# DETERMINATION OF RUNOFF CURVE NUMBER AND SEDIMENT YIELD FOR MAIZE GROWN ON A SOIL WITH DIFFERENT SLOPES

**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

**RAJ KAJI SHRESTHA**

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# CANDIDATE'S DECLARATION

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

I have not submitted the matter embodied in this dissertation for the award of any other degree.

SHRAMAM VINA NA KIMAPI SADHYAM

Dated: June, 2013
Place: IIT Roorkee

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# CERTIFICATE

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

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# ABSTRACT

The rainfall-runoff-sediment erosion process is a complex, dynamic and nonlinear process, which is affected by many factors. Reliable predictions of runoff and sediment yield from ungauged watersheds are difficult and time-consuming. Such predictions are often required in the design of hydraulic structures and formulation of watershed management strategies. The Soil Conservation Service Curve Number (SCS-CN) method is a well accepted tool for the estimation of volume of surface runoff from small watershed for a given rainfall. It converts rainfall to surface runoff using its parameter curve number (CN) which represents the runoff potential of watershed characteristics. CN values for different combinations of soil, land use and treatment classes are given in Section 4 of the National Engineering Handbook (NEH-4) (SCS, 1985). These tables were derived from the analysis of data from small watersheds in USA. Hence, it is preferable to derive the CN values for respective watersheds from recorded rainfall-runoff data.

This study aims at to determine the runoff CN and sediment yield in the Indian watersheds and to investigate experimentally the effect of watershed slope on generation of runoff and sediment yield. The SCS-CN method was used to determine the runoff curve number and SCS-CN based sediment yield model (coupling the SCS-CN method with USLE) was used to determine the sediment yield from the watershed. For this study, three plots (each of size 22m x 5m) having maize crop with three different slopes (viz., 1%, 3% and 5%) were established near Roorkee, Uttarakhand State, India. The soil of all field plots when tested for infiltration using double ring infiltrometer was found to fall in Hydrologic Soil Group 'C'.

In-situ data were collected through two types of events (viz., natural rainfall-runoff events and artificial rainfall-runoff events) separately. As expected, the CN-values and sediment yield were found to increase with slope of watershed, and vice versa, for the same soil, land use, and rainfall. Estimated runoff depth and sediment yield were compared with the corresponding observed data. The results showed that positive correlations were detected between observed and computed data.

Also, the present study explores the relationships of antecedent soil moisture content ($\theta_0$) with SCS-CN parameter potential maximum retention (S) and with potential soil

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erosion (A) by using the in-situ experimental data collected from the field plots. Besides the data expectedly exhibiting the plot of higher slope to generate the larger amount of sediment yield than that due to smaller slopes for the same rainfall, soil, and land use, the study finds improved model results with use of the proposed S - $\theta_0$ and A - $\theta_0$ relations.

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# LIST OF NOTATIONS

A = potential soil loss; a hydrologic soil group

A' = computed potential soil loss

$a_i$ = coefficient related to land use

AGNPS = Agricultural Non-Point Source Pollution Model

AMA = Antecedent Moisture Amount

AMC = Antecedent Moisture Condition

ANSWERS =A real Non-point Source Watershed Environment Response Simulation

B = a hydrologic soil group

C = runoff coefficient; a hydrologic soil group

CN = Curve Number

$CN_2$ = CN values for AMC II

$CN_3$ = CN values for AMC III

$CN_{2\alpha}$ = slope-adjusted CN for AMC II

$CN\infty$ = constant value of CN approached as $P\rightarrow\infty$

CREAMS = Chemicals, Runoff, and Erosion from Agricultural Management Systems

D = a hydrologic soil group

$D_i$ = rainfall volume during $i^{th}$ time interval

DR = sediment delivery ratio

$DR_i$ = delivery ratio of $i^{th}$ grid

EPIC = Erosion Productivity Impact Calculator

F = cumulative infiltration

GIS = Geographical Information System

ha = hectare

HHZ = Hawkins – Hejlmfelt – Zevenbergen approach for estimating CNs

$i_0$ = uniform rainfall intensity

I = maximum 30-min rainfall intensity of the storm

$I_a$ = initial abstraction

$I_f$ = initial flush

K = soil erodibility factor

$k_1$, $k_2$ = fitting constants

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$L$ = length in meters from the point of origin of the overland flow to the point where the sedimentation begins

