DETERMINATION OF RUNOFF CURVE NUMBER AND SEDIMENT YIELD FOR SUGARCANE GROWN ON A SOIL WITH DIFFERENT GRADES

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT
(CIVIL)

By

ANUBHAV CHAUDHARY

DEPARTMENT OF WATER RESOURCES DEVELOPMENT AND MANAGEMENT
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE -247 667 (INDIA)
JUNE, 2013

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation, entitled, **"DETERMINATION OF RUNOFF CURVE NUMBER AND SEDIMENT YIELD FOR SUGARCANE GROWN ON A SOIL WITH DIFFERENT GRADES"**, in partial fulfilment of the requirements for the award of the degree of **Master of Technology** in **"Water Resources Development (Civil)"**, submitted in the Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during a period from July 2012 to June 2013 under the supervision of Dr. S.K. Mishra, Associate Professor, Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee, India.

The matter presented in this dissertation has not been submitted by me for the award of any other degree of this or any other Institute.

Date: June 6 , 2013
Place: DWRD&M, IIT Roorkee

(ANUBHAV CHAUDHARY)
Enrollment No. 11548007

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Dr. S.K. Mishra)
Associate Professor
Department of Water Resources Development and Management
Indian Institute of Technology
Roorkee – 247 677

Date: June 10 , 2013

ABSTRACT

Runoff is one of the most important variables used in planning and design of hydraulic structures, and therefore, a number of models for its computation from a given rainfall event have been developed. The Soil Conservation Service Curve Number (SCS-CN) method is one of the most popular event-based methods and is widely used for estimation of direct surface runoff for a given storm rainfall event from small watersheds. This method is well established in hydrologic engineering. The primary reason for its wide applicability lies in the fact that it accounts for most runoff producing watershed characteristics: soil type, land use, surface condition and antecedent moisture condition. The only parameter of this methodology, i.e. the Curve Number (CN), is crucial for accurate runoff prediction.

Evidently, most studies have concentrated on the application of the existing SCS-CN method utilizing CN derived from NEH-4 tables or using GIS for watershed characteristics. No systematic effort appears to have been made for experimental verification of the effect of watershed slope and land use on CN, particularly for Indian watersheds. Thus employing the in-situ rainfall-runoff data, the present study derives parameter CN of the SCS-CN methodology for the experimental plots (size: 22 m x 5 m) of different slopes (viz., 1%, 3%, and 5%) and land use of sugarcane located in Roorkee, Uttarakhand, India. As expected, the plot of 5% slope yielded the largest runoff and, in turn, CN compared to those due to the plots of 3% and 1% grades, for the same rainfall, soil, and land use. The CN values derived from the observed data for AMC II condition and for three grades of 1%, 3% and 5% are 86.00, 88.25, and 91.42 for natural rainfall datasets. The derived CN values are fairly close to those from NEH-4 CN-values, supporting the applicability of NEH-4 CN values to Indian watersheds. CN was seen to continually increase with rainfall to a peak value and then decreased for all three grades of field plots, indicating all field plots to fall in violent category of watersheds.

Another crucial and important aspect of soil erosion deals with the removal of soil from land surface by wind or water. When rain drop falls on a surface, the soil particles are splashed. Higher is the velocity of impact, greater is the amount of soil splashed. The detached soil particles are then carried further, either by runoff or wind. This whole process is known as erosion, and sediment yield from a watershed is the resulting output of the erosion process. Thus, the process of rainfall-runoff-sediment yield in a watershed is a very complicated phenomenon that is controlled by a large number of known and unknown climatic, geologic and physiographic factors that vary both in time and space. In the present experimental work, an attempt has been made to determine event-based sediment yield using the model derived from coupling the SCS-CN method with Universal Soil Loss Equation (USLE).

As expected, the plot of 5% slope yielded the largest sediment yield compared to those due to the plots of 3% and 1% grades, for the same rainfall, soil, and land use. To signify the role of antecedent moisture content (θo), the present study explored the existence of its relationships with SCS-CN model parameter potential maximum retention (S) (or CN) (used for determination of runoff) and with potential soil loss (A) (used for determination of sediment yield) by using in-situ experimental data. A and S were found to increase and decrease, respectively, with increasing θo, and vice versa.

ACKNOWLEDGEMENT

It is my proud to express my sincere thankfulness to Dr. S.K. Mishra, Associate Professor, Water Resources Development and Management, Indian Institute of Technology, Roorkee for his valuable guidance and infilling support for the completion of this dissertation work. I am highly obliged to him for his keen interest, able guidance and encouragement throughout the work. I still remember, despite of his road accident (around 17 Nov to 20 Nov 2012), he came to the experimental farm, even in injured condition to instruct and observe the experimental work and that really encouraged and motivated me. Working under his guidance was a privileged and an excellent learning experience that I will take pleasure in for life time.

I would like to express my special thanks to Dr. Ashish Pandey, Assistant Professor, IITR; Dr. R. P. Pandey, Scientist 'F', National Institute of Hydrology, Roorkee; and Dr. Ambrish Kumar Tiwari, Principal Scientist (SWCE), Central Soil and Water Conservation Research and Training Institute, Dehradun, India for their assistance by feeding technical information regarding the experimental works.

I would like to extend my grateful thanks to the Professor and Head Dr. Deepak Khare, Department of Water Resources Development and Management, Indian Institute of Technology Roorkee and to all faculty members and staffs in this department for their kind guidance and support. I would like to thank all the friends, colleagues for their co-operation; good wishes; and encouragement throughout the hard working days.

I also sincerely express my gratitude to the Indian National Committee on Surface Water (Formerly INCOH) under Ministry of Water Resources, Govt. of India, New Delhi for funding this study through the R&D project on "Experimental Verification of SCS- Runoff Curve Numbers for Selected Soils and Land Uses", of which Dr. S.K. Mishra is the Principal Investigator.

I am short of words to express my feelings for all my family members' emotional support and adoring care at various stages. I am extremely grateful to my wife Asmita, and my lovely daughters Astha and Ashma for their persuasive inspiration, love, affection and patience throughout the study.

A motto “Nothing can stop us”, written on a hording board of Army Cantonment (Roorkee), along the way to experimental farm, really encouraged me to work hard in experimental field throughout the monsoon as well winter season, during rainfall to capture data.

Lastly, the greatest of my gratitude is towards the Almighty for giving me the power to fulfill the promises. All the efforts that could be made in this study have been possible by the grace of God who is the Generator, Operator and Destroyer of the world.

(Anubhav Chaudhary)

Enroll. No. 11548007

CONTENTS

LIST OF FIGURES

Figure No. Title Page

LIST OF TABLES

LIST OF NOTATIONS

A = Potential maximum erosion

AMC = Antecedent Moisture Condition (AMC I for dry, AMC II for normal, and AMC III for wet soil)

C = Runoff coefficient

CN = Curve Number

DR = Sediment delivery ratio

f = Infiltration rate

f_c = Minimum infiltration rate

I_a = Initial abstraction

Kg = Kilogram

Lps = Liter per second

LS = Slope length and steepness factor

M = 5-day antecedent moisture

m = meter

min = minute

mm = Millimeter

MUSLE = Modified Universal Soil Loss Equation

NEH = National Engineering Handbook

NRCS = National Resources Conservation Service

ORG = Ordinary Raingauge

P = Precipitation

P5 = 5-day antecedent precipitation amount

Q = Direct surface runoff

Qcomp = Computed direct surface runoff

Qobs = Observed direct surface runoff

R = Rainfall erosivity factor

RUSLE = Revised Universal Soil Loss Equation

S I = International System of Units

S = Potential maximum retention

S1 = Potential maximum retention for AMC1

SCS = Soil Conservation Service

SCS-CN = Soil Conservation Service Curve Number

SRRG = Self Recording Raingauge

TDR = Time Domain Reflectometry

T_p = Storm duration

US = United States

USDA = United States Department of Agriculture

USLE = Universal Soil Loss Equation

Vw = Volume of water

VWC = Volumetric Water Content

Y = Total sediment yield

Ycomp = Computed sediment yield

Yobs = Observed sediment yield

θ_o = Antecedent moisture amount

λ = Initial abstraction coefficient

% = Percentage

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The Soil Conservation Service (now known as Natural Resource Conservation Service, NRCS) Curve Number (SCS-CN) method is widely accepted for predicting surface runoff in small agricultural watersheds because of its simplicity, and the limited number of parameters required for runoff prediction (Ponce and Hawkins 1996). This method, used for estimation of direct surface runoff from storm rainfall, is well established in hydrologic engineering and environmental impact analyses (Ponce and Hawkins, 1996; Mishra and Singh 2003b; Mishra et al. 2006a). The method was developed in 1954 by the USDA-SCS, is described in the National Engineering Handbook Section 4: Hydrology (NEH-4), and is widely available elsewhere as well (Mishra and Singh 2003). The only parameter of this methodology, i.e. the Curve Number (CN), is crucial for accurate runoff prediction.

Based on the exhaustive field investigations carried out in the United States, CNs were derived for different land uses, soils, hydrologic condition, and management practices (SCS 1964; Chow et al. 1988; Pilgrim and Cordery 1993), and therefore, represent the runoff response characteristic of a drainage basin (SCS 1956; Mishra and Singh 2003). In spite of its apparent simplicity, the application of CN-procedure leads to a diversity of interpretations and confusion due to ignorance about its limitations (Hawkins 1979; Bosznay 1989; Hjelmfelt 1991; Pilgrim & Cordery 1993).

There are a few models (Sharpley and Williams 1990, and Huang et al. 2006) which incorporate the watershed slope in determination of CN to improve the estimation of surface runoff depth and volume (Huang et al. 2006). According to Sharpley and Williams (1990), CN can be adjusted for slope as follows:

$$\mathrm{CN2}\alpha = 1/3\ (\mathrm{CN3} - \mathrm{CN2})\ (1 - 2\ e^{-13.86\ \alpha}) + \mathrm{CN2} \tag{1.1}$$

where CN2α is the value of CN2 for a given slope; CN2 and CN3 are CN for antecedent moisture condition II (average) and III (wet), respectively; and α (mm^{-1}) is the slope of watershed. According to Huang et al. (2006),

$$\mathrm{CN2}\alpha = \mathrm{K} \times \mathrm{CN2} \tag{1.2}$$

where,

$$K = \frac{322.79+15.63\ \alpha}{\alpha+323.52} \tag{1.3}$$

The SCS–CN method has also been used in association with erosion models for computation of sediment yield. The popular erosion models employing the SCS-CN methodology include the Modified Universal Soil Loss Equation (MUSLE) (Williams 1975), Agricultural Non Point Source Model (AGNPS) (Young et al. 1987), SWAT (Arnold et al. 1993, 1998), Erosion-Productivity Impact Calculator (EPIC) (Williams et al. 1983) among others. The SCS-CN method also has some weak points, such as it does not consider the impact of rainfall intensity and its temporal distribution, it does not address the effects of spatial scale, it is highly sensitive to changes in values of its parameter, and it lacks in clearly guiding on how to vary AMC (Hawkins 1993; Ponce and Hawkins 1996).

Water, wind, and ice are the primary agents of soil erosion, with water being the most prominent of them (Mishra and Singh, 2003). The rainfall-runoff-generated soil erosion and, in turn, sediment yield are of vital concern to the fields of soil conservation and agriculture engineering. One factor which has received justifiable interest in studies of soil erosion process is the rainfall energy which is a function of rainfall intensity and antecedent moisture among others. Soil erosion process occurs when soil is exposed to rainfall and flowing water. It involves three stages: (i) detachment, (ii) transport, and (iii) deposition of soil (Meyer and Wischmeier 1969).

Most studies have concentrated on the application of the existing SCS-CN method utilizing CN derived from NEH-4 tables or using GIS for watershed characteristics. No systematic effort has been made for experimental verification of the effect of watershed slope and land use on CN, particularly for Indian watersheds. Thus, the objective of this experimental field plot study is to investigate the effect of slope on runoff and, in turn, CN for given rainfall and soil. Such a development would help refine the CN values for more accurate runoff prediction.

In this study, the effect of in-situ antecedent moisture content (θo) has been evaluated on runoff (or CN) and sediment yield by correlating θo with CN and potential soil loss (A) of Universal Soil Loss Equation (USLE). The requisite data of runoff and sediment yield have been derived from experimental field plots of three different slopes (1%, 3%, and 5%) having sugarcane crops.

1.2 OBJECTIVE OF THE STUDY

Although SCS-CN method has been applied successfully throughout the world, its predictive capability has not been tested systematically for Indian watersheds. Thus, the main objectives of the study are as follows:

i. To determine CN for different grades of plots having sugarcane.
ii. To investigate the effect of watershed slopes on CN for sugarcane.
iii. To investigate the applicability of NEH-4 CN values to field plots with sugarcane.
iv. To determine and investigate the effect of slope on sediment yield for sugarcane.
v. To suggest a procedure for CN estimation with aid of field measurements for natural as well artificial events.

1.3 ORGANISATION OF DISSERTATION

The contents of dissertation are divided into six chapters. A brief account of the chapter-wise contents is given as follows:

Chapter 1:	This chapter introduces briefly the SCS-CN methodology for runoff computation and its coupling with USLE for sediment yield determination.
Chapter 2:	It reviews the literature relevant to the study. Besides presenting a brief review of the SCS-CN method, the chapter also discusses the relevant aspects of soil erosion and sediment yield reported by various researchers.
Chapter 3:	It describes the methodology / procedure for the experimental work, and devices used to accomplish the work.
Chapter 4:	It describes the experimental set up required for this study and data collection for observation of rainfall-runoff and sediment yield.
Chapter 5:	It discusses the available data, effect of slope, soil moisture content, and watershed response etc. on rainfall-generated runoff and sediment yield.
Chapter 6:	It summarizes the important conclusions drawn from the study.

CHAPTER 2

LITERATURE REVIEW

2.1 SCS – CN METHOD

A large number of methods/models are available in hydrologic literature to simulate the complex process of rainfall – runoff in a watershed. One of the most widely used methods is the SCS – CN method (SCS, 1956). This method computes the surface runoff volume for a given rainfall event from small agricultural, forest, and urban watersheds (SCS, 1986). The method is simple to use and requires basic descriptive inputs that are converted to numeric values for estimation of watershed direct runoff volume (Bonta, 1997). A 'curve number' that is descriptive of runoff potential of watershed is required in the method. The method is widely used by hydrologists; engineers; and watershed managers as a simple watershed model, and as the runoff estimating component in more complex watershed models. According to Ponce and Hawkins (1996), "The SCS – CN method is a conceptual model of hydrology abstraction of storm rainfall, supported by empirical data. Its objective is to estimate direct surface runoff volume from storm rainfall depth, based on a curve number CN".

2.1.1. Historical Background

In year 1954, the United States Department of Agriculture, Soil Conservation Service (now called the Natural Resources Conservation Service (NRCS)) developed an exclusive procedure known as Soil Conservation Service Curve Number (SCS – CN) method for estimating direct runoff from storm rainfall. The SCS – CN method is a rainfall – runoff model and widely used to estimate direct storm runoff from total event rainfall (Mishra et al., 2005). The method has since witnessed innumerable applications all over the world. The method, which is basically empirical, was developed to provide a rational basis for estimating the effects of land treatment and landuse changes on runoff resulting from storm rainfall. Because of its simplicity, it has been used through the spectrum of hydrology, even for the range of problems not originally intended to solve. According to Garen and Moore (2005), the reason for the wide application of curve number method includes its simplicity, ease of use, widespread acceptance, and the significant infrastructure and institutional momentum for this procedure within NRCS. To the date, there has been no alternative that possesses so many advantages, which is why it has been and continues to be commonly used, whether or not it is, in a strict scientific sense, appropriate.

The SCS-CN methodology is the result of more than 20 years of studies of rainfall – runoff relationships carried out during the late 1930s and early 1940s for small rural watersheds, and the works of several investigators including Mockus (1949), Andrews (1954), and Ogrosky (1956). The passage of watershed protection and Flood Prevention Act in August 1954 was the major catalyst for the origin of methodology and it led to the recognition of methodology at the federal level. The data collected from experimental watersheds were, however, found to be limited and covering only a marginal fraction of the conditions affecting the rainfall-runoff process in watersheds (Andrews, 1954). Therefore, thousands of infiltrometer tests on field plots were conducted to develop a rational method for estimating runoff under various cover conditions. Following Sherman (1949) to plot direct runoff versus storm rainfall, Mockus (1949) proposed that the estimation of direct runoff for ungauged watersheds depends on soils, landuse, antecedent rainfall, duration of storm and rainfall amount associated, and average annual temperature and date of storm. Mockus (1949) communed these factors into an empirical index value b and proposed following relationship between storm rainfall depth P and direct runoff Q as (Mishra and Singh, 1999a):

$$Q = P(1 - 10^{-bP}) \tag{2.1}$$

Further, Mockus realized that the above equation gave better results for short storms than the larger ones and for mixed-cover rather than the single cover watersheds. Andrews (1954) independently grouped the infiltrometer data collected from Texas, Oklahoma, Arkansas, and Louisiana, and developed a graphical rainfall-runoff procedure taking into account the soil texture, type and amount of cover, and conservation practices, combined into what is referred to as soil-cover complex or soil-vegetation-landuse (SVL) complex (Miller & Cronshey, 1989). According to Rallison and Miller (1982) the Mockus empirical P-Q rainfall-runoff relationship and Andrews's SVL complex were the building blocks of the existing SCS-CN method document in Section-4, National Engineering Handbook (NEH-4) (Hydrology, 1985).

2.1.2. Advantages and Disadvantages

The Soil Conservation Service Curve Number (SCS-CN) method (SCS, 1956) is one of the most popular techniques for computing direct surface runoff from a rainstorm event (Ponce and Hawkins, 1996; Mishra and Singh, 2003b; Mishra et al., 2006a, b; Michel et al., 2005; and Sahu et al., 2007). This is well recognized in hydrologic, agriculture, and environmental engineering, its recognition is rooted in its convenience, simplicity, and responsiveness to the four readily available catchment properties; land treatment/use, soil type, surface condition, and antecedent moisture condition.

Though, this method is appealing to many practicing hydrologists and engineers by its simplicity, it contains some unknowns and inconsistency (Chen, 1982). Due to its origin and evolution as agency methodology, which effectively cut off it from rigors of peer review, other than the information contained in NEH - 4. Ponce and Hawkins (1996) critically examined this method; explained its conceptual and empirical bases; defined its capabilities, limitations, uses; and identified areas of potential research in the SCS-CN methodology.

The major advantages of the existing SCS-CN methodology are as follow:

i. This method is simple, predictable, stable, and lumped conceptual model.
ii. It relies on only one parameter CN.
iii. It is well recognized in hydrologic; agriculture; and environmental engineering.
iv. It is well suitable for ungauged catchments.
v. The features of this method are readily grasped and well documented.
vi. This method is simple in application to handle real world problems.
vii. Perhaps it is the single methodology available used widely in majority of the computer-based hydrologic simulation models used currently (Singh. 1995).
viii. This method requires only a few basic descriptive inputs that are changeable to numeric values for assessment of direct surface runoff.
ix. Its responsiveness to four readily grasped catchment properties: land use/treatment; soil type; surface condition; and antecedent moisture condition.
x. The method does best in agricultural sites, for which it was originally intended, and extended to urban sites.

The disadvantages of the existing SCS-CN methodology are given as below:

i. This method has lack of clear direction on how to vary antecedent moisture condition.

ii. It has lack of assumptions in development of NEH – 4 table.

iii. Application of this method to the catchment (area greater than 250 km^2) should be viewed with care.

iv. As this method was developed for United States using regional data, care is recommended for its use in other geographic or climatic regions.

v. The discrete relationship between CN and AMC classes permits sudden jump in CN, and hence corresponding quantum jump in calculated runoff.

vi. This method has lack of explicit provisions for spatial scale effects on the CN.

vii. This method does not have expression for time and hence it ignores the impact of intensity of rainfall and its temporal distribution.

viii. This method is not suitable for long term hydrologic simulation.

ix. The value of the initial abstraction coefficient (λ) is taken as 0.2. Thus pre-empting the regionalization based on geologic and climatic situation.

x. This method has poor performs on the forest sites.

xi. This method does not have any expression for antecedent moisture which plays a significant role in runoff generation process. Rather adjustments are made for it using the empirical mapping relationship.

2.1.3. Factors affecting curve numbers

The curve number (CN) indicates the runoff response characteristics of a watershed and it is influenced by soil type, land use/treatment, antecedent moisture condition, hydrologic condition, and climate of the watershed (SCS, 1956; Mishra and Singh, 2003). The combination of soil type, hydrologic condition, and land use/treatment is referred to as Hydrological Soil-Cover Complex (Miller and Cronshey, 1989). These characteristics primarily affect the infiltration potential of a watershed. NEH-4 (SCS, 1956) presents CN values for several typical Hydrological Soil-Cover Complexes.

1.0 Soil Type

Properties of soil such as organic matter, texture, aggregation and soil structure greatly influence the amount of runoff. In the SCS-CN method, these properties of soil are represented by a hydrological parameter i.e. the minimum rate of infiltration obtained for a bare soil after prolonged wetting. The influence of both the soil's surface condition (infiltration rate) and its horizon (transmission rate) are thereby included. The Soil Conservation Service identified four hydrologic groups of soils based on their infiltration and transmission rates as given below:

Group A: The soils falling in this group exhibit high infiltration rates even when they are thoroughly wetted, high rate of water transmission, and low runoff potential. Such soils include primarily deep, well to excessively drained sands or gravels.

Group B: These soils have moderate infiltration rates when thoroughly wetted and a moderate rate of water transmission. They include moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures, for example, shallow loess and sandy loam.

Group C: Soils in this group have low infiltration rates when thoroughly wetted and a low rate of water transmission. These soils primarily contain a layer that obstructs downward movement of water. Such soils are of moderately fine to fine texture as, for example, clay loams, shallow sandy loam and soils in low organic content.

Group D: These soils have very low infiltration rates when thoroughly wetted and a very low rate of water transmission. Such soils are primarily clay soils with a high swelling potential, soils with a permanently high water table, soils with a clay pan or lay layer at or near the surface, or shallow soils over nearly impervious material.

2.0 Land Use/Treatment

The land use describes the topmost surface of the soil system and has a definite bearing on infiltration. It explains watershed cover and comprises every kind of vegetation, mulch and litter, and fallow as well as nonagricultural uses, such as water surfaces, roads, roofs, etc. As forest soil is rich in organic matter, it allows greater infiltration than a paved one in urban areas. On a land surface with loose soil or an agricultural land whose particles are easily detached by the impact of rainfall, infiltration is affected by the process of rearrangement of these particles in the upper layers such that the pores are clogged and lead to reduction in infiltration rate. A grassy or vegetated land will facilitate decrease in such a clogging and permit more infiltration.

Land treatment concerns mainly to agricultural land-uses and includes mechanical practices such as terracing or, contouring and management practices such as grazing control, rotation of crops, or burning.

The following categories of land use are distinguished for the SCS-CN method:

- Fallow is the agricultural land use with the maximum potential for runoff because the land is kept bare.
- Row crops are field crops and these are planted in rows far enough apart, that most of the soil surface is directly exposed to rainfall.
- Small grains are planted in rows close enough, that the soil surface is not directly exposed to rainfall.
- Close-seeded legumes or rotational meadow are either planted in close rows or broadcasted. This kind of cover usually protects the soil throughout the year.
- Pasture range is inhabitant grassland used for grazing, whereas meadow is grassland protected from grazing and it is generally cut down for hay.
- Woodlands are usually small isolated groves of tress being raised for farm use.

3.0 Hydrologic Condition

The hydrologic condition of an agricultural watershed is defined in terms of the percent area of grass-cover. The larger the area of grass cover in a watershed, the lesser will be the runoff potential of the watershed and more will be infiltration. Such a situation describes the watershed to be in a good hydrologic condition, because it supports the protection of watershed from erosion for soil conservation purposes. Similarly, a watershed with lesser area of grass cover can be defined as in a poor hydrologic condition. Alternatively, a good hydrologic condition permits more infiltration than does a poor hydrologic condition. Hence, the hydrologic condition of a forest area also represents its runoff producing potential. In this way the CN will be the highest for poor, average for fair, and the lowest for good condition, leading to classify the hydrologic conditions into three groups: good, fair, and poor, depending on the areal extent of grasslands or native pasture or range. These conditions are based on cover effectiveness. Grazing on dry soils generally results in lowering of infiltration rates due to the compaction of the soil by hooves. Determination of curve number for forest areas for various hydrologic conditions is primarily guided by the U.S. Forest Service (USFS) (1959). And the SCS (1985) has also briefly described it.

4.0 Agricultural Management Practices

Agricultural management practices engross different types of vegetation, tillage, and surface cover. Freebairn et al. (1989) pointed up the effects of tillage practices (mould-board plough, chisel plough, and no till) on infiltration. Such practices primarily vary the porosity from 10 – 20%, depending on the soil texture and, in turn, enhance infiltration rates over non-tilled soils. It is shown (Rawls, 1983) that an increase in organic matter in the soil increases porosity or lowers bulk density, and therefore increases infiltration and, in turn, decreases the runoff potential.

5.0 Antecedent Moisture Condition

The antecedent moisture condition (AMC) refers to the wetness of the soil surface or the amount of moisture existing in the soil profile or, alternatively, the degree of saturation prior to the start of the storm. In an event, if the soil is fully saturated, the whole amount of rainfall will directly convert to runoff without infiltration losses and if the soil is fully dry, it is likely that the whole rainfall amount is absorbed by the soil, leading to no surface runoff. Thus, the antecedent moisture condition affects the process of rainfall – runoff considerably. In the SCS-CN method, the soil moisture condition is classified in three AMC classes as: AMC I, AMC II, and AMC III. AMC I refers to almost dry condition of a soil (i.e. the soil moisture content is at wilting point), AMC II refers to average or normal, and AMC III refers to the wet condition (i.e. the soil moisture content is at field capacity). Thus, the curve number related to AMC I refers to the dry CN or the lowest runoff potential while the CN corresponding to AMC III refers to the wet CN or the highest runoff potential. AMC classes are based on the 5-day antecedent rainfall (i.e. the accumulated total rainfall preceding the runoff under consideration). In the SCS-CN method, a distinction was made between the dormant and the growing season to allow for differences in evapo-transpiration. Using the NEH - 4 tables (SCS, 1956; 1985), the CN is first computed for AMC II which is later converted to AMC I or III depending on the AMC of the watershed.

In an effort to justify the rationale for developing individual curve numbers, Mockus (1964) explained: ‘The CN associated with the soil-cover complexes are median values, roughly representing average conditions of a watershed. We took the average condition to mean average soil moisture condition because we had to ignore rainfall intensity’. Since the sample variability in curve number can be due to infiltration, evapo-transpiration, soil moisture, lag time, rainfall intensity, etc., the AMC was supposedly used to represent this variability (Mishra and Singh, 2003).

Even though CN is treated as an exact value for a watershed, experiences (SCS, 1985; Hjelmfelt, 1991) signify that a set of curve numbers can exist for a given watershed. Ponce and Hawkins (1996) summarized the possible sources to lie in the spatial and temporal variability of rainfall, quality of measured rainfall-runoff data, and the variability of antecedent rainfall and the associated soil moisture. Until individual effects of each cause are investigated, the variation of CN can be attributed to random variation, which implies that confidence intervals are appropriate for characterizing the variation (Hjelmfelt, 1982; Hawkins et al., 1985). McCuen (2002) in his approach to estimate confidence interval for CN used the method of moments for parameter estimation and pooled data for assigning confidence intervals. Bhunya et al. (2003) described the random variation of CN as Gamma distributed for estimation of confidence intervals for CN – values ranging from 65 to 95.

2.1.4. SCS-CN Applications

Since its development, the SCS – CN method has witnessed myriad applications all over the world (Mishra and Singh, 2003), the method has been used in long-term hydrologic simulation and several models have been developed in the past three decades (Huber et al. 1976; Hawkins, 1978; Williams and LaSeur 1976; Soni and Mishra 1985; Mishra and Singh 2004a). A significant literature is also available on the SCS – CN method in the recent past, and several recent articles have reviewed the method at length. For example, McCuen (1982) offered guidelines for practical application of the method to hydrologic analyses. Ponce and Hawkins (1996) critically examined this method; argued its empirical basis; outlined its capabilities, limitations, and recognized areas of research in the SCS – CN methodology. Schneider and McCuen (2005), Bhunya et al. (2003), McCuen (2002), Bonta (1997), Hawkins (1993), and Hjelmfelt (1991), recommended procedures for determining CN for a watershed using field data. Steenhuis et al. (1995) utilized SCS – CN method to forecast the contributing area of a watershed and concluded that the SCS – CN equation is directly based on principles used in partial – area hydrology. Yu (1998) derived the SCS – CN method analytically assuming the exponential distribution for the spatial and temporal variation of the infiltration capacity and rainfall rate, respectively. Mishra and Singh (1999, 2002a) derived the method from the Mockus (1949) method and from linear and non-linear concepts, respectively. Mishra and Singh (2003) presented a state-of-the-art account and a mathematical treatment off the SCS – CN methodology, and its application to several areas, other than the originally intended one.

Mishra and Singh (2002 b) developed a modified SCS – CN method to include the antecedent soil moisture in the existing method. Jain et al. (2006a) applied existing SCS – CN method, its variant and the modified Mishra and Singh (2002b) model to a large set of rainfall – runoff data from small to large watersheds and concluded that the existing SCS – CN method was more suitable for high runoff producing agricultural watersheds than to watersheds showing pasture/range land use and sandy soils. This was in compliance with Ponce and Hawkins (1996) which states that the SCS – CN method performs best on agricultural watersheds, fairly on range sites and poorly on forest sites (Hawkins, 1984; 1993). Mishra et al. (2006) examined a number of initial abstraction-potential maximum retention relations incorporating antecedent moisture as a function of antecedent precipitation.

Yuan et al. (2001) modified the SCS – CN method to approximate subsurface drainage flow for five drainage monitoring stations. The flows computed in both calibration and validation were not considerably different from the observed subsurface flows. Jain et al. (2006b) incorporated storm duration and a nonlinear relation for initial abstraction (I_a) to present an enhanced version of the SCS – CN based Mishra and Singh (2002b) model. The proposed version was found to perform better than all other existing versions on watershed of USDA-ARS. Sahu et al. (2006) suggested a soil moisture accounting procedure for SCS – CN method.

SCS – CN method is also interpreted as an infiltration model (Aron et al., 1977; Chen, 1982; Ponce and Hawkins 1996). Hjelmfelt (1980) proposed an SCS – CN based infiltration equation comparable with Holtan and Overton infiltration equations, to compute the infiltration rate from rainfall of uniform intensity. Mishra (1998) and Mishra and Singh (2002b) brought in a term for steady state infiltration rate and suggested an infiltration equation by expressing the SCS – CN method in the form of the Horton method and presuming constant rainfall intensity. It has been applied for determination of infiltration and runoff rates (Mishra 1998; Mishra and Singh 2002b, 2004b).

Likewise the above applications, the SCS – CN method has also been used in connection with erosion models for computation of sediment yield. The Modified Universal Soil Loss Equation, MUSLE (Williams, 1975), Agricultural Non Point Source Model, AGNPS (Young et al., 1987), Soil and Water Assessment Tool, SWAT (Arnold et al., 1993, 1998), Erosion-

Productivity Impact Calculator, EPIC (Williams et al., 1983) are, but a few, examples. Sharda et al. (2002) used SCS – CN method coupled with USLE to compare runoff and soil loss from conservation bench terrace system and the conventional farming system.

To conclude, the SCS – CN method is a well recognized technique in applied hydrology and has been extensively utilized for determining direct surface runoff from the given rainfall on a watershed. Since the method relies only on one parameter, it is simple, easy to understand and applicable to those watersheds with a minimum of hydrologic information.

2.2 SCS-CN INSPIRED METHODS

2.2.1 Mishra et al. Model

The Mishra et al. (1998) model presumes curve number variation with time (t) dependent on AMC (Ponce and Hawkins, 1996) only. The worked out rainfall-excess Q is transformed to direct runoff amount Do_t using a linear regression approach, analogous to the unit hydrograph scheme. Taking base flow (O_b) as a fraction of F along with the time lag, the total daily flow, Q_t, is computed as the sum of Do_t and O_b. The model parameters are optimized using the objective function of minimizing the errors between the computed and observed data.

The main advantage of the Mishra et al. (1998) model is that, it allows the transformation of rainfall-excess to direct runoff and takes into account the base flow, enabling its application to even large basins. However, the model has the following limitations:

- It permits abrupt jumps in CN values when changing from one AMC to another AMC level.
- It does not differentiate between dynamic and static infiltration, similar to the Williams-Laseur and Hawkins models.
- The base flow is taken as a fraction of F, which is not rational. The water retained in the soil pores may not be available for base flow, rather the water that percolates down to meet the water table may appear at the outlet as base flow.
- The use of a linear regression equation raises the problem of mass balance, for the sum of the regression coefficients is seldom equal to 1.0 in long-term hydrological simulation.

2.2.2 Mishra-Singh Model

Due to the major weakness of discrete relationship of existing AMC approach, Mishra and Singh (2002a) suggested a continuous variation of antecedent moisture (M) directly within the runoff equation itself. In the basic SCS-CN hypothesis, F represents the infiltrated amount of infiltration equal to the maximum (P-Q) difference, which, in turn, is equal to the maximum (P-Q) difference, or equal to the volume of void, Vv. Therefore, Mishra and Singh (2002a) represented F/S ratio as degree of saturation (Sr) of the soil, and finally arrived C = Sr concept, Mishra and Singh (2002a) modified the basic equation for antecedent moisture M as:

$$\frac{Q}{Pa} = \frac{F+M}{S+M} \tag{2.2}$$

which is termed as 'Mishra-Singh Proportionality Concept'. A further substitution into the basic equation leads to

$$Q = \frac{(P-I_a)(P-I_a+M)}{(P-I_a+M+S)} \tag{2.3}$$

When $P > I_a$

$$M = \frac{S_1\,(P_5 - \lambda\,S_1)}{P_5+(1-\lambda)S_1} \text{, Q = 0 otherwise} \tag{2.4}$$

Here, P_5 = antecedent 5-day precipitation amount and S1 is the potential maximum retention corresponding to AMC I. Equation 2.3 can be further simplified as (Babu et al. 2006; Sahu et al. 2007):

$$M = \gamma\ P_5 \tag{2.5}$$

where γ = proportionality coefficient which can be determined using regression analysis.

