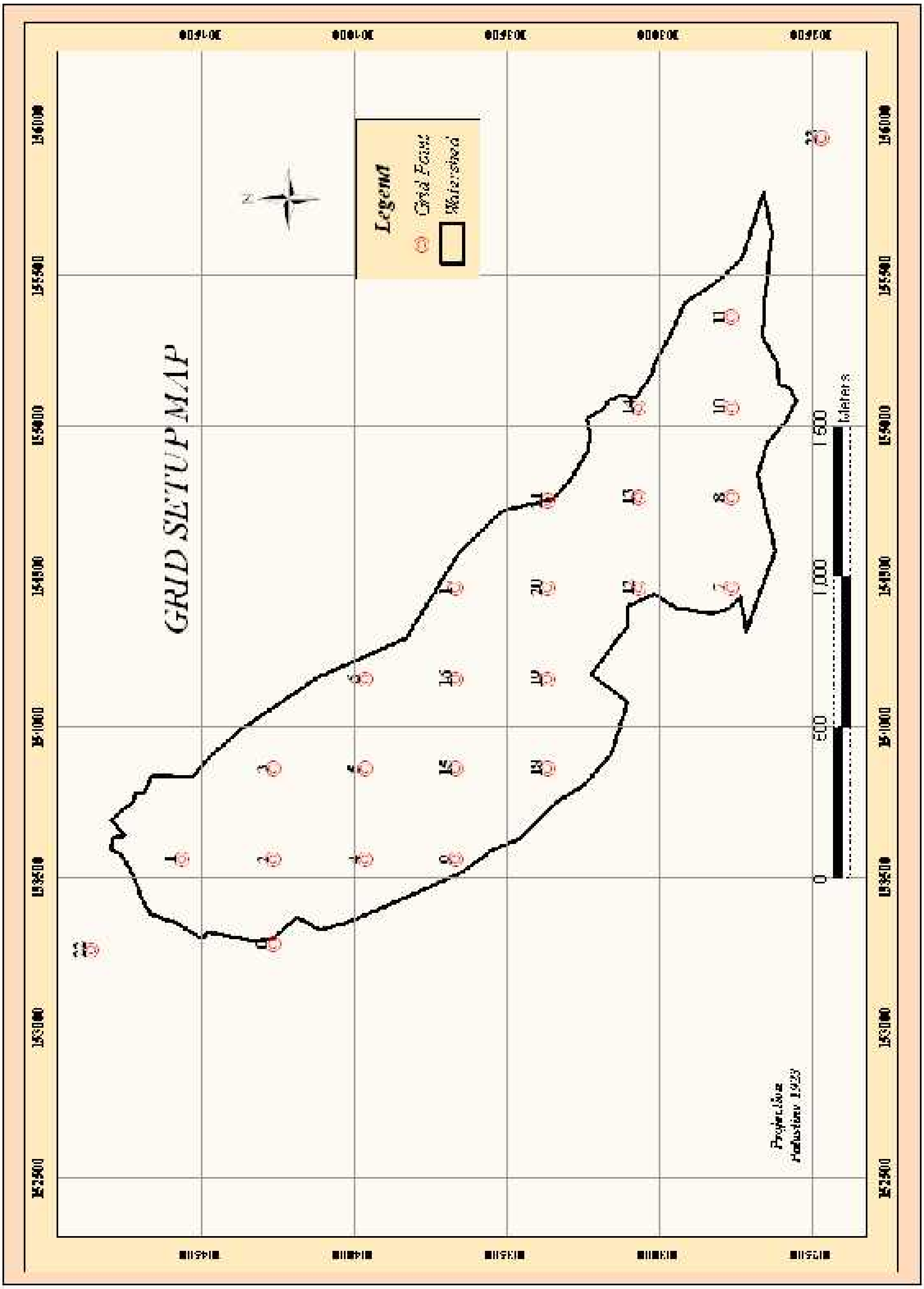


Figure (6.٢): Distribution of Grid Points

٦.3 Soil Tests

6.3.1 Introduction

Soil classification provides a systematic method of describing soils according to their probable engineering behavior. It involves classify soil into different groups, i.e. sand, clay, etc. There are many soils classification systems, but the most used are: the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) system.

The AASHTO system is using by transportation department and highways. And USCS system was modified in 1952, in order to make it suitable for dams, foundation and other construction projects. The USCS system will adopt in this project as it is related to dam's project. A sieve analysis and moisture content method will be used to classify the soil samples of the project.

For the purpose of the study, more than 50 samples of soil were collected from the study area and the experiment of sieve analysis and moisture contents were carried out in the Civil Engineering Department Laboratories.

6.3.2 Sieve analysis

Sieve analysis is consists of shaking the soil through a stack of wire screens with openings of known sizes; the definition of particle diameter for a sieve test is the side dimension of a square hole. The test procedure, which should be followed, depends on the soil in question. If nearly all its grains are so large that they cannot pass through square openings of 0.074 mm (No. 200 screen), the sieve analysis is preferable.

Test methodology

a) Equipment required

1. Set of sieves.
2. Brush (for cleaning sieves).
3. Balance (0.1 sensitivity).
4. Drying oven.
5. Large pane.

b) Method of work

1. Weigh to 0.1 g each sieve that is to be used. Make sure each sieve is clean before weighing it.
2. Select with care a test sample, which is representative of the soil to be tested; break the soil into its individual particles with by fingers or by a rubber tipped pestle.
3. Weigh to 0.1 g a specimen of approximately 500 g of oven-dried soil.
4. Sieve the soil through a nest of sieves with on hand, using a motion of horizontal rotation or using a mechanical shaker, if available. At least 10 minutes of hand sieving is desirable for soils with small particles.
5. Weigh to 0.1 g each sieve and the pan, with the soil retained on them.
6. Subtract the weights obtained in step 1 from step 5 to give the weight of soil retained on each sieve.
7. Percentage retained on and y sieve = $\frac{\text{wt. of soil retained} * 100}{\text{Total soil wt.}}$
8. Cumulative percentage retained on any sieve = sum of percentages retained on all coarser sieves.

9. Percentage finer than any sieve size = 100% - cumulative percentage retained.
10. Draw graph between log sieve sizes vs. % passed. The graph is known as the grain size distribution curve, which has been widely used in identification and classification. Corresponding 10%, 30%, and 60% passed, diameters obtained from the graph are designed as D_{10}, D_{30}, D_{60}. D_{10} is the grain size that corresponds to 10% of the samples pass by weight (10% of the particles are smaller than the diameter D_{10}), and so on D_{30}, D_{60}.
11. The coefficient of uniformity (Cu) and coefficient of curvature (Cc) are calculated as following :

$$Cu = \frac{D_{60}}{D_{10}} \quad \text{..........} \quad (6.1)$$

$$Cc = \frac{(D_{30})^2}{(D_{60})(D_{10})} \quad \text{..........} \quad (6.2)$$

More than 18 experiments were conducted in the laboratory. The results necessitated classifying the soil samples into three types:

a) Well graded sands.

b) Poorly graded sands.

c) Poor clay.

٦.4 Measurement of Infiltration

6.4.1 Introduction

One of the most important of catchment characteristics is the infiltration rate which is helped to classify the soil. It is usually measured by the depth in (mm) of the water layer that can be entered the soils in one hour (mm/hr).

Initial infiltration rate described dry soil where the water infiltrates rabidly. At the same time water replaces the air in the pores, and the water infiltrate become slowly and eventually reaches a steady rate which is called the basic infiltration rate. The size of soil particles (soil texture) and soil structure (the arrangement of the soil particles) control the infiltration rate.

6.4.2 Measurement of infiltration

Two methods are there in common use to measure infiltration rate:

1- Infiltrometer where the water is applied to the sample area.

2- Hydrograph analysis where the hydrograph of the observed runoff resulting from periods of natural rainfall on a watershed is studied and analyses.

One of the infiltrometer classification those in which the rate of infiltration is determined directly as the rate at which water must be applied to maintained constant depth.

٦.4.3 Double Rings Infiltrometer

A double ring infiltrometer is often used for measuring infiltration characteristics in the field, but the measurements using this are time consuming and tedious, especially when several tests are to be monitored at a site. This is because the infiltrometer in its present form requires continuous attention and therefore limits the number of tests that can be monitored at a site in a given time. An automated double ring infiltrometer has been developed to overcome these limitations. It consists of inner and outer rings, water level sensors, water container, depth sensor, solenoid valves, 12-volt car battery, laptop computer and software to perform recording and basic analysis of the infiltration data. The infiltrometer requires little attention once the test is started and the computer provides up-to-the-minute summary of infiltration results while the test is still in progress. The automated infiltrometer worked very satisfactorily during the field trials and has considerable potential as a research and teaching tool.

The ring shall be constructed of a stiff, corrosion resistant material such as metal, plastic or fiberglass. The shape of the rings can be square or circular with any size provided. There are two types of infiltrometer:

1- A single tube: A single tube has many disadvantages for example; the soil structure gets greatly disturbed when the tube is driven into the ground. The two concentric rings is the better method for this test.

2- Two concentric rings: Two concentric ring (double ring infiltrometer) made of mild steel and consisting of an outer ring of 60 cm dim. Moreover, inner rings of 30 cm dim as shown in Figure (6.3). Will use to measure the infiltration rates. The purpose of the outer ring is to eliminate the lateral spread of the water in the soil. Constant level of water should be maintained in both rings and then can be determined how long it will take to infiltrate a certain amount of water which is the infiltration rate.

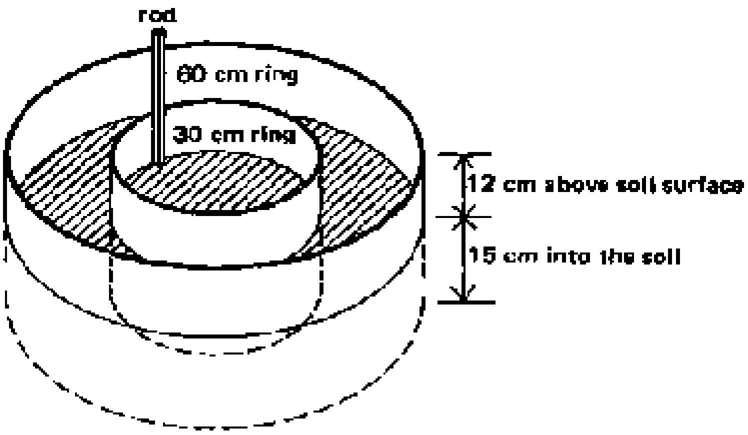


Figure (٦.3): Double Ring Infiltrometer

Test Methodology

(a) Equipment required

1- Shovel / hoe.

2. Hammer (2 kg).

3- Watch or clock.

4- 5 liter buckets.

5- Timber (75 × 75 × 400).

6- Hessian (300 × 300) or jute cloth.

7- At least 100 liters of water.