$L_s$ = slope-length factor

$l_i$ = flow length of the $i^{th}$ grid

LPF = Line of Perfect Fit

$M$ = antecedent moisture

$m$ = number of grids located in a flow path; rank

$M_p$ = erosion control practice

msl = mean sea level

NEH-4 = National Engineering Handbook - Section 4

NRCS = Natural Resources Conservation Service

$P$ = precipitation

$P_i$ = precipitation for $i^{th}$ storm

$P_5$ = 5-day antecedent precipitation amount

$Q$ = direct surface runoff

$Q_c$ = computed runoff

$Q_0$ = observed runoff

$q$ = peak runoff rate

$Q_e$ = estimated surface runoff

$Q_{ei}$ = estimated runoff for each rainfall event

$Q_5$ = runoff corresponding $P_5$

$R$ = rainfall factor

$R_r$ = rainfall energy factor

RCC = Reinforced Cement Concrete

$S$ = potential maximum retention

$S'$ = computed potential maximum retention

$S_e$ = estimated soil water storage

$S_i$ = potential max. retention for $i^{th}$ storm event

$S_I$ = potential maximum retention corresponding to AMC I

$S_r$ = degree of saturation

SCS = Soil Conservation Service

SMA = Soil Moisture Accounting

SVL = Soil-Vegetation-Land

SWAT = Soil and Water Assessment Tool

$t$ = time

TDR = Time Domain Reflectometry

TR = Technical Release

USDA = United States Department of Agriculture

USLE = Universal Soil Loss Equation

$V$ = soil moisture store level at time t

$V_0$ = soil moisture store level at the beginning of storm event

$V_{00}$ = pre-antecedent moisture level (5 days before)

$V_c$ = vegetative cover factor

V-I-S = Vegetation, Impervious surface, and Soil

VWC = Volumetric Water Content

$X_i$ = rainfall intensity

$Y$ = sediment yield

$Y_c$ = computed sediment yield

$Y_0$ = observed sediment yield

$Z$ = percent slope over the runoff length

$\lambda$ = initial abstraction coefficient

$\lambda_1$ = initial flush coefficient

$\alpha$ = watershed slope

$\gamma$ = coefficient for a given catchment

$\theta_0$ = antecedent soil moisture

$\theta_i$ = slope of the $i^{th}$ grid

$\varepsilon$ = dielectric permittivity

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# CHAPTER 1

# INTRODUCTION

## 1.1 GENERAL

A detail analysis of rainfall, runoff, and sediment yield is highly important for flood control, stream flow forecasting, reservoir design, formulation of watershed management strategies etc. The rainfall-runoff-sediment erosion process is a complex, dynamic and nonlinear process, which is affected by many factors. It is impossible to establish gauges in all watersheds to measure runoff volume and sediment yield; and reliable predictions of these amounts from ungauged watersheds are difficult and time-consuming.

There are several approaches to estimate runoff from ungauged watersheds. Among them, SCS-CN method is the one widely used because of its simplicity and applicability to these watersheds for which minimum hydrologic information is available. The SCS-CN method was originally developed by the Soil Conservation Service (now called the Natural Resources Conservation Service, NRCS), of the United State Department of Agriculture (USDA) in 1954, which was documented in Section 4 of the National Engineering Handbook (NEH-4) in 1956. The SCS-CN method converts rainfall to surface runoff using its key parameter CN which represents the runoff potential of a watershed characterized by hydrologic soil type, land use and treatment, ground surface condition and antecedent moisture condition (AMC) (Mishra and Singh, 2003a).

The runoff curve number (CN) values for an ungauged watershed with various conditions are available in the NEH-4 table, which were derived from small experimental watershed in USA and these CN values are presumably valid for the watershed slope less than 5%. CN values must be adjusted for watershed slope if it is higher than 5% (Ebrahimian M. et al., 2012). Therefore, use of the same NEH-4 table for every watershed may lead to wrong estimation of curve numbers and in turn runoff depths. Hence, it is suggested to determine CN values for watersheds using recorded rainfall-runoff data of the respective watersheds.

Sediment yield is defined as the total sediment outflow from a watershed. It includes both bed and suspended materials. Sediment yield is a function of the amount of gross erosion in the watershed and the efficiency of the stream system to transport eroded materials out of the watershed. Some parts of eroded materials from a watershed get deposited within the watershed, and some contribute to sediment yield.

Estimation of potential soil erosion and sediment yield are important for analysis of agricultural project planning, reservoir sedimentation, changes of river morphology, soil and water conservation planning, water quality modeling, design of efficient erosion control structures, etc. Water, wind, and ice are the primary agents of soil erosion, with water being the most prominent of them (Mishra and Singh, 2003a). The soil erosion process involves three stages, which are (i) detachment (ii) transport and (iii) deposition of soil (Meyer and Wischmeier, 1969). Soil erosion starts with detachment of soil particles from soil mass (Ellison, 1947), which is caused by raindrop impact and shear or drag force of flowing water. The detached soil particles are transported downslope primarily by flowing water, although there is a small amount of downslope transport by raindrop splash also (Walling, 1988) and deposited when the velocity of water decreases.

Methods for estimation of sediment yield can be grouped into two categories: (i) empirical methods and (ii) process-based methods. Empirical methods merge many soil erosion controlling factors such as rainfall characteristics, soil properties, ground cover conditions, etc. into single equation using empirical coefficients. The universal soil loss equation (USLE) is one of the examples of empirical models. This method is simple in application and, therefore, widely used.