2.2.3 Jain et al. Model

Jain et al. (2006) distinguished the existence of following issues in the conventional SCS-CN model: (1) Implementation of AMC procedure; (2) Ia-S relationship; and (3) Effect of storm intensity or duration in the runoff estimation. Based on these identified issues, Jain et al. (2006) suggested a new model formulation to enhance the SCS-CN model. This is expressed as follows:

$$Q = \frac{(P_c-I_{ad})(P_c-I_{ad}+M)}{P_c-I_{ad}+M+S} \tag{2.6}$$

where $P_c > I_{ad}$, otherwise Q = 0. A non-linear I_a – S relation has also been given as below:

$$I_{ad} = \lambda S\left[\frac{P_c}{P_c+S}\right]^{\alpha} \tag{2.7}$$

M, the 5-day antecedent moisture, is computed using the equation 2.5, as in Mishra and Singh model; and P_c and S are calculated as follows:

$$P_c = P_o \left(\frac{\bar{t}_p}{t_p}\right)^{\beta} \tag{2.8}$$

$$S = \frac{25400}{CN} - 254 \tag{2.9}$$

In these equations, Po = observed rainfall; Pc = adjusted rainfall; $\bar{t}$p = mean storm duration; and tp = storm duration. The above equations represent an enhanced form of the runoff curve number model (Jain et al. 2006) which incorporated storm duration, a non-linear Ia-S relation and a simple continuous moisture content in runoff estimation. This model has five parameters.

2.3 EROSION AND SEDIMENT YIELD

Soil erosion is the removal of surface material by wind or water. When rain drop comes down on a surface, the soil particles are splashed. Higher is the velocity of impact, greater is the amount of soil splashed. The detached soil particles are then carried further, either by runoff or wind. This whole process is known as erosion. Sediment yield is defined as the total sediment outflow from a watershed or a drainage basin, measurable at a point of reference and in a specific period of time (ASCE, 1970). Sediment yield from a watershed is the output form of an erosion process, and is difficult to estimate as it arises from a complex interaction of various hydro-geological processes, and the knowledge of the actual process and extent of suspended material is far less detailed (Juyal and Shastry, 1991).

The entire amount of erosion in a watershed is the gross erosion and sediment is the end product of erosion. However, all the eroded material does not get into the stream systems. Some of it is deposited at natural or man-made barriers within the watershed, and some is deposited within the channels and their flood plains. The portion of the eroded material that does travel through the drainage network and arrives at downstream measuring or control point is referred as the sediment yield at that point.

2.3.1. Background

Approximations of sediment yield are required for solution of number of problems such as design of dams and reservoirs, river morphology, design and planning of soil conservation practices, transport of pollutants, design of stable channels, determination of the effects of basin management, and non-point source pollution estimates. Increased awareness of environmental quality and desire to control non-point source pollution has considerably raised the need of sediment yield estimates (Singh, 1989).

A number of sediment yield models have been developed to deal the wide ranging soil and water resources problems. Williams (1981) classified the models on the ground of the problem aimed to be solved, like (i) erosion control planning, (ii) water resources planning and design, and (iii) water quality planning. The complication of the model in terms of the formulation is commonly dictated by the nature of the problem. For example, erosion control planning for agricultural field; reclaimed mines; construction sites; and forest management requires the simplest models. The only estimate needed in such applications is the average annual soil loss for various erosion control systems. On the other hand, sediment yield estimates needed for designing structures ranging from temporary sediment basins at construction sites to large dams and for evaluating the effects of hydraulic works on flood plain and channel degradation and deposition need to be sufficiently accurate, and hence need more complex models. Similarly, sediment yield models required to determine water quality depend on the water quality parameter to be modeled. For example, the sediment carrying high concentrations of pesticides and fertilizers, highly toxic chemicals, needed a short time step to determine changes in the concentration during rainfall-runoff events.

2.3.2. Sediment Yield Process

The suspended sediment loads in a stream are the result of processes of erosion and transport within the drainage basin area (Einstein, 1964). Supply and removal of suspended solids rely on the form and structure of the drainage area, vegetative cover as well as upon the climatic conditions (Nippes, 1971). The sediment transported in a stream is sub-divided into two categories, according to dominant mode of transport, suspended sediment load, and bed load (Kumar and Rastogi, 1987). Different authors (Chow, 1964; Graf. 1971; Shen, 1971) have computed that bed load amounts to the total sediment yield are usually small and may in some cases be ignored from total yield calculations. Therefore, in many areas suspended sediment yields may be considered to reflect watershed sediment yield processes. The process of sediment yield generally involves (i) detachment and transportation of soils particles by rainfall, (ii) detachment and transport of soil particles by runoff, and (iii) eventual deposition of soil particles. The sediment yield process may be considered to consist two phases: (a) the upland phase and (b) the lowland stream or the channel phase (Bennet, 1974).

(a) Upland Phase

The upland phase occurs on an upland area, which is the area within a watershed where runoff is predominantly overland flow (Foster and Meyer, 1975). The rainfall characteristics play significant role in finding out sediment yield in the upland phase. Major components affecting the sediment yield in this phase are (Singh 1989): (i) soil characteristics, (ii) climate, (iii) vegetation, (iv) topography, and (v) human activities. The upland phase is further divided mainly into three stages, i.e. sheet, rill, and gully erosion, which are followed by one another in time and, to some extent, in space, and collectively these stages are called as the source of erosion.

(b) Channel Phase

The channel phase receives sediment from the upland phase. A channel is defined as a well defined watercourse flowing through a valley in which the material composing of the valley has been deposited by the stream in the past (Bennett, 1974). Components like velocity and depth of flow, wash load, water temperature, channel slope, hydraulic roughness, discharge, and cross-sectional area are some of the pertinent variables affecting sediment yield in the channel phase.

2.3.3. Mechanics of Soil Erosion by Water

Mechanics of water erosion is often a two-fold process. Raindrops falling on soil surface can cause particles to detach and splash upward. Upon returning to the soils, splashed particles disperse and clog soil pores, causing surface crusting and a reduction in the soil's infiltration rate. The pounding action of rain may also compact the soil, further decreasing infiltration. When water is applied in excess of the soil's infiltration rate, water will puddle and the runoff leads to additional detachment of soil particles due to shear stress of flow and transport of these particles by the flowing water. Particle carry by water requires a critical speed to effectively carry sediment; when water velocity shows below this speed, deposition occurs. Because coarse particles fall out of suspension sooner than fine particles as runoff velocity slows down, they are more liable to remain on the field while fine particles are moved farther downstream.

Hence, for a given physiography, the energy required for the detachment and the transportation of soil particles is supplied by raindrops and the overland flow. Besides acting as energy source, raindrops also act as wetting source. Mode of detachment of soil particles by impact of raindrops varies with the degree of wetness of land surface (Garde and Kothyari, 1987). The shear strength of soil decreases with increasing wetness. The overland flow exerts shear stress on the surface thereby inducing both the detachment and transportation of soil particles. Maximum soil splash takes place when the land surface is covered by overland flow of small depth (Mutchler and Young, 1975). Deposition of detached material takes place when the carrying capacity of flow is less than the sediment load being transported.

The main forms of water erosion are sheet, rill, and gully erosion. (i) Sheet erosion is the removal of a thin layer of soil from the surface and is caused by overland flow moving uniformly throughout the surface. (ii) As the sheet erosion continues, water begins to focus in small channels or rills, and rill erosion occurs. Rills tend to be uniformly distributed over the field and are defined as being small enough to be smoothed over by cultivation practices. The concentration of running water causes rill erosion to be more erosive than sheet erosion. (iii) Gully erosion occurs when prominent quantities of runoff concentrate and create large channels in the landscape. Gullies are comparatively permanent features that cannot be removed by tillage.

2.3.4. Factors Affecting Erosion and Sediment yield

The four principal factors that affect soil erosion and quantity of sediment that may reach the outlet of a watershed are climate, soil properties, watershed characteristics and land cover characteristics.

Climate

Climate has always been observed to have a strong influence on erosion and sediment yield. Intensity, duration, and frequency of rain events all appear to play a role in the amount of soil that erodes. In general, the most severe erosion occurs when rains are of relatively short duration, but high intensity. Heavy raindrop action coupled with higher rain intensity than the soil infiltration capacity can lead to high surface runoff and large soil loss. Long and low intensity storms can also be highly erosive due to saturated soil conditions causing increased runoff (Morgan, 1995). Soil detachment by wind driven rain is different from that by rain falling under calm air (Lal, 1976). The wind action on rain drops may add to their erosive energy and also may increase the velocity of flow and thereby its transport capacity. The temperature plays an important role in the process of weathering which leads to disintegration of rocks. For the same rainfall, temperature also affects runoff and hence the sediment yield.

Soil Properties

Soil properties affecting water erosion and sediment yield include those that influence infiltration and soil stability, such as texture, organic matter, aggregation, soil structure and tilth. Soil erodibility or the vulnerability of soil to erosion refers to the resistance of soil to both detachment and transportation (Wischmeier and Smith, 1978). Key factors that affect erodibility are soil texture, soil permeability, soil structure, and amount of organic matter. Because water readily infiltrates into sandy soils, the runoff, and consequently the erosion potential, is relatively low. Clay, because of its stickiness, binds soil particles together and makes it resistant to erosion. However, once heavy rain or fast flowing water erodes the fine particles, they will travel great distances before settling. The soils with 40 to 60 percent silt content are more erodible in spite of large particles being resistant to transport and the fine particles offer resistance to detachment due to their cohesiveness. Soil with clay fraction between 9 to 30 percent is more susceptible to erosion (Evans, 1980). Organic matter consists of plant and animal litter in various stages of decomposition. Organic matter improves soil structure and increases permeability, water holding capacity, and soil fertility. Moldenhauer and Long (1964) studied the effect of different textures of soil on erosion under simulated rainfall. The relative soil loss at high intensity rainfall varied as follows: soil loss from silty clay > silty clay loam > silt > loam > fine sand. However, at low intensity rainfall the order of soil loss was as follows: soil loss from silty loam > silty clay > loam > silt > fine sand. With equal water loss, the order of erodibility was as follows: soil loss from fine sand > silty clay > silty clay loam > silt > loam. The works of Wischmeier and Mannering (1969), Wischmeier et al. (1971), and Alberts et al. (1980) on soil erodibility factor and its relationship with soil texture and available organic contents are worth mentioning.

Catchment Characteristics

Catchment area, slope, and drainage density are some of the catchment characteristics that influence the runoff production and thus the sediment yield (Jansen and Painter, 1974; Garde and Kothyari, 1987). Because fast moving water can carry more sediment than slow moving water, there is a greater potential to lose a larger amount of material on steep slopes than gradual slopes (Morgan, 1979). In an analysis of data from 27 catchments in India, Garde et al. (1983) concluded that the catchment slope was an important variable and established a relationship between the soil erosion per unit area (A) and the topographic factor, given by:

$$A = \frac{f}{(S^m * L^n)} , \qquad (2.10)$$

where S is the slope; L is the slope length; and m and n are the exponents rangingbetween 1.3 to 2.0 and 0.3 to 0.7, respectively. Many researchers have investigated the effect of slope steepness on the erosion and found a power relationship of the form of ($y = a\,x^b$); where y is the erosion; x is the slope steepness; and a and b are, respectively, the constant and exponent of the power relationship (Zingg, 1940). Schumm (1954) demonstrated the variation of sediment delivery ratio with catchment area and derived an inverse correlation between sediment yield per unit area and the area. A similar effect was observed by several other investigators (Roehl, 1962; Wilson, 1973; Taylor, 1983).

Land Cover

Vegetative cover reduces detachment of soil particles by intercepting raindrops and dissipating their energy. Type of land use and vegetative cover also influence the overland flow in terms of the roughness (Chow, 1959). Surface vegetation and residue act as dams and slow down the flow velocity and promote deposition. Roots of vegetation play significant role in reducing the soil erosion by binding the soil mass to increase its resistance to flow (Wischmeier, 1975). This factor was included in the Universal Soil Loss Equation as Cover Management Practice Factor, ‘C’. A wider range of the literature is available on the studies of the effects of residue on soil erosion rates (Meyer et al., 1975 a; Laflen and Colvin, 1981; Foster, 1982; Hussein and Laflen, 1982).

2.3.5. Concept of Sediment Delivery Ratio

The concept of sediment delivery ratio, DR, owes its origin to the observation that the erosion predicted by the USLE overestimates the amount of sediment delivered from hillslopes because sediment deposition often occurs on hillslopes whereas the USLE does not account for deposition. The sediment yield of a catchment is only a part of gross erosion that equals the gross erosion minus sediment deposited enroute to the point of reference. Sediment produced by sheet and rill erosion often moves only short distances and may get deposited away from the stream system. They may remain in the areas of their origin or be deposited on a milder slope downstream. Therefore, sediment yield is often computed based on the use of a sediment delivery ratio, DR, which is defined as the ratio of the sediment reaching the watershed outlet to the gross surface erosion. The dimensionless ratio, DR, is expressed mathematically as:

$$DR = \frac{Y}{A}, \tag{2.11}$$

where Y is the total sediment yield at watershed outlet and A is the total material eroded (gross erosion) on the watershed area above the outlet. Many factors including catchment physiography, sediment source, proximity and magnitude of source, transport system, texture of eroded material, depositional areas and land cover etc. affect sediment delivery ratio (Walling, 1983, 1988). However, variables such as catchment area, land slope, and land cover have been mainly used as parameters in empirical equations for DR (Hadley et al., 1985; Roehl, 1962; Williams and Berndt, 1972; Kothyari and Jain, 1997). The U.S. Soil Conservation Service has developed a generalized relationship between delivery ratio and catchment area. The inverse relationship between delivery ratio and catchment area has been explained in terms of decreasing slope and channel gradients and the increasing opportunity for deposition associated with increasing catchment size. Schumm (1954) also demonstrated an inverse correlation between sediment yield per unit area and catchment area. Walling (1983, 1988) summarized some relations between sediment delivery ratio and catchment characteristics.

2.4 SUMMARY

In brief, the SCS-CN method is one of the most popular techniques for computing direct surface runoff from a rainstorm event. It is well established in hydrologic, agriculture, and environmental engineering, its popularity is rooted in its convenience, simplicity, authoritative origins, and responsiveness to four readily available catchment properties; soil type, land use, surface condition, and antecedent moisture condition. In spite of its apparent simplicity, the application of SCS-CN procedure leads to a diversity of interpretations and confusion due to ignorance about its limitations. Difficulties in its application are mainly related to the classification of soils outside USA into four hydrological soil groups (viz., A, B, C, and D) and determination of AMC, an index of basin wetness.

In general, the review of literature reveals that soil erosion and related sediment yield are of vital concern to the fields of conservation and engineering. One factor which has received justifiable interest in studies of erosion processes and rates is that of rainfall energy and the rainfall energy is a function of factors such as rainfall intensity and antecedent moisture. As a result, a number of approaches that vary from simple empirical to physically based models involving mathematical treatment of detachment, transport and deposition processes have been used to estimate the sediment yield. USLE based approaches have been successfully used to estimate the sediment yield from the watersheds and the SCS-CN method has also been used in many of the sediment yield models to simulate surface runoff.

Evidently, most studies have concentrated on the application of the existing SCS-CN method utilizing CN derived from NEH-4 tables or using GIS for watershed characteristics. No systematic effort appears to have been made for experimental verification of the effect of watershed slope and land use on CN, particularly for Indian watersheds. Thus, in this experimental field plot study, attempt has been made to investigate the effect of slope on runoff and, in turn, CN for given rainfall, as well as the effect of antecedent moisture content on sediment yield.

CHAPTER 3

METHODOLOGY AND DEVICES USED

3.1 GENERAL

Utilizing the originally developed curve numbers, most studies have concentrated on the application of the existing SCS – CN method and no systematic effort appears to have been made for their verification for Indian watersheds. Hence measurement of soil losses and runoff from an area under controlled conditions is necessary to evaluate the influence of soil type, slope, and land management practices on runoff and soil loss. Such studies help in developing relations useful for soil loss estimation under given set of conditions.

The experimental design includes one independent variable i.e. slope or gradient. In the present study, an experimental field located in Roorkee, Distt. Haridwar, Uttarakhand (India) (Fig. 3.1a) was divided into three plots, each of 22m length and 5m width and of different slopes, viz., 1%, 3%, and 5% having sugarcane crop. The runoff and sediment yield are measured at the outlet of each plot. To this end, runoff and sediment yield were collected during rain storm as well as during flooding irrigation in separate chambers (each of 1mx1mx1m) constructed at the outlet of each plot and the variation in depth of water stored with respect to time was monitored continuously. To reduce the volume of runoff to be measured in collection chambers and hence size, multi-slot devisors (Fig. 3.1b) were used.

Fig.3.1 (a) Experimental Field and (b) Multi-slot Devisor

The intensity and amount of rainfall were measured using a self-recording raingauge, and with ordinary raingauge as well as for verification. Some natural rain events captured on different dates during the receding part of the monsoon season. Alternatively, sediment concentration is directly measured by suspended sediment sampler, quite for random cross checking. For the assessment of antecedent moisture condition, the moisture content was measured using soil moisture meter 'Fieldscout TDR 300' (probes of length 20 cm). To identify the hydrologic soil group, infiltration tests of the soil on each of three grades of plot were conducted using double ring infiltrometer.

3.1.1 Procedure

In general, the methodology to determine the runoff curve number and sediment yield can be described in steps as follows:

I. For sugarcane crop, prepare small agricultural plots with different slopes with the same soil as available naturally in the local area.

II. In a rainstorm, measure the rainfall, amount of runoff (using multi-slot devisor), and sediment yield (using suspended sediment sampler) at the outlet of each plot and measure soil moisture (using soil moisture meter) prior to each rainstorm.

III. Derive the curve number from the observed rainfall – runoff data and then a representative CN – value for a given land use, soil type and slope of the plot.

IV. Repeat above steps for different slopes of the plots.

V. Average the CN – values for all watershed slopes and compare them with those of NEH-4 (Section 4 of National Engineering Handbook).

VI. Using the collected data, validate the available SCS – CN based sediment yield and sediment graph models.

3.2 SCS-CN METHOD

The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of actual amount of direct surface runoff (Q) to total rainfall (P) (or maximum potential surface runoff) to the ratio of actual infiltration (F) to the amount of potential maximum retention, S. The second hypothesis relates the initial abstraction (I_a) to the potential maximum retention (S), also described as the potential post initial abstraction retention (McCuen, 2002). Expressed mathematically,

(a) Water balance equation

$$P = I_a + F + Q \tag{3.1}$$

(b) Proportional equality (First hypothesis)

$$\frac{Q}{(P-I_a)} = \frac{F}{S} \tag{3.2}$$

(c) $I_a - S$ relationship (Second hypothesis)

$$I_a = \lambda S \tag{3.3}$$

The values of P, Q and S are given in depth dimensions, while the initial abstraction coefficient λ is dimensionless. Though the original method was developed in U.S. customary units (in.), an appropriate conversion to SI units (cm) is possible (Ponce, 1989). In a typical case, a certain amount of rainfall is initially abstracted as interception, infiltration and surface storage before runoff begins, and a sum of these is termed as 'initial abstraction'.

The first or fundamental hypothesis is primarily a proportionality concept (Mishra and Singh, 2003a). Figure 3.2 graphically represents this proportionality concept. Apparently, as $Q \rightarrow (P - I_a)$, $F \rightarrow S$. This proportionality enables dividing ($P-I_a$) into two components: surface water Q and sub-surface water F for given watershed characteristics.

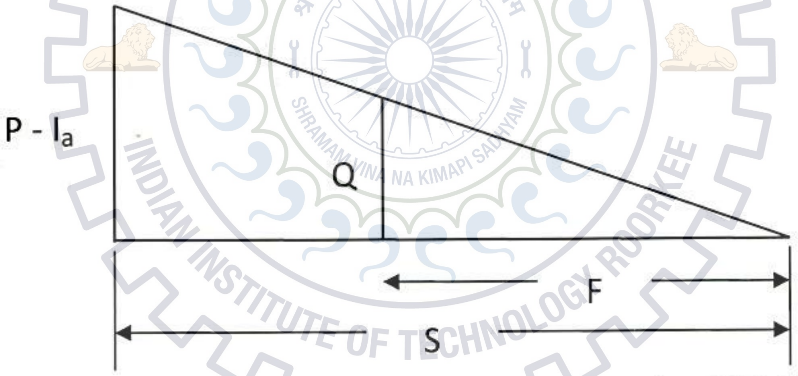


Fig. 3.2 Proportionality Concept of the existing SCS-CN

The parameter S of the SCS-CN method depends on soil type, land use, hydrologic condition, and antecedent moisture condition (AMC). The initial abstraction coefficient λ is frequently viewed as a regional parameter depending on geological and climatic factors (Boszany, 1989; Ramasastry and Seth, 1985). The existing SCS-CN method assumes λ to be equal to 0.2 for practical applications. Many other studies carried out in the United States and other countries (SCD, 1972; Springer et al., 1980; Cazier and Hawkins, 1984; Ramasastry and Seth, 1985; Boszany, 1989) report λ to vary in the range of (0, 0.3). However, as the initial abstraction component accounts for the short term losses such as interception, surface storage, and infiltration before runoff begins, λ can take any value ranging from 0 to ∞

(Mishra and Singh, 1999a). A study of Hawkins et al. (2001) suggested a value of $\lambda = 0.05$, giving a better fit to data and more appropriate for use in runoff calculations.

The second hypothesis is a linear relationship between initial abstraction Ia and potential maximum retention S. Coupling Eq. 3.1 and Eq. 3.2, the expression for Q can be written as:

$$Q = \frac{(P-Ia)^2}{P-Ia+S} \tag{3.4}$$

Eq. 3.4 is the general form of the popular SCS-CN method and is valid for $P \geq I_a$; $Q = 0$ otherwise. For $\lambda = 0.2$, the coupling of Eq. 3.3 and Eq. 3.4 results:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \tag{3.5}$$

Eq. 3.5 is the popular form of existing SCS-CN method. Thus, this method with $\lambda = 0.2$ is a one parameter model for computing surface runoff from daily storm rainfall. Since parameter S can vary in the range of $0 \leq S \leq \infty$, it is mapped onto a dimensionless curve number CN, varying in a more appealing range $0 \leq CN \leq 100$, as:

$$S = \frac{1000}{CN} - 10 \tag{3.6}$$

Where S is in inches. The difference between S and CN is that the former is a dimensional quantity (L) whereas the later is non-dimensional. CN = 100 represents a condition of zero potential maximum retention (S = 0), that is, an impermeable watershed. Conversely, CN = 0 represents a theoretical upper bound to potential maximum retention ($S = \infty$), that is an infinitely abstracting watershed. However, the practical design values validated by experience lie in the range (40, 98) (Van and Mullem, 1989). It is to explicitly mention here that CN has no intrinsic meaning: it is only a convenient transformation of S to establish a 0 to 100 scale (Hawkins, 1978). For a given set of rainfall and runoff data, S can be determined from Eq. 3.5 as:

$$S = 5(P + 2Q - \sqrt{(Q(4Q + 5P)}) \tag{3.7}$$

Notably, the SCS-CN method does not take into account the effect of slope on runoff yield and, in turn, on the resulting CN. If Eq. 3.6 is substituted into Eq. 3.5, then the resulting rainfall-runoff relationship can be expressed as follows:

$$Q = \frac{[CN(P+2)-200]^2}{CN[CN(P-8)+800]} \tag{3.8}$$

With a measured precipitation event and an average CN value for a watershed, application of Eq. 3.8 is bounded by the limits of P > (200/CN) – 2 and Q = 0 (Ponce and Hawkins, 1996).

In the course of continuous use of the SCS-CN model world-wide, several modifications for its better performance have been proposed. Some of the notable ones are:

- ✓ Incorporation of watershed slope (Sharpley and Williams 1990, and Huang et al. 2006).
- ✓ Improvement in initial abstraction ratio, λ (Mishra et al., 2006b).
- ✓ Incorporation of antecedent moisture (Sahu et al., 2007).
- ✓ Improvement in estimating of initial abstraction, Ia (Mishra et al, 2006b).

3.3 DETERMINATION OF CN

Despite widespread use of SCS-CN methodology, the accurate estimation of parameter CN is a topic of discussion among hydrologists and water resources community (Hawkins, 1978; Hjelmfelt, 1980; Chen, 1982; Ponce and Hawkins, 1996; Mishra and Singh, 2006). Originally CNs were developed using daily rainfall-runoff records corresponding to the maximum annual flows from gauged watersheds for which information on their soils, cover, and hydrologic condition was available (SCS, 1972). The rainfall (P)-runoff (Q) data were plotted on the arithmetic paper having a grid of plotted curve number, as shown in Fig. 3.3.

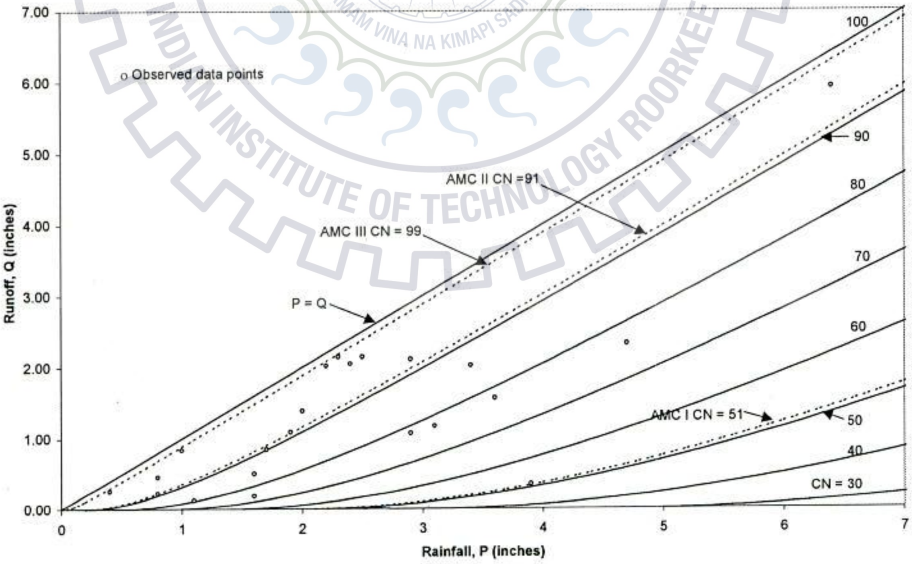


Fig. 3.3 Determination of CN for AMC I through AMC III using existing SCS-CN method.

CN corresponding to the curve that separated half of the plotted data from the other half was taken as the median curve number for the watershed. Thus developed curve numbers represented the averages or median site values for soil groups, cover, and hydrologic condition and corresponds to AMC II (CN_{II}). The upper enveloping curve was taken to correspond to AMC III (CN_{III}) and the lower curve to AMC I (CN_{I}). The average condition was taken to mean average response, which was later extended to imply average soil moisture condition (Miller and Cronshey, 1989). Depending on 5-day antecedent rainfall, CN_{II} is convertible to CN_{I} and CN_{III} using the relationships given by Sobhani (1975); Hawkins et al. (1985); Chow et al. (1988); Neitsch et al. (2002) as in Table 3.1, and directly from the NEH-4 tables (SCS, 1972; Mishra and Singh, 2003a), and these are applicable to ungauged watersheds.

Table 3.1 Popular AMC dependent CN conversion formulae

Method	**AMC I**	**AMC III**
Sobhani (1975)	$CN_{I}=\frac{CN_{II}}{2.334-0.01334\ CN_{II}}$	$CN_{III}=\frac{CN_{II}}{0.4036+0.005964\ CN_{II}}$
Hawkins et al. (1985)	$CN_{I}=\frac{CN_{II}}{2.281-0.01281\ CN_{II}}$	$CN_{III}=\frac{CN_{II}}{0.427+0.00573\ CN_{II}}$
Chow et al. (1988)	$CN_{I}=\frac{4.2\ CN_{II}}{10-0.058\ CN_{II}}$	$CN_{III}=\frac{23CN_{II}}{10+0.13\ CN_{II}}$
Neitsch et al. (2002)	$CN_{I}=CN_{II}-\frac{20(100-CN_{II})}{\{100-CN_{II}+\exp[2.533-0.0636\ (100-CN_{II})]\}}$	$CN_{III}=CN_{II}\exp\{0.00673\ (100-CN_{II})\}$

However, to estimate the average CN values (CN_{II}) mathematically from the rainfall (P)-runoff (Q) data of a gauged watershed, Hawkins (1993) suggested S (or CN) computation using the expression Eq. (3.7).

Another approach to estimate CN from rainfall (P) and runoff (Q) data is the rank-order method (Hjelmfelt, 1980), where the P-Q data are sorted out and rearranged on rank-order basis to have equal return periods as discussed in the following topic. However, the individual runoff values are not necessarily associated with the causative rainfall values (Hawkins, 1993). Bonta (1997) evaluated the potential of derived distributions to determine curve numbers form measured P-Q data, treating them as separate distributions. The derived-distribution method resulted in fewer variable estimates of CN for a wide range of sample sizes than the methods of Hawkins (1993) and Hjelmfelt (1980). The derived-distribution method also identifies watershed as standard, violent and complacent similar to Hawkins (1993). The derived-distribution method has potential even when data availability is limited. Schneider and McCuen (2005) developed a new log-normal frequency method to estimate curve numbers from measured P-Q data. The developed method was found to be more accurate than the rank-order method and by the above equation of S. Recently, Mishra and Singh (2006) investigated the variation of CN with AMC and developed a new power relationship between the S (or CN) and the 5-day antecedent rainfall. The developed CN-AMC relationship is applicable to gauged as well as ungauged watershed and eliminates the problem of sudden jump from one AMC level to other.

3.3.1 Frequency Matching Curve Numbers

This method corrects the fundamental problem of the runoff (Eq. 3.5) that can be traced to the concept used to derive Eq. 3.2. The problem in derivation of runoff (Eq. 3.5) is that a residual relationship remains between the watershed curve number and the magnitude of the rainfall volume used to derive CN. Originally, CN was expected to be a constant for each watershed. Because CN varies with magnitude of event rainfall that occurs at different frequencies, it is generally a function of the design return period interval or frequency – a fact rarely recognized in most designs.

Hawkins (1993) worked extensively with recorded rainfall and runoff data sets. The frequency matching concept is applied to treating rainfall and runoff data. The rainfall depths and the runoff depths are sorted separately, and then realigned on a rank-ordered basis to form P: Q pairs of equal return periods. The individual runoffs are not necessarily associated with the original causative rainfalls. The frequency matching approach was applied by rank-ordering the data and computing S for each paired event according to Eq. 3.7. The calculated curve number for each paired event was then displayed on a scatter plot as a function of precipitation volumes.

Depending on the watershed response to precipitation, the resulting plots fell into one of three categories. These three categories were identified as standard, violent, and complacent. The standard behavior is most common scenario. The standard response illustrates a decreasing curve number as precipitation increases. The curve number decreases until an asymptotic behavior is observed for larger, more extreme precipitation events. The violent response was observed in a watershed with an increasing curve number as precipitation increases. The curve number increases until an asymptotic behavior is observed at the larger, more extreme precipitation events. In the complacent behavior, the observed CN declines steadily with increasing rainfall depth, and no asymptotic behavior was observed. The complacent behavior was noted to be most ambiguous of the three responses. Hawkins

(1993) concluded that eighty percent of the watersheds fall into standard and violent categories.

The procedure for the asymptotic determination of observed watershed curve numbers is presented as follows (Hawkins, 1993):

1. Rank the rainfall and runoff depths independently in descending order.
2. Calculate curve numbers for each ordered pair, examine for each pair to show $Q < P$.
3. Plot the resulting curve numbers with respect to the corresponding precipitation.
4. Define the curve number from the asymptotic behavior as standard, violent or complacent.

3.4 UNIVERSAL SOIL LOSS EQUATION

Universal Soil Loss Equation (USLE) is an index method with factors that represent how climate, soil, topography, and land use affect soil erosion caused by raindrop impact and surface runoff. In general, erosion depends on the erosivity, caused by the amount and intensity of rainfall and runoff, and the resistance of soil surface or the degree of erodibility caused by intrinsic soil properties, adopted land use practices and the topography of the landscape as described by slope length and steepness. USLE captures this erosion influencing parameters into six factors whose product forms the simple structure of the model. The USLE (Wischmeier and Smith, 1965) estimates the potential soil erosion (sheet and rill), A, from upland areas, and it is expressed as:

$$A = R\ K\ LS\ C\ P \qquad (3.9)$$

Where A is the annual potential soil erosion (ton per ha per year); R is the rainfall erosivity factor; K is soil erodibility factor; LS is the slope length and steepness factor; C is the vegetative cover (or cropping management) factor; and P is the erosion control practice factor. This above equation expresses soil loss per unit area due to erosion by rainfall-runoff, excludes wind erosion, and does not yield direct sediment estimates. It is, however, more versatile than the earliest, most successful equation after Musgrave (1947).

Since the procedure for determining R-values suggested by Wischmeier and Smith (1965) is applicable for computation of annual erosion, its use in estimation of soil loss from a single storm would yield errors (Haan et al., 1994). Foster et al. (1977b) suggested a modification applicable to individual storm events as:

$$R = 0.5\ R_r + 0.35\ Q\ q^{1/3} \qquad (3.10)$$

Where R_r is the rainfall energy factor, Q is the runoff volume (cm), and q is the peak runoff rate (cm/hr). Since q is more related to detachment than Q (Williams and Berndt, 1977), a reduction in peak discharge by the vegetation cover will also reduce the sediment transport.

After the research and experience gained in this field using USLE equation since 1970s; it has provided insights to develop improved technology that has led to the designing of Revised USLE (Renard et al., 1991). The update is based on an extensive review of the USLE, and theory describing fundamental hydrologic and erosion processes. This update of USLE is referred to as Revised USLE (RUSLE).