8- Ring infiltrometer of 30 cm inner diameter and 60 cm outer diameter. Instead of the outer cylinder, a bund could be made to prevent lateral water flow.

9- Measuring rod graduated in mm (e.g. 300 mm ruler).

(b) Method of work

The following steps show how to carry out the experiment of infiltration measurements in the field.

1- Hammer the 30 cm diameter ring at least 15 cm into the soil. Use the timber to protect the ring from damage during hammering. Keep the side of the ring vertical and drive the measuring rod into the soil so that approximately 12 cm is left above the ground.

2- Hammer the 60 cm ring into the soil or construct an earth bund around the 30 cm ring to the same height as the 30 cm ring and place the Hessian inside the infiltrometer to protect the soil surface when pouring in the water.

3- Start the test by pouring water into the inner ring until the depth is approximately 70-100 mm. At the same time, add water in the space between the two rings or the ring and the bund to the same depth. Do this quickly.

4- The water in the bund or within the two rings to prevent a lateral spread of water from the infiltrometer.

5- Record the clock time when the test begins and note the water level.

6- After 1-2 minutes, record the drop in water level in the inner ring on the measuring rod and add water to bring the level back to approximately the original level at the start of the test. Record the water level. Maintain the water level outside the ring similar to the level inside.

7- Continue the test until the drop in water level is the same over the same time interval. Take reading frequently (e.g. every 1-2 minutes) at the beginning of the test, but extend the interval between readings as the time foes on (e.g. every 20-30 minutes).

CHAPTER

٧ *ANALYSIS AND DISCUSSION OF RESULTS*

٧.١ General
٧.٢ Land Use and Land Cover
٧.٣ Soil Classification
7.4 Infiltration Rate
7.5 Estimation of Surface Runoff

PREVIEW

This chapter deals with the analysis and calculation of runoff, here in the systematic steps to implement the SCS curve number runoff method in GIS using the spatial analyst

CHAPTER SEVEN

ANALYSIS AND DISCUSSION OF RESULTS

7.1 General

After finishing all field and experimental work and preparing the needed maps, the annual runoff was calculated for the Wadi Su'd watershed. The calculation was done through the map calculator using grid data and ArcGis.9 Spatial Analyst Extension.

Grid system divides the surface on which they are distributed into a matrix of identically squared sized cells. Each cell is filled in with a number that stores the object's attribute value at that location.

There are many things that ArcGis.9 Spatial Analyst can do with grids. It can estimate values for an entire surface from a limited number of measured sample points. This process was used to interpolate the infiltration measurement.

ArcGis.9 spatial analyst deals with a map as matrix, map algebra is math applied to grid, so it is possible to add, subtract and multiply the maps because grids are geographically referenced array of numbers. By combining and analyzing the land use map with the hydrologic soil group map, we derived the curve number map, and the depth and volume of direct runoff for Wadi Su'd watershed in Dura were estimated. This chapter discusses the results of the work.

7.2 Land Use and Land Cover

The conventional land use\land cover map of the watershed was obtained by the land survey technique using (GPS), and digitized map from a rectified aerial photo for Wadi Su'd watershed. Boundaries of different land use class were digitized in the (ArcGis.9), and the attribute where linked to them. Three land use\land cover classes were categorized in the watershed (see Table (7.1) and Figure (7.1)). The land use and land cover map for Wadi Su'd watershed is shown in Figure (7.2).

Table (7.1): Classes of Land Use/Cover of the Study Area

Land Use	Area (m^2)	Percentage of Area %
Agricultural	1304954.00	69.82
Pasture	531652.10	28.45
Residential	32269.60	1.73
SUM	١٨٦٨٨٧٦	**100**

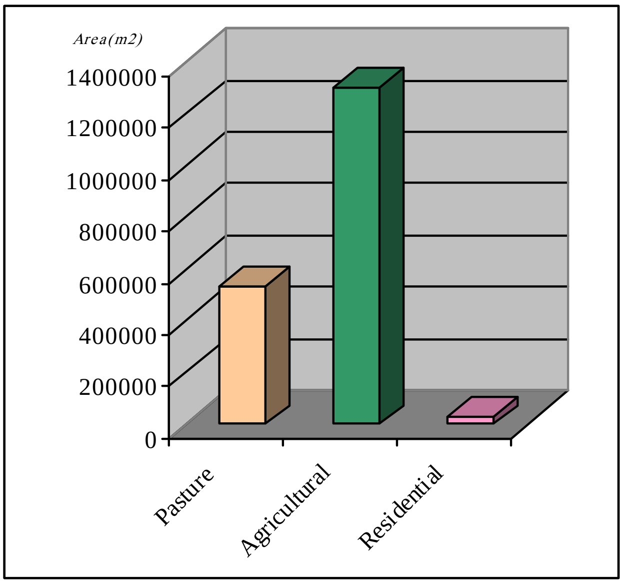


Figure (7.1): Classes of Land Use/Cover of the Study Area

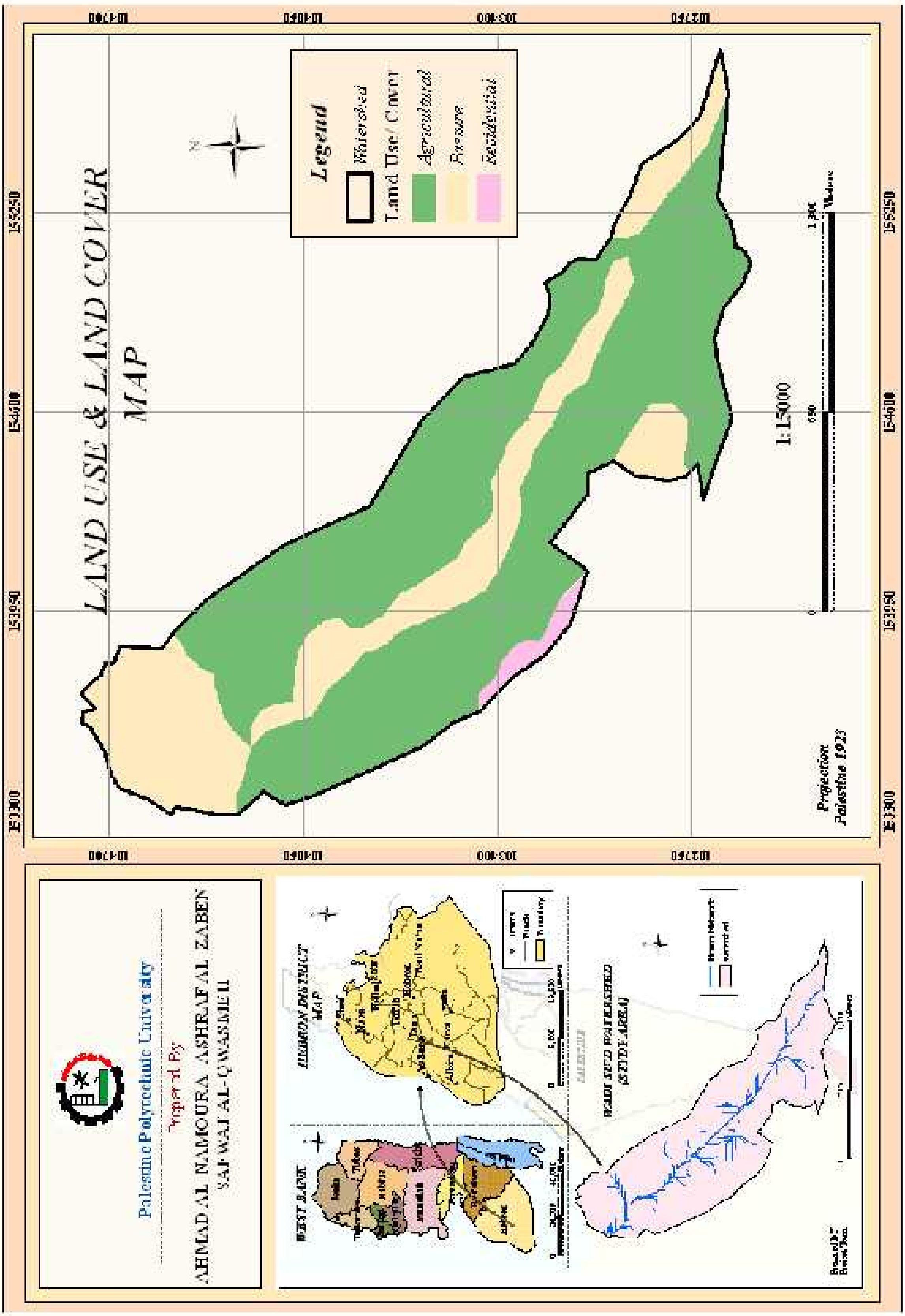


Figure (7.2): Land Use and Land Cover Map for Wadi Su'd Watershed

7.3 Soil Classification

According to laboratory soil testing result, the soil of Wadi Su'd watershed can be classified into three types; well-graded sand, poorly-graded sand and poor-clay, distributed at the watershed as shown in Table (7.2) and Figure (7.3). Poorly graded sand has high infiltration rate compared to well-graded sand and poor-clay. Soil classification map for Wadi Su'd watershed is presented in Figure (7.4).

Table (7.2): Classification of Soils in the Study Area

Soil classification	**Area (m^2)**	**Percentage of Area %**
Poor-Clay	940969.5	50.3٥
Well-Sand	824475.2	44.1١
Poor-Sand	103431.2	5.5٤
SUM	١٨٦٨٨٧٦	**100**