Alternatively, the processed-based methods attempt to solve the fundamental equations of flow of water and transport of sediment. The practical application of these models is still limited because of uncertainty in specifying model parameter values and also due to the difference between the scales of application (Hadley et al., 1985; Wu et al., 1993).

This study aims at to determine the runoff curve number and sediment yield from small agricultural plots of size 22m length and 5m width located near Roorkee, Uttarakhand State, India. To investigate experimentally the effect of watershed slope on runoff curve number and generation of sediment yield, three plots with different slopes of 1%, 3% and 5%, having same type of soil and land use (here maize crop), were prepared. The in-situ data of runoff and sediment yield were collected through natural rainfall and artificial (flooding water supply) system. To determine the runoff CN and sediment yield, the SCS-CN method and SCS-CN-based sediment yield model (coupling of the SCS-CN method with USLE, which was developed by Mishra et al., 2006c) were used, respectively. Also, in this study, relationships of antecedent soil moisture content to potential maximum retention (S) and potential soil erosion (A) were established to compute the surface runoff and sediment yield.

## 1.2 OBJECTIVES OF THE STUDY

i) To determine CN for different slopes of plots having maize crop.

ii) To investigate the effect of watershed slopes on CN for maize crop.

iii) To investigate the applicability of NEH-4 CN values to field plots with maize crop.

iv) To determine and investigate the effect of slope on sediment yield for maize crop.

v) To suggest a procedure for CN estimation with aid of field measurements for natural as well as artificial events.

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## 1.3 ORGANIZATION OF DISSERTATION

The contents of the dissertation report are divided into six chapters, a brief account of which detailed as follows.

Chapter 1 covers the introduction about the SCS-CN method, Sediment yield along with objectives of the study.

Chapter 2 provides a brief literature review on the related topic.

Chapter 3 explains about the methodology and devices used to achieve the objectives of study.

Chapter 4 describes the activities performed during experimental farm setup and in-situ data collection.

Chapter 5 explains the analysis of the data and discussion of the results.

Chapter 6 gives the outputs and conclusion the study.

## CHAPTER 2

# LITERATURE REVIEW

As the main objectives of this study are related to runoff curve number and sediment yield, the review of literature has been carried out with focus on SCS-CN methodology and sediment yield.

## 2.1 SCS-CN METHODOLOGY

One of the main objectives of this study is to determine the runoff curve number in Indian watershed using existing SCS-CN method and to investigate the effect of watershed slopes on the curve number. Hence, in this section, the literature on SCS-CN methodology and its applications in watershed hydrology for computation of surface runoff has been reviewed.

### 2.1.1 Historical background

In mid of 1930's, an acute need of hydrologic data for design of conservation practices was realized and ultimately, the Soil Conservation Service (SCS) was established under the United States Department of Agriculture (USDA) with the main objectives of setting up demonstration conservation projects and overseeing the design and construction of soil and conservation measures. With the passage of the Flood Control Act of 1936 (Public Law 74-738), the USDA was permitted to carry out surveys and investigations of watersheds to establish measures for retarding water flow and preventing soil erosion. SCS realized that there was a need of carrying out infiltration studies for collecting hydrologic data (Mishra and Singh, 2003a). Thousands of infiltrometer tests, mostly using a sprinkling-type infiltrometer, were conducted on agricultural plots of land in the late 1930s and early 1940s to determine the effects of soil conservation procedures on rainfall-runoff mechanisms (Ponce and Hawkins 1996, Rallison 1980).

Sherman (1942, 1949) proposed a plot of direct runoff versus storm rainfall, and subsequently, Mockus (1949) used data on soil, land use, antecedent rainfall, storm duration, and average annual temperature to estimate surface runoff in ungaged catchments (Mishra and Singh, 1999a). This work, combined with a graphical procedure for predicting runoff from the soil-vegetation-land complex developed by

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Andrews (1954), was generalized and named the SCS-CN method as found in the Soil Conservation Service National Engineering Handbook Section 4: Hydrology (NEH-4) (USDA 1985). The first version of the handbook was printed in 1954, with subsequent revisions in 1956, 1964, 1965, 1971, 1972, 1985, and 1993 (Ponce and Hawkins 1996).

### 2.1.2 Factors affecting runoff CN

As defined before, the SCS-CN method is used to determine volume of surface runoff from small watershed for a given rainfall amount, which uses its key parameter CN representing the runoff potential of a watershed. The selection of proper curve number for a particular watershed is of utmost importance since the runoff output is much sensitive to the CN value. Following are the major watershed characteristics that affect the SCS-CN parameter S or curve number (CN).

- Hydrologic soil group
- Land use
- Land treatment
- Hydrologic condition
- Antecedent moisture condition
- Initial abstraction and Climate
- Rainfall intensity and duration, Turbidity etc.