The RUSLE has some significant improvement over the various factors, which can be briefly summarized as below:

- ✓ Minor changes in R-factors.
- ✓ Expanded information on soil erodibility.
- ✓ A slope-length factor that varies with soil susceptibility to rill erosion.
- ✓ A nearly linear slope steepness relationship that reduces computed soil loss values for very steep slopes.
- ✓ A sub-factor method for computing values for the cover-management factor.
- ✓ Improved factor values for the effects of contouring, terracing, strip cropping, and management practices for rangeland.

Another version, which is known as the Modified Universal Soil Loss Equation – the MUSLE (Williams, 1975) follows the structures of USLE, with the exception that the rainfall factor is replaced by the runoff factor. The model calculates sediment yield for a storm instead of gross erosion.

3.5 SCS-CN BASED SEDIMENT YIELD MODEL

The model for computing total sediment yield from a rainfall event was derived by coupling the SCS-CN method with USLE. The coupling is based on three hypotheses: (1) the runoff coefficient, C (dimensionless), is equal to the degree of saturation, S_r (dimensionless); (2) the USLE can be signified in terms of SCS-CN parameter potential maximum retention, S (L); and (3) the sediment delivery ratio, DR (dimensionless), can be equated to C or S_r. The volumetric analysis of the potential erosion led to the inference that the ratio of actual potential maximum erosion, A (M), per unit area to actual potential maximum retention, S (=A/S ratio) is constant for a watershed. Based on the analytical development, seven variations of the sediment yield model were formulated for different combinations of initial abstraction, Ia, antecedent moisture, M, and initial flush, I_f. These model variations were applied to the rainfall, runoff, sediment yield data. Nash and Sutcliffe (1970) efficiency exhibited that the performance of the model directly based on the existing SCS-CN method was comparable with sediment yield, Y (M), as:

$$Y = \frac{(P-0.2\,S)A}{P+0.8\,S} \tag{3.11}$$

Where P is the total rainfall (P) from the storm event. The CN values computed from the sediment yield model and from the existing SCS-CN method exhibited a quadratic relationship.

The lumped sediment yield models, developed using the SCS-CN proportionality concept, performed satisfactorily well. Being simple, the model has ample potential for field applications, for this has only a few parameters determinable from watershed characteristics.

3.6 DEVICES USED

3.6.1 Multi-Slot Divisor

The multi-slot devisor developed by R.V. Geib in U.S.A. is generally used as a standard device for measurement of runoff volume from small plots (Harrold and Krimgold, 1968). The devisor divides the flow in 3, 5, 7, 9, 11, 13 or 15 aliquots, depending on the number of slots in the divisor. One of the aliquots is conveyed to storage tank. The device is based on the principle that a uniform horizontal velocity of approach is maintained in the devisor box through the entire head variations to obtain equal division of flow. Extensive tests were conducted on this divisor by Soil Conservation Service, USDA, at U.S. National Bureau of Standards. The multi-slot devisor is a near precision device which is quite reliable and time proven (Mutchler, 1963).

The selection of a suitable size of the divisor will depend on the expected rate of runoff and the ratio of the runoff to be stored in the collecting tank. The design criteria of the multi-slot divisor are based on the following information:

- Maximum runoff volume expected in 24 hours.
- Peak rate of runoff expected from the plot for the design frequency.
- Maximum soil loss expected from the heaviest storm.

The size of the collecting tank and consequently the cost can be substantially reduced by collecting the runoff using multi-slot divisor. The device has the following advantages:

- It is simple in design and operation.
- There is no risk of mechanical failure as experienced in recording instruments.
- Data reduction and processing are relatively simple.

The multi-slot divisor, in spite of several advantages, has its own limitations in use. The device is generally limited to sample flows up to 4 cusecs. The use of the device is limited to the determination of runoff volume only and, therefore, it is not much used in watershed research where other characteristics of runoff are also to be analyzed.

3.6.2 Soil Moisture Meter

Soil moisture is a critical and potentially highly variable component of the soil environment. Time-domain reflectometry (TDR) is a proven technology for quickly and accurately determining volumetric water content (VWC) in soil (Technical Bulletin No. 20110512, May 12, 2011. www.specmeters.com).

Volumetric Water Content (VWC)

The soil can be thought of as being composed of soil, water, and air. VWC is the ratio of the volume of water in a given volume of soil to the total soil volume. In other words, VWC will equal the percent pore space of the soil. This can be expressed as either a decimal or a percent. Three soil moisture levels of importance can be defined as follows:

Saturation: All soil pores are filled with water.

Field Capacity: The condition that exists after a saturated soil is allowed to drain to a point where the pull of gravity is no longer able to remove any additional water.

Permanent Wilting Point: The highest moisture content at which a plant can no longer extract water from the soil.

Time Domain Reflectometry (TDR)

The underlying principle of TDR involves measuring the travel time of an electromagnetic wave along a waveguide. The speed of the wave in soil depends on the bulk dielectric permittivity (ε) of the soil matrix. The fact that water (ε = 80) has a much greater dielectric constant than air (ε = 1) or soil solids (ε = 3 – 7) is exploited to determine the VWC of the soil. The VWC measured by TDR is an average over the length of the waveguide.

Electronics in the TDR 300 generates and senses the return of a high energy signal that travels down and back, through the soil, along the waveguide composed of the two replaceable, stainless steel rods. The sampling volume is an elliptical cylinder that extends approximately 3 cm out form the rods. The high frequency signal information is then converted to volumetric water content. High amounts of clay or high electrical conductivity (EC>2 dS/m) will attenuate the high-frequency signal and affect the reading displayed by the meter. Very high organic matter content will similarly affect the VWC reading.

The Field Scout's shaft-mounted probe allows the user to easily and rapidly take many measurements. The user can quickly transition between taking VWC readings in standard and high-clay mode. The meter's built-in data-logger can record data from several sites and eliminate the need to record data manually. Through the software (included) the user can download the data, change the logger settings and program the logger to record relative water content at multiple sites.

Reading can be taken in three standard environments- air, distilled water, and playground sand saturated with distilled water. It is important that any troubleshooting be done with distilled water, as it was found that readings taken in tap water can differ greatly from the expected results observed in distilled water. Reading taken in air can be taken by simply holding the meter so the rods are completely surrounded by air. When readings are taken in water and saturated sand, the container should have a diameter of at least 3 inches (7.5cm) and should be tall enough so the rods can be completely immersed or inserted. When saturating the sand, it is appropriate to fill the container about 1/3 full of water and then add sand. This ensures that there will be no trapped air bubbles that can be present if water is added to the top and stirred in.

Reading should be taken with the meter in 'Standard VWC' mode. The meter should read VWC = 0% in air. In saturated sand, it should read between 35% and 45%. The table below shows the approximate ranges of volumetric water content that are expected for the different rod lengths in distilled water. Note: the meter does not read 100% in water because the soil moisture calibration equations were created to be most accurate in the volumetric water contents typically found in mineral soils.

Rod Length	8 inches (20cm)	4.8 inches (12cm)	3 inches (7.5cm)	1.5 inches (3.8cm)
Water (%)	60 – 65	70 – 75	75 – 80	65 – 70

3.6.3 Suspended Solids Analyzer

The Suspended Solids Analyzer (InsiteIG Model 3150) is a handheld analyzer designed for the measurement of suspended solids in aqueous solutions. The microprocessor-based electronics of the model 3150 analyzer provide a high degree of flexibility and ease of use. The instrument is designed to operate in a variety of applications. The sensor operates on the principle of single gap light absorption as means of detecting the presence of suspended solids.

Using a near-infrared wave length (880 nano-meters) virtually eliminates shifts in calibration caused by color variations in the process being measured. As almost all processes will have slight changes in color, using near-infrared reduces calibration events and provides better accuracy.

CHAPTER 4

EXPERIMENTAL SETUP AND DATA COLLECTION

4.1 GENERAL

As this experimental dissertation work aims at to determine SCS runoff curve number and sediment yield for Indian watersheds, an agricultural field (size about 70.0 m x 50.0 m) was hired, which was available near the existing experimental farm of the Department of Water Resources Development and Management (DWRD&M), IIT Roorkee. This farm lies in a village Toda Kalyanpur, Roorkee, which is about 6.0 km east-south from IIT Roorkee. The farm has plain topography and was being initially used for agricultural purposes. Location map of the experimental area is shown in Fig. 4.1. Toda Kalyanpur lies in Tehsil Roorkee, District Haridwar, and State Uttrakhand of India. It has latitude 29^{0} 50’ 9” N and longitude 77^{0} 55’ 21” E. Its elevation/altitude is 266 meters above mean sea level.

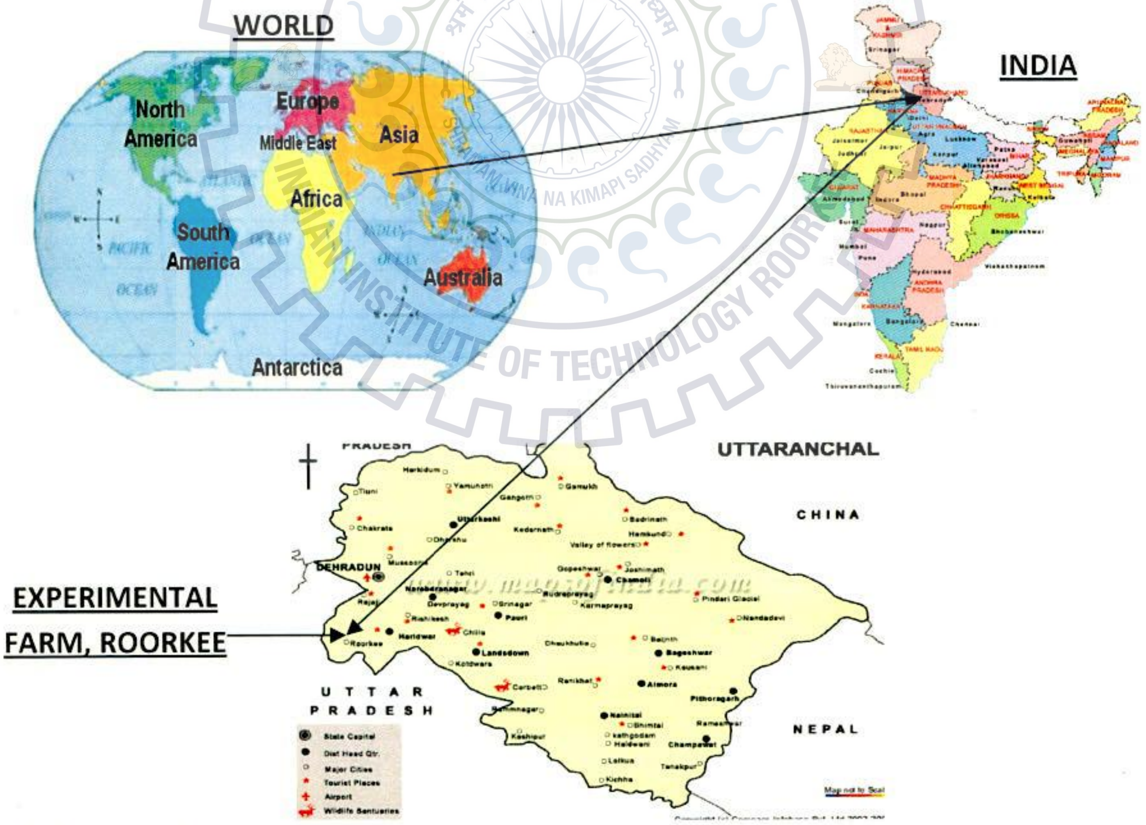


Fig. 4.1 Location map of the Experimental Farm

4.1.1 Soil Type

Soil is an important component of the rainfall-runoff-sediment yield process. Soils are broadly classified as sand, silt, and clay on the basis of the grain size which decreases in their order. The finer particle sizes are divided into sand (0.05 to 2.0 mm), silt (0.002 to 0.05 mm) and clay (less than 0.002 mm). Soil texture is determined by the relative quantities of these materials. There are 12 textural classifications as described in the textural triangle (Fig. 4.2). Soil particle analysis determines the size of soil particles. The sieve analysis of the soil of each grade of plot was carried out in the WRD&M Departmental laboratory. The plot of 1% slope had 81.52% of sand and 18.02% of fine particles; plot of 3% slope had 73.22% of sand and 26.27% of fine particles; and plot of 5% slope had 74.17% of sand and 25.31% of fine particles. Thus, from Fig. 4.2, it can be concluded that the experimental farm of each plot had loamy sand.

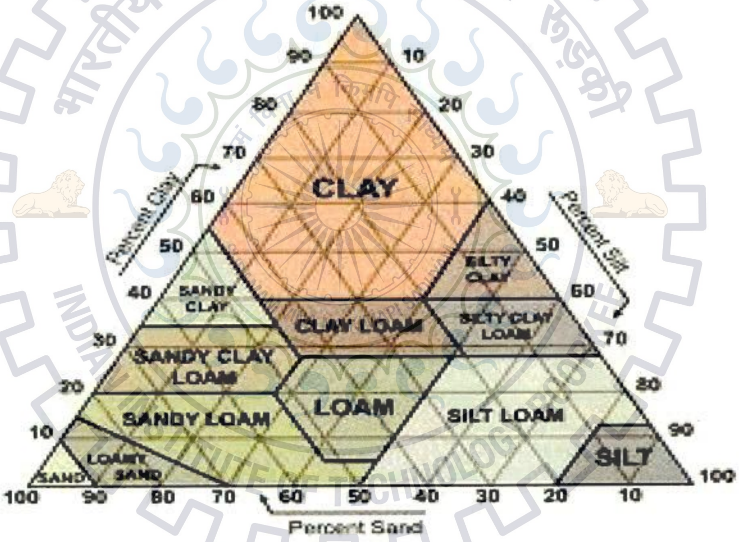


Fig.4.2. Soil Textural Classification of the U.S. Public Road Administration

4.1.2 Hydrological Soil Group

The Soil Conservation Service identified four hydrologic groups of soils A, B, C, and D, based on their infiltration and transmission rates. The major criterion that governs the above soil classification is the magnitude of the minimum infiltration rate (f_c). Sandy soils exhibit the highest f_c, whereas clay soils exhibit the lowest f_c. The classification based on the minimum infiltration rates is given in Table 4.1 (McCuen, 1982).

Table 4.1 Description of hydrologic soil groups

Hydrologic Soil Group	Minimum infiltration rate (inch/hr)
A	0.30 – 0.45
B	0.15 – 0.30
C	0.05 – 0.15
D	0 – 0.05

To identify the hydrologic soil group, infiltration tests of the soil on each of three grades of plots were conducted using double ring infiltrometer. From the above test, the minimum infiltration rates of three grades (1%, 3% and 5%) of plots were 3.69 mm/hr, 3.69 mm/hr, and 2.67 mm/hr, respectively. This shows the minimum infiltration rates to lie between 1.27 mm/hr (0.05 inch/hr) and 3.81 mm/hr (0.15 inch/hr) which suggest the soil to fall in Hydrologic Soil Group C. The Fig. 4.3 shows the result of double ring infiltrometer field test.

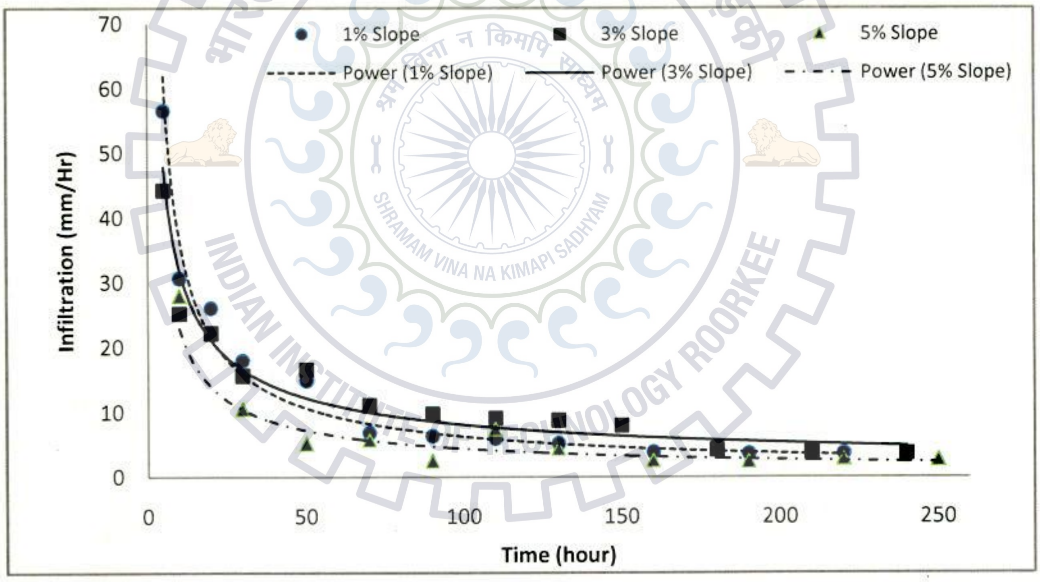


Fig. 4.3 Infiltration capacity curves for three different grades

4.2 EXPERIMENTAL SETUP

"Plan the work and work the Plan" is more appropriate proverb to achieve the target within time frame. Where all the parameters are not in control, it is very difficult to accomplish the target within the time frame and the same happened during the phase of establishing the experimental farm and had to miss the major rainstorms for observations. However, some of the natural rain events could be captured during winter season also. To conduct the experimental work under the controlled conditions, the following activities were taken up.

4.2.1 Establishment of Farm

A. Hiring of Farm

The activities related to dissertation work started from July 2012, i.e. with the beginning of Autumn Semester began. This dissertation topic is based on experimental work, and therefore, first of all a farm was hired to conduct the works. A farm (size about 70.0 m x 50.0 m) was found near the existing experimental farm of Department of Water Resources Development and Management (WRD&M), IIT Roorkee. This farm is situated in village Toda Kalyanpur, Roorkee, which is about 6.0 km east-south from IITR. An agreement of lease was made with land owner for three years with extension option on mutual understanding.

B. Preparation of Plots

Three numbers of plots at different grades (1%, 3% and 5%) were prepared employing tractor having a leveler in its back (Fig. 4.4a). Initially each plot was made of size 23.0 m x 21.0 m, which is then divided into four small plots of size 22 m x 5 m in each grade of plots (Fig. 4.4b). Hence, 12 numbers of plots of required size were prepared for study. Pegs and strings with white chalk were used for marking the plots with its level, which guided the tractor to pile up soils accordingly. The frequent movement of tractors on deposited soil compacted the plots enough requiring no further compaction.

(a) (b)

Fig.4.4 (a) Land preparation and (b) Making Plots of required size

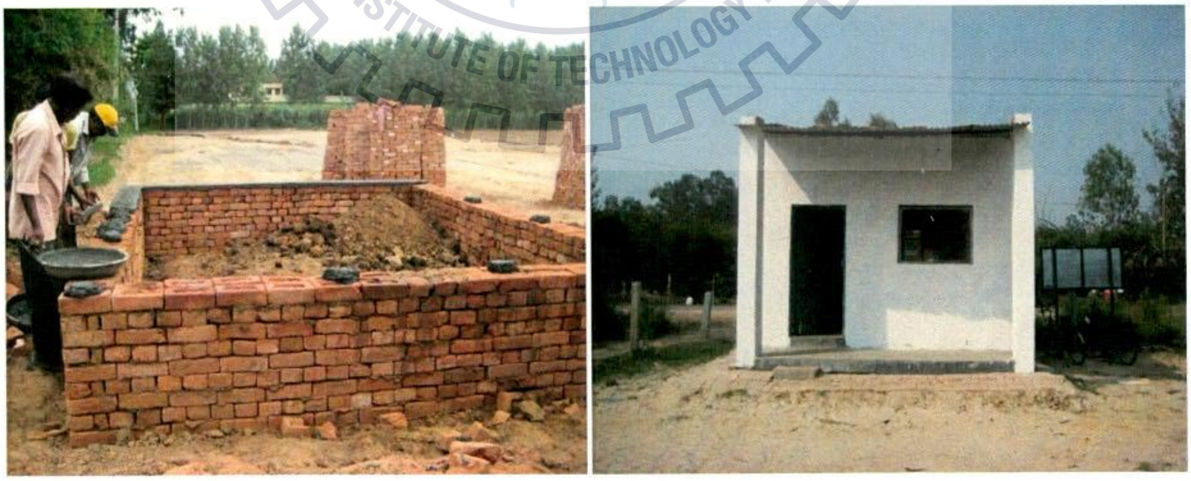
A pond of size about 8.0 m x 4.0 m and 2.5 m depth was constructed with the help of excavator (Fig. 4.5) to catch the runoff water from the farm since there is no drainage facility available. The water collected during rains was pumped out as per requirement.

(a) (b)

Fig. 4.5 Construction of Pond/Ditch

C. Construction of Shelter/Control Room

A room (size 12' x 10') as a shelter in the site was constructed which can be used for storing the tools and equipment. This room is also being used for the watchman who has been appointed for the security and caretaker of the farm. The photographs during construction and finishing of the room are shown in Fig. 4.6.



(a) (b)

Fig. 4.6 (a) DPC Level of Room and (b) Finishing of Room

D. Display and Safety of Farm

A sign board (Fig. 4.7a) displays the name of experimental farm, name of host institution, and the sponsor. As the farm is located in village area, there is chance of animal grazing inside the farm as well for other safety purpose, fencing of the farm was essential. So reinforced cement concrete pillars are constructed and fixed at boundary of farm. Barbed wire is tied up in four rows to the pillars to obstruct the movement from outside (Fig. 4.7b).

(a) (b)

Fig. 4.7 (a) Display of the project site and (b) Pillars with Barbed Wire at Boundary

E. Planting of Sugarcane Crops

As it was late to sow the seeds of sugarcane, small plants of sugarcane of about 40 days (Fig. 4.8) were purchased from local farmer. Plants were dug out with roots along with soil from the farmer's land and planted on same day on three plots of different grades (1%, 3% and 5%) and fortunately, rainfall occurred next day. Watering was done for sugarcane whenever it was felt necessary.

(a) (b)

Fig. 4.8 Plantation of Sugarcane

F. Construction of plot boundary and approach Channel

To collect the runoff discharge from the plots, boundary was constructed along the plot boundary at its most downstream end (Fig. 4.9). This helped move the runoff discharge as well as sediment yield towards the measuring chamber. A lateral slope of 1:100 in the plot was provided and the width of channel boundary was kept as 25 cm.


(a) (b)

Fig. 4.9 Construction of plot boundary

Similarly, approach channels were constructed to convey the collected runoff as well the sediment yield from the plot to the measuring chamber as shown in Fig. 4.10.


(a) (b)

Fig. 4.10 Construction of approach channel

G. Construction of Measuring Chambers

To collect and measure runoff as well as sediment yield from the respective plots, 12 numbers of chambers are constructed (Fig. 4.11). The sizes of the chambers are kept as 1.0m x 1.0m x 1.0m to make a one cubic meter chamber for ease in volumetric measurements. The chambers are constructed along the centre line of the plots to receive the flow normally/ symmetrically. A multi-slot divisor with five slots was placed with each chamber which reduced the size of the chamber by five times of the otherwise required size and hence it was economical.


(a) (b)

Fig. 4.11 Construction of Measuring Chamber

4.2.2. Instrumentation and Installation of Devices

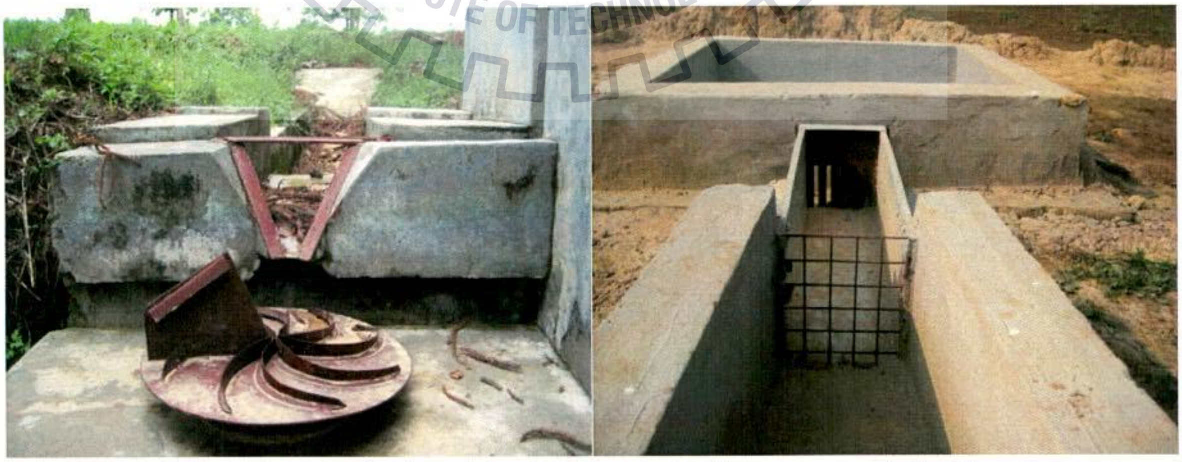
An ordinary rain gauge (ORG) and a self recording rain gauge (SRRG) were procured and installed at the site to measure rainfall regularly. An oven was also purchased and it is installed in the departmental laboratory where electricity supply is much better than the site. Oven was used for drying the sediment samples for computation of sediment yield from the plots. Hundreds of bottles of one liter were procured for taking sample of runoff and sediment yield. The photographs related to rainfall recording devices are shown in Figs. 4.12 and 4.13.


(a) (b)

Fig. 4.12 Setup of (a) Ordinary Rain Gauge and (b) Self – Recording Rain Gauge

Fig. 4.13 Installation of ORG and SRRG

Initially it was planned to use Coshocton Wheel (Fig. 4.14a) to collect the rainfall generated runoff and sediment yield. To have better acquaintance, a visit to *Central Soil and Water Conservation Research and Training Institute* (CSWCRTI), Dehradun, India, was made. With courtesy of Dr. P.K. Mishra, Director, and Dr. Ambrish Kumar Tiwari, Principal Scientist (SWCE), a visit to '*Selakui Watershed Management Project*', a research farm was made. For the size of the plots under study was small (plot area less than 0.1 ha), having runoff less than 0.15 cumec, Multi–Slot Devisors were considered to be more appropriate than the Coshocton Wheel. One piece of multi-slot devisor was got manufactured from Dehradun as a sample and similar multi-slot devisors were got manufactured in Roorkee. The photograph of a multi-slot devisor is shown in Fig. 4.14b.



(a) (b)

Fig. 4.14 (a) Coshocton Wheel and (b) Multi-Slot Devisor

4.3 DATA COLLECTION

As the dissertation work is based on experimental work, no secondary data were used, The data required were observed in the farm itself by establishing the required equipments. The major data required for analysis of work are event rainfall, soil moisture, soil type, hydrologic soil group, rainfall generated runoff, and sediment yield. Almost two months (from hiring to instrumentation setup) continuous and dedicated effort led to the establishment of the experimental farm, and observations on rainfall-runoff and sediment yield data started from September 2012 onwards. Since it was a receding phase of the monsoon, only a few number of rain-storms could be captured. However, some natural rainfall-runoff-sediment yield data were also captured during winter season. Before each rainstorm, soil moisture was measured by a soil moisture instrument (Fig. 4.15a) and after each rainstorm, sediment yield collected in the chamber were measured by the suspended solid analyzer (Fig. 4.15b). The daily rainfall data were taken from both ORG and SRRG. The measurement of daily soil moisture prior to each rain event and the measurement of rainfall from ORG after each rainfall is shown in Fig. 4.15c and Fig. 4.15d.

(a) (b)

Fig. 4.15 (a) Soil Moisture Meter (b) Suspended Solid Analyzer

(c) (d)

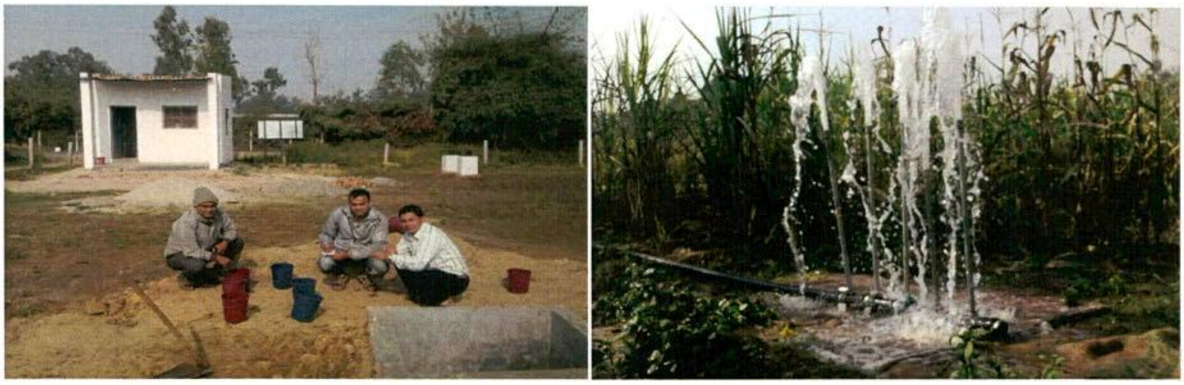
Fig. 4.15 (c) Measurement of Soil Moisture and (d) Measurement of Rainfall using ORG

To identify the hydrologic soil group, infiltration tests of the soil on each of three grades of plots were conducted using double ring infiltrometer (Fig. 4.16a). The grain sizes were analysed using sieve analysis in the laboratory (Fig. 4.16b) to classify the soils of each experimental plot of each grade.

Fig. 4.16a Double Ring Infiltrometer Test in each experimental plot.

Fig. 4.16b Sieve Analysis Test of soil sample of each grade of plot.

After the rainy season, a sprinkler system was established as a substitute of natural rainfall system. While running the system, it was found that its discharge intensity was more (about 5 times) in centre or nearby than that at the outer periphery of the designed range (Fig. 4.17a). Therefore, the sprinkler was removed and only the risers (G.I. Pipes) were used converting sprinkler system to flooding irrigation to sugarcane (Fig. 4.17b). But due to high pressure of falling water from the riser, local erosion started which affected the sediment yield data of the whole plot. Through hit and trail, finally the pipes were fitted with risers and these were laid on ground surface with their outlets were covered with jute bags to protect the local soil erosion and to distribute flow uniformly across the whole width of plot (Fig. 4.17c). This system was found to work satisfactorily, and thus, data for artificial flooding could be collected.



(a) (b)

Fig. 4.17 (a) Trail for Sprinkler System (b) Trial for Flooding through Riser (G.I. Pipe)

(c)

Fig. 4.17(c) Trial for Uniform flooding using pipe

After each event, surface runoff collected in the chamber of size 1.0 x 1.0 x 1.0 cum was measured with Steel Ruler of 1.0m length (Fig. 4.18a) and the collected sediment yield in the chamber was stirred well with leg and the sample was collected in a bottle of one liter (Fig. 4.18b) which was marked with date, number, and the grade of plot (Fig. 4.18c).

(a) (b)

Fig. 4.18 (a) Runoff Measurement (b) Collecting Sample for Sediment Yield

(c)

Fig. 4.18 (c) Sediment sampling

Simultaneously, the data collected from the field were brought to the department laboratory where oven was used to dry the sample to determine the sediment yield from the respective plots. To obtain the sediment concentration, the dry weight of sediment samples was determined after oven drying the sample at 105^{0}C for 24 hours. Thus, sediment yield from the one liter of sample was computed along with total runoff depth. Some of the photographs related to laboratory works are shown in Fig. 4.19.

(a) (b)

Fig. 4.19 (a) Preparing Sediment Sample and (b) Weighing of Oven Dry Sediment

Time to time supervision and instruction from the faculty of WRD&M, IITR, and Scientists from National Institute of Hydrology, Roorkee, led to the successful completion of the experimental work. Some related photographs are shown in Fig. 4.20.

Fig. 4.20 Supervision of IIT Roorkee faculty

CHAPTER 5

RESULTS AND DISCUSSION

5.1 GENERAL

The rainfall-runoff-sediment yield analysis presented in this study is based on only seven monsoon season rainfall events and as sugarcane being a perennial crop, additional eight winter rainfall events i.e. altogether 15 rainfall-runoff-sediment yield events of monsoon and winter season were captured as shown in Table 5.1. Besides, experiments were also conducted with flooding irrigation, yielding six (artificial) rainfall-runoff events. Here, it is worth emphasizing that the (artificial) rainfall-runoff events thus derived exclude the process of interception. In addition, the time of travel being relatively much less, yields higher runoff (and, in turn, higher CN) due to availability of less opportunity time for infiltration. Infiltration tests of the soil on each of three grades of plots were conducted using double ring infiltrometer and the minimum infiltration rates of three plots of 1%, 3%, and 5% slopes were 3.69 mm/hr, 3.69 mm/hr, and 2.67 mm/hr, respectively, which lie in the range (1.27 – 3.81) mm/hr, describing the soil to fall in hydrologic soil group 'C'.

5.2 NATURAL RAINFALL-RUNOFF EVENTS

5.2.1 Rainfall Generated Surface Runoff

After each rainstorm, surface runoff collected in the chamber of size 1.0 x 1.0 x 1.0 cum was measured with Steel Ruler of 1.0m length. As the chamber as well as the water conveying channel is open to the sky (Fig. 5.1), the rainfall depth for this open area is deducted from the measured depth of runoff from the chamber. The surface runoff thus collected was multiplied by 5 to account for the all 5 numbers of slots of the multi-slot devisor. The calculation of surface runoff for each plot and event is presented in Table 5.2.

Fig. 5.1 Open chamber and channel.

5.2.2 Rainfall Generated Sediment Yield

The dry weight of sediment samples was determined in the laboratory of the department after oven drying the sample at 105^0C for 24 hours and it is used to derive the sediment concentration of the sample. Thus, obtained sediment yield from one liter of sample was computed with total runoff depth as shown in Table 5.3.