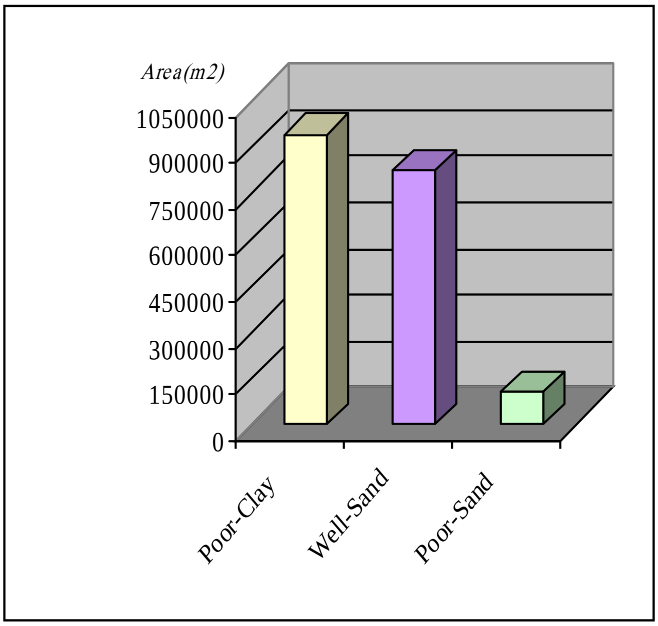


Figure (7.3): Classification of Soil in the Study Area

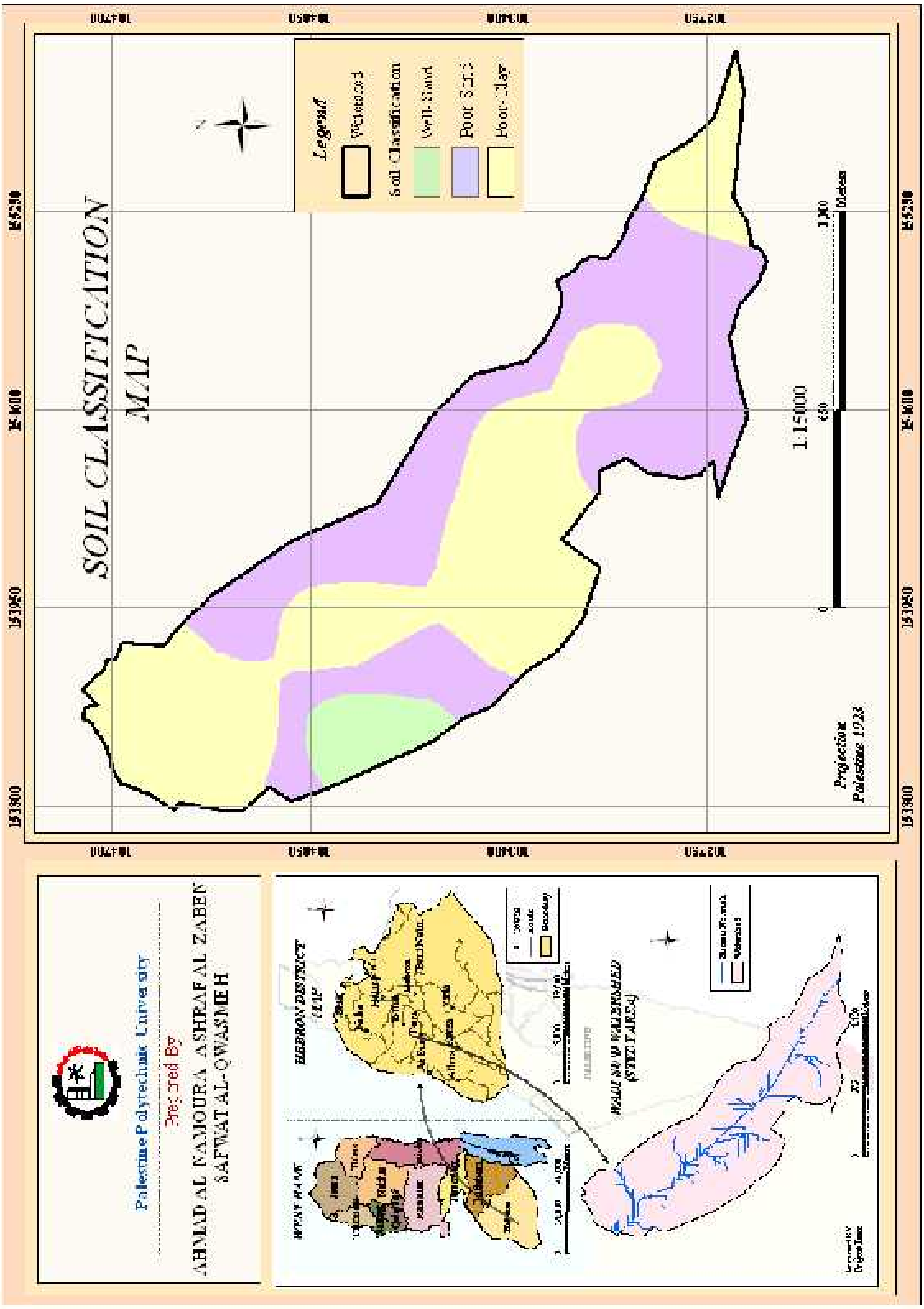


Figure (7.4): Soil Classification Map for Wadi Su'd Watershed

7.4 Infiltration Rate

The measured values of infiltration rates, using a Double Ring Infiltrometer (DRI) at 23 sites covering different land use types, are presented in Table (7.3).

Figure (7.3): Infiltration Values of Grid Points

NO	X-coordinate (m)	X-coordinate (m)	Infiltration Rate (mm/hr)
1	153562	104565	0
2	153562	104265	0
3	153862	104265	108
4	153562	103965	240
5	153862	103965	0
6	154162	103965	140
7	154461	102765	100
8	154764	102765	110
9	153562	103665	195
10	155064	102765	108
11	155364	102765	18
12	154461	103065	130
13	154764	103065	29
14	155064	103065	150
15	153862	103665	84
16	154162	103665	90
17	154461	103665	140
18	154861	103365	36
19	154162	103365	0
20	154462	103365	0
21	154752	103365	120
22	153254	104860	0
23	1555954	102467	10

After that, the infiltration measurements were interpolated using (Spline) Method. Point interpolation estimates the values of all locations on a surface from a limited number of sample data points. The logic of the process is that spatially distributed objects are spatially correlated. Interpolation can be used to estimate unknown values for any geographic point data you have: elevation, rainfall and so on. ArcGis.9 offer three different interpolation methods: Spline, IDW and Kriging.

Spline method estimates grid cell values by fitting a minimum curvature surface to resample data. It is like a flexible sheet of plastic that passes through each data point but otherwise bends as little as possible.

Inverse Distance Weighted (IDW) estimates grid cell values by averaging of sample data points near the cell. The closer point to the center of the cell being estimated, the more influence or weight it has in the averaging process.

Kriging is a complex procedure that requires greater knowledge about spatial statistics than can be conveyed in this command reference. Before using Kriging you should have a thorough understanding of the fundamentals of Kriging and have assessed the appropriateness of your data for modeling with this technique.

These methods produced good estimates, but neither estimates unknown value with perfect accuracy. Better results will be obtained if more sample data are present and have effective distribution over the study area. The Interpolation operation that applied into ArcGis.9 using Spline and the values of infiltration rate for Wadi Su'd watershed is shown in Figure (7.5).

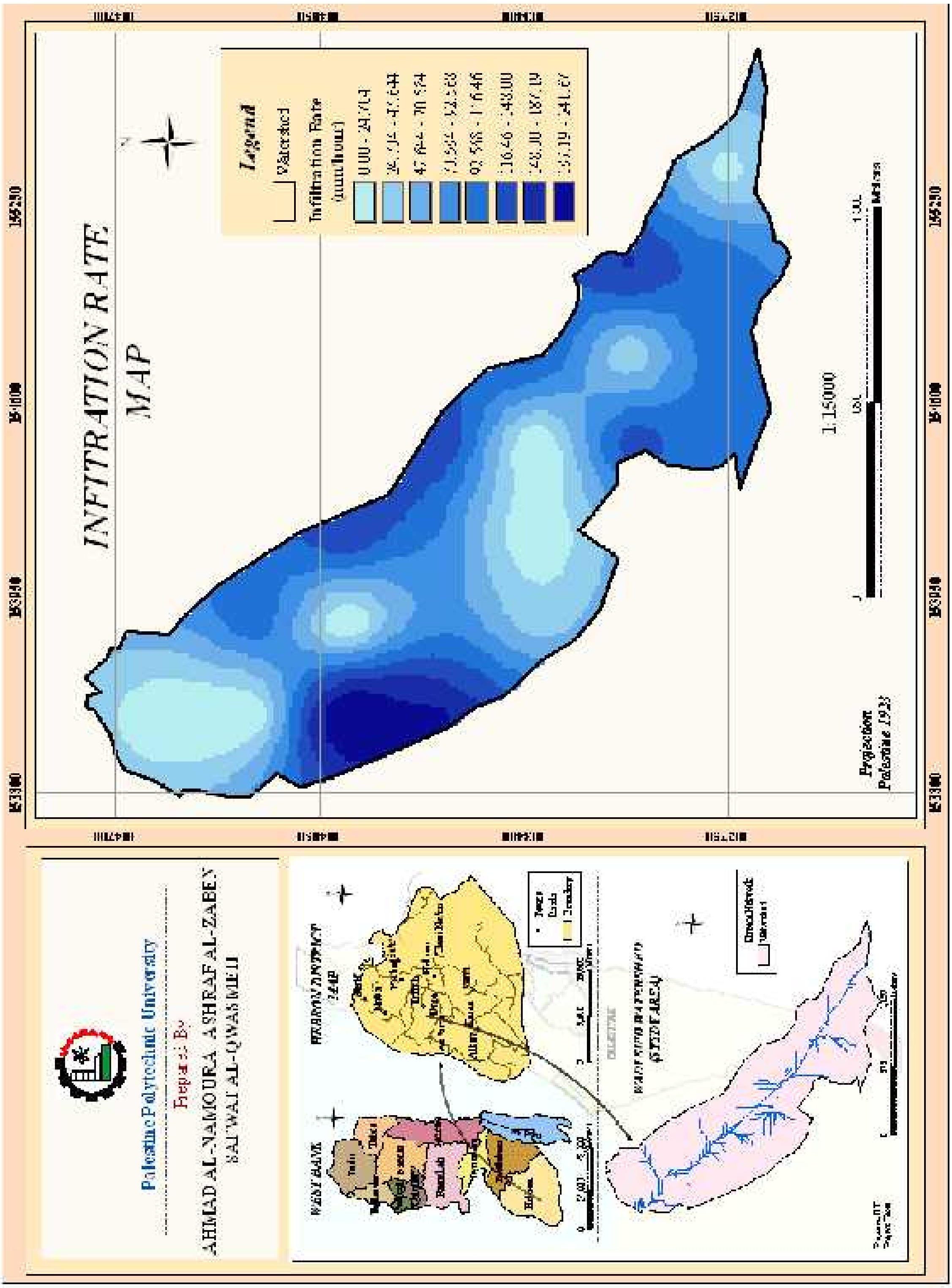


Figure (7.5): Infiltration Rate Map for Wadi Su'd Watershed

7.5 Estimation of Surface Runoff

7.5.1 Introduction

The surface runoff in the West Bank, which occurs on the dry riverbeds in winter after heavy rainfall, is sporadic. The rainfall intensity, duration of the rainfall storm, land use, soils; elevation, surface slope and the shape of the catchment are the deciding factors.

The non existence of surface water bodies in the study area limits the runoff to the overland flow, therefore, whenever the term runoff is used it referrers to the surface runoff (Qannam, 2003).

The measurements of the runoff in the West Bank are very rare and the majority of the available data is only estimations, e.g. 7-14 % of the annual rainfall (Rofe and Raffety, 1963), and 5 % (Gvirtzman, 1994). Wadi Su'd watershed (study area) is not gauged; therefore, to estimate the surface runoff for this watershed the US Soil Conservation Service method (SCS) were applied.