The combination of soil type, vegetation cover and land use/ treatment is referred to as soil-vegetation-land use (SVL) complex (Miller and Cronshey, 1989). These characteristics primarily affect the infiltration potential of a watershed. For a given rainfall amount, the magnitude of Q depends on S or the infiltration potential.

#### i) Hydrologic Soil Group

The soil type of a watershed significantly affects the runoff potential of the watershed. Soils are broadly classified as sand, silt, and clay on the basis of the grain size. Infiltration rates of soils largely affected by the size of pores in soil mass, depends on the grain sizes. Other major factors in this category include soil texture, structure, hydraulic conductivity and initial moisture content. Loose conductive sandy soil will

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have larger infiltration rate than the tightly packed soil. In the same way, a dry soil will exhibit larger infiltration rate than the wet soil.

The Soil Conservation Service identified four hydrologic groups of soils A, B, C and D, based on their infiltration and transmission rates. The runoff potential increases (and hence curve number increases) as the soil type changes from Group A to Group D. The characteristics of various soil groups classified above have been described by Mishra and Singh (2003a) as below.

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

*Group B:* The soils falling in Group B have moderate infiltration rates when thoroughly wetted and consist primarily of moderately deep to deep, moderately well to well drained soils with fine, moderately fine to moderately coarse textures, for example, shallow loess and sandy loam. These soils exhibit moderate rates of water transmission.

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

*Group D:* The soils falling in Group D have very low rates of infiltration when they are thoroughly wetted. Such soils are primarily clay soils of high swelling potential, soils with a permanent high water table, soils with a clay layer at or near the surface, and shallow soils over nearly impervious material. These soils exhibit a very slow rate of water transmission.

This classification is based on the fact that the soils that are similar in depth, organic matter content, structure, and the degree of swelling when saturated will respond in an essentially similar fashion during a storm of excessively high rainfall intensities. The classification based on the minimum infiltration rates is given in the following table (McCuen, 1982).

Table 2.1: Description of hydrologic 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 |

### ii) Land use

The land use describes the surface condition of the watershed and is related to the degree of cover. It includes every kind of vegetation, litter and mulch, and fallow as well as nonagricultural uses, such as water surfaces, roads, roofs, etc. It affects infiltration. Vegetated lands have more infiltration rate and hence generate less amount of runoff in comparison to barren lands.

The land use can be broadly classified into urban land, agricultural land, and woods and forest. Urban lands have low or insignificant permeability. It includes residential areas, paved parking lots, streets and roads, commercial and industrial areas, developing areas, open spaces including lawns, parks etc.

The agriculture land uses are classified as fallow land, row crops, small grain crops, close-seeded legumes or rotational meadow, pasture or range, and meadow. Fallow refers to bare agricultural land having the highest runoff potential. Planting the crops in rows on contours increases infiltration and hence decreases runoff.

Woods are usually small isolated grooves of trees raised for farm use. Forest generally covers a considerable part of watershed. Humus increases with age of forest. Because of porous nature, it increases infiltration and hence decreases runoff.

### iii) Land treatment

Land treatment is a modification of the existing land cover and describes the management of cultivated agricultural lands. It includes mechanical practices, such as contouring and terracing, and management practices, such as crop rotation and grazing control. Also, agricultural management systems involve different types of tillage (moldboard plough, chisel plough). Brakensiek and Rawls (1988) reported that moldboard plough increases soil porosity by 10-20%, depending on the soil texture and increases infiltration rates. Rawls, 1983 concluded that an increase in organic matter in the soil lowers bulk density or increase porosity, and hence increases infiltration and decreases the runoff potential.

### iv) Hydrologic Condition

Hydrologic condition of a watershed indicates the effects of cover type and treatment on infiltration and runoff. It is defined to be Poor, Fair, and Good on the basis of percent area of grass cover, as shown in the following table. A watershed having larger area of grass cover allows more infiltration and less runoff and this situation of watershed is said to be in good hydrologic condition because it favors the protection of watershed from soil erosion. Similarly, a watershed having lesser area of grass cover can be defined as poor hydrologic condition. The curve number will be the highest for poor, average for fair, and lowest for good hydrologic condition.

Table 2.2: Classification of native pasture or range (Source: SCS, 1971)

| S. No. | Vegetation condition | Hydrologic condition |
|---|---|---|
| 1 | Heavily grazed and no mulch or plant cover less than ½ of the area. | Poor |
| 2 | Not heavily grazed and plant cover less than ½ to ¾ of the area. | Fair |
| 3 | Lightly grazed and plant cover on more than ¾ of the area. | Good |

### v) Antecedent moisture condition (AMC)

The Soil Conservation Service defines antecedent moisture condition (AMC) as an index of the watershed wetness (Hjelmfelt, 1991). Mishra and Singh (2003a) has defined the AMC as the wetness of soil surface or the amount of moisture available in soil profile, alternatively the degree of saturation prior to occurrence of rainstorm. Watersheds with low initial soil moisture are not conducive to high runoff. Conversely, watersheds with high initial soil moisture are likely to produce large amount of runoff with less infiltration losses. Hence the soil moisture condition in the watershed before runoff occurs significantly influence the CN value.