5.2.3 Potential Maximum Retention and Curve Number

The SCS-CN method is usually used in a prediction mode with CN values derived from the handbook methods using the soil and vegetation information. For more appropriate prediction, it is necessary that CN-values be derived for the watersheds on which it is to be employed. Thus, CN should be determined from the event rainfall (P) and runoff (Q) data observed in the watershed. Thus, P and Q with $Q > 0$ lead to an S(or CN)-value via Eq. 5.1 and Eq. 5.2. Table 5.4 shows the CNs obtained for each event and grade of plot.

$$S = 5(P + 2Q - \sqrt{(Q(4Q + 5P))} \tag{5.1}$$

$$CN = 25400/(S + 254) \tag{5.2}$$

5.2.4 Curve Numbers for Different AMCs

Hjelmfelt et al. (1981) found that the established AMC relationships described the 90%, 50%, and 10% cumulative probabilities of the runoff depth for a given rainfall via SCS-CN method. These correspond to AMC I, II and III respectively. Hence CNs determined for each event (Table 5.4) was arranged in descending order for each grade of plot separately and these were assigned rank. The CNs for three AMCs were derived considering CN values corresponding to 90%, 50%, and 10% cumulative probability of exceedance (Table 5.5) which correspond to AMC I through AMC III, respectively.

Table 5.1. Observed Natural Rainfall, Moisture Content, Surface Runoff Depth and Sediment Yield

Event No.	Date	Rainfall (P) (mm)	Antecedent Moisture Content from the plot of grade (θ_0) (%)			Surface Runoff Depth measured in the chamber from the plot of grade (mm)			Sediment Yield from the plot of grade (mg/lit)		
			1%	3%	5%	1%	3%	5%	1%	3%	5%
1	12-Sep-12	8.40	30.40	27.10	26.60	1.67	1.83	2.50	4040.40	5025.13	7000.00
2	13-Sep-12	22.20	32.70	30.70	30.10	14.43	17.37	35.07	2040.82	3030.30	7446.81
3	14-Sep-12	30.20	32.50	27.40	27.60	23.80	28.90	36.03	1515.15	2000.00	5000.00
4	15-Sep-12	1.00	33.20	27.30	28.70	0.00	0.00	0.00	-	-	-
5	17-Sep-12	42.10	34.50	32.00	31.00	51.60	54.10	58.67	1000.00	3000.00	5000.00
6	18-Sep-12	29.10	34.80	32.10	31.84	39.67	43.47	54.20	1500.00	2500.00	3000.00
7	19-Sep-12	7.00	34.20	29.10	31.70	0.00	0.00	0.00	-	-	-
8	18-Jan-13	56.20	28.40	27.60	26.80	39.83	47.97	49.53	226.80	714.43	2362.89
9	05-Feb-13	48.20	29.80	27.90	26.60	27.47	36.17	50.07	146.46	229.00	892.86
10	06-Feb-13	22.40	29.30	29.10	26.90	10.40	13.33	20.83	-	-	-
11	16-Feb-13	43.20	28.60	25.60	24.40	41.13	44.07	60.87	428.57	397.00	1085.00
12	17-Feb-13	53.80	32.40	29.80	27.60	57.23	63.27	74.30	-	-	-
13	22-Feb-13	8.00	31.40	30.50	29.50	0.00	0.00	1.80	-	-	-
14	23-Feb-13	9.20	31.15	31.43	30.93	1.87	2.60	7.37	316.33	295.83	495.92
15	24-Feb-13	5.20	27.80	28.80	27.33	0.00	0.00	0.00	-	-	-

Table 5.2 Calculation of rainfall generated surface runoff depth

Event No.	Rainfall	Measured Runoff depth from 1 no. of slot in cm			Deduction of volume (due to open area)	Runoff (cum) = measured runoff x 5 - Deduction of volume (due to open area)			Observed Surface Runoff (Q) from the plot of grade (mm)		
	mm	1%	3%	5%	cum	1%	3%	5%	1%	3%	5%
1	8.40	1.67	1.83	2.50	0.01663	0.0003	0.0083	0.0418	0.00	0.08	0.38
2	22.20	14.43	17.37	35.07	0.04396	0.5017	0.6487	1.5337	4.56	5.90	13.94
3	30.20	23.80	28.90	36.03	0.05981	0.8910	1.1460	1.5025	8.10	10.42	13.66
4	1.00	0.00	0.00	0.00							
5	42.10	51.60	54.10	58.67	0.08337	2.1631	2.2881	2.5166	19.66	20.80	22.88
6	29.10	39.67	43.47	54.20	0.05763	1.6954	1.8854	2.4219	15.41	17.14	22.02
7	7.00	0.00	0.00	0.00							
8	56.20	39.83	47.97	49.53	0.11129	1.4350	1.8420	1.9200	13.05	16.75	17.45
9	48.20	27.47	36.17	50.07	0.09545	0.8962	1.3312	2.0262	8.15	12.10	18.42
10	22.40	10.40	13.33	20.83	0.04436	0.2982	0.4447	0.8197	2.71	4.04	7.45
11	43.20	41.13	44.07	60.87	0.08555	1.6288	1.7758	2.6158	14.81	16.14	23.78
12	53.80	57.23	63.27	74.30	0.10654	2.3288	2.6308	3.1823	21.17	23.92	28.93
13	8.00	0.00	0.00	1.80	0.01584			0.0108			0.10
14	9.20	1.87	2.60	7.37	0.01822	0.0022	0.0389	0.2772	0.02	0.35	2.52
15	5.20	0.00	0.00	0.00	0.01030						

Table 5.3 Calculation of Sediment Yield

Event No.	Rainfall (P) (mm)	Observed Surface Runoff (Q) from the plot of grade (mm)			Sediment Yield (mg/lit)			Observed Sediment Yield (Yo) (kg)		
		1%	3%	5%	1%	3%	5%	1%	3%	5%
1	8.40	0.003	0.076	0.380	4040.40	5025.13	7000.00	0.001	0.042	0.293
2	22.20	4.561	5.897	13.943	2040.82	3030.30	7446.81	1.024	1.966	11.421
3	30.20	8.100	10.418	13.659	1515.15	2000.00	5000.00	1.350	2.292	7.512
4	1.00	0.000	0.000	0.000	-	-	-	-	-	-
5	42.10	19.665	20.801	22.879	1000.00	3000.00	5000.00	2.163	6.864	12.583
6	29.10	15.412	17.140	22.017	1500.00	2500.00	3000.00	2.543	4.713	7.266
7	7.00	0.000	0.000	0.000	-	-	-			
8	56.20	13.046	16.746	17.455	226.80	714.43	2362.89	0.325	1.316	4.537
9	48.20	8.148	12.102	18.420	146.46	229.00	892.86	0.131	0.305	1.809
10	22.40	2.711	4.043	7.452	-	-	-	-	-	-
11	43.20	14.807	16.143	23.780	428.57	397.00	1085.00	0.698	0.705	2.838
12	53.80	21.171	23.916	28.930	-	-	-	-	-	-
13	8.00	0.000	0.000	0.098	-	-	-	-	-	-
14	9.20	0.020	0.354	2.520	316.33	295.83	495.92	0.001	0.012	0.137
15	5.20	0.000	0.000	0.000	-	-	-	-	-	-

Table 5.4 Calculation of Potential Maximum Retention (S) and Curve number (CN) for natural events on plots of sugarcane

Event	Date	Precipitation (P)	Plot at 1 % slope			Plot at 3 % slope			Plot at 5 % slope		
			Runoff (Q)	S for λ = 0.2	CN	Runoff (Q)	S for λ = 0.2	CN	Runoff (Q)	S for λ = 0.2	CN
		mm	mm	mm	CN = 25400/(S+254)	mm	mm	CN = 25400/(S+254)	Mm	mm	CN = 25400/(S+254)
1	12-Sep-12	8.40	0.003	40.26	86.32	0.076	33.81	88.25	0.380	25.46	90.89
2	13-Sep-12	22.20	4.561	35.21	87.82	5.897	29.11	89.72	13.943	9.32	96.46
3	14-Sep-12	30.20	8.100	39.29	86.60	10.418	31.17	89.07	13.659	22.60	91.83
4	15-Sep-12	1.00									
5	17-Sep-12	42.10	19.665	30.11	89.40	20.801	27.70	90.17	22.879	23.66	91.48
6	18-Sep-12	29.10	15.412	17.11	93.69	17.140	14.04	94.76	22.017	7.12	97.28
7	19-Sep-12	7.00									
8	18-Jan-13	56.20	13.046	81.81	75.64	16.746	66.78	79.18	17.455	64.28	79.80
9	05-Feb-13	48.20	8.148	86.41	74.62	12.102	66.11	79.35	18.420	44.53	85.08
10	06-Feb-13	22.40	2.711	47.86	84.14	4.043	38.61	86.80	7.452	23.98	91.37
11	16-Feb-13	43.20	14.807	44.88	84.98	16.143	40.93	86.12	23.780	23.73	91.46
12	17-Feb-13	53.80	21.171	48.05	84.09	23.916	41.22	86.04	28.930	30.81	89.18
13	22-Feb-13	8.00							0.098	31.03	89.11
14	23-Feb-13	9.20	0.020	41.36	86.00	0.354	29.06	89.73	2.520	11.76	95.58
15	24-Feb-13	5.20									

Table 5.5 Curve numbers for different AMCs based on probability of exceedance (natural events)

Sugarcane Plot at 1 % slope				**Sugarcane Plot at 3 % slope**				**Sugarcane Plot at 5 % slope**			
Rank	CN in Descending Order	% Rank = (n/(m+1))*100	Remarks	Rank	CN in Descending Order	% Rank = (n/(m+1))*100	Remarks	Rank	CN in Descending Order	% Rank = (n/(m+1))*100	Remarks
1	93.69	8.33	AMC III	1	94.76	8.33	AMC III	1	97.28	7.69	AMC III
2	89.40	16.67		2	90.17	16.67		2	96.46	15.38	
3	87.82	25.00		3	89.73	25.00		3	95.58	23.08	
4	86.60	33.33		4	89.72	33.33		4	91.83	30.77	
5	86.32	41.67		5	89.07	41.67		5	91.48	38.46	
6	86.00	50.00	AMC II	6	88.25	50.00	AMC II	6	91.46	46.15	AMC II
7	84.98	58.33		7	86.80	58.33		7	91.37	53.85	
8	84.14	66.67		8	86.12	66.67		8	90.89	61.54	
9	84.09	75.00		9	86.04	75.00		9	89.18	69.23	
10	75.64	83.33	AMC I	10	79.35	83.33	AMC I	10	89.11	76.92	
11	74.62	91.67		11	79.18	91.67		11	85.08	84.62	AMC I
								12	79.80	92.31	

5.3 ARTIFICIAL RAINFALL-RUNOFF EVENTS

After the monsoon season, similar experiments were conducted with flooding irrigation to each plot with the aid of pipes (six in numbers) used in sprinkler irrigation. The discharge through each of six numbers of pipes was measured three times and average discharge computed for each pipe number 1 to 6 (Table 5.6).

Table 5.6 Discharge measurement through pipes

Pipe No.	Measurement-I	Measurement-II	Measurement-III	Average (lps)
Pipe 1	1.02	1.04	1.05	1.04
Pipe 2	0.93	0.806	0.804	0.85
Pipe 3	0.928	0.94	0.926	0.93
Pipe 4	1.03	1.02	0.94	1.00
Pipe 5	1.27	1.3	1.3	1.29
Pipe 6	0.97	1.0	0.91	0.96

Runoff depth and sediment yield concentration with suspended solid analyzer were measured each minute (Appendices D) as water was supplied to the field artificially. The cumulative water supply during experiment and cumulative runoff depth in the chamber at the end of the experiment were taken as total precipitation and total runoff depth for that event, respectively. The potential maximum retention and curve number were determined as described above for natural system and shown in Table 5.7. The Curve numbers for three AMCs derived as above for natural events are shown in Table 5.8.

Table 5.7 Computation of Potential Maximum Retention (S) and Curve Number (CN) for artificial events

Event	Date	Duration	Precipitation (P)	Intensity	Runoff (Q)	Moisture Content (θo)	S	CN
		min	mm	mm/hr	mm	%	Ia = λS, λ = 0.2	CN = 25400/(S+254)
							S = 5 (P + 2 Q - (Q (4 Q + 5 P))^0.5)	
Sugarcane Plot at 1 % slope								
1	28-Nov-12	37	55.96	90.75	32.35	23.93	28.03	90.06
2	02-Jan-13	28.5	61.05	128.53	38.23	25.58	25.81	90.78
3	04-Jan-13	20.5	39.78	116.43	24.07	26.18	18.15	93.33
4	13-Jan-13	38.5	68.19	106.27	30.72	24.35	51.32	83.19
5	16-Jan-13	40	47.86	71.80	24.01	23.23	30.76	89.20
6	03-Feb-13	29	57.12	118.18	39.25	26.00	19.08	93.01
Sugarcane Plot at 3 % slope								
1	27-Nov-12	25	50.01	120.02	29.08	17.92	24.75	91.12
2	02-Jan-13	25	53.28	127.87	25.03	17.60	37.79	87.05
3	03-Jan-13	13	24.48	112.98	14.07	25.15	12.4	95.35
4	13-Jan-13	24.5	40.38	98.88	22.87	23.80	21.03	92.35
5	16-Jan-13	29	34.36	71.10	20.55	22.70	16.08	94.05
6	03-Feb-13	22	42.84	116.84	33.53	23.75	9.15	96.52
Sugarcane Plot at 5 % slope								
1	28-Nov-12	23.5	34.12	87.11	28.04	21.04	5.79	97.77
2	02-Jan-13	19	39.96	126.19	29.27	16.90	10.97	95.86
3	04-Jan-13	17	33.66	118.80	31.32	25.15	2.05	99.20
4	12-Jan-13	19.5	33.20	102.15	25.95	20.60	7.12	97.27
5	16-Jan-13	21.5	25.16	70.21	18.56	22.30	6.74	97.42
6	03-Feb-13	19	36.72	115.96	34.55	21.78	1.89	99.26

Table 5.8 Curve numbers for different AMCs based on probability of exceedance (artificial events)

Sugarcane Plot at 1 % slope				Sugarcane Plot at 3 % slope				Sugarcane Plot at 5 % slope			
Rank	CN in Descending Order	% Rank = (n/(m+1))* 100	Remarks	Rank	CN in Descending Order	% Rank = (n/(m+1))* 100	Remarks	Rank	CN in Descending Order	% Rank = (n/(m+1)) *100	Remarks
1	93.33	14.29	AMC III	1	96.52	14.29	AMC III	1	99.26	14.29	AMC III
2	93.01	28.57		2	95.35	28.57		2	99.20	28.57	
3	90.78	42.86	AMC II	3	94.05	42.86	AMC II	3	97.77	42.86	AMC II
4	90.06	57.14		4	92.35	57.14		4	97.42	57.14	
5	89.20	71.43		5	91.12	71.43		5	97.27	71.43	
6	83.19	85.71	AMC I	6	87.05	85.71	AMC I	6	95.86	85.71	AMC I

5.4 ANALYSIS FOR RAINFALL-GENERATED RUNOFF AND CURVE NUMBER

5.4.1 Comparison of CN with those in NEH-4 Table

For the experimental farm having sugarcane crops grown in straight rows on hydrological soil group C with fair hydrological condition, the NEH-4 CN-values lie in the range 85 to 88 for AMC II condition. As seen from Table 5.9, the CN values derived from the observed data for the same AMC II condition and for three grades of 1%, 3% and 5% are 86.00, 88.25, and 91.42 and 90.42, 93.20, and 97.59 for natural and artificial datasets, respectively.

The CN-values obtained from natural events are seen to be quite close to NEH-4 CN-values, indicating satisfactory match between the two, and therefore, support the applicability of NEH-4 CN values to Indian watersheds. However, the CN-values obtained from artificial dataset are higher as they exclude interception losses and their times of travel of runoff are relatively much less, and thus, yield higher runoff and, in turn, higher CN due to availability of less opportunity time for infiltration.

Table 5.9 Statistical derivation of CNs with different AMCs

AMC	**Curve Number (CN)**					
	Natural Events			**Artificial Events**		
	1%	3%	5%	1%	3%	5%
I	74.82	79.21	81.39	83.19	87.05	95.86
II	86.00	88.25	91.42	90.42	93.20	97.59
III	92.83	93.84	97.03	93.33	96.52	99.26

5.4.2 Effect of Watershed Slope on Runoff

The rainfall generated runoff data from different grades of field plots are plotted (Fig. 5.2) against the corresponding rainfall (Table 5.1). It is noticed that the highest grade plot yields the highest magnitude of runoff for a given land use, rain event, and soil. It is for the reason that the larger slope reduces the time of travel of runoff on the watershed, and therefore, provides lesser duration of stay in the watershed allowing lesser infiltration and, in turn, greater runoff appearing at the outlet of the watershed.

As the supply of water (taken as rainfall) differs from one plot to the other in flooding irrigation (Table 5.7), it was not possible to compare the runoff generation potential for different grades of plot as in case of the above natural rainfall-runoff events, in which the rainfall depth was same for each plot for an event. However, from Fig. 5.3, linearly increasing trends of runoff can be observed with increasing rainfall for each grades of plot which is consistent with the expectation.

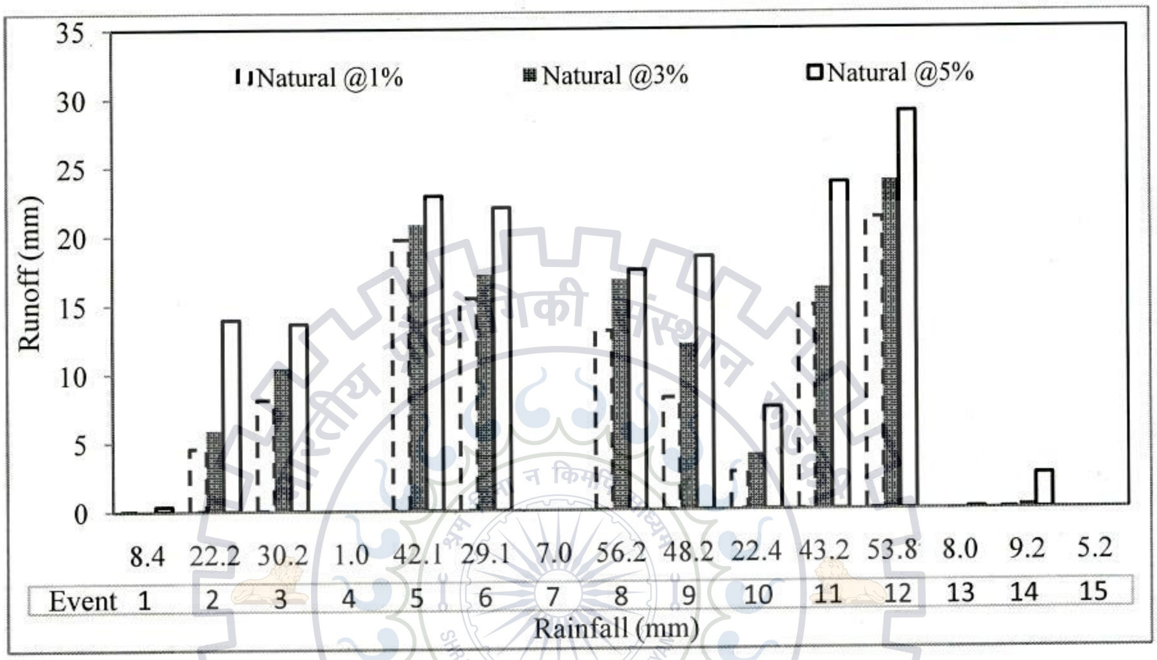


Fig. 5.2 Effect of slope (%) on runoff (for natural event). Third parameter = slope.

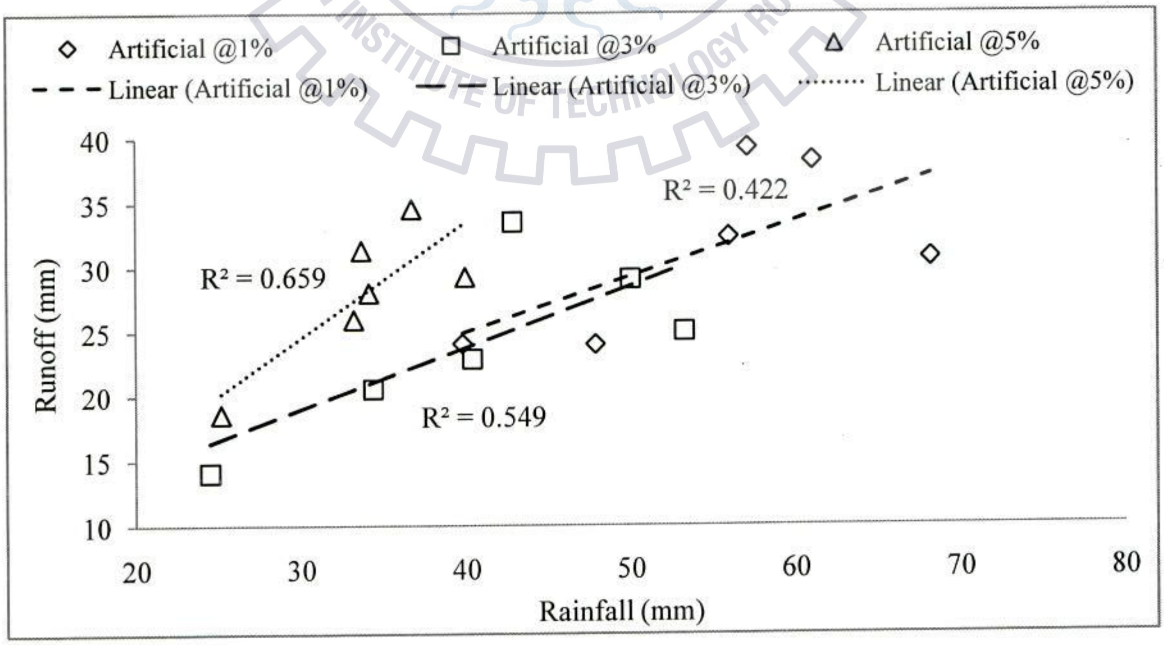


Fig. 5.3 Effect of slope (%) on runoff (for artificial event). Third parameter = slope.

5.4.3 Effect of Watershed Slope on CN

Using Eq. 5.1 and Eq. 5.2, CN values were computed for each natural storm event (Fig 5.4) as well as for each event derived from flooding irrigation. It is seen that CN increases as the grade of plot increases. Thus, there exists a consistency in the results indicating that the higher grade plot has higher CN or runoff producing potential, and vice versa.

Considering CN as 87 from NEH-4 table, which is valid up to 5% slope (Huang et al., 2006) as above, the slope-adjusted CN-values can be calculated from Eq. 5.3 and Eq. 5.4 as 86.84 and 86.92 for 1% and 3%, respectively. Note, at AMC II, for 1%, 3%, and 5% slopes, the CN-values derived from natural rainfall-runoff events are 86.00, 88.25, and 91.42 respectively, and these are 90.42, 93.20, and 97.59, respectively, for flooding irrigation dataset (Table 5.9), indicating similar trends of increasing CN with increasing slope, and vice versa.

$$CN2\alpha = K \times CN2 \qquad (5.3)$$

Where, $$K = \frac{322.79+15.63\,\alpha}{\alpha+323.52} \qquad (5.4)$$

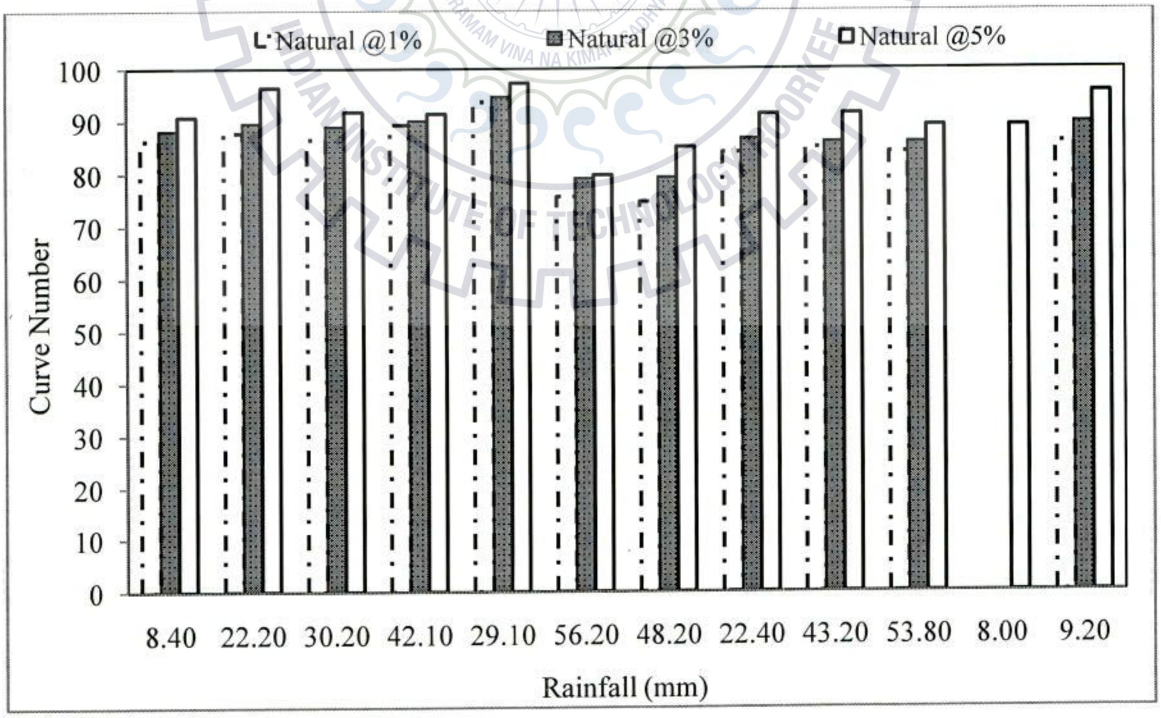


Fig. 5.4 Effect of slope (%) on CN for different natural rainfall-runoff events

5.4.4 Effect of Slope on CN-Rainfall Relation

Based on the behaviour of CN with variation of storm depth, Hawkins (1993) classified the natural watersheds into three types as complacent, standard, and violent. In complacent response, CN declines with increasing rainfall depth, but without approaching a fixed equilibrium value in the period of record. However, in the standard response, which is the most common, CN declines with increasing rainfall depth but approaching a constant or near-stable value asymptotically at higher rainfalls. Violent response is characterized by complacent behaviour with declining CNs at the lower rainfalls, but with a sudden change to a much higher runoff response at some threshold elevated rainfall depth. A constant CN with increasing rainfall is usually exhibited by the standard and violent watersheds (Hawkins, 1993) and eighty percent of the natural watersheds fall in the standard and violent categories.

In the present experimental setup, the rainfall and runoff data were ranked in descending order and paired. Curve numbers were then calculated (Tables 5.10 and 5.11) according to Hawkins' asymptotic approach. The watershed observed curve number was determined asymptotically from the event plots of CN on the ordinate and precipitation on the abscissa. Hence for both types of events (natural as well as due to flooding irrigation), (Fig. 5.5) shows all three grades of field plots falling in violent category of watersheds, for CN continually increases with rainfall to a peak value and then decreases. The data points are however not sufficient to analyze the asymptotic behavior of CN.

Table 5.10 Asymptotic curve number (for natural event)

Precipitation in descending order (P)	Sugarcane Plot at 1 % slope			Sugarcane Plot at 3 % slope			Sugarcane Plot at 5 % slope		
	Runoff in descending order (Q)	S for λ = 0.2	CN	Runoff in descending order (Q)	S for λ = 0.2	CN	Runoff in descending order (Q)	S for λ = 0.2	CN
mm	mm	mm	CN = 25400/(S+254)	mm	mm	CN = 25400/(S+254)	mm	mm	CN = 25400/(S+254)
56.20	21.171	52.77	82.80	23.916	45.60	84.78	28.930	34.64	88.00
53.80	19.665	52.23	82.94	20.801	49.04	83.82	23.780	41.54	85.94
48.20	15.412	53.64	82.57	17.140	48.19	84.05	22.879	33.68	88.29
43.20	14.807	44.88	84.98	16.746	39.26	86.61	22.017	27.07	90.37
42.10	13.046	48.26	84.03	16.143	38.74	86.77	18.420	32.95	88.52
30.20	8.148	39.10	86.66	12.102	26.40	90.59	17.455	15.13	94.38
29.10	8.100	36.70	87.38	10.418	28.89	89.79	13.943	20.06	92.68
22.40	4.561	35.75	87.66	5.897	29.59	89.57	13.659	10.05	96.19
22.20	2.711	47.24	84.32	4.043	38.06	86.97	7.452	23.56	91.51
9.20	0.020	41.36	86.00	0.354	29.06	89.73	2.520	11.76	95.58
8.40	0.003	40.26	86.32	0.076	33.81	88.25	0.380	25.46	90.89

Table 5.11 Asymptotic curve number (for artificial event)

Precipitation in descending order (P)	Runoff in descending order (Q)	S	CN
mm	mm	Ia = λS, λ = 0.2	CN = 25400/(S+254)
Sugarcane Plot at 1 % slope			
68.19	39.25	34.44	88.06
61.05	38.23	25.81	90.78
57.12	32.35	29.76	89.51
55.96	30.72	30.9	89.15
47.86	24.07	30.64	89.24
39.78	24.01	18.25	93.30
Sugarcane Plot at 3 % slope			
53.28	33.53	22.27	91.94
50.01	29.08	24.75	91.12
42.84	25.03	21	92.36
40.38	22.87	21.03	92.35
34.36	20.55	16.08	94.05
24.48	14.07	12.4	95.35
Sugarcane Plot at 5 % slope			
39.96	34.55	4.98	98.08
36.72	31.32	5.01	98.07
34.12	29.27	4.49	98.26
33.66	28.04	5.31	97.95
33.20	25.95	7.12	97.27
25.16	18.56	6.74	97.42

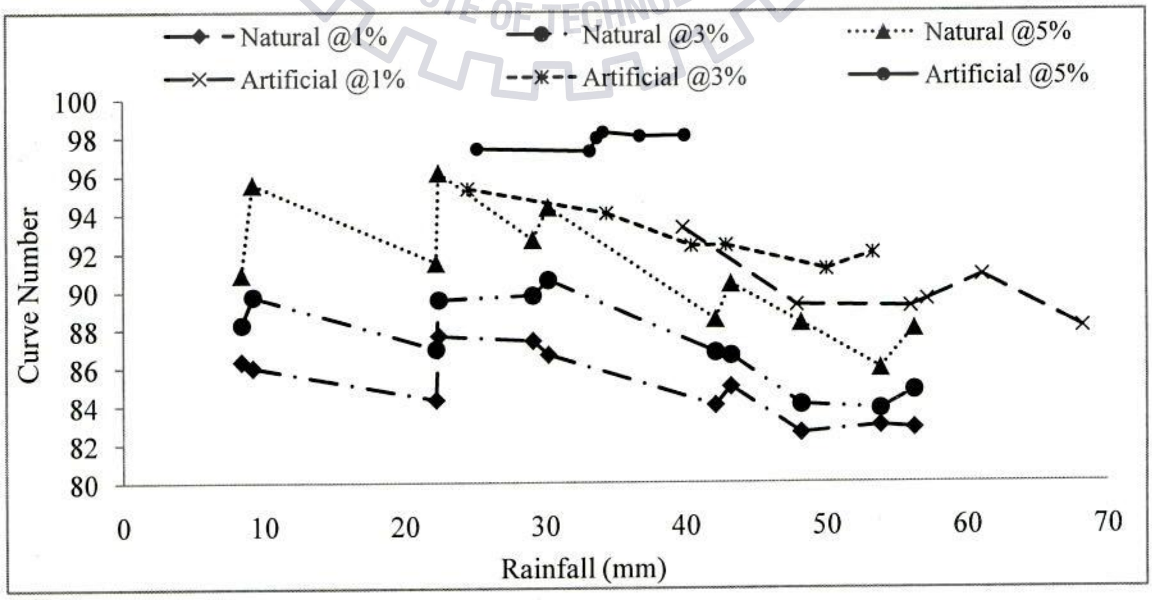


Fig. 5.5 Variation of CN with rainfall

5.4.5 Effect of Watershed Slope on Antecedent Moisture Content (θ_o)

Moisture content (θ_o) measured prior to the occurrence of each natural rainfall event from different grades of plots is depicted in Fig. 5.6 against the total rainfall (Table 5.1). As seen, the highest grade plot exhibits the lowest value of θ_o, for the same rain event, soil, and land use. In other words, as the slope of plot increases, the moisture holding capacity of soil decreases, and vice versa. It is for the reason that the larger slope plots have lesser infiltration and, in turn, lower moisture holding capacity of the plot. It is worth emphasizing that the rainfall was not uniform during flooding irrigation, and therefore, there is no relationship between rainfall and moisture content is apparent. However, from Table 5.7, it can be concluded that, similar to natural event case, the lowest grade plots exhibit the highest moisture holding capacity, and vice versa.

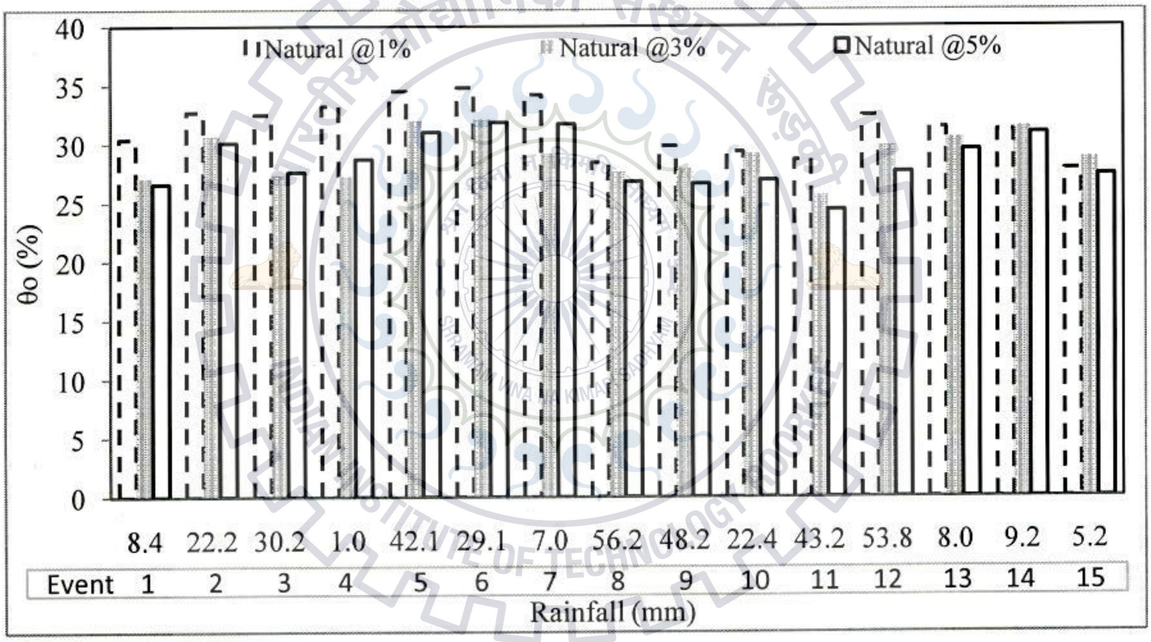


Fig. 5.6 Effect of slope (%) on antecedent moisture content (θ_o). Third parameter = slope.