In the SCS method a basic parameter to be calculated is the curve number (CN), the value of which depends mainly on the, hydrological soil group, and antecedent moisture class. The results of these parameters for Wadi Su'd watershed are described below; and the values of curve number are calculated and used for estimating the runoff depth and volume for the study area.

7.5.2 Hydrological soil group classification

By using the interpolated layer, soil were classified into three categories (hydrological soil groups). The data of infiltration rates were divided into three groups: Group C (0-80) mm/hr, Group B (80-160) mm/hr and Group A (160-240) mm/hr based on grade condition of the soil (poorly or well graded). This logical condition is applied in ArcGis.9, and the hydrologic soil group classification are given in Table (7.4) and displayed in Figure (7.6). The final map of hydrologic soil group for Wadi Su'd watershed is shown in Figure (7.7).

Table (7.4): Classification of Hydrological Soil Group

Hydrologic Soil Group	Area (m^2)	Percentage of Area %
Group (C)	940969.5	50.3٥
Group (B)	824475.2	44.1١
Group (A)	103431.2	5.5٤
SUM	١٨٦٨٨٧٦	**100**

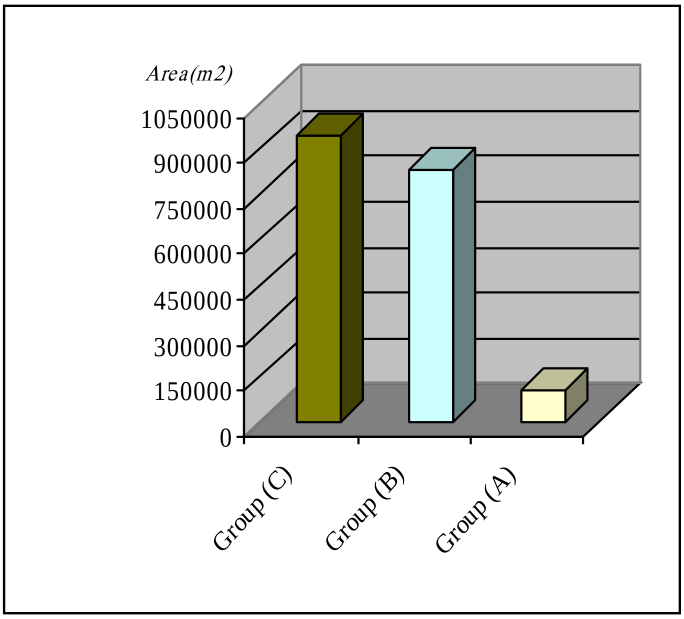


Figure (7.6): Classification of Hydrological Soil Group

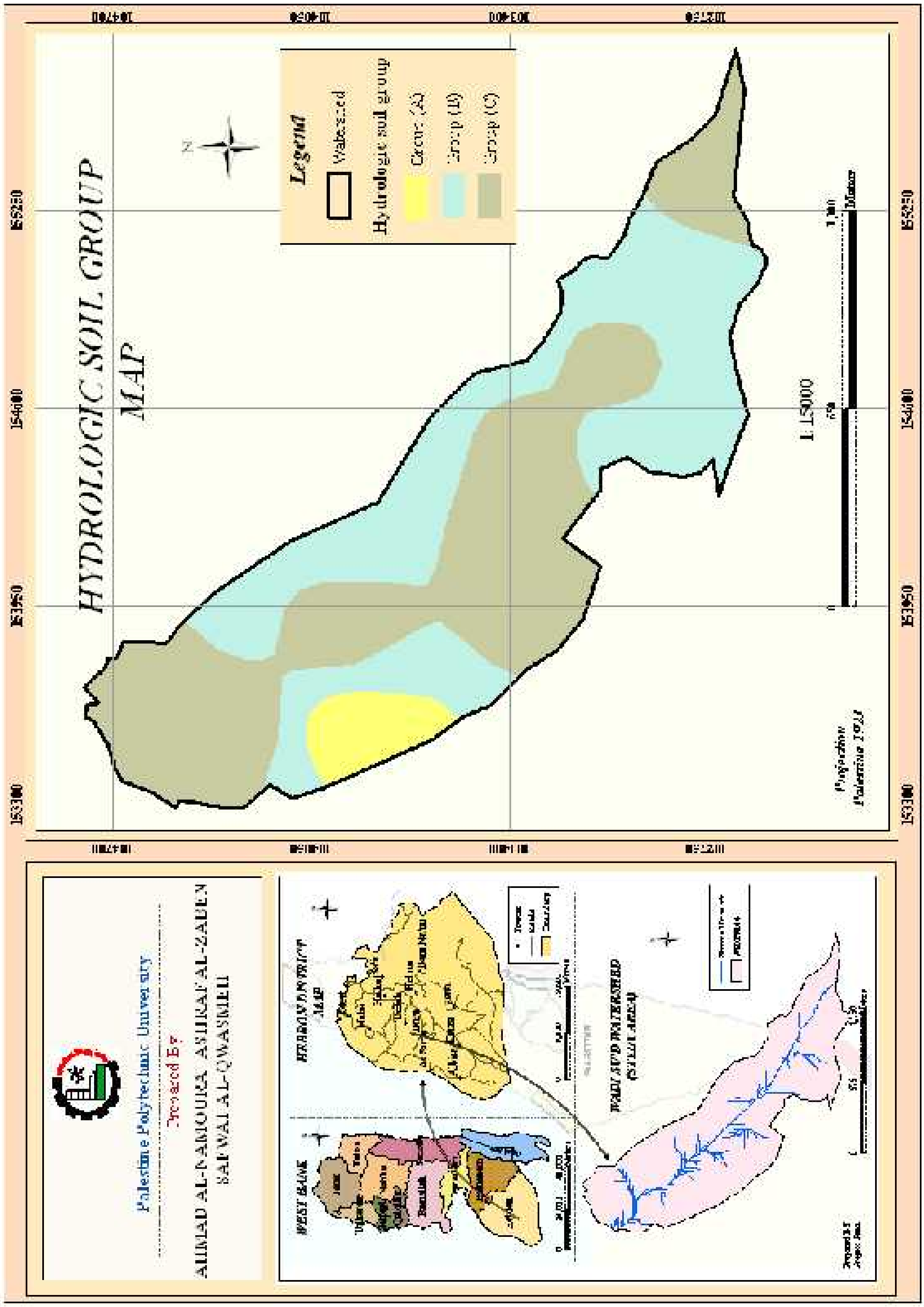


Figure (7.7): Hydrological Soil Group Map for Wadi Su'd Watershed

7.5.3 Estimation of curve number

To create and detect the curve number values for each classified area; the hydrological soil group and the land use results were used. By applying expression in ArcGis.9 and evaluating this expression, the curve number can be determined. The values of curve number for each area are presented in Table (7.5) and displayed in Figure (7.8). The curve number map for Wadi Su'd watershed shown in Figure (7.9).

Table (7.5): Values of Curve Number (CN)

Land Use	Hydrologic Soil Group	*(CN)*	Area(m^2)	Percentage of Area %
Agricultural	(A)	64	100180.64	5.36
	(B)	75	728884.60	39.00
	(C)	82	478424.62	25.59
Pasture	(A)	39	650.00	0.06
	(B)	61	92179.01	4.93
	(C)	74	438516.30	23.46
Residential	(B)	70	4941.31	0.26
	(C)	80	25100.50	1.34