The SCS developed three AMC levels and categorized as: AMC I (dry condition), AMC II (normal condition), and AMC III (wet condition). Where, the AMC I have the lowest runoff potential; AMC II have the average runoff potential; and AMC III have the highest runoff potential. The term antecedent is taken to vary from previous 5 to 30 days. However, there is no explicit guideline available to vary the soil moisture with the antecedent rainfall of certain duration. The National Engineering Handbook (SCS, 1971) uses the antecedent 5-days rainfall amount for AMC and it is generally used in practice (Table 2.3).

These three AMC I, AMC III, and AMC II conditions of the watershed statistically correspond to respective 90%, 10%, and 50% cumulative probability of exceedance of runoff depth for a given rainfall (Hjelmfelt et al., 1982). SCS (1956) provided tables to determine CN values for ungauged watersheds valid for AMC II (normal condition). Also, for their conversion from AMC I (dry) to AMC III (wet) or AMC II (normal), some fairly accurate mathematical expressions are also available, which are given in the Table (2.4):

Incorporation of antecedent moisture in the existing SCS-CN method in terms of three AMC levels permits unreasonable sudden jumps in the CN-variation. To avoid these problems, Mishra and Singh (2002a) suggested an SCS-CN-based equation to compute the antecedent moisture from 5-day antecedent precipitation for computation of runoff.

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Table 2.3: Antecedent Soil Moisture Conditions (AMC)

| AMC | Total 5-days antecedent rainfall (cm) | |
|---|---|---|
| | Dormant season | Growing season |
| I | Less than 1.3 | Less than 3.6 |
| II | 1.3 to 2.8 | 3.6 to 5.3 |
| III | More than 2.8 | More than 5.3 |

Table 2.4: AMC-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) | $CN_I = \frac{4.2CN_{II}}{10 - 0.058\ CN_{II}}$ | $CN_{III} = \frac{23CN_{II}}{10 + 0.13\ CN_{II}}$ |
| Neitsch et al. (2002) | $CN_I = CN_{II} - \frac{20(100 - CN_{II})}{[100 - CN_{II} + \exp\{2.533 - 0.0636(100 - CN_{II})\}]}$ | $CN_{III} = CN_{II}\exp\{0.00673(100 - CN_{II})\}$ |
| Mishra et al. (2008) | $CN_I = \frac{CN_{II}}{2.2754 - 0.012754\ CN_{II}}$ | $CN_{III} = \frac{CN_{II}}{0.430 + 0.0057\ CN_{II}}$ |

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### vi) Initial abstraction and climate

Initial abstraction is the term used to describe the amount of rainfall that doesn't contribute to runoff. There are numerous processes that intercept rainfall. Some rainfall never even reaches the ground, instead being intercepted by leaves on trees. Some rainfall is evaporated back into the atmosphere. Some rainfall that reaches the ground, some is infiltrated and some just ponds with no outlet. Hence, initial abstraction consists of interception, evaporation, surface detention, and infiltration; and the abstracted rainfall amount finally goes back to atmosphere through evaporation. SCS-CN method is based on the concept that the runoff begins only after the initial abstraction is satisfied. Evaporation is primarily governed by metrological factors, such as radiation, temperature, humidity, wind, sun-shine hours etc., which describe the climate. Thus, the effect of the climatic condition of the watershed is accounted for the existing SCS-CN method in terms of the initial abstraction. The initial abstraction reduces the runoff potential of the watershed and hence reduces the curve number.

### vii) Rainfall intensity and duration, Turbidity

For a given rainfall amount, the runoff will be more in high rainfall intensity and vice versa. It is because if the rainfall amount is constant, the greater the rainfall intensity, the lesser will be the time duration and vice versa. Hence, a greater intensity rainfall yields lesser time for rain water to stay over the land surface, leading to a lesser amount of infiltration and consequently, a greater amount of runoff.

Also, a high intensity rainfall breaks down the soil structure and forms a layer of fine soils which clog the pores of soil mass leading to reduction in the infiltration rate causes increase of runoff, in turn CN. This is the reason that a fallow land exposed to raindrop produces higher runoff than does the covered land.

On agriculture land or a land surface with loose soil 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 leading to reduction in the infiltration rate.

The term turbidity refers to impurities of water that affect infiltration by clogging of soil pores. The contaminated water with dissolved minerals, such as salts, affects the soil structure and consequently, infiltration.

### 2.1.3 Effect of watershed slope on runoff CN

The watershed slope is an important factor to determine runoff CN. However, SCS-CN does not take into account the effect of watershed slope on runoff generation because cultivated land in general has slopes of less than 5% in United States, and this range does not influence the CN value to any great extent.