5.4.6 Effect of Antecedent Moisture Condition (AMC) on CN

CN values for three AMCs were derived considering CN values corresponding to 90%, 50%, and 10% cumulative probabilities of exceedance to represent AMC I through AMC III, respectively. These CN values for three different grades of plots under three AMCs for both cases of rainfall are given in Table 5.9 and depicted in Fig. 5.7 which shows that, in both cases of natural and artificial events, as AMC increases from I (dry) to III (wet), CN increases for a watershed slope, and vice versa. Similarly, for a given AMC, as the watershed slope increases, CN increases, and vice versa.

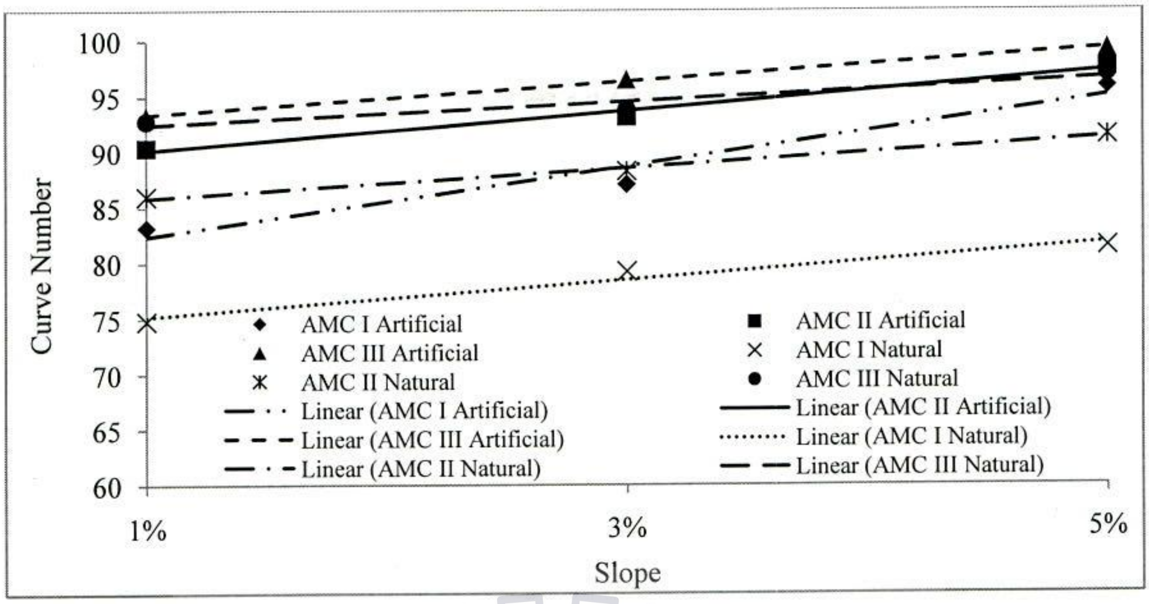


Fig. 5.7 Effect of slope (%) on CN at AMC conditions

5.4.7 Relation between CN and θ_o

The values of S (mm) calculated form Eq. 5.1 for each event were plotted against the respective observed (θ_o) (%) for each grade of watershed for both cases of events as in Fig. 5.8, which shows a linear relationship. If AMC is described by θ_o, these relations lead to infer that as θ_o increases, S decreases linearly and, in turn, CN increases, which is consistent with the expectation and it holds for both natural and artificial datasets.

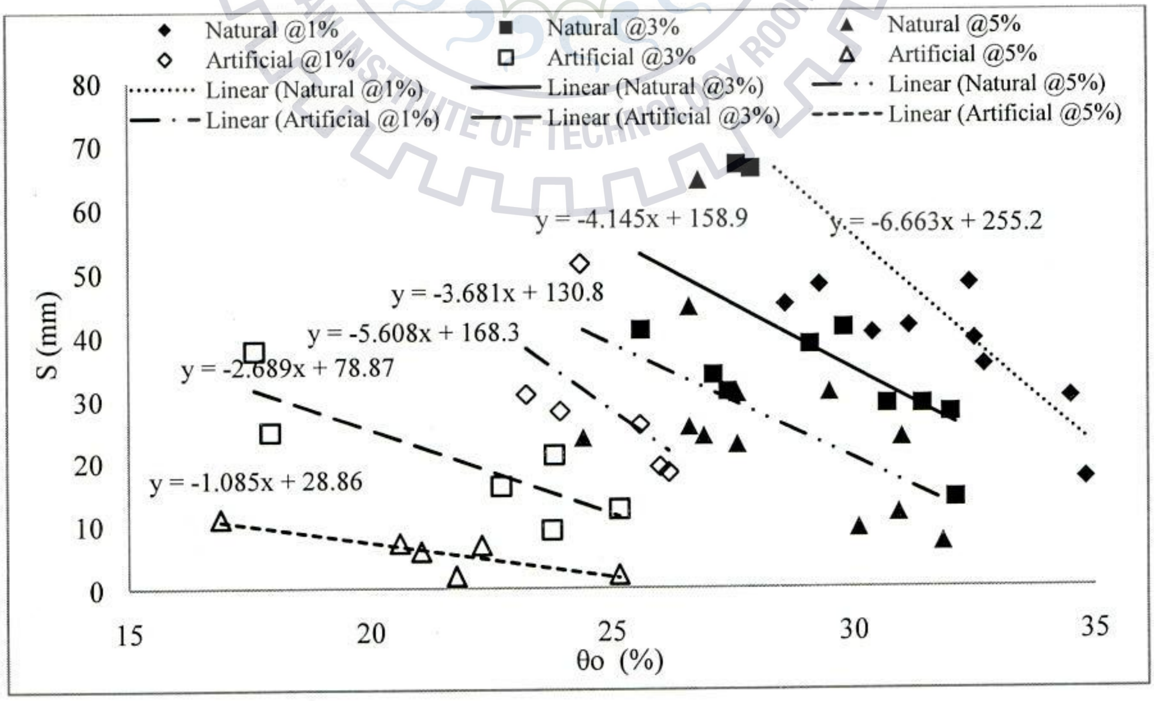


Fig. 5.8 Relation between antecedent moisture content (θ_o) (%) and S (mm).

5.4.8 Validation of CN-θ_o Relationship

The resulting linear CN-θ_o relations derived from Fig. 5.8 are validated by plotting the computed direct surface runoff in both cases of events against the respective observed runoff values, calculated as in Table 5.12 (a & b) for both cases and are shown in Fig. 5.9. Notably, the computed runoff values correspond to those S-values derived from CN-θ_o relations (Fig. 5.8) and the respective observed rainfall. Fig. 5.9 reveals that the data points lie quite close to the line of perfect fit (LPF). The closeness of data points to LPF indicates satisfactory workability of the CN-θ_o relationship (Fig. 5.8).

Table 5.12a Calculation of direct surface runoff using CN-θ_o relations (for natural events)

Plot @ 1%, best fit eq =	**y = -6.663 x + 255.2**				Plot @ 3%, best fit eq =	**y = -4.145 x + 158.9**				Plot @ 5%, best fit eq =	**y = -3.681 x + 130.8**			
P	Q obs	θo	S computed	Q computed	P	Q obs	θo	S computed	Q computed	P	Q obs	θo	S computed	Q computed
mm	mm	%	mm	mm	mm	mm	%	mm	mm	mm	mm	%	mm	mm
8.40	0.00	30.40	52.64	0.090	8.40	0.08	27.10	46.57	0.018	8.40	0.38	26.60	32.89	0.10
22.20	4.56	32.70	37.32	4.172	22.20	5.90	30.70	31.65	5.300	22.20	13.94	30.10	20.00	8.67
30.20	8.10	32.50	38.65	8.261	30.20	10.42	27.40	45.33	6.720	30.20	13.66	27.60	29.20	11.08
42.10	19.66	34.50	25.33	21.992	42.10	20.80	32.00	26.26	21.515	42.10	22.88	31.00	16.69	27.10
29.10	15.41	34.80	23.33	12.499	29.10	17.14	32.10	25.85	11.504	29.10	22.02	31.84	13.60	17.41
56.20	13.05	28.40	65.97	16.972	56.20	16.75	27.60	44.5	24.371	56.20	17.45	26.80	32.15	30.24
48.20	8.15	29.80	56.64	14.539	48.20	12.10	27.90	43.25	18.891	48.20	18.42	26.60	32.89	23.25
22.40	2.71	29.30	59.97	1.539	22.40	4.04	29.10	38.28	4.100	22.40	7.45	26.90	31.78	5.38
43.20	14.81	28.60	64.64	9.655	43.20	16.14	25.60	52.79	12.472	43.20	23.78	24.40	40.98	16.13
53.80	21.17	32.40	39.32	24.750	53.80	23.92	29.80	35.38	26.590	53.80	28.93	27.60	29.20	29.81
9.20	0.02	31.15	47.65	0.002	9.20	0.35	30.50	32.48	0.208	8.00	0.10	29.50	22.21	0.49
										9.20	2.52	30.93	16.93	1.49

Table 5.12b Calculation of direct surface runoff using CN-θ_o relations (for artificial events)

Plot @ 1%, best fit eq = **y =-5.608 x + 168.3**					Plot @ 3%, best fit eq = **y =-2.689x+78.87**					Plot @ 5%, best fit eq = **y = -1.085x + 28.86**				
P	Q obs	θo	S computed	Q computed	P	Q obs	θo	S computed	Q computed	P	Q obs	θo	S computed	Q computed
mm	mm	%	mm	mm	mm	mm	%	mm	mm	mm	mm	%	mm	mm
55.96	32.35	23.93	34.13	29.00	50.01	29.08	17.92	30.68	25.82	34.12	28.04	21.04	6.03	27.82
61.05	38.23	25.58	24.88	38.84	53.28	25.03	17.60	31.54	28.10	39.96	29.27	16.90	10.52	29.62
39.78	24.07	26.18	21.51	22.09	24.48	14.07	25.15	11.24	14.77	33.66	31.32	25.15	1.57	31.85
68.19	30.72	24.35	31.75	40.86	40.38	22.87	23.80	14.87	26.76	33.20	25.95	20.60	6.51	26.49
47.86	24.01	23.23	38.05	20.69	34.36	20.55	22.70	17.83	19.51	25.16	18.56	22.30	4.66	20.32
57.12	39.25	26.00	22.49	36.87	42.84	33.53	23.75	15.01	28.94	36.72	34.55	21.78	5.23	31.11

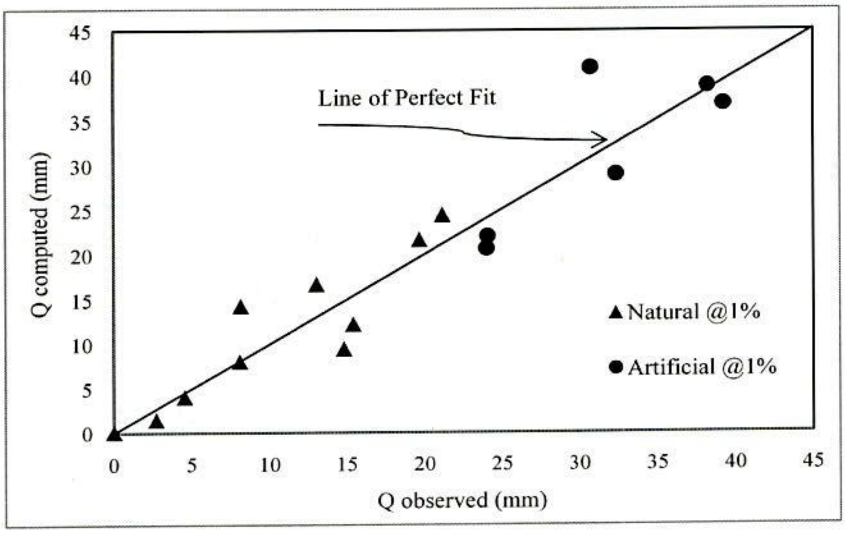


Fig. 5.9 (a) Computed and observed direct surface runoff for 1% slopes.

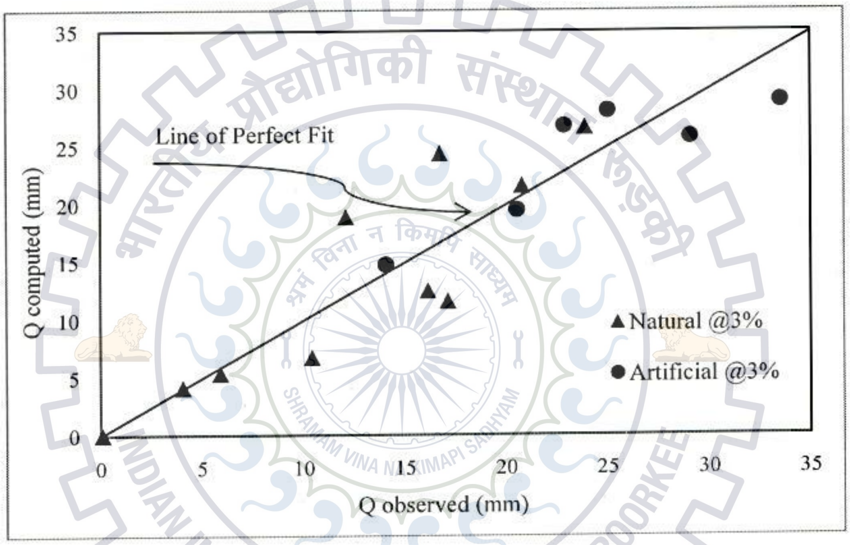


Fig. 5.9 (b) Computed and observed direct surface runoff for 3% slopes.

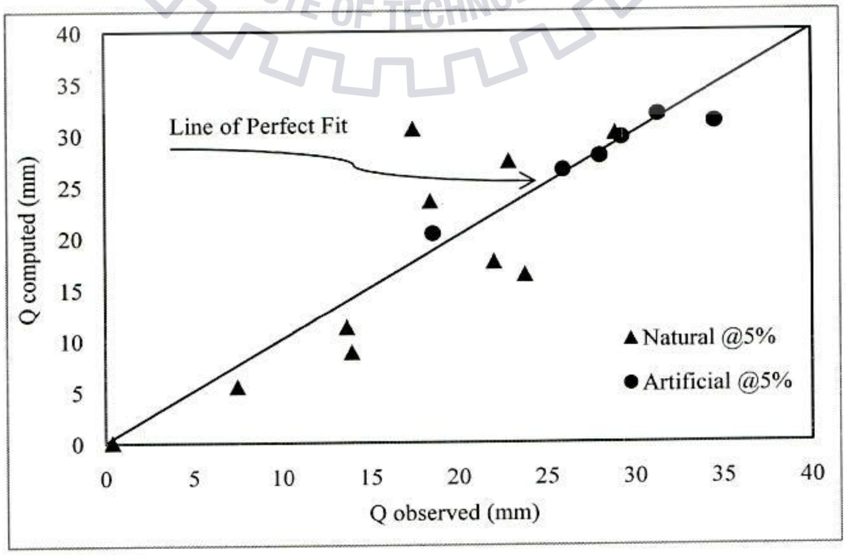


Fig. 5.9 (c) Computed and observed direct surface runoff for 5% slopes.

5.5 ANALYSIS FOR RAINFALL-RUNOFF GENERATED SEDIMENT YIELD

5.5.1 Effect of Watershed Slope on Sediment Yield

The rainfall and runoff generated sediment yield data were observed for different grades of field plots and these are shown against the corresponding rainfall (Table 5.13). In this table, the events of 12 Sept. 2012 and 23 Feb. 2013 were not accounted for the analysis as the recorded rainfall and sediment yield were not significant in quantity. It is seen that the highest grade plot yields the highest magnitude of sediment for a given land use, rain event, and soil, and vice versa as also shown in Fig. 5.10. It is for the reason that the movement of detached soil particles from the land surface depends on the sediment load in the flow and the velocity of flow, and the latter is higher for higher grade of plot.

Table 5.13 Observed rainfall, surface runoff, antecedent moisture content, and sediment yield.

Date	Rainfall (P) (mm)	Observed Surface Runoff (Q) (mm) from the plot of grade			Antecedent Moisture Content (θ_0) (%)			Observed Sediment Yield (Yo) (kg) from the plot of grade		
		1%	3%	5%	1%	3%	5%	1%	3%	5%
12-Sep-12	8.40	0.00	0.08	0.38	30.40	27.10	26.60	0.00	0.04	0.29
13-Sep-12	22.20	4.56	5.90	13.94	32.70	30.70	30.10	1.02	1.97	11.42
14-Sep-12	30.20	8.10	10.42	13.66	32.50	27.40	27.60	1.35	2.29	7.51
17-Sep-12	42.10	19.66	20.80	22.88	34.50	32.00	31.00	2.16	6.86	12.58
18-Sep-12	29.10	15.41	17.14	22.02	34.80	32.10	31.84	2.54	4.71	7.27
18-Jan-13	56.20	13.05	16.75	17.45	28.40	27.60	26.80	0.33	1.32	4.54
05-Feb-13	48.20	8.15	12.10	18.42	29.80	27.90	26.60	0.13	0.31	1.81
16-Feb-13	43.20	14.81	16.14	23.78	28.60	25.60	24.40	0.70	0.71	2.84
23-Feb-13	9.20	0.02	0.35	2.52	31.15	31.43	30.93	0.00	0.01	0.14

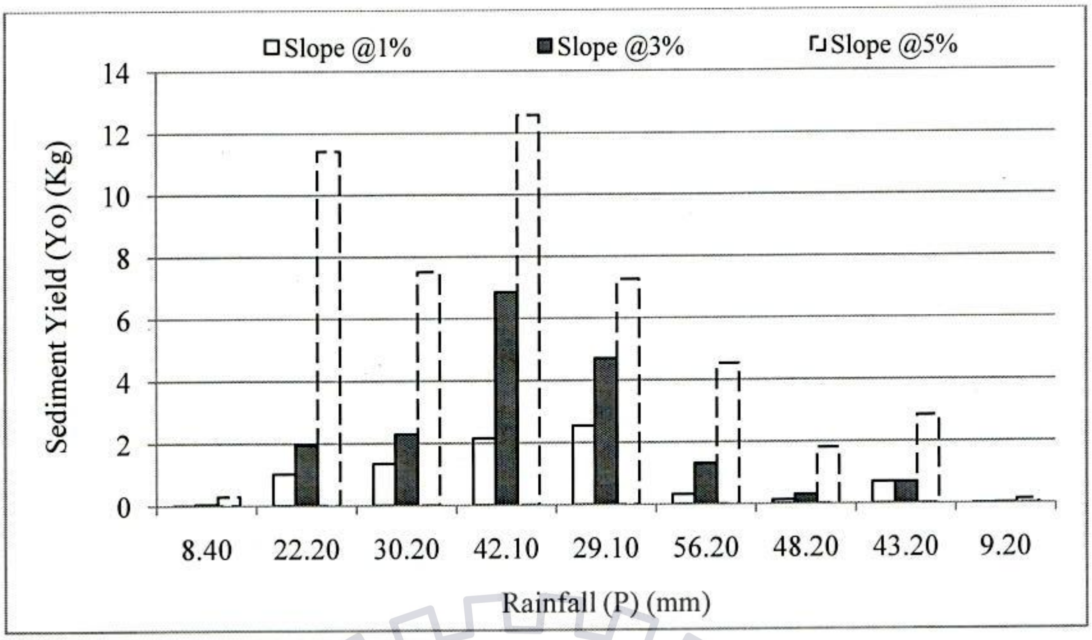


Fig. 5.10 Effect of slope (%) on Sediment Yield. Third parameter = slope.

5.5.2 Effect of Antecedent Moisture Content (θ_0) on Sediment Yield

The observed sediment yield data from different grades of field plots, except the first and last events of Table 5.13 as rainfall and sediment yield values are not significant, are plotted against the measured Antecedent Moisture Content (θ_0) (Fig. 5.11), which shows the existence of a strong correlation between the two. Fig. 5.11 shows that the sediment yield increases as θ_0 of the soil increases, and vice versa, indicating a strong θ_0 - Y_0 relationship.

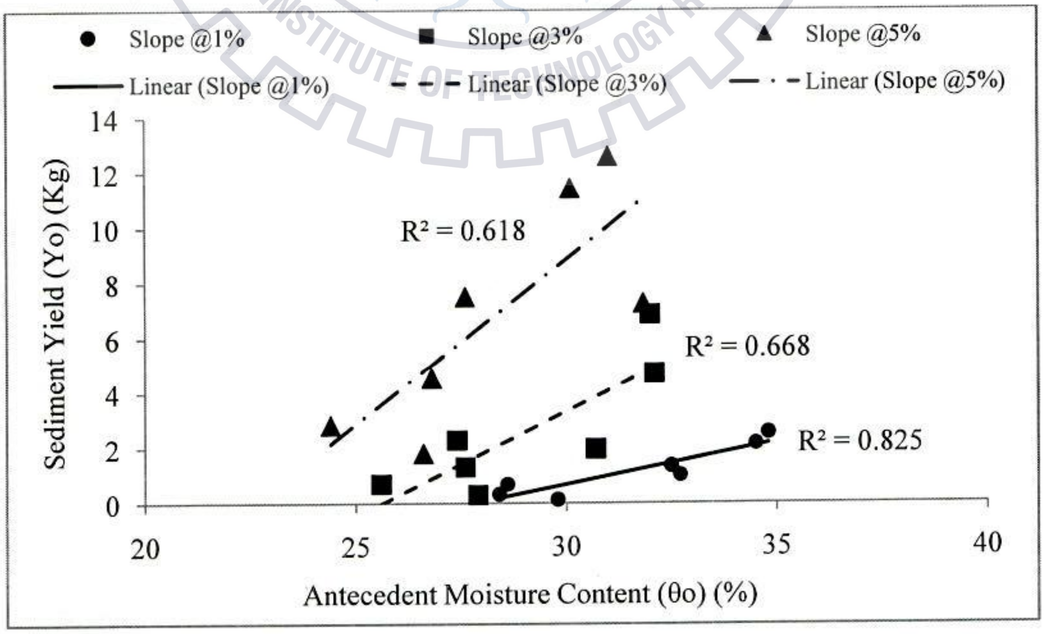


Fig. 5.11 Relation between antecedent moisture content (θ_o) (%) and Yo (Kg).

5.5.3 Relation between S and θo

As discussed in the runoff curve number section, the observed θ_o (%) were plotted against the respective values of S (mm), computed from Eq. 5.1, for each grade of watershed (Fig. 5.12), which shows a linear relationship between θ_o and S. Here describing AMC as θ_o, these relations infer that as θ_o increases, S decreases linearly, and vice versa.

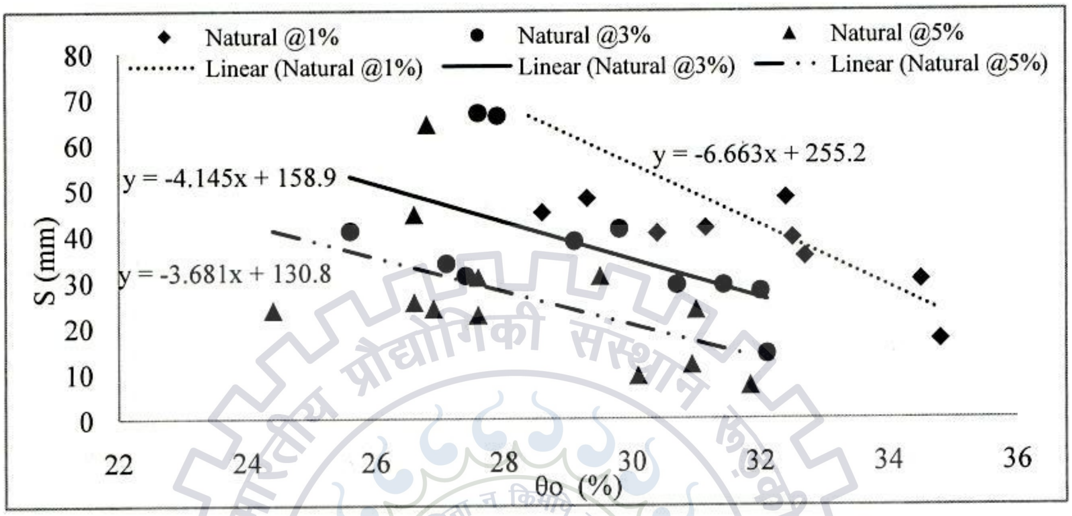


Fig. 5.12 Relation between antecedent moisture content (θ_o) (%) and S (mm).

5.5.4 Relation between Potential Maximum Erosion (A) and θo

The values of Potential Maximum Erosion (A) (kg) computed from Eq. 3.11 for each event when plotted (Fig. 5.13) against the respective observed θ_0 (%) for each grade of plot indicated a linear relationship. It is seen that as θo increases, A increases linearly and, in turn, sediment yield increases, and vice versa.

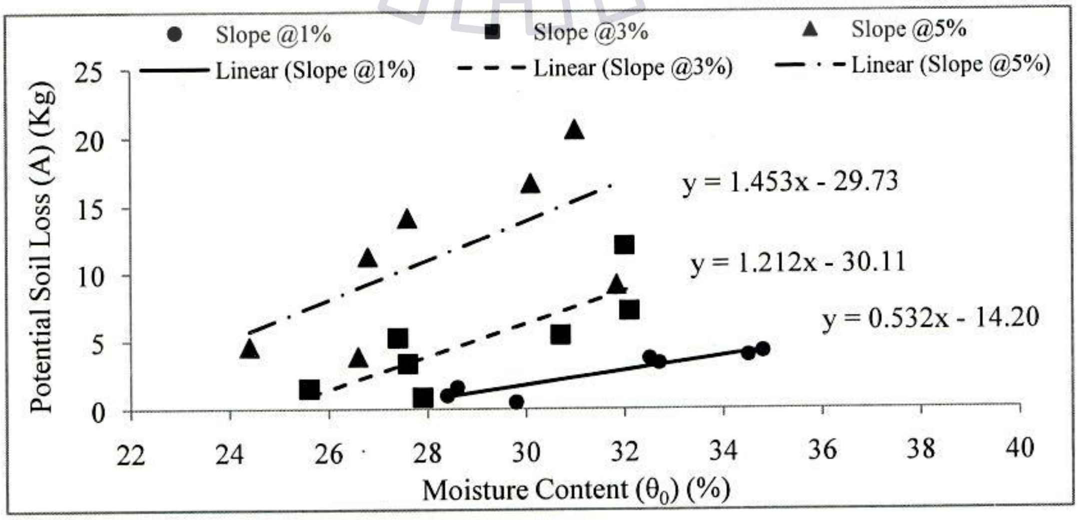


Fig. 5.13 Relation between antecedent moisture content (θ_o) (%) and A (Kg).

5.5.5 Validation of S-θo and A-θo Relations

The resulting linear S-θ_o and A-θ_o relations derived from respective Fig. 5.12 and Fig. 5.13 are validated by plotting the computed sediment yield against the respective observed sediment yield values, as in Fig. 5.14. Here, the computed sediment yield values correspond to those S and A values derived from S-θ_o (Fig. 5.12) and A-θ_o (Fig. 5.13) relations and the respective observed rainfall as shown in Table 5.14. Fig. 5.14 reveals that the data points lie quite close to the line of perfect fit (LPF). The closeness of data points to LPF indicates satisfactory workability of the S-θ_o and A-θ_o relationship. Thus, these linear relations can be used to compute sediment yield directly from the inputs of observed P and θ_0. These relations also signify the role of antecedent moisture content (θ_o) in determination of runoff and sediment yield.

Table 5.14 Calculation of sediment yield using S-θ_o and A-θ_o relations (for natural events)

Rainfall (P) (mm)	Antecedent Moisture Content (θ_0) (%)			Sediment Yield from Sample Yo (kg)			Sobs			Aobs = Yo (P + 0.8 S)/(P - 0.2 S)			Acomp = $m\theta_0 + c$		
	1%	3%	5%	1%	3%	5%	1%	3%	5%	1%	3%	5%	1%	3%	5%
8.40	30.40	27.10	26.60	0.00	0.04	0.29									
22.20	32.70	30.70	30.10	1.02	1.97	11.42	35.21	29.11	9.32	3.40	5.46	16.66	3.20	7.10	14.01
30.20	32.50	27.40	27.60	1.35	2.29	7.51	39.29	31.17	22.60	3.72	5.27	14.12	3.09	3.10	10.37
42.10	34.50	32.00	31.00	2.16	6.86	12.58	30.11	27.70	23.66	3.97	12.06	20.55	4.15	8.67	15.31
29.10	34.80	32.10	31.84	2.54	4.71	7.27	17.11	14.04	7.12	4.24	7.23	9.13	4.31	8.80	16.53
56.20	28.40	27.60	26.80	0.33	1.32	4.54	81.81	66.78	64.28	0.99	3.37	11.27	0.91	3.34	9.21
48.20	29.80	27.90	26.60	0.13	0.31	1.81	86.41	66.11	44.53	0.50	0.88	3.86	1.65	3.70	8.92
43.20	28.60	25.60	24.40	0.70	0.71	2.84	44.88	40.93	23.73	1.61	1.53	4.59	1.02	0.92	5.72
9.20	31.15	31.43	30.93	0.00	0.01	0.14									

Rainfall (P) (mm)	Antecedent Moisture Content (θ_0) (%)			Sediment Yield from Sample Yo (kg)			Scomp = $m\theta_0 + c$			Acomp = $m\theta_0 + c$			Yc =A (P - 0.2 S)/ (P + 0.8 S)		
	1%	3%	5%	1%	3%	5%	1%	3%	5%	1%	3%	5%	1%	3%	5%
8.40	30.40	27.10	26.60	0.00	0.04	0.29									
22.20	32.70	30.70	30.10	1.02	1.97	11.42	37.32	31.65	20.00	3.20	7.10	14.01	0.90	2.37	6.67
30.20	32.50	27.40	27.60	1.35	2.29	7.51	38.65	45.33	29.20	3.09	3.10	10.37	1.14	0.99	4.72
42.10	34.50	32.00	31.00	2.16	6.86	12.58	25.33	26.26	16.69	4.15	8.67	15.31	2.47	5.06	10.70
29.10	34.80	32.10	31.84	2.54	4.71	7.27	23.33	25.85	13.60	4.31	8.80	16.53	2.21	4.23	10.91
56.20	28.40	27.60	26.80	0.33	1.32	4.54	65.97	44.50	32.15	0.91	3.34	9.21	0.36	1.72	5.60
48.20	29.80	27.90	26.60	0.13	0.31	1.81	56.64	43.25	32.89	1.65	3.70	8.92	0.65	1.77	4.98
43.20	28.60	25.60	24.40	0.70	0.71	2.84	64.64	52.79	40.98	1.02	0.92	5.72	0.32	0.35	2.64
9.20	31.15	31.43	30.93	0.00	0.01	0.14									

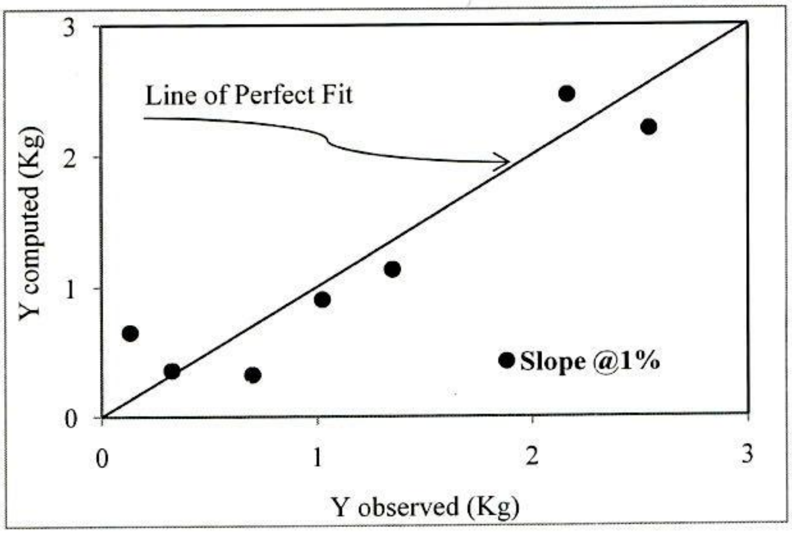


Fig. 5.14a Computed and observed sediment yield at 1% slope.

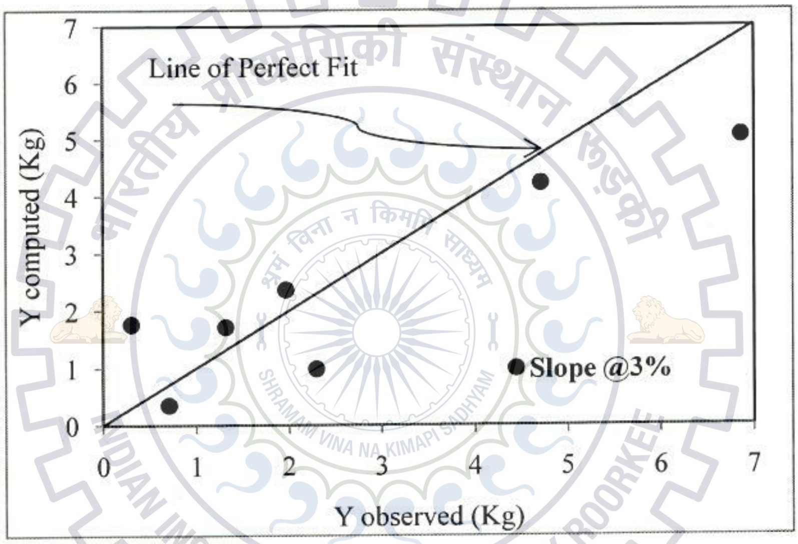


Fig. 5.14b Computed and observed sediment yield at 3% slope.