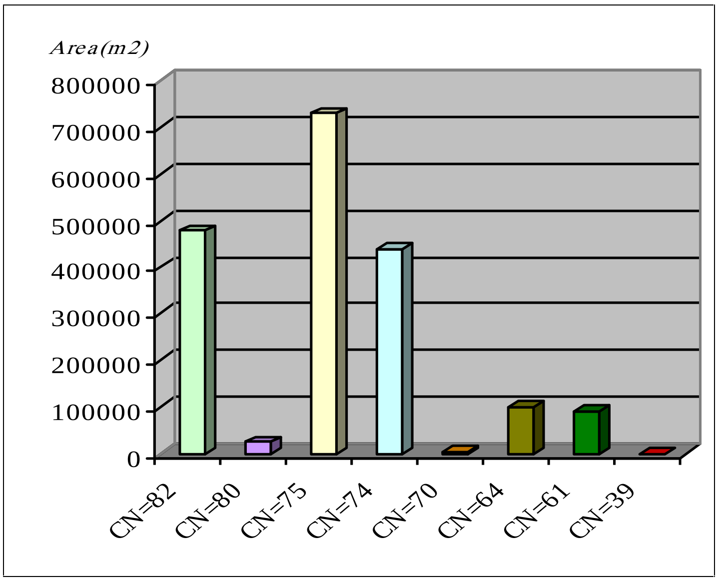


Figure (7.8): Values of Curve Number

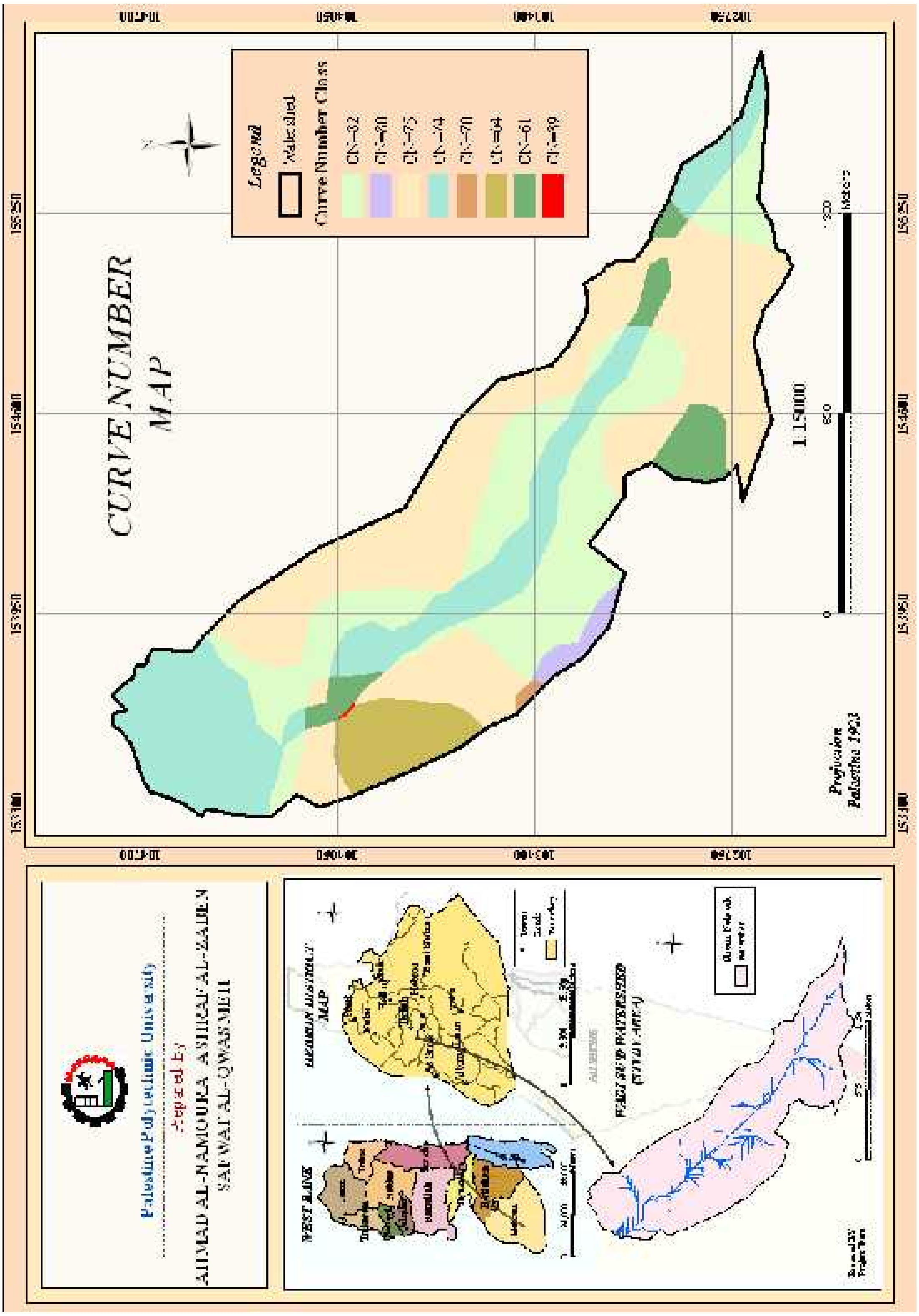


Figure (7.9): Curve Number Map for Wadi Su'd Watershed

Based on the data given in Table (7.5), the composite curve number was found by using the following equation

$$CN = \frac{\sum A_i * CN_i}{\sum A_i} \qquad \text{.......(7.1)}$$

Where:

CN : Composite curve number

A_i : Area for each curve number

CN_i : Curve number

The composite curve number for the study area (Wadi Su'd watershed) is:

$$CN = \frac{140761110.50}{1868876.00} = 75$$

The CN is rounded 75 as the normal condition (AMCII), CN for the other two condition; the dry condition (AMCI) and the wet condition (AMCIII) were obtained using equations (5.7) and (5.8)

$$CN_{(I)} = \frac{4.2 * 75}{10 - (0.058 * 75)} = 57$$

$$CN_{(III)} = \frac{23 * 75}{10 + (0.13 * 75)} = 88$$

The values of curve number for the three antecedent moisture conditions are listed in Table (7.6)

Table (7.6): Curve Number for Three Antecedent Moisture Conditions

AMC	I	II	III
CN	57	75	88

7.5.4 Rainfall data

Although the average annual rainfall recorded at Dura Meteorological Station for the period 2000 –2006 is 500 mm, there are considerable variations in the quantity of the annual rainfall from year to year. The maximum recorded annual rainfall was 645.3 mm in 2002/2003 season, while the minimum was 287.8 mm in 2005/2006 season as shown in Figure (7.10).

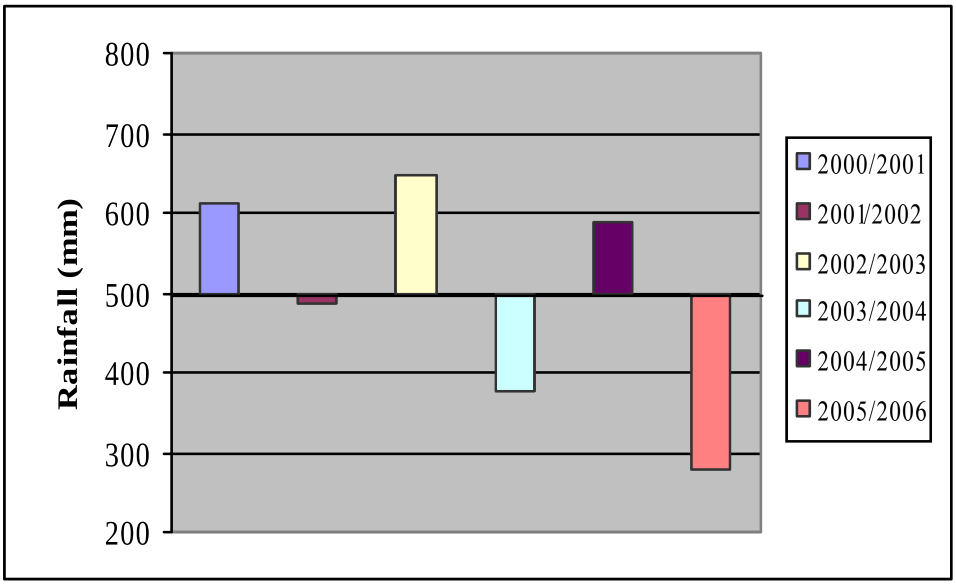


Figure (7.10): The Annual Rainfall Variation at the Dura Meteorological Station during the Period (2000 – 2006)

Generally, the wet season in the area of Wadi Su'd stretch over eight months (October to May). But most of the rain falls during the period (November to April). About two thirds of the rainfall amount falls between December and February as shown in Figure (7.11).

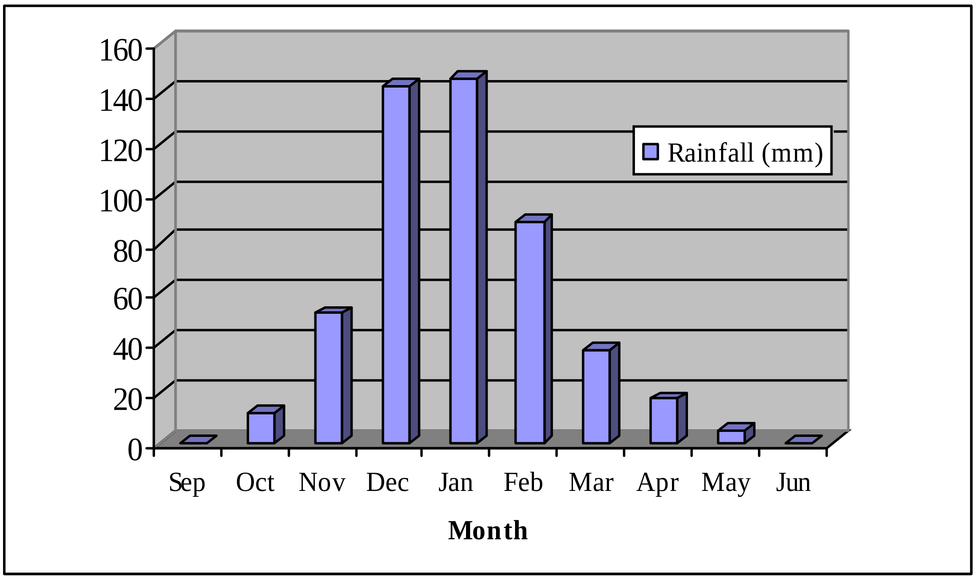


Figure (7.11): The Average Monthly Rainfall Recorded at the Dura Meteorological Station during the Period (2000 – 2006)

7.5.5 Rainfall and runoff analysis

To calculate the surface runoff depth, apply the hydrological equations (5.5) and (5.6). These equations depend on the value of rainfall (P) and watershed storage (S) which calculated from adjusted curve number. Thus, before applying equation (5.5) the value of (S) should be determined for each antecedent moisture condition (AMC) as shown below.

There are three conditions:

1- For normal condition (AMC II) the rainfall must be greater than initial abstraction ($P > I$) and else the runoff equal zero. Here,

$$S = (\frac{1000}{75} - 10) * 25.4 = 84.667 \text{ mm}$$

$I = 0.2\ S = 0.2 * 84.667 = 16.933$ mm

Then, the runoff occurs when $P > 16.933$ mm.

2- For dry condition (AMC I) the rainfall must be greater than initial abstraction (P >I) and else the runoff equal zero. Here,

$$S = (\frac{25400}{57} - 254) = 191.614 \text{ mm}$$

$I = 0.2\ S = 0.2 * 191.614 = 38.322$ mm

Then, there will be a runoff if $P > 38.322$ mm.

3- For wet condition (AMC III) the rainfall must be greater than initial abstraction (P >I) and else the runoff equal zero. Here,

$$S = (\frac{25400}{88} - 254) = 34.636 \text{ mm}$$

$I = 0.2\ S = 0.2 * 34.636 = 6.927$mm

Then, when $P > 6.927$ mm there will be a runoff occurs.

These results are summarized in the Table (7.7)

Table (7.7): Values Used in Hydrological Equations

AMC	CN	S	P>0.2S
I	57	191.614	38.322
II	75	84.667	16.933
III	88	34.636	6.927

The Rainfall data and the result of surface runoff depth for the last five rainfall seasons in the study area are tabulated in the Tables: (7.8), (7.9), (7.10), (7.11), (7.12) and (7.13).

Table (7.8): Runoff Depth in the Study Area for Season (2000/2001)

Year	Months	Day	Storm Rainfall (mm)	Antec.Rainfall (mm)	AMC	(CN)	(S)	Runoff by Day (mm)
2000/2001	**10**	16	5	0	I	57	191.614	0
		21	2.9	5	I	57	191.614	0
		24	3.3	2.9	I	57	191.614	0
		25	2	6.2	I	57	191.614	0
		26	10.4	8.2	I	57	191.614	0
	11	29	1.8	0	I	57	191.614	0
	12	1	10	1.8	I	57	191.614	0
		2	7	11.8	I	57	191.614	0
		9	9.2	0	I	57	191.614	0
		10	18.8	9.2	I	57	191.614	0
		12	3.4	28	III	88	34.636	0
		13	16	31.4	III	88	34.636	1.883
		14	20	47.4	III	88	34.636	3.582
		16	1.7	39.4	III	88	34.636	0
		20	3.6	1.7	I	57	191.614	0
		21	54.6	5.3	I	57	191.614	1.274
		23	10	58.2	III	88	34.636	0.250
		25	75	68.2	III	88	34.636	45.117
		26	15	139.6	III	88	34.636	1.525
	1	3	1	0	I	57	191.614	0
		6	3.7	1	I	57	191.614	0
		20	43.8	0	I	57	191.614	0.152
		23	6	43.8	III	88	34.636	0
		24	20.6	49.8	III	88	34.636	3.869
		25	98.6	70.4	III	88	34.636	66.534
		27	26	125.2	III	88	34.636	6.772
	2	4	0.5	0	I	57	191.614	0
		5	25	0.5	I	57	191.614	0
		6	6.4	25.5	II	75	84.666	0
		8	17.6	31.9	III	88	34.636	2.514
		15	6.4	0	I	57	191.614	0
		16	4	6.4	I	57	191.614	0
		17	3	10.4	I	57	191.614	0
		18	9.5	13.4	II	75	84.666	0
		21	15.2	16.5	II	75	84.666	0
		22	13.7	27.7	II	75	84.666	0
	3	10	5.5	0	I	57	191.614	0
		24	8.6	0	I	57	191.614	0
	4	8	3.4	0	I	57	191.614	0
	5	2	11.2	0	I	57	191.614	0
		3	11	11.2	I	57	191.614	0
SUM		**41**	**610.4**					**133.472**