Haggard et al. (2002) executed an experiment on small plots (1.5 m x 3 m) having silty loam on 11 slopes (from 0 to 28%) in northwest Arkansas, USA, and rainfall of 70 mm/hr intensity for an hour. They found that up to a slope of 15%, surface runoff increased logarithmically with the slope of plots, at which steeper slopes did not cause more runoff. In Pakistan, Shafiq and Ahmad (2001) studied on plots having silt loam with different slopes (viz. 1%, 5% and 10%) under medium rainfall intensity, and found that runoff occurred 11.2%, 18.1% and 26.6% of the rainfall amount from the 1%, 5%, and 10% slope of plots respectively. Although, the effect of watershed slope plays a vital role on runoff generation, very few attempts have been made to include a slope factor into the CN method. Philip (1991) found reduction in infiltrating on sloping land. According to his study, the infiltration into a 58% sloping plots having homogeneous and isotropic Yolo clay soil was decreased by 15% compared with a horizontal surface. Using a recession time equation developed by Woolhiser et al. (1970), based on the kinematic wave approximation, Evett and Dutt (1985) found that recession time decreased by 59% when the slope was increased from 1 to 15%. The reduced recession time results in less opportunity for infiltration and in more surface runoff.

Sharpley and Williams (1990) developed a relation for slope-adjusted CN,

$$CN_{2\alpha} = 1/3\,(CN_3 - CN_2)\,(1 - 2e^{-13.86\,\alpha}) + CN_2 \qquad (2.1)$$

where, $CN_2$ and $CN_3$ are the CN values given in the NEH-4 table for AMC II and AMC II respectively, and $\alpha$ is the soil slope. This Sharpley and Williams (1990) method assumes that $CN_2$ tabulated in the NEH-4 table (SCS, 1972) corresponds to a slope of 5%. Using this relation (Eq. 2.1), SWAT model also incorporated the effect of watershed slope. Huang et al. (2006) claimed that Eq. (2.1) does not appear to have been verified in the field.

In China, Huang et al. (2006) studied the effect of watershed slope on runoff under simulated rainfall for 11 years in order to modify the existing SCS-CN method for land slope. They developed a slope-adjusted CN equation as follows:

$$CN_{2\alpha} = CN_2 \frac{322.79 + 15.63(\alpha)}{\alpha + 323.52} \tag{2.2}$$

where, $CN_{2\alpha}$ is the slope-adjusted CN, $CN_2$ is CN value given in the NEH-4 table for AMC II and $\alpha$ is watershed slope between 14 and 140%.

### 2.1.4 Determination of CN from Hawkins – Hejlmfelt – Zevenbergen (HHZ) approach

Hawkins et al. (1985) developed a procedure for computing catchment CNs from historical rainfall-runoff records, which is based on probability assessments and first proposed by Hjelmfelt (1980). The HHZ approach identifies a subset of events that contains the necessary information about the catchment response. This subset corresponds to the condition $P/S_e > 0.456$, which indicates a 90% probability of runoff occurrence. Such a set is primarily a set of the largest rainfall events (but not necessarily the highest runoff events). The procedure for finding a CN using HHZ is as follows:

Step 1: Remove all non-runoff producing events from the sample. These events are not appropriate for CN identification.

Step 2: For the remaining runoff-producing events, sort all events in descending order of rainfall.

Step 3: Starting from the largest rainfall event, compute the storage parameter $S_i$ from the following equation,

$$S = 5\left\{P + 2Q - \sqrt{Q(4Q + 5P)}\right\} \tag{2.3}$$

Step 4: Check for the cutoff value $P_i/S_i > 0.456$.

Step 5: If $P_i/S_i > 0.456$, add the next biggest storm to the calculation. Compute $S_i$ for this storm and compute $S_e$, the average value corresponding to the storms that have entered the calculation. Go back to Step 4.

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Step 6: Include all events where $P_i/S_e > 0.456$. This means that if $P/S_e$ becomes less than 0.456, continue the procedure until no more cases of $P/S_e$ are > 0.456. Once this subset of events is identified, from the following equation, compute the CN from $S_e$ corresponding to the last incidence of $P/S_e > 0.456$.

$$\mathrm{CN} = \frac{25400}{S + 254} \tag{2.4}$$

Step 7: Compute the estimated runoff $Q_{ei}$ for each rainfall event by substituting $P_i$ for $P$ and $S_e$ for $S$ in the following equation. It should be checked for the condition $P_i > 0.2S_e$. Some of the events will not satisfy the condition. In these cases, $Q_e = 0.00$.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{2.5}$$

Step 8: Plot the observed $Q_i$ against the estimated $Q_{ei}$. It should be noticed if there is a spread about the 1:1 line (the line can be drawn by plotting the $Q_i$ against itself on both axes).

It should be noted that not all datasets provide a good sample for this method. Some datasets will not contain any storms with $P_i/S_i > 0.456$, and HHZ must not be used. Such "empty" datasets imply that the catchment has a low CN that cannot be identified from the available record (Hawkins et al., 1985).