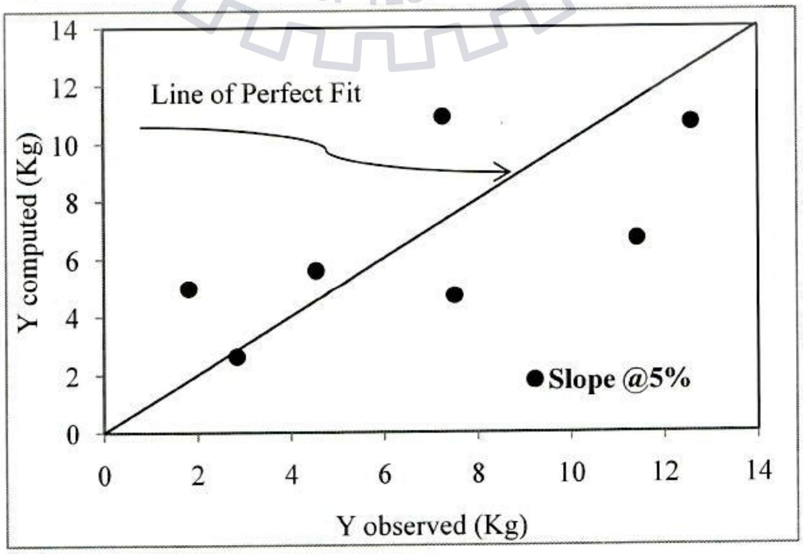


Fig. 5.14c Computed and observed sediment yield at 5% slope.

CHAPTER 6

SUMMARY AND CONCLUSIONS

From the present field based experimental study, based on the observed natural and artificial rainfall-runoff events carried out on sugarcane field plots (size: 22m x 5m) of three different grades (1%, 3% and 5%) and soil of hydrologic soil group C, the following conclusions can be derived:

6.1 RUNOFF CURVE NUMBER (CN)

- The 5% grade plot yields the highest magnitude of runoff for a given rainfall, soil, and land use than the 3% and 1% grades of plots. In other words, as the slope increases, the runoff increases, and vice versa.
- The CN-values derived from the observed data for AMC II condition and for three grades of 1%, 3% and 5% are 86.00, 88.25, and 91.42 and 90.42, 93.20, and 97.59 for natural and artificial datasets, respectively.
- The CN values derived for sugarcane fields from natural events is fairly close to those from NEH-4 table CN-values (85 to 88), generally supporting the applicability of NEH-4 CN values to Indian watersheds. However, the CN values derived from artificial dataset do not match the NEH-4 table values, largely due to exclusion of interception losses and lesser infiltration due to larger intensity of water supply.
- All three grades of sugarcane field plots fall in the violent category of watersheds, as CN continually increases with rainfall to a peak value and then decreases.
- For a watershed slope and land use, CN increases, as AMC increases from AMC I to AMC III, and vice versa. Similarly, for a given AMC and land use, as the watershed slope increases, CN increases, and vice versa.
- The 5% grade plot exhibits the lowest moisture holding capacity for a given rain event, soil and land use than 3% and 1% grade plots, and vice versa.
- As antecedent moisture content (θ_o) of a plot increases, S decreases linearly and, in turn, CN increases. The resulting runoff values being close to the observed runoff supported the workability of the proposed S- θ_o relationship.

6.2 SEDIMENT YIELD

- The 5% grade plot yields the highest magnitude of sediment yield for a given rainfall, soil, and land use with respect to the 3% and 1% grades of plots. In other words, as the slope increases, sediment yield increases, and vice versa.
- As antecedent moisture content (θo) of a plot increases, S decreases and A increases linearly and, in turn, sediment yield increases. The resulting sediment yield values being close to the observed sediment yield supported the workability of the proposed S-θo and A-θo relationship.
- The sediment yield from a plot can be determined only with rainfall and antecedent moisture content as input data, i.e. with known S- θo and A- θo relationship of the respective plot.

6.3 MAJOR CONTRIBUTIONS OF THE STUDY

The major contributions of the study can be summarized as follows:

- As derived CN values are fairly close to those from NEH-4 table CN-values, the study supports the applicability of NEH-4 CN values to Indian watersheds.
- The study explored the further investigation/research to link the moisture content in determination of rainfall generated runoff and sediment yield as this study shows the runoff and sediment yield from a plot can be determined only with rainfall and S- θo and A- θo relationship.

REFERENCES

1. Alberts, E. E., Moldenhauer, W. C., and Foster, G. R. (1980), 'Soil aggregates and primary particles transported in rill and interrill flow,' Proc. Soil Sci. Soc. Am. J., 44. Pp. 590-595.
2. Andrews, R. G. (1954), 'The use of relative infiltration indices in computing runoff (unpublished), Soil Conservation Service, Fort Worth, Texas, pp. 6.
3. Arnold, J. G., Allen, P. M., and Bernhardt, G. (1993), 'A comprehensive surface-groundwater flow model,' J. of Hydrology, 142: 47-69.
4. Arnold, J. G., Srinivasan, R., Muttiah, R. S., and Williams, J. R. (1998), 'Large area hydrologic modeling and assessment, Part I: Model development,' J. Am. Water Resour. Assoc., 34(1): 73-89.
5. Aron, G., Miller, A.C., and Lakatos, D.E. (1977), 'Infiltration formula based on SCS curve number,' J. of Irrigation and Drainage Division, ASCE, 103(IR4), pp. 419-427.
6. ASCE (1970), 'Sediment source and sediment yield,' J. Hydraulics Division, ASCE, 96 (HY6), pp. 1283-1329.
7. Babu, Suresh P., and Venugopal K. (2006), 'Soil conservation service curve number estimation for runoff prediction-revisited,' J. of Hydrology, Elsevier, Manuscript No.: HYDROL4792, pp. 19
8. Bennett, j. P. (1974), 'Concept of mathematical modeling of sediment yield,' Water resources Research, 10, pp.485-492
9. Bhuniya, P. K., Mishra, S. K., and Berndtsson, R. (2003), 'Discussion on estimation of confidence interval for curve numbers,' J. Hydrol. Engg., ASCE, 8 (4), pp. 232-233.
10. Bonta, J. V. (1997), 'Determination of watershed curve number using derived distributions,' J. Irrig. and Drain. Engg., ASCE, 123 (1): 28-36
11. Bosznay, M. (1989), 'Generalisation of SCS curve number method,' J. Irrig. And Drain. Engg., ASCE, 115(1): 139-144
12. Cazier, D. J., and Hawkins, R. H. (1984), 'Regional application of the curve number method,' Water Today and Tomorrow, Proc. ASCE, Irrigation and drainage Division Special Conference, ASCE, New Work, N. W., pp.710.
13. Chen, C.L. (1982), 'Infiltration formulas by curve number procedure,' J. of Hydraulics Division, ASCE, 108(HY7), pp. 823-829.
14. Chow, V. T. (1959), 'Open Channel Hydraulics,' McGraw-Hill, New York.

15. Chow, V. T. (1964), 'Handbook of Applied Hydrology,' McGraw-Hill Book Co. Inc., New York.

16. Chow, V.T., Maidment, D.R., and Mays, L.W. (1988), 'Applied Hydrology,' McGraw-Hill, New York.

17. Einstein, H. A. (1964), 'Sedimentation, Part II. River Sedimentation,' In: V. T. Chow (Ed.), Handbook of Applied Hydrology, McGraw-Hill, New York, N. Y., pp. 17-35-17-67.

18. Ellison, W.D. (1947), 'Soil erosion studies,' Agricultural Engineering 23: 146-156, 197-201, 245-248, 297-300, 349-351, 402-405, 442-444.

19. Evans, R. (1980), 'Mechanics of water erosion and their spatial and temporal controls: an empirical viewpoint,' In: Kirkby, J and morgan, R. P. C. (eds.), Soil Erosion, Wiley. Pp. 109-128.

20. Foster, G. R (1982), 'Modeling the erosion processes,' In: Haan, C.T., Johnson, H., and Brakensiek, D.L. (eds.), hydrological Modeling of small watersheds, ASAE Monograph No. 5, American society of Civil Engineers, St. Joseph, Michigan: 297-380.

21. Foster, G. R., and Meyer, L. D. (1975), 'Mathematical simulation of upland erosion by fundamental erosion mechanics. In: Present and Prospective Technology for predicting sediment yields and sources,' Agricultural Research Service, USDA, Washington, DC, pp.190-207.

22. Foster, G.R., Meyer, L.D., and Onstad, C.A. (1977), 'A runoff erosivity factor and variable slope length exponents for soil loss estimates,' Trans. ASAE, 20(4), 683–687.

23. Freebairn, D. M., Gupta, S. C., Onstad, C. A., and Rawls, W. J. (1989), 'Antecedent rainfall and tillage effects upon infiltration,' J. Soil sci. Soc. Am. 53, pp. 1183-1189.

24. Gandini, M.L. and Usunoff, E.J. (2004), 'SCS Curve Number estimation using remote sensing NDVI in a GIS environment,' J. of Environmental Hydrology, 12 (Paper 16).

25. Garde, R. J., and Kothyari, U. C. (1987), 'Sediment yield estimation. J. Irrigation and Power, CBIP, India, 44(3):97-123.

26. Garde, R. J., Ranga Raju, K. G., Swamee, P. K., Miraki, G. P., and Molanezhad, M. (1983), 'Mathematical modeling of sedimentation processes in reservoirs,' Hydraulics Engg. Report No. HYD 8304, University of Roorkee, India.

27. Garen, D., and Moore, D. S. (2005), 'Curve number hydrology in water quality modeling: use, abuse, and future directions. J. American eater Resources Association, 41 (2), 377-388.

28. Graf, W. H. (1971), 'Hydraulics of sediment transport,' McGraw-Hill, New York, N. Y., pp. 513.

29. Haan, C. T., Barfield, B. J., and Hayes, J. C. (1994), 'Design hydrology and sedimentology for small catchments,' Academic Press, New York.

30. Hadley, R.F., Lal,R., Onstad, C.A., Walling, D.E., and Yair, A. (1985), 'Recent developments in erosion and sediment yield studies,' UNESCO (IHP), Paris, p 127.

31. Hairsine, P.B. and Rose, C.W. (1991), 'Rainfall detachment and deposition: sediment transport in the absence of flow-driven process,' Soil Science Society of America Journal 55: 320-324.

32. Harrold, L. L. and Krimgold, D. B. (1968), 'Devices for measuring rates and amounts of runoff employed in Soil Conservation Research,' U. S. Soil Conservation Service Tech. paper 1951, pp. 42.

33. Hawkins, R. H. (1993), 'Asymptotic Determination of Runoff Curve Numbers from Data,' J. of Irrigation and Drainage Engineering, Vol. 119, No. 2.

34. Hawkins, R. H. (1996), 'Discussion on SCS-runoff equation revisited for variable-source runoff areas,' by Steenhuis et al. (1995), J. Irrigation and Drainage Engineering, 122 (5), pp. 319-322.

35. Hawkins, R. H., Hjelmfelt, A.T. Jr, and Zevenbergen, A. W. (1985), 'Runoff probability, storm depth , and curve numbers,' j. Irrig. And drain. Engg., ASCE, 111(4), pp. 330-339.

36. Hawkins, R. H., Woodward, D. E., and Jiang R. (2001), 'Investigation of the runoff curve number abstraction ratio,' Paper presented at USDA-NRCS Hydraulic Engineering Workshop, Tucson, Arizona.

37. Hawkins, R.H. (1978), 'Runoff curve number with varying site moisture,' j. Irrigation and Drainage Division, ASCE, 104(IR40, pp. 389-398.

38. Hawkins, R.H. (1979b), 'Runoff curve number from partial area watersheds,' J. of Irrigation and Drainage Engineering Division, ASCE, 105(HY4), pp. 375-389.

39. Hawkins, R.H. (1984), 'A comparison of predicted and observed runoff curve numbers,' Proc. Special conf. Irrig. And Drain. Div., ASCE, New York, NY, pp. 702-709.

40. Hjelmfelt, Jr, A.T. (1980), 'Curve number procedure as infiltration method,' J. of Hydraulics Division, ASCE, 106(HY6), pp. 1107-1110.

41. Hjelmfelt, Jr, A.T. (1982), 'Closure to empirical investigation of the curve number technique,' J. hydraulics div., ASCE, 108 (HY4), pp. 614-616.

42. Hjelmfelt, Jr, A.T. (1991), 'Investigation of curve number procedure,' J. of Hydraulic Engineering Division, ASCE, 117(6), pp.725-737.

43. Huang, M., Jacgues, G., Wang, Z., and Monique, G. (2006), 'A modification to the Soil Conservation Service curve number method for steep slopes in the Loess plateau of China,' Hydrological processes, 20(3), pp. 579-589.

44. Huber, W. C., Heaney, J. P., Bedient, B. P., and Bender, J. P. (1976), 'Environmental resources management studies in the Kissimmee river basin,' Report No. ENV-05-76-3, Department of Environmental Engineering Science, University of Florida, Gainesville, F.L.

45. Hussein, M. H., and laflen, J. M. (1982), 'Effetc of crop canopy and residue on rill and interrill soil erosion,' Trans. ASAE, 25 (5), pp. 1310-1315.

46. Hydrology (1985), National Engineering Handbook, Supplement A., Sect. 4, Chapter 10, Soil Conservation Service, USDA, Washington, D.C.

47. IGBP-BAHC (International Geosphere–Biosphere Programme) (1997), 'Modeling the transport and transformation of terrestrial materials to freshwater and coastal ecosystems,' IGBP Report, vol. 39. IGBP, Stockholm, Sweden.

48. Jain, M.K., Mishra, S.K., Babu, P. Suresh, Venugopal, K., and Singh, V.P. (2006),'An enhanced runoff curve number model incorporating storm duration and non-linear Ia-S relation,' J. Hydrologic Engrg, ASCE, Vol. 11, No. 6, pp. 631-635.

49. Jansen, J. M. L., and Painter, R. B. (1974), 'Predicting sediment yield from climate and topography,' J. Hydrology, 21. Pp. 371-380.

50. Juyal, G. P., and Shastry, G. (1991), 'Erosion losses and process studies for spurs for stream bank erosion control,' Annual Rep. 1990-1991, Central Soil and Water Conservation Research and Training Institute (CSWCRT), Dehradun, India, pp.88-90.

51. Kothyari, U. C., and Jain, S. K. (1997), 'Sediment yield estimation using GIS,' J. Hydrol. Sciences, 42(6), pp. 833-843.

52. Kumar, S., and Rastogi, r. A. (1987), 'Conceptual catchment model for estimation of suspended sediment flow,' J. hydrology, 95, pp. 155-163.

53. Laflen, J. M., and Colvin, T. S. (1981), 'Effect of crop residue on soil loss from continuous row cropping,' Trans. ASAE, 24 (32), pp. 605-609.

54. Lal, R. (1976), 'Soil erosion problems on an alfisol in western Nigeria and their control. Int. Ints. Of Tropical agriculture, Ibadan, Nigeria, 1:208.

55. Lal, R. (1998), ' Soil erosion impact on agronomic productivity and environment quality,' Crit Rev Plant Sci, 17(3), 319–464.

56. McCuen, R. H. (1982), 'A guide to hydrologic analysis using SCS methods,' Prentice-Hall Inc., Englewood Cliffs, New Jersey.

57. McCuen, R. H. (2002), 'Approach to confidence interval estimation for curve numbers,' J. Hydrologic Engineering, 7, 1, pp. 43-48.

58. Meyer, L.D., and Wischmeier, W.H. (1969), 'Mathematical simulation of the processes of soil erosion by water,' Trans Am Soc Agric Eng, 12(5), 754–758.

59. Meyer, L.D., Foster, G. R., and Nikolov, S. (1975), 'Effect of flow rate and canopy on rill erosion,' Trans. ASAE, pp. 905-911.

60. Michel, C., Andreassian, V., and Perrin, C. (2005), 'Soil Conservation Service Curve Number Method: How to mend a wrong soil moisture accounting procedure,' Water Resources Research, 41, W02011, doi:10.1029/2004WR003191.

61. Miller, N., and Cronshey, R. (1989), 'Runoff curve numbers, the next step, proc., Int. Conf. On Channel Flow and Catchment Runoff,' University of Virginia, Charlottesville, Va.

62. Mishra, S. K., Jain, M. K., Pandey, R. P., and Singh, V. P. (2005), 'Catchment area-based evaluation of the AMC-dependent SCS-CN-based rainfall-runoff models,' hydrological Processes, 19, 2701-2718.

63. Mishra, S.K. and Singh, V.P. (1999), 'Another Look at SCS-CN Method,' J. of Hydrologic Engrg., pp. 257-264.

64. Mishra, S.K. (1998), 'Operation of a multipurpose reservoir,' Unpub. Ph.D. Thesis, Univ. of Roorkee, Roorkee, India.

65. Mishra, S.K. and Singh, V.P. (2002a), 'SCS-CN method: Part-I: Derivation of SCS-CN based models,' Acta Geophysica Polonica, 50(3), 457-477.

66. Mishra, S.K. and Singh, V.P. (2002b), 'SCS-CN based hydrologic simulation package, Mathematical models in small watershed hydrology, Singh, V.P. and D.K. Frevert, (Eds.) Water Resources Publication, Littleton, Co., pp. 391-464.

67. Mishra, S.K. and Singh, V.P. (2003a), 'Soil Conservation Service Curve Number (SCS-CN) Methodology,' Kluwer Academic Publishers, Dordrecht, ISBN 1-4020-1132-6.

68. Mishra, S.K. and Singh, V.P. (2003b), 'SCS-CN method Part II: Analytical Treatment,' Acta Geophysica Polonica, 51 (1), pp. 107-123.

69. Mishra, S.K. and Singh, V.P. (2004a), 'Long term hydrological simulation based on the soil conservation service curve number,' Hydrological Processes, 18 (7), pp. 1291-1313.

70. Mishra, S.K. and Singh, V.P. (2004b), 'Validity and extension of the SCS-CN method for computing infiltration and rainfall-excess rates,' Hydrological Processes, 18, pp. 3323-3345.

71. Mishra, S.K. and Singh, V.P. (2006), 'A re-look at NEH-4 curve number data and antecedent moisture condition criteria,' Hydrological Processes, 20, pp. 2755-2768.

72. Mishra, S.K., Rawat, S.S., Pandey, R.P., Chakraborty, S., Jain, M.K., and Chaube, U.C. (2012),'Relation between runoff curve number and PET,' J. Hydrologic Engrg., Manuscript HEENG-1496. (Accepted)

73. Mishra, S.K., Sahu, R.K., Eldho, T.I., and Jain, M.K. (2006a). "An improved Ia-S relation incorporating antecedent moisture in SCS-CN Methodology." J. Water Resources Management, Vol. 20, No. 5, pp. 643-660.

74. Mishra, S.K., Sahu, R.K., Eldho, T.I., and Jain, M.K. (2006b). 'A generalized relation between initial abstraction and potential maximum retention in SCS-CN-based model,' J. River Basin Management, IAHR, Vol. 4, Issue 4, pp. 245-253.

75. Mishra, S.K., Singh, R.D., and Nema, R.K. (1998), 'A modified SCS-CN method for watershed modeling, Proc., Int. Conf. on Watershed Management and Conservation, Central Board of Irrigation and Power, New Delhi, India, Dec. 8-10.

76. Mockus, V. (1949), 'Estimation of total (peak rates of) surface runoff for individual storms,' Exhibit A of Appendix B, Interim Survey Report Grand (Neosho) River Watershed, USDA, Dec. 1.

77. Mockus, V. (1964), 'Letter to Orrin Ferris, March 5,6 p. In: Rallison, R.E. Origin and evolution of the SCS runoff equation,' Proc. ASCE Symp. Watershed management, Boise, Idaho, July, 1980.

78. Moldenhauer, W. C., and Long, D. C. (1964), 'Influence of rainfall energy on soil loss and infiltration rates: I. Effect over a range of texture,' Soil Sci. Soc. Am. Proc. Pp. 813-817.

79. Morgan, R. P. C. (1979), 'Soil Erosion,' Longman Group Ltd., London.

80. Morgan, R. P. C. (1995), 'Soil Erosion and Conservation,' Second ed., Longman Group Ltd., England.

81. Musgrave, G.W. (1947), 'The quantitative evaluation of factors in water erosion, a first approximation,' J. Soil Wat. Conserv., 2(3), pp. 133-138.

82. Mutcher, C. K. (1963), 'Runoff plot design and installation for soil erosion studies,' Agri. Res. Serv., USDA, ARS, pp. 41-79.

83. Mutchler, C. K., and Young, R. A. (1975), 'Soil detachments by raindrops.,' In: Present and Prospective Technology for predicting sediment yields and sources. ARS-S-40. USDA-ARS, pp. 113-117.

84. Nayak, T.R. and Jaiswal, R.K. (2003), 'Rainfall-runoff modeling using satellite data and GIS for Bebas river in Madhya Pradesh,' IE (I) Journal 84, pp. 47-50.

85. Neitsch, S. L., Arnold, j. G., Kiniry, J. R., Williams, J. R., and King, K. W. (2002), 'Soil and water assessment tool (SWAT): Theoretical documentation, Version 2000,' Texas Water Resources Iinstitute, College Station, Texas, TWRI Report TR-191.

86. Nippes, K. R. (1971), 'A new method of computation of the suspended sediment load,' proc. Symp. Mathematical Models in Hydrology, Vol. II, pp. 659-666.

87. Ogrosky, H. O. (1956), 'Service objectives in the field of hydrology,' (unpublished), Soil Conservation Service, Lincoln, Nebraska, pp.5.

88. Pandey, A. and Sahu, A. K. (2002), 'Generation of curve number using remote sensing and Geographical Information System,' http://www.GISdevelopment.net.

89. Parson, D. A. (1954), 'Coshocton-type runoff samplers,' ARS. 41-2, USDA.

90. Pilgrim, D.H., and Cordery, I. (1993), 'Flood Runoff,' Chapter 9 in Handbook of Hydrology, McGraw-Hill, Inc, New York NY.

91. Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., and Blair, R. (1995), 'Environmental and economic costs of soil erosion and conservation benefits,' Science 267:1117–1123

92. Ponce, V. M. (1989), 'Engineering Hydrology: Principles and Practice,' Prentice-Hall, Englewood Cliffs, N.J.

93. Ponce, V. M., and Hawkins, R. H. (1996), 'Runoff Curve Number: Has It Reached Maturity?,' J. Hydrol. Engrg., ASCE, Vol. 1, pp. 11-19.

94. Rallison, R. E., and Miller, N. (1982), 'Past, present, and future,' Proc., Int. Symp. Rainfall-Runoff Relationship, Singh, V. P. (Ed.), Water Resources Pub., P.O. Box 2841, Littleton, Colorado.

95. Ramasastry, K. S., and Seth, S. M. (1985), 'Rainfall-Runoff relationships,' Rep. RN-20, National Institute of Hydrology, Roorkee, India.

96. Rawls, W. J. (1983), 'Estimating soil bulk density from particle size analysis and organic matter content,' Soil Science, 135 (2), pp. 123-125.

97. Renard, K. G., Foster, G.R., Weesies, G.A., and Porter, J.P. (1991), 'RUSLE, Revised Universal Soil Loss Equation,' J. of Soil and Water Conserv, January-February, 30-33.

98. Roehl, J. W. (1962), 'Sediment source areas, delivery ratios, and influencing morphological factors,' Publ. No. 59, Int. Assoc. Hydrol. Sci., pp. 202-213.

99. Sahu, R. K., Mishra, S.K., Eldho, T.I., and Jain, M.K. (2007), 'An advanced soil moisture accounting procedure for SCS curve number method,' J. Hydrological Processes, Volume 21, Issue 21, October, Pages: 2872-2881.

100. SCD (1972), 'Handbook of Hydrology,' Soil Conservation Service Department, Ministry of Agriculture, New Delhi, India.

101. Schneider, L. E., and McCuen, R. H. (2005), 'Statistical guidelines for curve number generation,' J. Irrigation and Drainage Engineering, ASCE, 131 (3), pp. 282-290.

102. Schumm, S. A. (1954), 'Relation of drainage basin relief to sediment loss,' Symp. On Continental Erosion, IAHS, 36, pp. 216-219.

103. SCS (1956, 1964, 1972, 1985, 1986), 'Hydrlogy,' National Engineering Handbook, Supplement A, Section 4, Soil Conservation Service, USDA, Washington, D.C.

104. Sharda, V.N., Juyal, G.P., and Singh, P.N. (2002), 'Hydrologic and sedimentologic behavior of a conservation bench terrace in a sub-humid climate,' Trans. of ASAE, 45(5), pp. 1433-1441.

105. Sharpley, A. N. and Williams, J. R. (1990), 'EPIC- Erosion/Productivity Impact Calculator: 1. Model determination,' US Department of Agriculture. Tech. Bull., No. 1768.

106. Shen, H. W. (1971), 'River Mechanics, Vol. I,' Colorado State University, Fort Collis, Colo., pp.13-1-13-26.

107. Singh, V. P. (1989), 'Hydrologic Systems: Vol. 2: Watershed Modeling,' Prentice Hall, Englewood Cliffs, N. J.

108. Singh, V. P. (1995), 'Chapter 1, Watershed modeling in: computer models of watershed hydrology, V. P. (Ed.), Water Resources Publications, Littleton, Colo., pp. 1-22.

109. Sobhani, G. (1975), 'A review of selected small watershed design method for possible adoption to Iranian conditions,' M.S. Thesis, Utah State University, Logan, Utah.

110. Soni, B., and Mishra, G. C. (1985), 'Soil water accounting using SCS hydrologic soil classification, case study,' national Institute of Hydrology, Roorkee, India.

111. Springer, E. P., McGurk, B. J., Hawkins, R. H., and Goltharp, G. B. (1980), 'Curve numbers from watershed data,' Proc., Irrigation and Drainage Symp. On Watershed Management, ASCE, New Work, N. Y., 938-950.

112. Steenhuis, T. S., Winchell, M., Rossing, J., Zollweg, J. A., and Walter, M. F. (1995), 'SCS runoff equation revisited for variable-source runoff areas,' J. Irrig. And Drain. Engg., ASCE, 121 (3), pp.234-238.

113. Taylor, B. D. (1983), 'Sediment rates in coastal southern U.S.,' J. Hydr. Div., ASCE, 109 (1), pp. 71-85.

114. Turner, B.L., Clark, W.C., Kates, R.W., Richards, J.F., Matthews, J.T., and Meyer, W.B. (1990), 'The earth as transformed by human action,' Cambridge Univ. Press, Cambridge.

115. USFS (1959), 'Forest and Range Hydrology Handbook,' U.S. Forest Service Publication, Washington, D.C.

116. Van-Mullem, J.A. (1989), 'Runoff and peak discharge using Green-Ampt model,' J. Hydraulic Engineering, ASCE, 117(3), pp. 354-370.

117. Walling, D.E. (1983), 'The sediment delivery problems,' J. Hydrology, 65, pp. 209-237.

118. Walling, D.E. (1988), 'Erosion and sediment yield research-some recent perspectives,' J. Hydrol. 100:113–141.

119. Williams, J.D. and LaSeur, W.V. (1976), 'Water yield model using SCS curve numbers,' J. of Hydraulics Division, ASCE, 102(HY9), pp. 1241-1253.

120. Williams, J.D., and Berndt, H. D. (1972), 'Sediment yield compute with Universal Soil Loss Equation,' J. hyd. Div., ASCE, 98 (HY12), pp. 2087-2098.

121. Williams, J.D., and Berndt, H. D. (1977), 'Sediment yield prediction based on watershed hydrology,' Trans. ASAE, 20, pp. 1100-1104.

122. Williams, J.R. (1975), 'Sediment yield prediction with Universal equation using runoff energy factor, In: Present and Prospective Technology for predicting sediment yields and sources, USDA-ARS, S-40, USDA, pp. 244-252.

123. Williams, J.R. (1981), 'Mathematical modelling of watershed sediment yield,' Paper presented at the Int. Symp. On Rainfall-Runoff Modeling, May 18-21, at Mississippi State University, Mississippi State, Miss.

124. Williams, J.R., Dyke, P.T., and Jones, C.A. (1983), 'EPIC: A model for assessing the effects if erosion on soil productivity,' In Analysis of Ecological Systems: State of the Art in Ecological Modeling. Eds W.K. Laurenroth et al., Elsevier, Amsterdam, pp. 553-572.

125. Wilson, L. (1973), 'Seasonal sediment yield patterns of U.S. rivers,' Water Resources Research, 8.

126. Wischmeier W.H. (1975), 'Estimating the soil loss equation's cover and management factor for undistributed areas,' In: Present and Prospective Technology for predicting sediment yields and sources, ARS-S-40, USDA-ARS, pp. 113-117.

127. Wischmeier W.H., and Mannering, j. V. (1969), 'Relation of soil properties to its erodibility,' Soil Sci. soc. Am. Proc., 33, pp. 131-137.

128. Wischmeier W.H., and Smith, D.D. (1978), 'Predicting rainfall erosion losses,' Agricultural Handbook no. 537, US Dept of Agriculture, Science and Education Administration

129. Wischmeier W.H., Johnson, C. B., and Cross, B. V. (1971), 'A soil erodibility nomograph for farmland and construction sites,' J. Soil and Water Cons., 26. Pp. 189-193.

130. Wischmeier, W.H. and Smith, D.D. (1965), 'Predicting Rainfall-erosion Losses from Cropland East of Rocky Mountains,' U.S.D.A. Agricultural Handbook No. 282, Washington D.C.

131. Young, R.A., Onstad, C.A., Bosch, D.D., and Anderson, W.P. (1987), 'AGNPS: An agricultural non-point source pollution model: a large water analysis model,' US Department of Agriculture and Consumer Research Report No.35, p. 77.

132. Yu, B. (1998), 'Theoretical justification of SCS method for runoff estimation,' J. Irrig. And drain. Engg., ASCE, 124 (60, pp. 306-310.

133. Zhan, X. and Huang, M.L. (2004), 'ArcCN-Runoff: An ArcGIS tool for generating curve number and runoff maps,' Environmental Modeling & Software, 19, pp. 875-879.

134. Zingg, A. W. (1940), 'Degree and length of land slope as it affects soil loss in runoff,' Agricultural Engineering, 21. Pp. 59-64.