Table (7.9): Runoff Depth in the Study Area for Season (2001/2002)

Year	Months	Day	Storm Rainfall (mm)	Antec.Rainfall (mm)	AMC	(CN)	(S)	Runoff by Day (mm)
2001/2002	**10**	27	2.3	0	I	57	191.614	0
		28	1	2.3	I	57	191.614	0
		29	2.8	3.3	I	57	191.614	0
	11	7	4.6	0	I	57	191.614	0
		17	3.9	0	I	57	191.614	0
		18	12.5	3.9	I	57	191.614	0
		22	7.2	16.4	II	75	84.666	0
		24	3.2	7.2	I	57	191.614	0
		26	2.5	10.4	I	57	191.614	0
	12	1	3.6	0	I	57	191.614	0
		5	46	3.6	I	57	191.614	0.295
		6	21	49.6	III	88	34.636	4.065
		15	3.5	0	I	57	191.614	0
		20	37	3.5	I	57	191.614	0
		21	10.3	37	III	88	34.636	0.299
	1	3	22	0	I	57	191.614	0
		4	2.7	22	II	75	84.666	0
		8	47	24.7	II	75	84.666	7.879
		9	40	49.7	III	88	34.636	16.15
		10	20.5	87	III	88	34.636	3.821
		12	2.4	107.5	III	88	34.636	0
		20	19	0	I	57	191.614	0
		21	18.7	19	II	75	84.666	0.036
		23	16.3	37.7	III	88	34.636	1.996
		29	30.2	0	I	57	191.614	0
		30	14	30.2	III	88	34.636	1.199
	2	10	11.5	0	I	57	191.614	0
		12	15.3	11.5	I	57	191.614	0
		13	20.5	26.8	II	75	84.666	0.144
		27	2.4	0	I	57	191.614	0
	3	20	2.2	0	I	57	191.614	0
		28	16.7	0	I	57	191.614	0
		30	20	16.7	I	57	191.614	0
	4	21	5	0	I	57	191.614	0
	5	15	4.8	0	I	57	191.614	0
SUM		**35**	**492.6**					**35.884**

Table (7.10): Runoff Depth in the Study Area for Season (2002/2003)

Year	Months	Day	Storm Rainfall (mm)	Antec.Rainfall (mm)	AMC	(CN)	(S)	Runoff by Day (mm)
2002/2003	**10**	16	3	0	I	57	191.614	0
		20	4.5	3	I	57	191.614	0
		30	9	0	I	57	191.614	0
		31	10	9	I	57	191.614	0
	11	5	5	10	I	57	191.614	0
		12	3.2	0	I	57	191.614	0
		23	4	0	I	57	191.614	0
		24	2.4	4	I	57	191.614	0
		29	4.5	2.4	I	57	191.614	0
	12	9	15	0	I	57	191.614	0
		10	31.5	15	II	75	84.666	2.138
		11	44	46.5	III	88	34.636	19.166
		12	4.5	90.5	III	88	34.636	0
		15	2	80	III	88	34.636	0
		17	13	6.5	I	57	191.614	0
		18	10.5	15	II	75	84.666	0
		20	90.6	25.5	II	75	84.666	34.274
		21	11	114.1	III	88	34.636	0.428
		22	1	125.1	III	88	34.636	0
		23	25	113.1	III	88	34.636	6.196
		25	9	127.6	III	88	34.636	0.117
		26	2.5	46	III	88	34.636	0
		30	8	11.5	I	57	191.614	0
	1	3	7.1	8	I	57	191.614	0
		14	3	0	I	57	191.614	0
		15	13	3	I	57	191.614	0
		18	3.8	16	II	75	84.666	0
		19	4.5	19.8	II	75	84.666	0
		20	29.3	21.3	II	75	84.666	1.576
		21	3.3	37.6	III	88	34.636	0
	2	4	6	0	I	57	191.614	0
		8	14	6	I	57	191.614	0
		14	42.2	0	I	57	191.614	0.076
		15	15.5	42.2	III	88	34.636	0
		21	5	0	I	57	191.614	0
		22	4	5	I	57	191.614	0
		23	3	9	I	57	191.614	0
		28	60	3	I	57	191.614	2.203
	3	7	11	0	I	57	191.614	0
		11	3	11	I	57	191.614	0
		12	23	14	I	57	191.614	0
		18	3.5	0	I	57	191.614	0
		20	7	3.5	I	57	191.614	0
		21	3	10.5	I	57	191.614	0
		22	5	13.5	I	57	191.614	0
		24	18	15	I	57	191.614	0

		25	10	33	I	57	191.614	0
	4	15	2.5	0	I	57	191.614	0
		20	2.2	2.5	I	57	191.614	0
		21	2.5	2.2	I	57	191.614	0
		26	13	2.5	I	57	191.614	0
		27	14.7	13	II	75	84.666	0
SUM		**52**	**645.300**					**66.174**

Table (7.11): Runoff Depth in the Study Area for Season (2003/2004)

Year	Months	Day	Storm Rainfall (mm)	Antec.Rainfall (mm)	AMC	(CN)	(S)	Runoff by Day (mm)
2003/2004	**12**	2	7.5	0	I	57	191.614	0
		4	11.3	7.5	I	57	191.614	0
		6	3.9	18.8	II	75	84.6667	0
		15	9	0	I	57	191.614	0
		18	63.2	9	I	57	191.614	2.858
	1	8	24.5	0	I	57	191.614	0
		9	18.5	24.5	II	75	84.666	0.028
		13	25.5	43	III	88	34.636	6.482
		14	39.7	44	III	88	34.636	15.933
		15	38.6	65.2	III	88	34.636	15.129
		23	6	0	I	57	191.614	0
		27	2	6	I	57	191.614	0
		28	11.5	8	I	57	191.614	0
	2	1	15	13.5	II	75	84.666	0
		2	4	26.5	II	75	84.666	0
		5	10	19	II	75	84.666	0
		6	3.5	29	III	88	34.636	0
		15	15	0	I	57	191.614	0
		16	11	15	II	75	84.666	0
		19	7.5	26	II	75	84.666	0
		20	8.4	33.5	III	88	34.636	0.060
		22	14.1	15.9	II	75	84.666	0
	3	6	9	0	I	57	191.614	0
		7	13.5	9	I	57	191.614	0
		14	1.5	0	I	57	191.614	0
		15	1	1.5	I	57	191.614	0
SUM		**26**	**374.700**					**40.490**

Table (7.12): Runoff Depth in the Study Area for Season (2004/2005)

Year	Months	Day	Storm Rainfall (mm)	Antec.Rainfall (mm)	AMC	(CN)	(S)	Runoff by Day (mm)
2004/2005	**10**	29	10	0	I	57	191.614	0
	11	17	31	0	I	57	191.614	0
		19	10	31	III	88	34.636	0.250
		22	27.5	41	III	88	34.636	7.666
		23	87.8	37.5	III	88	34.636	56.622
		27	49.7	115.3	III	88	34.636	23.634
	12	7	9	0	I	57	191.614	0
		8	6	9	I	57	191.614	0
		16	15.5	0	I	57	191.614	0
		25	28	0	I	57	191.614	0
	1	3	36.6	0	I	57	191.614	0
		4	29	36.6	III	88	34.636	8.591
		6	47	65.6	III	88	34.636	21.494
		24	45	0	I	57	191.614	0.224
	2	5	4	0	I	57	191.614	0
		7	20	4	I	57	191.614	0
		8	24	24	II	75	84.666	0.544
		9	23.6	48	III	88	34.636	5.417
		11	13	67.6	III	88	34.636	0.905
		12	11	80.6	III	88	34.636	0.428
	3	8	12.1	0	I	57	191.614	0
		9	26	12.1	I	57	191.614	0
		10	8	38.1	II	75	84.666	0
		11	4	46.1	II	75	84.666	0
	4	3	8	0	I	57	191.614	0
		4	4	8	I	57	191.614	0
SUM		**2٦**	**589.800**					**12٥.٧٧٥**

Table (7.13): Runoff Depth in the Study Area for Season (2005/2006)

Year	Months	Day	Storm Rainfall (mm)	Antec.Rainfall (mm)	AMC	(CN)	(S)	Runoff by Day (mm)
2005/2006	**10**	20	4.3	0	I	57	191.614	0
	11	5	4	0	I	57	191.614	0
		6	8.5	4	I	57	191.614	0
		7	8.5	12.5	I	57	191.614	0
		15	2.6	0	I	57	191.614	0
		16	2	2.6	I	57	191.614	0
		20	1.6	4.6	I	57	191.614	0
		21	23	3.6	I	57	191.614	0
	12	17	5	0	I	57	191.614	0
		23	21	0	I	57	191.614	0
		25	42.7	21	II	75	84.666	6.012
	1	4	3.2	0	I	57	191.614	0
		13	26	0	I	57	191.614	0
		14	2	26	II	75	84.666	0
		16	3.5	28	III	88	34.636	0
		17	9	31.5	III	88	34.636	0.117
		18	6	40.5	III	88	34.636	0
		27	4	0	I	57	191.614	0
		28	2.5	4	I	57	191.614	0
	2	3	15	0	I	57	191.614	0
		14	6.2	0	I	57	191.614	0
		15	15	6.2	I	57	191.614	0
		17	10	21.2	II	75	84.666	0
	3	10	12.5	0	I	57	191.614	0
	4	1	23	0	I	57	191.614	0
		4	3.2	23	I	57	191.614	0
		5	18.5	26.2	I	57	191.614	٠
		16	3.5	0	I	57	191.614	0
		24	1.5	0	I	57	191.614	0
SUM		**2٩**	**287.8**					**6.129**

7.5.6 Predict of runoff volume

As a result of the calculations, based on the SCS method, it was found that the average annual surface runoff rate (depth) for the last five years in Wadi Su'd watershed is equal to 68 mm multiple by the area of the watershed ($A=1868877m^2$) gives the total average volume of runoff as ($127,083.6\ m^3$), which represents 13.6 % of the total annual rainfall. The annual rainfall and runoff during (2000-2006) in the study area are shown in Table (7.14) and represented in Figure (7.12).

Table (7.14): The Average Annual Runoff Depth and Volume in the Study Area.