### 2.1.5 Advantages and Limitations

The SCS-CN method has several advantages over other methods. Following are the main advantages of the SCS-CN method (Ponce and Hawkins, 1996; Mishra and Singh, 2003a):

- It is simple conceptual method for estimation of the direct runoff amount from a storm rainfall amount, and is well supported by empirical data and wide experience.
- It is easy to apply and useful for ungauged watersheds.
- It accounts for many of the watershed characteristics affecting runoff generation including soil type, land use and treatment, surface condition, and antecedent moisture condition, incorporating them in a single CN parameter.

- The method relies only on one parameter CN, which is a function of the watershed characteristics.

Some of the limitations and disadvantages of the existing SCS-CN method are presented below:

- The three AMC levels used with the SCS-CN method permit unreasonable sudden jumps in the computed runoff.
- There is a lack of clear guidance on how to vary antecedent moisture condition.
- The initial abstraction coefficient ($\lambda$), which is largely depends on climatic and geologic conditions (Ponce and Hawkins, 1996), has been taken as constant (=0.2). To use the value of $\lambda$ other than 0.2, one must redevelop new equations by using the original rainfall-runoff data to establish new S or CN relationships for each cover and hydrologic soil group.
- This method does not contain any expression for time and, therefore, does not account the impact of rainfall intensity and its temporal distribution.
- The method does not consider effect of watershed slope.
- No explicit provision for spatial scale effects.
- The method is highly sensitive to changes in values of its parameter.
- Poor applicability to forest sites (Hawkins, 1993; Mishra and Singh, 2003a).
- The method is applicable to only small watersheds. Ponce and Hawkins (1996) cautioned against its use to watersheds larger than 250 sq. km.
- The method is not applicable to compute runoff from snowmelt or frozen ground.
- The CN procedure is less accurate for small rainfall and runoff.
- The SCS runoff procedures apply only to direct surface runoff; it cannot be used for large sources of subsurface flow or high ground water levels that contribute to runoff.
- When the weighted CN is less than 40, another procedure should be used to determine runoff.

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### 2.1.6 Applications

The SCS-CN method is used to compute volume of surface runoff for a given rainfall event from small agriculture, urban and forest watersheds (SCS, 1986). It has been widely used in the United States and across the world, and has more recently been integrated into several rainfall-runoff models. The main reasons for its wide applicability and acceptability lie in the fact that it accounts for many of the watershed characteristics affecting runoff generation including soil type, land use and treatment, surface condition, and antecedent moisture condition, incorporating them in a single CN parameter (Ponce and Hawkins, 1996; Mishra and Singh, 2003a).

Mishra and Singh (2002b) developed a modified SCS-CN method to incorporate antecedent soil moisture in the existing method. Jain et al. (2006b) applied 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 having pasture/ range land use and sandy soils. This was conformity with Ponce and Hawkins (1996) that the SCS-CN method performs best on agricultural watersheds, fairly on range sites and poorly on forest sites (Hawkins, 1984; 1993). In recent days, an integrated study of runoff modeling using SCS-CN and GIS technique has gained significance for estimation of surface runoff (Amutha and Pochelvan, 2009; Soulis et al.,2009; Pradhan et al.,2010; Inayathulla et al., 2013).

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Though the SCS-CN method was primarily intended for event-based rainfall-runoff modeling of the ungauged watersheds, it has been applied successfully in the field of hydrology and watershed management and environmental engineering, such as long-term hydrologic simulation, prediction of infiltration and rainfall excess rates, hydrograph simulation, metal partitioning, modeling of sediment yield and transport of urban pollutants, determination of evapotranspiration, determination of irrigation water requirement, determination of sub-surface flow, etc. (Mishra and Singh, 2003a). The SCS-CN model has also been adopted by many hydrological models to determine runoff, such as CREAMS (Knisel, 1980), ANSWERS (Beasley et al., 1980), AGNPS (Young et al., 1987), EPIC (Sharply and Williams, 1990) and SWAT (Neitsch et al., 2005). Thus, it reflects the vast applicability of the method among the hierarchy of hydrologic models.

## 2.2 RECENT UPDATES

Ponce and Hawkins (1996) critically examined the CN method; clarified its conceptual and empirical basis; delineated its capabilities, limitations, and uses; and identified further areas of research. The SCS-CN method is based on a non-linear rainfall-runoff relation and it is an infiltration loss model, although it may account for interception and surface storage losses through its initial abstraction feature (Ponce and Hawkins, 1996). Using the observed rainfall and runoff data, many researchers demonstrated that the key SCS-CN parameter, CN, has variable nature and it is not a constant for a watershed (Hjelmfelt et al. 1982; McCuen 2002), rather varies with rainfall. Mishra and Singh (1999a) derived SCS-CN equation from the water balance equation with the assumption that the rate of change of potential maximum retention with effective precipitation is a linear function of potential maximum retention. Mishra and Singh (2003a) provided the current state of the art of the SCS-CN methodology, its enhanced analytical treatment, and applications to areas other than the originally intended one, such as sediment yield, non-point source pollution, among others. Hjelmfelt (1991), Hawkins (1993), Bonta (1997), McCuen (2002), Bhunya et.al. (2003), and Schneider and McCuen (2005) suggested procedures for determining CN for a watershed using field data.