APPENDICES

APPENDIX A

Infiltration Test (Double Ring Infiltrometer)

Diameter of inner circle, d = **20.0** cm

Area of inner circle infiltrometer = **314.16** cm^2

Place : Toda Kalyanpur, Roorkee

Watch Time	Time	**Water Level**		**Volume of Water Added**
		Before Filling Reading	After Filling Reading	
	minute	mm	mm	ml
Date: 5th October 2012			**Plot @ 5% slope**	
10:50 AM	0		130	
11:00 AM	10	125	130	146
11:20 AM	20	126	130	110
11:40 AM	20	128	130	54
12:00 PM	20	128	130	60
12:20 PM	20	129	130	26
12:40 PM	20	128	130	78
1:00 PM	20	128	130	46
1:30 PM	30	129	130	40
2:00 PM	30	129	130	38
2:30 PM	30	129	130	44
3:00 PM	30	129	130	42

Watch Time	Time	**Water Level**		**Volume of Water Added**
		Before Filling Reading	After Filling Reading	
	minute	mm	mm	ml
Date: 5th October 2012			**Plot @ 3% slope**	
3:25 PM	0		130	
3:30 PM	5	126	130	116
3:35 PM	5	128	130	66
3:45 PM	10	125	130	116
3:55 PM	10	127	130	82
4:15 PM	20	124	130	174
4:35 PM	20	126	130	116
4:55 PM	20	127	130	102
5:15 PM	20	127	130	96
5:35 PM	20	127	130	92
5:55 PM	20	127	130	84
6:25 PM	30	128	130	66
6:55 PM	30	128	130	60
7:25 PM	30	128	130	58

Watch Time	Time	**Water Level**		**Volume of Water Added**
		Before Filling Reading	After Filling Reading	
	minute	mm	mm	ml
Date: 6th October 2012			**Plot @ 1% slope**	
10:35 AM	0		130	
10:40 AM	5	125	130	148
10:45 AM	5	127	130	80
10:55 AM	10	125	130	136
11:05 AM	10	126	130	94
11:25 AM	20	124	130	156
11:45 AM	20	127	130	72
12:05 PM	20	128	130	66
12:25 PM	20	128	130	62
12:45 PM	20	128	130	54
1:15 PM	30	128	130	60
1:45 PM	30	128	130	56
2:15 PM	30	128	130	58

Plot number 11 at 1% slope

Diameter of inner circle, d =			20.0	cm	Area of inner circle infiltrometer = $314.16\ cm^2$								
A	B	C	D		E	F	G	H	I	J	K	L	M
S.No.	Watch Time	Time of Reading	Water Level		Volume of Water Added	Cumulative Time Determine from C	Time Interval Determine from C	Infiltration Determine from D	Infiltration Capacity Calculate from G & H	Cumulative Infiltration Determine from H	Infiltration Determine from E	Infiltration Capacity Calculate from G & K	Infiltration Capacity Calculated from L
			Before Filling Reading	After Filling Reading									
		minute	mm	mm	ml	minute	minute	mm	mm/min	mm	mm	mm/min	mm/hr
1	10:35 AM	0		130		Start = 0				Start = 0			
2	10:40 AM	5	125	130	148	5	5	5	1.000	1.00	4.71	0.942	56.53
3	10:45 AM	5	127	130	80	10	5	3	0.600	1.60	2.55	0.509	30.56
4	10:55 AM	10	125	130	136	20	10	5	0.500	2.10	4.33	0.433	25.97
5	11:05 AM	10	126	130	94	30	10	4	0.400	2.50	2.99	0.299	17.95
6	11:25 AM	20	124	130	156	50	20	6	0.300	2.80	4.97	0.248	14.90
7	11:45 AM	20	127	130	72	70	20	3	0.150	2.95	2.29	0.115	6.88
8	12:05 PM	20	128	130	66	90	20	2	0.100	3.05	2.10	0.105	6.30
9	12:25 PM	20	128	130	62	110	20	2	0.100	3.15	1.97	0.099	5.92
10	12:45 PM	20	128	130	54	130	20	2	0.100	3.25	1.72	0.086	5.16
11	1:15 PM	30	128	130	60	160	30	2	0.067	3.32	1.91	0.064	3.82
12	1:45 PM	30	128	130	56	190	30	2	0.067	3.38	1.78	0.059	3.57
13	2:15 PM	30	128	130	58	220	30	2	0.067	3.45	1.85	0.062	3.69

Plot number 07 at 3% slope

Diameter of inner circle, d = 20.0 cm

Area of inner circle infiltrometer = 314.16 cm^2

A	B	C	D		E	F	G	H	I	J	K	L	M
S.No.	Watch Time	Time of Reading	Water Level		Volume of Water Added	Cumulative Time Determine from C	Time Interval Determine from C	Infiltration Determine from D	Infiltration Capacity Calculate from G & H	Cumulative Infiltration Determine from H	Infiltration Determine from E	Infiltration Capacity Calculate from G & K	Infiltration Capacity Calculated from L
			Before Filling Reading	After Filling Reading									
		minute	mm	mm	ml	minute	minute	mm	mm/min	mm	mm	mm/min	mm/hr
1	3:25 PM	0		130		Start = 0				Start = 0			
2	3:30 PM	5	126	130	116	5	5	4	0.800	0.80	3.69	0.738	44.31
3	3:35 PM	5	128	130	66	10	5	2	0.400	1.20	2.10	0.420	25.21
4	3:45 PM	10	125	130	116	20	10	5	0.500	1.70	3.69	0.369	22.15
5	3:55 PM	10	127	130	82	30	10	3	0.300	2.00	2.61	0.261	15.66
6	4:15 PM	20	124	130	174	50	20	6	0.300	2.30	5.54	0.277	16.62
7	4:35 PM	20	126	130	116	70	20	4	0.200	2.50	3.69	0.185	11.08
8	4:55 PM	20	127	130	102	90	20	3	0.150	2.65	3.25	0.162	9.74
9	5:15 PM	20	127	130	96	110	20	3	0.150	2.80	3.06	0.153	9.17
10	5:35 PM	20	127	130	92	130	20	3	0.150	2.95	2.93	0.146	8.79
11	5:55 PM	20	127	130	84	150	20	3	0.150	3.10	2.67	0.134	8.02
12	6:25 PM	30	128	130	66	180	30	2	0.067	3.17	2.10	0.070	4.20
13	6:55 PM	30	128	130	60	210	30	2	0.067	3.23	1.91	0.064	3.82
14	7:25 PM	30	128	130	58	240	30	2	0.067	3.30	1.85	0.062	3.69

Plot number 03 at 5% slope

Diameter of inner circle, d =			20.0	cm				Area of inner circle infiltrometer = 314.16 cm^2				
A	B	C	D		E	F	G	H	I	J	K	L	M
S.No.	Watch Time	Time of Reading	Water Level		Volume of Water Added	Cumulative Time Determine from C	Time Interval Determine from C	Infiltration Determine from D	Infiltration Capacity Calculate from G & H	Cumulative Infiltration Determine from H	Infiltration Determine from E	Infiltration Capacity Calculate from G & K	Infiltration Capacity Calculated from L
			Before Filling Reading	After Filling Reading									
		minute	mm	mm	ml	minute	minute	mm	mm/min	mm	mm	mm/min	mm/hr
1	10:50 AM	0		130		Start = 0				Start = 0			
2	11:00 AM	10	125	130	146	10	10	5	0.500	0.50	4.65	0.465	27.88
3	11:20 AM	20	126	130	110	30	20	4	0.200	0.70	3.50	0.175	10.50
4	11:40 AM	20	128	130	54	50	20	2	0.100	0.80	1.72	0.086	5.16
5	12:00 PM	20	128	130	60	70	20	2	0.100	0.90	1.91	0.095	5.73
6	12:20 PM	20	129	130	26	90	20	1	0.050	0.95	0.83	0.041	2.48
7	12:40 PM	20	128	130	78	110	20	2	0.100	1.05	2.48	0.124	7.45
8	1:00 PM	20	128	130	46	130	20	2	0.100	1.15	1.46	0.073	4.39
9	1:30 PM	30	129	130	40	160	30	1	0.033	1.18	1.27	0.042	2.55
10	2:00 PM	30	129	130	38	190	30	1	0.033	1.22	1.21	0.040	2.42
11	2:30 PM	30	129	130	44	220	30	1	0.033	1.25	1.40	0.047	2.80
12	3:00 PM	30	129	130	42	250	30	1	0.033	1.28	1.34	0.045	2.67

APPENDIX B

Sieve Analysis for Grain Size Distribution

Sample - 1

Date Tested: April 22, 2013

Sample Number: **1 % slope**

Visual Classification of Soil: Brown clayey to silty soil

Weight of Container: 75.175 gm

Weight of Container + Dry Soil: 575.178 gm

Weight of Dry Soil (Wd): 500.003 gm

Sieve Number	Sieve Opening (mm)	Mass of Soil Retained on each Sieve (Wr) (gm)	Percentage of Mass Retained on each Sieve	Cumulative % Retained	Percentage Passing
20	0.850	2.716	0.54	0.54	99.46
30	0.600	20.006	4.00	4.54	95.46
40	0.425	52.936	10.59	15.13	84.87
50	0.300	20.933	4.19	19.32	80.68
60	0.250	71.788	14.36	33.68	66.32
100	0.150	65.503	13.10	46.78	53.22
170	0.090	159.835	31.97	78.75	21.25
200	0.075	13.837	2.77	81.52	18.48
Pan	`---	90.086	18.02	99.54	

Total Weight (Wr)= **497.64**

Mass Loss during Sieve Analysis = (Wd - Wr)/Wd x 100 = 0.47 < 2 % OK

% Gravel = 0

% Sand = 81.52

% Fines = 18.02

Sample - 2

Date Tested: April 22, 2013

Sample Number: **3 % slope**

Visual Classification of Soil: Brown clayey to silty soil

Weight of Container: 75.175 gm

Weight of Container + Dry Soil: 575.184 gm

Weight of Dry Soil (Wd): 500.009 gm

Sieve Number	Sieve Opening (mm)	Mass of Soil Retained on each Sieve (Wr) (gm)	Percentage of Mass Retained on each Sieve	Cumulative % Retained	Percentage Passing
20	0.850	10.952	2.19	2.19	97.81
30	0.600	12.327	2.47	4.66	95.34
40	0.425	37.05	7.41	12.07	87.93
50	0.300	3.345	0.67	12.74	87.26
60	0.250	86.696	17.34	30.08	69.92
100	0.150	93.189	18.64	48.72	51.28
170	0.090	111.877	22.37	71.09	28.91
200	0.075	10.654	2.13	73.22	26.78
Pan	`---	131.36	26.27	99.49	

Total Weight (Wr)= **497.45**

Mass Loss during Sieve Analysis = (Wd - Wr)/Wd x 100 = 0.51 < 2 % OK

% Gravel = 0

% Sand = 73.22

% Fines = 26.27

Sample - 3

Date Tested: April 22, 2013

Sample Number: **5 % slope**

Visual Classification of Soil: Brown clayey to silty soil

Weight of Container: 75.175 gm

Weight of Container + Dry Soil: 575.194 gm

Weight of Dry Soil (Wd): 500.019 gm

Sieve Number	Sieve Opening (mm)	Mass of Soil Retained on each Sieve (W) (gm)	Percentage of Mass Retained on each Sieve	Cumulative % Retained	Percentage Passing
20	0.850	1.802	0.36	0.36	99.64
30	0.600	6.121	1.22	1.58	98.42
40	0.425	19.062	3.81	5.39	94.61
50	0.300	14.197	2.84	8.23	91.77
60	0.250	76.624	15.32	23.55	76.45
100	0.150	96.099	19.22	42.77	57.23
170	0.090	147.567	29.51	72.28	27.72
200	0.075	9.467	1.89	74.17	25.83
Pan	`---	126.542	25.31	99.48	

Total Weight (Wr)= **497.481**

Mass Loss during Sieve Analysis = (Wd - Wr)/Wd x 100 = 0.51 < 2 % OK

% Gravel = 0
% Sand = 74.17
% Fines = 25.31

APPENDIX C

Details of Field Data taken for Natural Events

Measurement details	**Plot @ 1% Slope**					**Plot @ 3% Slope**					**Plot @ 5% Slope**				
	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average
	Date		**12 Sept. 2012**			Time		9:00 AM			Rainfall (P)		**8.40**		mm
Runoff depth in chamber (mm)	1.30	2.10	1.60		**1.67**	2.10	1.80	1.60		**1.83**	2.50	2.50	2.50		**2.50**
Antecedent Moisture Content (θ_0) (%)	33.80	32.90	32.30	31.80	**32.70**	31.90	31.40	30.20	29.30	**30.70**	31.10	30.60	29.90	28.80	**30.10**
Sediment Yield (mg/lt) (Bottle No.)				B.N.	**5**				B.N.	**3**				B.N.	**1**
	Date		**13 Sept. 2012**			Time		9:00 AM			Rainfall (P)		**22.20**		mm
Runoff depth in chamber (mm)	14.10	15.20	14.00		**14.43**	17.50	17.80	16.80		**17.37**	35.00	35.00	35.20		**35.07**
Antecedent Moisture Content (θ_0) (%)	33.40	32.70	32.20	31.70	**32.50**	28.40	27.70	26.90	26.60	**27.40**	28.80	28.00	27.10	26.50	**27.60**
Sediment Yield (mg/lt) (Bottle No.)				B.N.	**11**				B.N.	**9**				B.N.	**7**
	Date		**14 Sept. 2012**			Time		9:00 AM			Rainfall (P)		**30.20**		mm
Runoff depth in chamber (mm)	23.50	24.00	23.90		**23.80**	28.70	28.60	29.40		**28.90**	34.20	36.80	37.10		**36.03**
Antecedent Moisture Content (θ_0) (%)	34.20	34.80	31.80	32.00	**33.20**	25.10	26.80	28.40	28.90	**27.30**	34.00	24.80	29.00	27.00	**28.70**
Sediment Yield (mg/lt) (Bottle No.)	3490			B.N.	**17**	5850			B.N.	**15**	17650			B.N.	**13**
	Date		**15 Sept. 2012**			Time		9:00 AM			Rainfall (P)		**1.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	31.20	32.60	31.80	34.50	**32.53**	28.40	24.00	27.30	30.10	**27.45**	33.20	29.30	21.80	26.20	**27.63**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	

Details of Field Data taken for Natural Events

Measurement details	**Plot @ 1% Slope**					**Plot @ 3% Slope**					**Plot @ 5% Slope**				
	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average
	Date		**16 Sept. 2012**			Time		9:00 AM			Rainfall (P)		**0.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	33.70	34.00	34.30	36.00	**34.50**	29.60	31.40	34.20	32.80	**32.00**	33.20	28.70	32.30	29.80	**31.00**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		**17 Sept. 2012**			Time		9:00 AM			Rainfall (P)		**42.10**		mm
Runoff depth in chamber (mm)	51.00	53.40	50.40		**51.60**	53.70	56.50	52.10		**54.10**	57.80	59.30	58.90		**58.67**
Antecedent Moisture Content (θ_0) (%)	35.70	35.10	34.60	33.80	**34.80**	33.40	32.70	31.80	30.50	**32.10**	32.90	32.10	31.50	30.85	**31.84**
Sediment Yield (mg/lt) (Bottle No.)	5140			B.N.	**23**	9790			B.N.	**21**	16750			B.N.	**19**
	Date		**18 Sept. 2012**			Time		9:00 AM			Rainfall (P)		**29.10**		mm
Runoff depth in chamber (mm)	38.10	41.70	39.20		**39.67**	43.40	45.50	41.50		**43.47**	53.10	54.90	54.60		**54.20**
Antecedent Moisture Content (θ_0) (%)	34.50	34.00	33.20	35.10	**34.20**	25.40	28.40	29.80	32.80	**29.10**	36.20	29.50	30.70	30.40	**31.70**
Sediment Yield (mg/lt) (Bottle No.)	3860			B.N.	**29**	6655			B.N.	**27**	10850			B.N.	**25**
	Date		**19 Sept. 2012**			Time		9:00 AM			Rainfall (P)		**7.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	32.30	34.30	31.80	33.40	**32.95**	29.80	29.30	28.70	30.70	**29.63**	34.80	28.70	30.10	29.30	**30.73**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	

Details of Field Data taken for Natural Events

Measurement details	Plot @ 1% Slope					Plot @ 3% Slope					Plot @ 5% Slope				
	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average
	Date		20 Sept. 2012			Time		9:00 AM			Rainfall (P)		0.00		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	30.10	30.70	27.60	30.10	**29.63**	30.90	29.80	26.80	30.10	**29.40**	31.50	27.00	26.80	25.70	**27.75**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		21 Sept. 2012			Time		9:00 AM			Rainfall (P)		0.00		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	29.50	30.90	28.40	33.40	**30.55**	24.00	24.30	23.40	27.30	**24.75**	32.30	29.00	25.40	28.20	**28.73**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		22 Sept. 2012			Time		9:00 AM			Rainfall (P)		0.00		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	27.60	27.90	28.20	29.00	**28.18**	20.90	24.00	24.50	25.90	**23.83**	30.70	23.20	23.70	25.40	**25.75**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		23 Sept. 2012			Time		9:00 AM			Rainfall (P)		0.00		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	23.70	26.80	27.00	27.60	**26.28**	19.80	19.80	20.10	26.80	**21.63**	28.70	23.70	20.40	24.80	**24.40**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	

Details of Field Data taken for Natural Events

Measurement details	**Plot @ 1% Slope**					**Plot @ 3% Slope**					**Plot @ 5% Slope**				
	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average
	Date		**05 Oct. 2012**			Time		12:10 PM			Rainfall (P)		**0.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	22.90	20.60	19.80	19.60	**20.73**	16.50	21.20	20.10	19.30	**19.28**	17.00	15.70	18.40	16.60	**16.93**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		**17 Jan. 2013**			Time		10:00 AM			Rainfall (P)		**0.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	26.40	27.30	29.20	30.70	**28.40**	29.80	28.10	26.70	25.80	**27.60**	27.80	27.20	26.90	25.30	**26.80**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		**18 Jan. 2013**			Time		1:00 PM			Rainfall (P)		**56.20**		mm
Runoff depth in chamber (mm)	39.50	39.80	40.20		**39.83**	47.10	46.80	48.50	49.47	**47.97**	49.30	49.80	49.50		**49.53**
Antecedent Moisture Content (θ_0) (%)	36.70	35.80	34.60	33.90	**35.25**	34.20	33.70	32.10	31.60	**32.90**	33.40	32.90	31.70	30.70	**32.18**
Sediment Yield (mg/lt) (Bottle No.)	1460			B.N.	**139**	2540			B.N.	**138**	6590			B.N.	**137**
	Date		**04 Feb. 2013**			Time		10:00 AM			Rainfall (P)		**0.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	31.40	30.10	28.40	29.30	**29.80**	30.00	28.20	27.10	26.30	**27.90**	27.60	26.90	26.60	25.30	**26.60**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	

Details of Field Data taken for Natural Events

Measurement details	Plot @ 1% Slope					Plot @ 3% Slope					Plot @ 5% Slope				
	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average
	Date		**05 Feb. 2013**			Time		12:00 PM			Rainfall (P)		**48.20**		mm
Runoff depth in chamber (mm)	26.90	27.60	27.90		**27.47**	35.60	36.30	36.60		**36.17**	49.70	50.00	50.50		**50.07**
Moisture Content (θ_0) (%)	30.70	27.70	29.50		**29.30**	27.90	28.70	30.70		**29.10**	31.10	25.10	24.50		**26.90**
Sediment Yield (mg/lt) (Bottle No.)	940			B.N.	**152**	1260			B.N.	**151**	4600			B.N.	**150**
	Date		**06 Feb. 2013**			Time		3:00 PM			Rainfall (P)		**22.40**		mm
Runoff depth in chamber (mm)	11.05	10.55	9.60		**10.40**	14.20	13.60	12.20		**13.33**	21.50	20.80	20.20		**20.83**
Antecedent Moisture Content (θ_0) (%)	29.30	27.90	27.60		**28.27**	28.40	27.00	28.40		**27.93**	30.90	26.50	27.00		**28.13**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		**15 Feb. 2013**			Time		10:00 AM			Rainfall (P)		**0.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	30.70	29.40	27.60	26.70	**28.60**	27.40	26.10	25.20	23.70	**25.60**	25.90	24.70	23.90	23.10	**24.40**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		**16 Feb. 2013**			Time		10:30 AM			Rainfall (P)		**43.20**		mm
Runoff depth in chamber (mm)	39.90	41.80	41.70		**41.13**	43.30	44.50	44.40		**44.07**	60.70	61.10	60.80		**60.87**
Antecedent Moisture Content (θ_0) (%)	33.90	33.10	31.80	30.80	**32.40**	31.30	30.20	29.30	28.40	**29.80**	29.30	28.10	26.90	26.10	**27.60**
Sediment Yield (mg/lt) (Bottle No.)	1380			B.N.	**155**	1820			B.N.	**154**	5080			B.N.	**153**

Details of Field Data taken for Natural Events

Measurement details	Plot @ 1% Slope					Plot @ 3% Slope					Plot @ 5% Slope				
	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average
	Date		**17 Feb. 2013**			Time		10:30 AM			Rainfall (P)		**53.80**		mm
Runoff depth in chamber (mm)	58.10	57.20	56.40		**57.23**	64.25	63.10	62.45		**63.27**	75.30	74.20	73.40		**74.30**
Antecedent Moisture Content (θ_0) (%)	32.30	30.40	31.50		**31.40**	31.50	30.90	28.60		**30.33**	33.00	27.90	29.50		**30.13**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		**18 Feb. 2013**			Time		10:30 AM			Rainfall (P)		**0.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	32.10	30.90	29.70		**30.90**	30.40	29.20	27.90		**29.17**	30.30	28.30	27.70		**28.77**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		**19 Feb. 2013**			Time		10:30 AM			Rainfall (P)		**0.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	31.70	30.80	30.10		**30.87**	29.60	28.30	27.10		**28.33**	29.80	26.70	25.30		**27.27**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		**20 Feb. 2013**			Time		10:30 AM			Rainfall (P)		**0.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	31.60	30.90	29.70		**30.73**	30.70	29.10	29.30		**29.70**	29.20	27.90	27.20		**28.10**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	

Details of Field Data taken for Natural Events

Measurement details	Plot @ 1% Slope					Plot @ 3% Slope					Plot @ 5% Slope				
	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average
	Date		**21 Feb. 2013**			Time		10:30 AM			Rainfall (P)		**0.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	32.60	31.10	30.50		**31.40**	31.60	30.80	29.10		**30.50**	30.80	29.50	28.20		**29.50**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		**22 Feb. 2013**			Time		10:15 AM			Rainfall (P)		**8.00**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	2.00	1.70	1.70		**1.80**
Antecedent Moisture Content (θ_0) (%)	30.40	29.50	33.20	31.50	**31.15**	31.50	31.80	32.00	30.40	**31.43**	35.10	29.50	28.20		**30.93**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	
	Date		**23 Feb. 2013**			Time		11:45 AM			Rainfall (P)		**9.20**		mm
Runoff depth in chamber (mm)	1.40	1.80	2.40		**1.87**	2.60	3.10	2.10		**2.60**	7.00	7.50	7.60		**7.37**
Antecedent Moisture Content (θ_0) (%)	27.60	29.00	26.80		**27.80**	28.70	29.50	28.20		**28.80**	30.70	25.90	25.40		**27.33**
Sediment Yield (mg/lt) (Bottle No.)				B.N.	**163**				B.N.	**161**	1680			B.N.	**159**
	Date		**24 Feb. 2013**			Time		11:30 AM			Rainfall (P)		**5.20**		mm
Runoff depth in chamber (mm)	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**	0.00	0.00	0.00		**0.00**
Antecedent Moisture Content (θ_0) (%)	27.60	29.30	30.40		**29.10**	27.30	26.20	23.70		**25.73**	27.40	26.40	25.10		**26.30**
Sediment Yield (mg/lt) (Bottle No.)				B.N.					B.N.					B.N.	

APPENDIX D

Details of Field Data taken for Artificial Events

Discharge Measurement for Flooding System

Trail	Q_i	Q_{ii}	Q_{iii}	Avg Q (lps)
Main Pipe	7.1	6.48	6.97	**6.85**
Pipe 1	1.02	1.04	1.05	**1.04**
Pipe 2	0.93	0.81	0.80	**0.85**
Pipe 3	0.93	0.94	0.93	**0.93**
Pipe 4	1.03	1.02	0.94	**1.00**
Pipe 5	1.27	1.30	1.30	**1.29**
Pipe 6	0.97	1.00	0.91	**0.96**

Pipe	**Main Pipe HDPE 75 mm dia.**		
Time (T), sec =	1.12	1.15	1.17
Volume (V), lt =	7.954	7.456	8.16
Discharge (Q) = V/T	7.1	6.48	6.97
Average Q, lps =	**6.85**		

Pipe	**Outlet 1**			**Outlet 2**		
Time (T), sec =	3.90	4.07	8.00	8.29	9.35	9.12
Volume (V), lt =	3.965	4.236	8.436	7.734	7.534	7.33
Discharge (Q) = V/T	1.02	1.04	1.05	0.93	0.81	0.80
Average Q, lps =	**1.04**			**0.85**		
Pipe	**Outlet 3**			**Outlet 4**		
Time (T), sec =	8.10	7.95	8.05	8.18	3.68	4.33
Volume (V), lt =	7.52	7.492	7.458	8.402	3.748	4.09
Discharge (Q) = V/T	0.93	0.94	0.93	1.03	1.02	0.94
Average Q, lps =	**0.93**			**1.00**		
Pipe	**Outlet 5**			**Outlet 6**		
Time (T), sec =	7.09	3.99	3.75	8.46	3.50	4.08
Volume (V), lt =	9.002	5.204	4.892	8.236	3.504	3.728
Discharge (Q) = V/T	1.27	1.30	1.30	0.97	1.00	0.91
Average Q, lps =	**1.29**			**0.96**		

Measurement on Sugarcane Plot @ 1% Slope, Plot No. 9

Soil Moisture (%) :	25.2	21.8	23.8	24.9	
Average Soil Moisture (%) =	**23.93**		Date:	**28-Nov-12**	
Pipe used =	1, 2 & 6		Discharge =	**2.85**	lps

Watch Time	**Measured Cumulative Runoff** cm	**Sediment** mg/lt	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
03:19:00					Supply of Water
03:30:00			17.10	17.10	Tc, Runoff starts
03:38:00	5.80	540	12.44	29.54	
03:39:00	8.90	513	1.55	31.09	
03:40:00	11.30	473	1.55	32.65	
03:41:00	13.60	481	1.55	34.20	
03:42:00	16.50	473	1.55	35.75	
03:43:00	19.00	456	1.55	37.31	Bottle number 74
03:44:00	21.60	470	1.55	38.86	
03:45:00	24.60	472	1.55	40.42	
03:46:00	27.50	476	1.55	41.97	
03:47:00	30.50	484	1.55	43.53	
03:48:00	33.00	490	1.55	45.08	
03:49:00	36.30	479	1.55	46.64	
03:50:00	39.20	481	1.55	48.19	
03:51:00	41.70	459	1.55	49.74	
03:52:00	44.90	387	1.55	51.30	
03:53:00	47.70	380	1.55	52.85	Bottle number 75
03:54:00	50.70	372	1.55	54.41	
03:55:00	53.60	376	1.55	55.96	
03:56:00	56.60	375	0.00	55.96	Electricity is off
03:57:00	59.40	374	0.00	55.96	
03:58:00	62.20	371	0.00	55.96	
03:59:00	65.20	358	0.00	55.96	
04:00:00	68.00	350	0.00	55.96	
04:01:00	70.20	353	0.00	55.96	Bottle number 76
04:02:00	72.00	351	0.00	55.96	
04:03:00	73.40	358	0.00	55.96	
04:04:00	74.50	350	0.00	55.96	
04:05:00	75.10	356	0.00	55.96	
04:06:00	75.50	348	0.00	55.96	
04:08:00	76.20	358	0.00	55.96	
04:10:00	76.80	360	0.00	55.96	
04:12:00	77.00	366	0.00	55.96	No Runoff

Measurement on Sugarcane Plot @ 1% Slope, Plot No. 9

Soil Moisture (%) :	25.9	23.4	25.7	27.3	
Average Soil Moisture (%) =	**25.58**		Date:	**02-Jan-13**	
Pipe used =	2, 3, 4 & 5		Discharge =	**4.07**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
04:43:00					Supply of Water
04:52:30			19.98	19.98	Tc, Runoff starts
04:57:00	2.60		9.99	29.97	
04:58:00	6.20		2.22	32.19	
04:59:00	9.50	644	2.22	34.41	
05:00:00	12.90	625	2.22	36.63	
05:01:00	16.30	634	2.22	38.85	
05:02:00	20.40	613	2.22	41.07	
05:03:00	24.80	599	2.22	43.29	
05:04:00	29.10	594	2.22	45.51	Bottle number 109
05:05:00	32.60	581	2.22	47.73	
05:06:00	36.50	598	2.22	49.95	
05:07:00	40.70	567	2.22	52.17	
05:08:00	44.60	564	2.22	54.39	
05:09:00	49.10	578	2.22	56.61	
05:10:00	53.30	574	2.22	58.83	
05:11:00	56.80	551	2.22	61.05	
05:12:00	62.00	548	0	61.05	Electricity is off
05:13:30	68.20	551	0	61.05	
05:14:00	70.50	548	0	61.05	Bottle number 110
05:15:00	74.80	544	0	61.05	
05:16:00	77.00	542	0	61.05	
05:17:00	80.40	543	0	61.05	
05:18:00	82.80	543	0	61.05	
05:19:00	84.00	539	0	61.05	Bottle number 111
05:20:00	85.80	543	0	61.05	
05:22:00	86.00	540	0	61.05	No Runoff

Measurement on Sugarcane Plot @ 1% Slope, Plot No. 9

Soil Moisture (%) :	27.9	26.8	25.7	24.3	
Average Soil Moisture (%) =	**26.18**		Date:		**04-Jan-13**
Pipe used =	2, 3, 4 & 6	Discharge =		**3.74**	lps

Time	Measured Cumulative Runoff	Sediment	Discharge (Rainfall) Depth	Cumulative Discharge (Rainfall) Depth	Remarks
Watch Time	cm	mg/lt	mm	mm	
03:22:30					Supply of Water
03:31:00	0		17.34	17.34	Tc, Runoff starts
03:35:00	4.60		8.16	25.50	
03:36:00	7.90	509	2.04	27.54	
03:37:00	11.40	487	2.04	29.58	
03:38:00	15.80	467	2.04	31.62	
03:39:00	19.30	462	2.04	33.66	
03:40:00	23.90	442	2.04	35.70	
03:41:00	28.00	420	2.04	37.74	
03:42:00	32.80	414	2.04	39.78	Bottle number 113
03:43:00	37.80	404	0	39.78	Electricity is off
03:44:00	41.60	406	0	39.78	
03:45:00	45.40	401	0	39.78	
03:46:00	48.80	400	0	39.78	Bottle number 114
03:47:00	51.60	399	0	39.78	
03:48:00	53.50	397	0	39.78	
03:49:00	55.00	400	0	39.78	
03:50:00	55.30	394	0	39.78	
03:52:00	56.30	392	0	39.78	
03:53:00	56.80	390	0	39.78	
03:54:00	56.90	390	0	39.78	No Runoff

Measurement on Sugarcane Plot @ 1% Slope, Plot No. 9

Soil Moisture (%) :	26.2	24.8	23.2	23.2	
Average Soil Moisture (%) =	**24.35**		Date:		**13-Jan-13**
Pipe used =	1, 5 & 6		Discharge =	**3.29**	lps

Watch Time	Measured Cumulative Runoff cm	Sediment mg/lt	Discharge (Rainfall) Depth	Cumulative Discharge (Rainfall) Depth	Remarks
11:19:00					Supply of Water
11:29:30	0		18.84	18.84	Tc, Runoff starts
11:35:00	2.7		9.87	28.71	
11:36:00	4.20		1.79	30.51	
11:37:00	6.00		1.79	32.30	
11:38:00	8.00	381	1.79	34.10	
11:39:00	10.20	352	1.79	35.89	
11:40:00	11.90	335	1.79	37.69	
11:41:00	14.00	323	1.79	39.48	
11:42:00	16.30	318	1.79	41.27	Bottle number 123
11:43:30	19.90	313	2.69	43.97	
11:45:00	23.10	300	2.69	46.66	
11:46:00	26.00	299	1.79	48.45	
11:47:00	27.80	298	1.79	50.25	
11:48:00	30.60	294	1.79	52.04	
11:49:00	33.00	296	1.79	53.84	
11:50:00	35.80	293	1.79	55.63	Bottle number 124
11:51:00	37.20	295	1.79	57.42	
11:52:00	40.10	294	1.79	59.22	
11:53:00	42.20	302	1.79	61.01	
11:54:00	44.80	299	1.79	62.81	
11:55:00	47.40	295	1.79	64.60	
11:56:00	49.80	293	1.79	66.40	
11:57:00	52.60	291	1.79	68.19	
11:57:30	53.70	290	0.00	68.19	Electricity is off
11:58:00	54.80	289	0.00	68.19	
11:59:00	57.50	287	0.00	68.19	
12:00:00	60.00	282	0.00	68.19	
12:01:00	62.60	276	0.00	68.19	
12:02:00	64.60	274	0.00	68.19	
12:03:00	66.40	273	0.00	68.19	
12:04:00	67.60	273	0.00	68.19	
12:05:00	68.30	274	0.00	68.19	
12:06:00	69.10	274	0.00	68.19	
12:07:00	69.60	270	0.00	68.19	
12:09:00	70.10	270	0.00	68.19	No Runoff

Measurement on Sugarcane Plot @ 1% Slope, Plot No. 9

Soil Moisture (%) :	24.5	23.2	21.8	23.4	
Average Soil Moisture (%) =	**23.23**		Date:		**16-Jan-13**
Pipe used =	5 & 6	Discharge =		**2.25**	lps

Watch Time	Measured Cumulative Runoff cm	Sediment mg/lt	Discharge (Rainfall) Depth	Cumulative Discharge (Rainfall) Depth	Remarks
12:11:00					Supply of Water
12:22:00	0		13.50	13.50	Tc, Runoff starts
12:30:00	4.5		9.82	23.32	
12:31:00	6.20		1.23	24.55	
12:32:00	8.00	328	1.23	25.77	
12:33:00	9.90	315	1.23	27.00	
12:34:00	11.40	304	1.23	28.23	
12:35:00	13.20	305	1.23	29.45	Bottle number 134
12:36:00	15.00	300	1.23	30.68	
12:37:00	16.80	302	1.23	31.91	
12:38:00	18.40	294	1.23	33.14	
12:39:00	20.60	290	1.23	34.36	
12:40:00	22.10	292	1.23	35.59	
12:41:00	24.00	289	1.23	36.82	
12:42:00	26.00	284	1.23	38.05	
12:43:00	28.00	283	1.23	39.27	
12:44:00	30.00	283	1.23	40.50	
12:45:00	31.60	281	1.23	41.73	
12:46:00	33.40	286	1.23	42.96	Bottle number 135
12:47:00	34.90	291	1.23	44.18	
12:48:00	36.50	299	1.23	45.41	
12:49:00	38.50	295	1.23	46.64	
12:50:00	40.40	295	1.23	47.86	
12:51:00	42.30	289	0.00	47.86	Electricity is off
12:52:00	44.20	277	0.00	47.86	Bottle number 136
12:53:00	46.10	278	0.00	47.86	
12:54:00	48.00	279	0.00	47.86	
12:55:00	50.00	276	0.00	47.86	
12:56:00	51.80	278	0.00	47.86	
12:57:00	53.20	275	0.00	47.86	
12:58:00	54.50	275	0.00	47.86	
12:59:00	55.30	276	0.00	47.86	
13:00:00	56.00	278	0.00	47.86	
13:01:00	56.20	279	0.00	47.86	
13:03:00	57.00	276	0.00	47.86	
13:05:00	57.30	276	0.00	47.86	No Runoff

Measurement on Sugarcane Plot @ 1% Slope, Plot No. 9

Soil Moisture (%) :	25.9	26.2	25.4	26.5	
Average Soil Moisture (%) =	**26.00**		Date:		**03-Feb-13**
Pipe used =	2, 3, 4 & 6	Discharge =		**3.74**	lps

Watch Time	**Measured Cumulative Runoff** cm	**Sediment** mg/lt	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
10:19:00					Supply of Water
10:28:00	0		18.36	18.36	Tc, Runoff starts
10:32:00	3.8		8.16	26.52	
10:33:00	6.50	330	2.04	28.56	
10:34:00	10.10	309	2.04	30.60	
10:35:00	13.70	300	2.04	32.64	
10:36:00	17.70	291	2.04	34.68	
10:37:00	20.80	304	2.04	36.72	
10:38:00	25.00	295	2.04	38.76	Bottle number 141
10:39:00	28.80	292	2.04	40.80	
10:40:00	32.20	286	2.04	42.84	
10:41:00	36.50	277	2.04	44.88	
10:42:00	40.50	292	2.04	46.92	
10:43:00	44.20	274	2.04	48.96	
10:44:00	48.10	273	2.04	51.00	
10:45:00	52.00	272	2.04	53.04	
10:46:00	56.20	269	2.04	55.08	Bottle number 142
10:47:00	60.00	267	2.04	57.12	
10:48:00	63.70	265	0	57.12	Electricity is off
10:49:00	67.80	266	0	57.12	
10:50:00	71.50	264	0	57.12	
10:51:00	75.80	262	0	57.12	
10:52:00	79.20	259	0	57.12	
10:53:00	82.50	257	0	57.12	Bottle number 143
10:54:00	84.40	256	0	57.12	
10:55:00	85.50	254	0	57.12	
10:56:00	86.80	259	0	57.12	
10:57:00	88.20	261	0	57.12	
10:58:00	88.40	260	0	57.12	
11:00:00	89.40	262	0	57.12	
11:01:00	89.70	262	0	57.12	No Runoff