Years	Total Rainfall (mm)	Total Runoff (mm)	Runoff Percentage	Volume (m^3) Runoff × Area
2000/2001	٦١٠.٤	١٣٣.٤	٢١.٨	249442.6
2001/2002	492.6	35.8	٧.٢	67062.7
2002/2003	645.3	66.1	١٠.٢	123671.0
2003/2004	374.7	40.4	١١.٦	75670.7
2004/2005	589.8	12٥.٧	٢١.٣	235057.8
2005/2006	287.8	6.1	٢.١	11454.3
Average	**500**	**68**	**١٣.٦**	**١٢٧٠٨٣.٦**

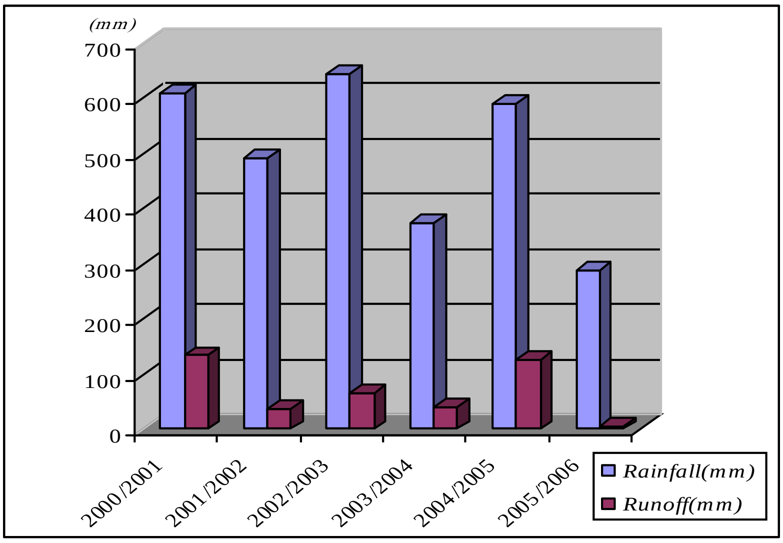


Figure (7.12): The Annual Rainfall and Runoff during (2000-2006) in the Study Area.

The direct runoff in Wadi Su'd watershed (study area) resulting from a given precipitation and antecedent moisture condition can be estimated using an appropriate curve number shown in Figure (7.13).

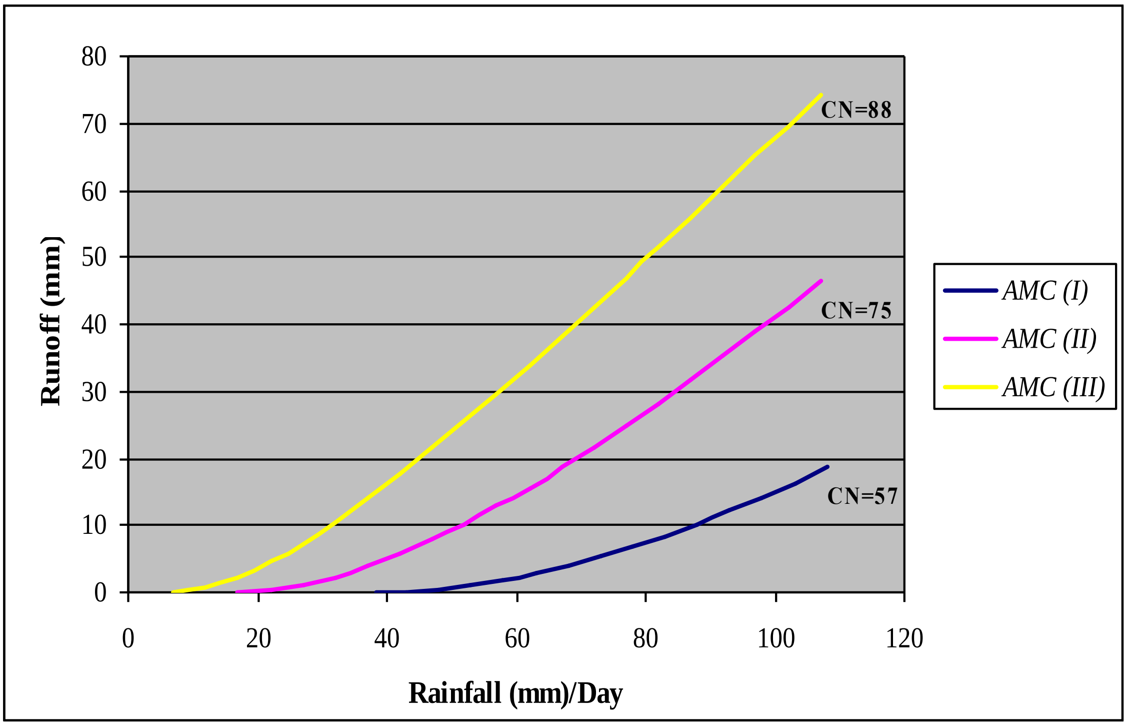


Figure (7.13): Estimation Direct Runoff Amounts from Storm Water.

7.5.7 Water balance in Wadi Su'd watershed

The final result in this study determine the water balance parameters of Wadi Su'd watershed in Dura area whereas the precipitation (500 mm/year) is the main input parameter in the water balance and the measured infiltration (80 mm/year), estimated runoff (68 mm/year) and calculated evaporation (352 mm/year) are the major output parameters. The results of water budget in the study area are shown in Figure (7.14).

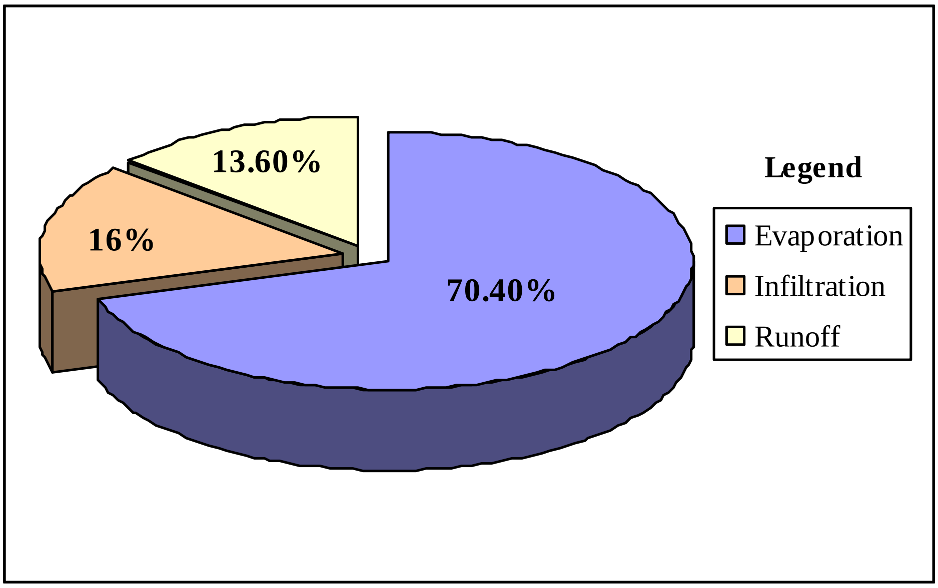


Figure (7.14): Water Balance of Wadi Su'd Watershed

CHAPTER

٨ *CONCLUSIONS AND RECOMMENDATIONS*

8.1 Conclusions
8.2 Recommendations

PREVIEW

In the previous chapters, were discussed the problem of the project, hydrological models, Soil type and spatial hydrology., the conclusions will presents according to the results obtained from the field in the final report.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

In this project an attempt is made to study the hydrologic features of Wadi Su’d watershed in Dura area of the West Bank and estimate the amount of runoff from same watershed were the records of runoff is not available. Many methods can be used to determine the runoff from ungaged watershed. Soil Conservation Service (SCS) Curve Number method is a simple, widely use and efficient method for determining the amount of runoff from a rainfall even in a particular area. In the present study, the method was used to estimate the direct surface runoff from Wadi Su’d watershed and with the help of Geographical Information System (GIS). The main conclusions drawn from the present study are:

1) Since there were no runoff observations available from this watershed, the results could not be compared with the measured values.

2) Three land use/land cover classes were categorized in Wadi Su'd watershed (see Figure 7.1), namely; agricultural, pasture and residential.

3) The experimental results of the soil classification show that the soil of Wadi Su'd watershed can be classified into three types; well graded sand, poorly graded sand and poorly-clay, distributed at the watershed as shown in Figure (7.3).

4) The measured values of infiltration rates, using Double Ring Infiltrometer for Wadi Su'd watershed show that the infiltration rates are comparatively high and ranges between 0-250 mm/hour as presented in Figure (7.6).

5) The results of soil classification, infiltration rates and land use were used to determine the hydrology soil groups and the corresponding curve numbers for normal, dry and wet conditions in order to estimate the runoff from Wadi Su'd watershed. The study were classified into three hydrologic soil groups as shown in Table (7.4) and displayed in Figure (7.8). The composite curve number for normal condition is 75, where for the dry and wet conditions are 57 and 88 respectively.

6) The calculations and results, based on the SCS method, shows that the average annual runoff depth for the last five years in Wadi Su'd watershed is equal to 68mm, and if the total area of the watershed is 1868877 m^2, the total volume of water that can be collected is around 127083.6 cubic meter, which represents 13.6 % of the total annual rainfall.

7) The results determined the water balance parameters for Wadi Su'd watershed as, precipitation 500mm (100%), evaporation 352mm (70.4%), infiltration 80mm (16%) and surface runoff 68mm (13.6%).

8) In the present project, the methodology for determination of runoff for Wadi Su’d using GIS and SCS method was described. This approach could be applied in other Palestinian watersheds for planning of various conservations measures.

8.2 Recommendations

There are many important points that can be recommended:

1- This project is very important for Dura city to solve the water shortage problem. So it is recommended to build up a small dam in this watershed for collection of water runoff.

2- The results obtained can not compare to any measured values due to the absence of any gauge measurements in this watershed. Setting-up water gauges in the watershed will help in compare the results between the measured valued and the data obtained from SCS curve number method, and apply the same method in other watersheds.

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APPENDIX – (A)

Soil Classification and Infiltration Measurement

Soil classification using sieve analysis method:

To classify a sample of soil of (1000 gm.): sample # 14

Sieve number or size in mm	Wt. Retained in each sieve (gm0	Cumulative Wt. retained on each sieve (gm)	Pass (gm)	% Finer
4	208.0	208.0	792	79.2
10	157.0	365.0	843	63.5
20	262.8	627.8	737.2	37.22
40	143.3	771.1	856.7	22.89
60	71.9	843.0	928.1	15.7
140	86.5	929.5	913.5	7.05
200	24.7	954.2	975.3	4.58
Pan	45.8	1000	954.2	0.0

✓ **Calculations:-**

1- Cumulative wt. =w1+w2= 208.0 + 157.0 =365.0 gm. and so on.

2- Pass = w-(w1-w2) = 1000 – 365.0 = 635 gm.

3- % Finer = w-(w1+w2)/w*100 =(1000-365.0)/500*100 = 63.5%.

4- From the grain size distribution curve below:

D10 =0.15, D30=0.81, D60=2

5- From the equations (6.1) and (6.2):

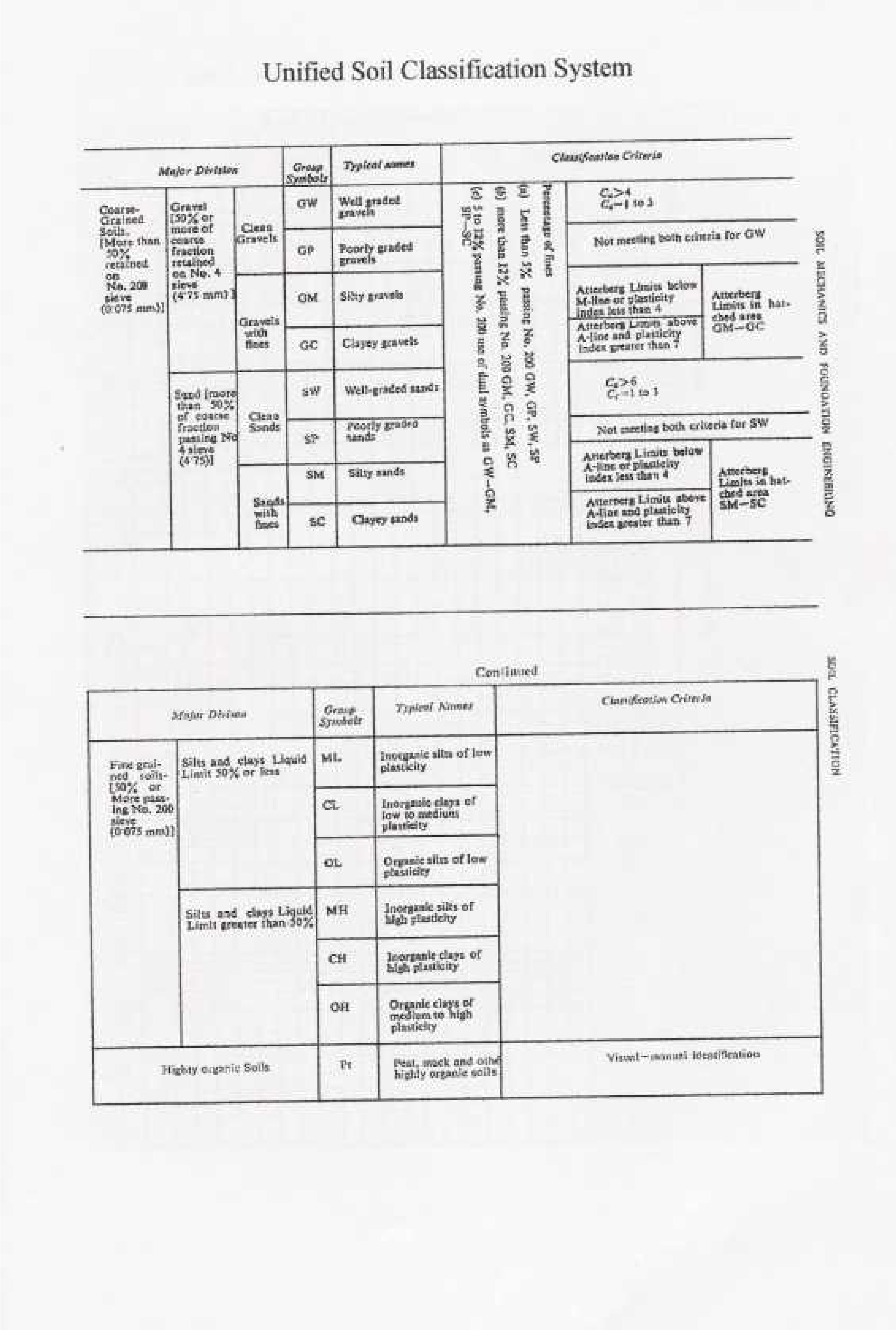
$$Cu = \frac{2}{0.15} = 13.3$$

$$Cc = \frac{(0.81)^2}{(0.15)(2)} = 2.19$$

6- From the table (United Soil Classification System):

Soil Type (well graded sand)

APPENDIX – (A)



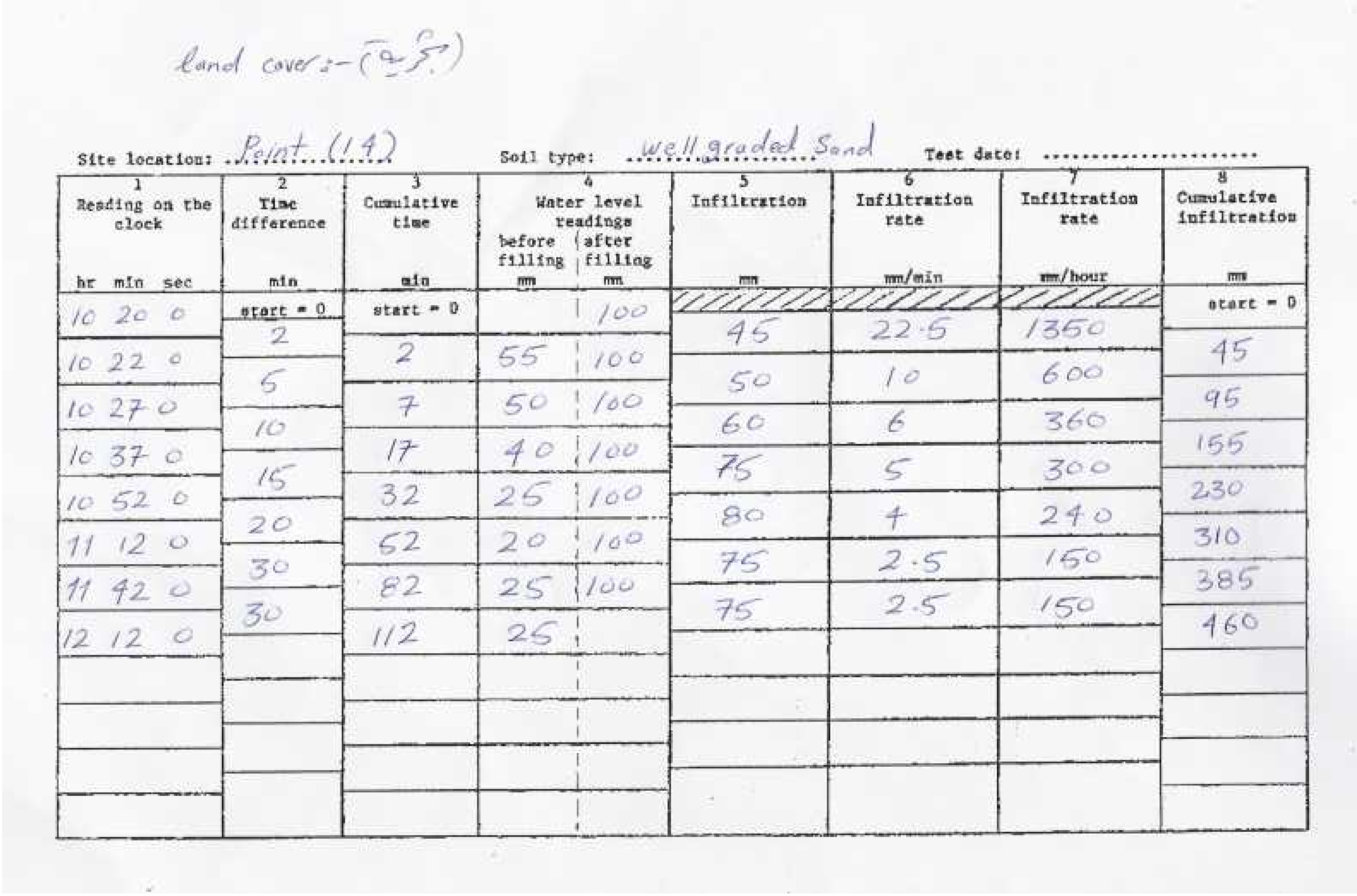
Unified Soil Classification System

Major Division			*Group Symbols*	*Typical names*	*Classification Criteria*		
Coarse-Grained Soils. [More than 50% retained on No. 200 sieve (0·075 mm)]	Gravel [50% or more of coarse fraction retained on No. 4 sieve (4·75 mm)]	Clean Gravels	GW	Well graded gravels	Percentage of fines (a) Less than 5% passing No. 200 GW, GP, SW, SP (b) more than 12% passing No. 200 GM, GC, SM, SC (c) 5 to 12% passing No. 200 use of dual symbols as GW–GM, SP–SC	$C_u > 4$ $C_c = 1$ to 3	
			GP	Poorly graded gravels		Not meeting both criteria for GW	
		Gravels with fines	GM	Silty gravels		Atterberg Limits below M-line or plasticity index less than 4	Atterberg Limits in hatched area GM–GC
			GC	Clayey gravels		Atterberg Limits above A-line and plasticity index greater than 7	
	Sand [more than 50% of coarse fraction passing No 4 sieve (4·75)]	Clean Sands	SW	Well-graded sands		$C_u > 6$ $C_c = 1$ to 3	
			SP	Poorly graded sands		Not meeting both criteria for SW	
		Sands with fines	SM	Silty sands		Atterberg Limits below A-line or plasticity index less than 4	Atterberg Limits in hatched area SM–SC
			SC	Clayey sands		Atterberg Limits above A-line and plasticity index greater than 7	

Continued

Major Division		*Group Symbols*	*Typical Names*	*Classification Criteria*
Fine grained soils-[50% or More passing No. 200 sieve (0·075 mm)]	Silts and clays Liquid Limit 50% or less	ML	Inorganic silts of low plasticity	
		CL	Inorganic clays of low to medium plasticity	
		OL	Organic silts of low plasticity	
	Silts and clays Liquid Limit greater than 50%	MH	Inorganic silts of high plasticity	
		CH	Inorganic clays of high plasticity	
		OH	Organic clays of medium to high plasticity	
Highly organic Soils		Pt	Peat, muck and other highly organic soils	Visual–manual identification

Infiltration Data



land cover:- ([illegible])

Site location: Point (14) Soil type: well graded Sand Test date: ....

1 Reading on the clock hr min sec	2 Time difference min	3 Cumulative time min	4 Water level readings before filling mm	 after filling mm	5 Infiltration mm	6 Infiltration rate mm/min	7 Infiltration rate mm/hour	8 Cumulative infiltration mm
10 20 0	start = 0	start = 0		100	▨	▨	▨	start = 0
10 22 0	2	2	55	100	45	22.5	1350	45
10 27 0	5	7	50	100	50	10	600	95
10 37 0	10	17	40	100	60	6	360	155
10 52 0	15	32	25	100	75	5	300	230
11 12 0	20	62	20	100	80	4	240	310
11 42 0	30	82	25	100	75	2.5	150	385
12 12 0	30	112	25		75	2.5	150	460

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Appendix- (A)