Measurement on Sugarcane Plot @ 3% Slope, Plot No. 5

Soil Moisture (%) :	20.9	18.1	16.5	16.2	
Average Soil Moisture (%) =	**17.93**		Date:		**28-Nov-12**
Pipe used =	1, 2, 3 & 4	Discharge =		**3.82**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
04:20:00					Supply of Water
04:25:30			11.46	11.46	Tc, Runoff starts
04:31:00	7.90	1180	11.46	22.92	
04:32:00	11.40	1230	2.08	25.00	
04:33:00	14.00	1250	2.08	27.09	
04:34:00	16.80	1290	2.08	29.17	Bottle number 62
04:35:00	20.60	1330	2.08	31.25	
04:36:00	23.90	1360	2.08	33.34	
04:37:00	27.30	1410	2.08	35.42	
04:38:00	30.50	1420	2.08	37.51	
04:39:00	34.20	1380	2.08	39.59	
04:40:00	37.90	1290	2.08	41.67	Bottle number 63
04:41:00	41.30	1070	2.08	43.76	
04:42:00	45.20	1080	2.08	45.84	
04:43:00	48.50	1030	2.08	47.92	
04:44:00	52.40	1040	2.08	50.01	
04:45:00	56.60	1030	0.00	50.01	Electricity is off
04:46:00	59.50	1030	0.00	50.01	
04:47:00	63.00	1070	0.00	50.01	
04:48:00	66.40	1090	0.00	50.01	
04:49:00	68.30	1110	0.00	50.01	Bottle number 64
04:50:00	68.50	1160	0.00	50.01	
04:50:30	68.70	1180	0.00	50.01	
04:51:00	69.20	1160	0.00	50.01	
04:52:00	69.60	1180	0.00	50.01	
04:54:00	69.90	1230	0.00	50.01	
04:56:00	69.90	1300	0.00	50.01	No Runoff

Measurement on Sugarcane Plot @ 3% Slope, Plot No. 5

Soil Moisture (%) :	18.4	18.4	15.4	18.2	
Average Soil Moisture (%) =	**17.6**		Date:		**02-Jan-13**
Pipe used =	2, 3, 4 & 5	Discharge =		**4.07**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
03:56:00					Supply of Water
04:02:00			13.32	13.32	Tc, Runoff starts
04:07:00	5.60		11.1	24.42	
04:08:00	7.80	863	2.22	26.64	
04:09:00	10.50	849	2.22	28.86	
04:10:00	13.80	829	2.22	31.08	
04:11:00	16.40	825	2.22	33.30	
04:12:00	19.30	831	2.22	35.52	
04:13:00	22.40	790	2.22	37.74	Bottle number 106
04:14:00	24.90	816	2.22	39.96	
04:15:00	28.00	820	2.22	42.18	
04:16:00	31.50	819	2.22	44.40	
04:17:00	34.40	780	2.22	46.62	Bottle number 107
04:18:00	37.90	796	2.22	48.84	
04:19:00	40.80	780	2.22	51.06	
04:20:00	44.10	777	2.22	53.28	
04:21:00	47.10	776	0	53.28	Electricity is off
04:22:00	50.50	790	0	53.28	
04:23:00	53.70	762	0	53.28	
04:24:00	57.00	763	0	53.28	
04:25:00	58.60	742	0	53.28	
04:26:00	59.40	756	0	53.28	
04:28:00	59.70	754	0	53.28	No Runoff, Bottle number 107

Measurement on Sugarcane Plot @ 3% Slope, Plot No. 5

Soil Moisture (%) :	25.4	28.4	23.4	23.4	
Average Soil Moisture (%) =	**25.15**			Date:	**03-Jan-13**
Pipe used =	2, 3, 4 & 6	Discharge =		**3.74**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
04:22:00					Supply of Water
04:27:00	0		10.2	10.20	Tc, Runoff starts
04:30:00	4.50		6.12	16.32	
04:31:00	7.80	1230	2.04	18.36	
04:32:00	11.20	1220	2.04	20.40	
04:33:00	14.50	1170	2.04	22.44	
04:34:00	18.20	1170	2.04	24.48	
04:35:00	22.10	1140	0	24.48	Electricity is off
04:36:00	25.50	1100	0	24.48	Bottle number 112
04:37:00	29.20	1110	0	24.48	
04:38:00	31.70	1120	0	24.48	
04:39:00	33.40	1120	0	24.48	
04:40:00	33.80	1110	0	24.48	
04:42:00	34.10	1140	0	24.48	No Runoff

Measurement on Sugarcane Plot @ 3% Slope, Plot No. 5

Soil Moisture (%) :	23.2	24	23.7	24.3	
Average Soil Moisture (%) =	**23.8**		Date:		**13-Jan-13**
Pipe used =	1, 5 & 6	Discharge =		**3.29**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
12:13:30					Supply of Water
12:19:30	0		10.77	10.77	Tc, Runoff starts
12:23:00	5.30		6.28	17.05	
12:24:00	6.50		1.79	18.84	
12:25:00	8.40	580	1.79	20.64	
12:26:00	10.30	569	1.79	22.43	
12:27:00	13.50	600	1.79	24.23	
12:28:00	15.80	645	1.79	26.02	Bottle number 125
12:29:00	17.90	657	1.79	27.82	
12:30:00	21.10	651	1.79	29.61	
12:31:00	23.40	657	1.79	31.40	
12:32:00	26.50	684	1.79	33.20	
12:33:00	29.10	667	1.79	34.99	
12:34:00	32.20	678	1.79	36.79	
12:35:00	34.80	661	1.79	38.58	Bottle number 126
12:36:00	37.80	652	1.79	40.38	
12:37:00	40.60	624	0.00	40.38	
12:38:00	43.40	628	0.00	40.38	Electricity is off
12:39:00	45.90	622	0.00	40.38	
12:40:00	49.00	609	0.00	40.38	
12:41:00	51.40	606	0.00	40.38	
12:42:00	52.80	612	0.00	40.38	
12:43:00	53.50	619	0.00	40.38	
12:44:00	53.80	630	0.00	40.38	
12:45:00	54.10	634	0.00	40.38	No Runoff, Bottle number 127

Measurement on Sugarcane Plot @ 3% Slope, Plot No. 5

Soil Moisture (%) :	24.5	22.3	22	22	
Average Soil Moisture (%) =	**22.7**		Date:		**16-Jan-13**
Pipe used =	5 & 6	Discharge =		**2.25**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
11:24:00					Supply of Water
11:31:00	0		8.59	8.59	Tc, Runoff starts
11:35:00	4.00		4.91	13.50	
11:36:00	6.10		1.23	14.73	
11:37:00	7.50	552	1.23	15.95	
11:38:00	9.40	530	1.23	17.18	
11:39:00	11.10	519	1.23	18.41	
11:40:00	13.00	517	1.23	19.64	
11:41:00	14.80	516	1.23	20.86	Bottle number 131
11:42:00	17.10	520	1.23	22.09	
11:43:00	19.00	512	1.23	23.32	
11:44:00	21.00	508	1.23	24.55	
11:45:00	22.80	510	1.23	25.77	
11:46:00	25.20	495	1.23	27.00	
11:47:00	27.00	494	1.23	28.23	
11:48:00	29.00	482	1.23	29.45	
11:49:00	30.80	499	1.23	30.68	Bottle number 132
11:50:00	33.00	498	1.23	31.91	
11:51:00	35.10	514	1.23	33.14	
11:52:00	37.20	501	1.23	34.36	
11:53:00	39.20	495	0.00	34.36	Electricity is off
11:54:00	40.90	493	0.00	34.36	Bottle number 133
11:55:00	42.80	515	0.00	34.36	
11:56:00	44.80	510	0.00	34.36	
11:57:00	46.50	516	0.00	34.36	
11:58:00	47.50	532	0.00	34.36	
11:59:00	47.90	497	0.00	34.36	
12:00:00	48.20	489	0.00	34.36	
12:01:00	48.20	491	0.00	34.36	No Runoff

Measurement on Sugarcane Plot @ 3% Slope, Plot No. 5

Soil Moisture (%) :	25.4	25.1	22.2	22.3	
Average Soil Moisture (%) =	**23.75**		Date:		**03-Feb-13**
Pipe used =	2, 3, 4 & 6	Discharge =		**3.74**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
11:11:00					Supply of Water
11:17:00	0		12.24	12.24	Tc, Runoff starts
11:20:00	7.70	585	6.12	18.36	
11:21:00	11.50	565	2.04	20.40	
11:22:00	15.30	532	2.04	22.44	
11:23:00	19.50	478	2.04	24.48	
11:24:00	24.00	443	2.04	26.52	
11:25:00	27.60	417	2.04	28.56	Bottle number 144
11:26:00	31.80	399	2.04	30.60	
11:27:00	35.90	388	2.04	32.64	
11:28:00	40.00	383	2.04	34.68	
11:29:00	44.40	377	2.04	36.72	
11:30:00	48.80	376	2.04	38.76	Bottle number 145
11:31:00	52.90	382	2.04	40.80	
11:32:00	57.00	363	2.04	42.84	
11:33:00	61.40	359	0	42.84	Electricity is off
11:34:00	65.80	360	0	42.84	
11:35:00	69.80	354	0	42.84	
11:36:00	74.00	353	0	42.84	Bottle number 146
11:37:00	76.20	351	0	42.84	
11:38:00	77.50	349	0	42.84	
11:39:00	78.10	331	0	42.84	
11:40:00	78.60	339	0	42.84	
11:41:00	78.80	346	0	42.84	
11:43:00	79.00	349	0	42.84	No Runoff

Measurement on Sugarcane Plot @ 5% Slope, Plot No. 1

Soil Moisture (%) :	19.8	20.4	21.8	22.15	
Average Soil Moisture (%) =	**21.04**		Date:		**28-Nov-12**
Pipe used =	2, 3 & 4		Discharge =	**2.78**	lps

Time	Measured Cumulative Runoff	Sediment	Discharge (Rainfall) Depth	Cumulative Discharge (Rainfall) Depth	Remarks
Watch Time	cm	mg/lt	mm	mm	
12:42:30					Supply of Water
12:46:30			6.07	6.07	Tc, Runoff starts
12:51:30	7.40		7.58	13.65	
12:52:30	9.40	24900	1.52	15.16	
12:53:00	11.20	25100	0.76	15.92	
12:54:00	14.80	26900	1.52	17.44	
12:55:00	18.50	25500	1.52	18.95	Bottle number 68
12:56:00	21.90	23700	1.52	20.47	
12:57:00	25.40	23200	1.52	21.99	
12:58:00	29.40	22400	1.52	23.50	
12:59:00	33.10	21700	1.52	25.02	
01:00:00	36.70	21300	1.52	26.54	
01:01:00	40.60	20600	1.52	28.05	Bottle number 69
01:02:00	44.00	21900	1.52	29.57	
01:03:00	48.10	21000	1.52	31.09	
01:04:00	51.60	21700	1.52	32.60	
01:05:00	55.40	21300	1.52	34.12	
01:06:00	58.90	20700	0.00	34.12	Electricity is off
01:07:00	62.60	20500	0.00	34.12	Bottle number 70
01:08:00	64.50	19200	0.00	34.12	
01:09:00	65.50	17400	0.00	34.12	
01:10:00	65.60	16600	0.00	34.12	
01:12:00	66.00	15600	0.00	34.12	No Runoff

Measurement on Sugarcane Plot @ 5% Slope, Plot No. 1

Soil Moisture (%) :	18.2	19.5	14.5	15.4	
Average Soil Moisture (%) =	**16.9**		Date:		**02-Jan-13**
Pipe used =	2, 3, 4 & 5	Discharge =		**4.07**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
03:16:00					Supply of Water
03:20:00			8.88	8.88	Tc, Runoff starts
03:23:00	7.60	30000	6.66	15.54	
03:24:00	11.90	30000	2.22	17.76	
03:25:00	16.40	30000	2.22	19.98	Bottle number 102
03:26:00	20.90	30000	2.22	22.20	
03:27:00	25.40	30000	2.22	24.42	
03:28:00	29.30	30000	2.22	26.64	Bottle number 103
03:29:00	33.00	30000	2.22	28.86	
03:30:00	36.80	30000	2.22	31.08	
03:31:00	41.50	30000	2.22	33.30	
03:32:00	45.70	29200	2.22	35.52	Bottle number 104
03:33:00	49.60	29700	2.22	37.74	
03:34:00	54.80	28100	2.22	39.96	
03:35:00	58.80	27800	0	39.96	Electricity is off
03:36:00	63.60	27000	0	39.96	
03:37:00	67.10	26600	0	39.96	
03:38:00	68.70	25800	0	39.96	
03:39:00	69.20	23900	0	39.96	
03:40:00	69.30	23100	0	39.96	
03:42:00	69.60	18700	0	39.96	No Runoff, Bottle number 105

Measurement on Sugarcane Plot @ 5% Slope, Plot No. 1

Soil Moisture (%) :	29.8	27.3	23.4	20.1	
Average Soil Moisture (%) =	**25.15**		Date:		**04-Jan-13**
Pipe used =	2, 3, 4 & 6	Discharge =		**3.74**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
04:32:30					Supply of Water
04:34:30			4.08	4.08	Tc, Runoff starts
04:37:00	4.40		5.1	9.18	
04:38:00	8.20	20000	2.04	11.22	
04:39:00	12.40	19800	2.04	13.26	
04:40:00	16.40	19300	2.04	15.30	
04:41:00	20.60	19000	2.04	17.34	
04:42:00	24.50	18700	2.04	19.38	Bottle number 117
04:43:00	28.90	19900	2.04	21.42	
04:44:00	33.00	19800	2.04	23.46	
04:45:00	37.40	20100	2.04	25.50	
04:46:00	41.70	20200	2.04	27.54	
04:47:00	46.00	20600	2.04	29.58	Bottle number 118
04:48:00	50.50	20100	2.04	31.62	
04:49:00	54.80	19500	2.04	33.66	
04:49:30	57.00	19400	0	33.66	Electricity is off
04:50:00	59.40	19300	0	33.66	
04:51:00	63.70	19000	0	33.66	
04:52:00	66.40	18200	0	33.66	Bottle number 119
04:53:00	66.90	17800	0	33.66	
04:55:00	67.00	17100	0	33.66	No Runoff

Measurement on Sugarcane Plot @ 5% Slope, Plot No. 1

Soil Moisture (%) :	25.4	21.5	17.6	17.9	
Average Soil Moisture (%) =	**20.6**		Date:		**12-Jan-13**
Pipe used =	1, 5 & 6	Discharge =		**3.29**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
12:21:30					Supply of Water
12:24:00			4.49	4.49	Tc, Runoff starts
12:26:00	2.80		3.59	8.08	
12:27:00	4.90		1.79	9.87	
12:28:00	8.00	15700	1.79	11.66	
12:29:00	11.40	15600	1.79	13.46	
12:30:00	14.60	15300	1.79	15.25	
12:31:00	17.90	16100	1.79	17.05	
12:32:00	21.60	15500	1.79	18.84	Bottle number 120
12:33:00	24.90	15300	1.79	20.64	
12:34:00	28.40	15200	1.79	22.43	
12:35:00	32.70	14800	1.79	24.23	
12:36:00	35.60	15300	1.79	26.02	
12:37:00	39.50	14600	1.79	27.82	
12:38:00	42.70	14400	1.79	29.61	Bottle number 121
12:39:00	46.00	14300	1.79	31.40	
12:40:00	49.40	14800	1.79	33.20	
12:41:00	52.80	14600	0.00	33.20	Electricity is off
12:42:00	56.40	14000	0.00	33.20	
12:43:00	57.50	13600	0.00	33.20	Bottle number 122
12:44:00	58.20	12800	0.00	33.20	
12:45:00	58.50	12100	0.00	33.20	No Runoff

Measurement on Sugarcane Plot @ 5% Slope, Plot No. 1

Soil Moisture (%) :	25.9	23.4	17.9	22	
Average Soil Moisture (%) =	**22.3**		Date:		**16-Jan-13**
Pipe used =	5 & 6	Discharge =		**2.25**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
10:36:30					Supply of Water
10:39:00	0		3.07	3.07	Tc, Runoff starts
10:42:00	2.80		3.68	6.75	
10:43:00	4.30		1.23	7.98	
10:44:00	6.40		1.23	9.20	
10:45:00	8.30	10500	1.23	10.43	
10:46:00	10.40	10400	1.23	11.66	
10:47:00	12.70	10100	1.23	12.89	
10:48:00	14.60	10100	1.23	14.11	
10:49:00	16.90	9820	1.23	15.34	Bottle number 128
10:50:00	19.40	9850	1.23	16.57	
10:51:00	21.30	9640	1.23	17.80	
10:52:00	23.70	9470	1.23	19.02	
10:53:00	26.20	9320	1.23	20.25	
10:54:00	28.20	9280	1.23	21.48	
10:55:00	30.70	9040	1.23	22.70	Bottle number 129
10:56:00	33.00	9150	1.23	23.93	
10:57:00	35.50	8680	1.23	25.16	
10:58:00	37.80	8810	0.00	25.16	Electricity is off
10:59:00	40.00	8790	0.00	25.16	
11:00:00	41.80	8670	0.00	25.16	
11:01:00	42.40	8540	0.00	25.16	
11:02:00	42.60	8350	0.00	25.16	
11:03:00	42.70	7740	0.00	25.16	No Runoff

Measurement on Sugarcane Plot @ 5% Slope, Plot No. 1

Soil Moisture (%) :	26.2	22.3	20.7	17.9	
Average Soil Moisture (%) =	**21.78**		Date:		**03-Feb-13**
Pipe used =	2, 3, 4 & 6	Discharge =		**3.74**	lps

Time	**Measured Cumulative Runoff**	**Sediment**	**Discharge (Rainfall) Depth**	**Cumulative Discharge (Rainfall) Depth**	**Remarks**
Watch Time	cm	mg/lt	mm	mm	
11:51:00					Supply of Water
11:52:30	0		3.06	3.06	Tc, Runoff starts
11:55:00	4.5		5.1	8.16	
11:56:00	8.40	12200	2.04	10.2	
11:57:00	12.50	11800	2.04	12.24	
11:58:00	16.60	12200	2.04	14.28	
11:59:00	21.40	12000	2.04	16.32	
12:00:00	25.20	11900	2.04	18.36	Bottle number 147
12:01:00	29.40	11700	2.04	20.40	
12:02:00	34.30	11400	2.04	22.44	
12:03:00	38.80	11100	2.04	24.48	
12:04:00	43.10	11000	2.04	26.52	
12:05:00	47.40	11100	2.04	28.56	Bottle number 148
12:06:00	52.20	10700	2.04	30.6	
12:07:00	56.50	10400	2.04	32.64	
12:08:00	61.00	10200	2.04	34.68	
12:09:00	65.40	10100	2.04	36.72	
12:10:00	70.00	9900	0	36.72	Electricity is off
12:11:00	74.40	9780	0	36.72	
12:12:00	77.60	9610	0	36.72	
12:13:00	78.30	9480	0	36.72	Bottle number 149
12:14:00	78.60	9152	0	36.72	
12:15:00	78.70	8540	0	36.72	No Runoff

APPENDIX E

Details of Experimental Analysis of Sediment Yield

Details of Experimental Analysis of Sediment Yield for Natural Events

Sample/Bottle No.	1	3	5	7	9	11	13	15
Plot No./Slope	1, 5%	5, 3%	9, 1%	1, 5%	5, 3%	9, 1%	1, 5%	5, 3%
Sample collected date	12 Sept. 2012	12 Sept. 2012	12 Sept. 2012	13 Sept. 2012	13 Sept. 2012	13 Sept. 2012	14 Sept. 2012	14 Sept. 2012
Weighing date	7 Nov. 2012	9 Nov. 2012	9 Nov. 2012	12 Nov. 2012	12 Nov. 2012	27 Nov. 2012	27 Nov. 2012	3 Dec. 2012
Volume of sample (ml)	990	990	1000	940	990	980	1000	1000
Number of Pan								1 + 2
Dry weight of Pan (gm)	611	620	561	605	563	604	559	604
Dry weight of Sample + Pan (gm)	615	631	568	612	566	606	564	606
Dry weight of sediment (gm)	4.0	11.0	7.0	7.0	3.0	2.0	5.0	2.0
Sediment concentration, ppm (mg/lt)	4040.0	11111.0	7000.0	7447.0	3030.0	2041.0	5000.0	2000.0

Sample/Bottle No.	17	19	21	23	25	27	29	150
Plot No./Slope	9, 1%	1, 5%	5, 3%	9, 1%	1, 5%	5, 3%	9, 1%	1, 5%
Sample collected date	14 Sept. 2012	17 Sept. 2012	17 Sept. 2012	17 Sept. 2012	18 Sept. 2012	18 Sept. 2012	18 Sept. 2012	5 Feb. 2013
Weighing date	3 Dec. 2012	4 Dec. 2012	4 Dec. 2012	5 Dec. 2012	5 Dec. 2012	6 Dec. 2012	6 Dec. 2012	20 Feb. 2013
Volume of sample (ml)	990	1000	1000	1000	1000	1000	1000	980
Number of Pan	5 + 6	1 + 2	5 + 6	1 + 2	5 + 6	1 + 2	5 + 6	4 + 5
Dry weight of Pan (gm)	559	604	559	604	559	604	559	569.173
Dry weight of Sample + Pan (gm)	560.5	609	562	605	562	606.5	560.5	570.048
Dry weight of sediment (gm)	1.5	5.0	3.0	1.0	3.0	2.5	1.5	0.875
Sediment concentration, ppm (gm/lt)	1515.0	5000.0	3000.0	1000.0	3000.0	2500.0	1500.0	893.0

Details of Experimental Analysis of Sediment Yield for Natural Events

Sample/Bottle No.	151	152	153	154	155	137	138	139
Plot No./Slope	5, 3%	9, 1%	1, 5%	5, 3%	9, 1%	1, 5%	5, 3%	9, 1%
Sample collected date	5 Feb. 2013	5 Feb. 2013	16 Feb. 2013	16 Feb. 2013	16 Feb. 2013	18 Jan. 2013	18 Jan. 2013	18 Jan. 2013
Weighing date	20 Feb. 2013	21 Feb. 2013	20 Feb. 2013	20 Feb. 2013	26 Feb. 2013	21 Feb. 2013	21 Feb. 2013	21 Feb. 2013
Volume of sample (ml)	1000	990	1000	1000	490	970	970	970
Number of Pan	7 + 13	5 + 12	2 + 6	8 + 12	2	4 + 7	2 + 8	6 + 13
Dry weight of Pan (gm)	580.673	559.348	557.338	580.718	279.81	573.58	576.113	578.861
Dry weight of Sample + Pan (gm)	580.902	559.493	558.423	581.115	280.02	575.872	576.806	579.081
Dry weight of sediment (gm)	0.229	0.145	1.085	0.397	0.210	2.292	0.693	0.220
Sediment concentration, ppm (mg/lt)	229.0	146.0	1085.0	397.0	429.0	2363.0	714.0	227.0

Sample/Bottle No.	159	161	163					
Plot No./Slope	1, 5%	5, 3%	9, 1%					
Sample collected date	23 Feb. 2013	23 Feb. 2013	23 Feb. 2013					
Weighing date	27 Feb. 2013	27 Feb. 2013	27 Feb. 2013					
Volume of sample (ml)	490	480	490					
Number of Pan	7	12	2					
Dry weight of Pan (gm)	279.34	284.415	279.81					
Dry weight of Sample + Pan (gm)	279.583	284.557	279.965					
Dry weight of sediment (gm)	0.243	0.142	0.155					
Sediment concentration, ppm (mg/lt)	496.0	296.0	316.0					

Details of Experimental Analysis of Sediment Yield for Artificial Events

Sample/Bottle No.	55	56	57	68	69	70	62	63
Plot No./Slope	1, 5%	1, 5%	1, 5%	1, 5%	1, 5%	1, 5%	5, 3%	5, 3%
Sample collected date	26 Nov. 2012	26 Nov. 2012	26 Nov. 2012	28 Nov. 2012	28 Nov. 2012	28 Nov. 2012	27 Nov. 2012	27 Nov. 2012
Weighing date	25 Feb. 2013	25 Feb. 2013	25 Feb. 2013	26 Feb. 2013	26 Feb. 2013	26 Feb. 2013	28 Feb. 2013	28 Feb. 2013
Volume of sample (ml)	500	500	500	490	480	490	500	500
Number of Pan	8	7	6	8	12	5	2	4
Dry weight of Pan (gm)	296.303	279.34	277.528	296.303	284.415	274.933	279.81	294.24
Dry weight of Sample + Pan (gm)	301.816	285.397	280.974	300.945	291.433	278.552	280.274	294.882
Dry weight of sediment (gm)	5.513	6.057	3.446	4.642	7.018	3.619	0.464	0.642
Sediment concentration, ppm (mg/lt)	11026.0	12114.0	6892.0	9473.0	14621.0	7386.0	928.0	1284.0

Sample/Bottle No.	64	74	75	76	106	107	108	102
Plot No./Slope	5, 3%	9, 1%	9, 1%	9, 1%	5, 3%	5, 3%	5, 3%	1, 5%
Sample collected date	27 Nov. 2012	28 Nov. 2012	28 Nov. 2012	28 Nov. 2012	2 Jan. 2013	2 Jan. 2013	2 Jan. 2013	2 Jan. 2013
Weighing date	28 Feb. 2013	1 Mar. 2013	1 Mar. 2013	1 Mar. 2013	5 Mar. 2013	5 Mar. 2013	5 Mar. 2013	6 Mar. 2013
Volume of sample (ml)	500	510	500	510	500	500	510	500
Number of Pan	6	13	7	4	13	4	7	7
Dry weight of Pan (gm)	277.528	301.333	279.340	294.240	301.333	294.240	279.340	279.340
Dry weight of Sample + Pan (gm)	278.123	301.597	279.549	294.644	301.638	294.729	279.607	285.669
Dry weight of sediment (gm)	0.595	0.264	0.209	0.404	0.305	0.489	0.267	6.329
Sediment concentration, ppm (mg/lt)	1190.0	518.0	418.0	792.0	610.0	978.0	524.0	12658.0

Details of Experimental Analysis of Sediment Yield for Artificial Events

Sample/Bottle No.	103	104	105	109	110	111	123	124
Plot No./Slope	1, 5%	1, 5%	1, 5%	9, 1%	9, 1%	9, 1%	9, 1%	9, 1%
Sample collected date	2 Jan. 2013	2 Jan. 2013	2 Jan. 2013	2 Jan. 2013	2 Jan. 2013	2 Jan. 2013	13 Jan. 2013	13 Jan. 2013
Weighing date	6 Mar. 2013	6 Mar. 2013	7 Mar. 2013	7 Mar. 2013	7 Mar. 2013	7 Mar. 2013	7 Mar. 2013	7 Mar. 2013
Volume of sample (ml)	490	500	500	500	490	500	500	500
Number of Pan	2	12	7	6	2	5	4	8
Dry weight of Pan (gm)	279.810	284.415	279.340	277.528	279.81	274.933	294.24	296.303
Dry weight of Sample + Pan (gm)	286.696	290.249	282.79	277.855	280.02	275.207	294.64	296.564
Dry weight of sediment (gm)	6.886	5.834	3.450	0.327	0.210	0.274	0.400	0.261
Sediment concentration, ppm (mg/lt)	14053.0	11668.0	6900.0	654.0	429.0	548.0	800.0	522.0

Sample/Bottle No.	113	114	125	126	127	128	129	130
Plot No./Slope	9, 1%	9, 1%	5, 3%	5, 3%	5, 3%	1, 5%	1, 5%	1, 5%
Sample collected date	4 Jan. 2013	4 Jan. 2013	13 Jan. 2013	13 Jan. 2013	13 Jan. 2013	16 Jan. 2013	16 Jan. 2013	16 Jan. 2013
Weighing date	8 Mar. 2013	8 Mar. 2013	8 Mar. 2013	8 Mar. 2013	8 Mar. 2013	12 Mar. 2013	12 Mar. 2013	12 Mar. 2013
Volume of sample (ml)	500	500	500	500	490	490	490	500
Number of Pan	5	6	13	8	2	12	4	6
Dry weight of Pan (gm)	274.933	277.528	301.333	296.303	279.810	284.415	294.240	277.528
Dry weight of Sample + Pan (gm)	275.346	277.812	301.678	296.707	280.09	286.975	296.739	280.021
Dry weight of sediment (gm)	0.413	0.284	0.345	0.404	0.280	2.560	2.499	2.493
Sediment concentration, ppm (mg/lt)	826.0	568.0	690.0	808.0	571.0	5224.0	5100.0	4986.0

Details of Experimental Analysis of Sediment Yield for Artificial Events

Sample/Bottle No.	131	132	133	134	135	136	112	117
Plot No./Slope	5, 3%	5, 3%	5, 3%	9, 1%	9, 1%	9, 1%	5, 3%	1, 5%
Sample collected date	16 Jan. 2013	16 Jan. 2013	16 Jan. 2013	16 Jan. 2013	16 Jan. 2013	16 Jan. 2013	3 Jan. 2013	4 Jan. 2013
Weighing date	12 Mar. 2013	12 Mar. 2013	12 Mar. 2013	12 Mar. 2013	12 Mar. 2013	13 Mar. 2013	13 Mar. 2013	13 Mar. 2013
Volume of sample (ml)	500	500	510	490	500	500	500	500
Number of Pan	13	7	8	2	5	4	8	13
Dry weight of Pan (gm)	301.333	279.340	296.303	279.81	274.933	294.24	296.303	301.333
Dry weight of Sample + Pan (gm)	301.773	279.617	296.697	280.043	275.265	294.626	296.741	306.042
Dry weight of sediment (gm)	0.440	0.277	0.394	0.233	0.332	0.386	0.438	4.709
Sediment concentration, ppm (mg/lt)	880.0	554.0	773.0	476.0	664.0	772.0	876.0	9418.0

Sample/Bottle No.	118	119	120	121	122	141	142	143
Plot No./Slope	1, 5%	1, 5%	1, 5%	1, 5%	1, 5%	9, 1%	9, 1%	9, 1%
Sample collected date	4 Jan. 2013	4 Jan. 2013	12 Jan. 2013	12 Jan. 2013	12 Jan. 2013	3 Feb. 2013	3 Feb. 2013	3 Feb. 2013
Weighing date	13 Mar. 2013	13 Mar. 2013	13 Mar. 2013	13 Mar. 2013	13 Mar. 2013	20 Mar. 2013	20 Mar. 2013	20 Mar. 2013
Volume of sample (ml)	500	500	510	510	500	510	490	490
Number of Pan	12	6	7	2	5	12	6	8
Dry weight of Pan (gm)	284.415	277.528	279.340	279.810	274.933	284.415	277.528	296.303
Dry weight of Sample + Pan (gm)	290.258	281.052	283.898	283.71	277.093	284.928	277.985	296.805
Dry weight of sediment (gm)	5.843	3.524	4.558	3.900	2.160	0.513	0.457	0.502
Sediment concentration, ppm (mg/lt)	11686.0	7048.0	8937.0	7647.0	4320.0	1006.0	933.0	1024.0

Details of Experimental Analysis of Sediment Yield for Artificial Events

Sample/Bottle No.	144	145	146	147	148	149		
Plot No./Slope	5, 3%	5, 3%	5, 3%	1, 5%	1, 5%	1, 5%		
Sample collected date	3 Feb. 2013	3 Feb. 2013	3 Feb. 2013	3 Feb. 2013	3 Feb. 2013	3 Feb. 2013		
Weighing date	20 Mar. 2013	20 Mar. 2013	20 Mar. 2013	20 Mar. 2013	20 Mar. 2013	21 Mar. 2013		
Volume of sample (ml)	500	490	500	500	510	990		
Number of Pan	4	2	13	5	7	6 + 7		
Dry weight of Pan (gm)	294.24	279.810	301.333	274.933	279.34	556.868		
Dry weight of Sample + Pan (gm)	294.869	280.193	301.83	277.862	280.987	560.838		
Dry weight of sediment (gm)	0.629	0.383	0.497	2.929	1.647	3.970		
Sediment concentration, ppm (mg/lt)	1258.0	782.0	994.0	5858.0	3229.0	4010.0		

Sample/Bottle No.								
Plot No./Slope								
Sample collected date								
Weighing date								
Volume of sample (ml)								
Number of Pan								
Dry weight of Pan (gm)								
Dry weight of Sample + Pan (gm)								
Dry weight of sediment (gm)								
Sediment concentration, ppm (mg/lt)								

LIST OF PUBLICATIONS

PUBLISHED

1. **Anubhav Chaudhary**, S.K. Mishra, Ashish Pandey (2013), 'Experimental verification of the effect of slope on runoff and curve numbers', Journal of IWRS, 33 (1), pp. 40-46. (**Manuscript No. 1344).**

UNDER REVIEW

1. Mishra, S.K., **Anubhav Chaudhary**, Shrestha, R. K., Pandey, A., Pandey, R. P., 'Curve number derivation for experimental plots of different slopes and land uses,' Journal of Hydrologic Engineering, ASCE, (**Manuscript No. HEENG – 1808)**.
2. Mishra, S.K., **Anubhav Chaudhary**, Shrestha, R. K., Pandey, A., 'Experimental verification of the effect of slope and land use on SCS curve number,' Journal of Water Resources Management, Springer, (**Manuscript No. WARM-D-13-00200)**.
3. Mishra, S.K., **Anubhav Chaudhary**, Shrestha, R. K., Pandey, A., Pandey, R. P., 'Role of antecedent moisture content in determination of runoff and sediment yield,' Journal of Water Resources Management, Springer, (**Manuscript No. WARM-D-13-00381)** (Editor Assigned).