Hong and Adler (2008) developed a global SCS-CN runoff map using land cover, soils and antecedent moisture conditions. Canters et al. (2006) calculated CN at the catchment level by combining impervious surface, vegetation, bare soil and watershed information. Dutta et al. (2006) calculated CN employing the information on water body, dense forest, and soil. Ludlow (2009) discussed a composite CN calculation method by integrating vegetation, impervious surface and soil, and suggested an average CN value of the whole catchment. Apparently, most previous studies showed that impervious surface played an important role in computing CN, because it affected the infiltration of surface water. Fan et al. (2013) developed a method to calculate composite CN by using remote sensing variables, including vegetation, impervious surface, and soil (V-I-S). The following text provides a few important updates/ advancements in SCS-CN modeling.

### 2.2.1 Yu (1998) model

Yu (1998) pointed out one of the assumptions of SCS-CN method that is the ratio of the actual retention to the potential retention is the same as the ratio of actual runoff to potential runoff and found the assumption not to be theoretically or empirically sound. He derived an exact relationship between rainfall and runoff in the form of SCS-CN equation theoretically employing two assumptions: (a) the spatial variation of infiltration capacity has an exponential distribution and (b) the temporal variation of rainfall rate also follows an exponential distribution. A theoretical basis for the SCS method allows an independent validation of the method by testing how rainfall intensity and infiltration capacity actually vary in time and space, respectively.

### 2.2.2 Mishra and Singh (1999a)

Mishra and Singh (1999a) showed analytically a connection between the SCS-CN hypothesis and Mockus (1949) method and derived the modified and general forms of the SCS-CN method. They found the modified method to be an improvement over the existing one in some field applications. They examined the curve number (CN) scaling equation and hypothesized that CN could vary between 50 and 100.

### 2.2.3 Modified SCS-CN method

Followings are the fundamental equations used in the existing SCS-CN method:

$$P = I_a + F + Q \quad \text{(Water balance equation)} \tag{2.6}$$

$$\frac{Q}{(P - I_a)} = \frac{F}{S} \quad \text{(First hypothesis)} \tag{2.7}$$

$$I_a = \lambda S \quad \text{(Second hypothesis)} \tag{2.8}$$

The variability of antecedent rainfall and the associated soil moisture amount is an important source of the inherent curve number variability encountered in applications of the SCS-CN method (Ponce and Hawkins, 1996). Mishra and Singh (2002a) proposed a model which allowed variation in $\lambda$ and, in turn, initial abstraction ($I_a$), obviating its dependence on the antecedent moisture (M). Using the $C = S_r$ concept, where C is the runoff coefficient ($=Q/(P - I_a)$ and $S_r$ = degree of saturation, Mishra and

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Singh (2002a) modified Eq. (2.7) of the existing SCS-CN method incorporating antecedent moisture (M) as:

$$\frac{Q}{P - I_a} = \frac{F + M}{S + M} \tag{2.9}$$

Up on substituting Eq. (2.9) into Eq. (2.6) leads to:

$$Q = \frac{(P - I_a)(P - I_a + M)}{(P - I_a + M + S)} \tag{2.10}$$

Here, $I_a$ is the same as in Eq. (2.8) and M is computed with the assumption that (a) the watershed is dry 5-days before the onset of rainfall and (b) the antecedent moisture (M) on the day of onset of rainfall is equal to the amount of water infiltrated (F) due to antecedent 5-day rainfall amount ($P_5$) at a time.

$$M = \frac{S_I(P_5 - \lambda S_I)}{P_5 + (1 - \lambda)S_I} \tag{2.11}$$

where, $P_5$ is the 5-day antecedent precipitation amount and $S_I$ is the potential maximum retention corresponding to AMC I. Also, $S_I$ can be treated as absolute maximum retention capacity, then,

$$S_I = S + M \tag{2.12}$$

Combining Eq. (2.11) and (2.12), we get

$$M = 0.5[-(1 + \lambda)S + \sqrt{(1 - \lambda)^2 S^2 + 4P_5 S}\,] \tag{2.13}$$

Here + sign before the square root is retained for $M \geq 0$, and $P_5 \geq \lambda S$.

In the original SCS-CN method, $I_a$ is given by Eq. (2.8), which does not incorporate antecedent moisture M. Though the Mishra-Singh (2002a) model allows variation in λ and, in turn, $I_a$, it obviates its dependence on the antecedent moisture M. It is of common experience that $I_a$ relies on interception, surface storage, and infiltration and all these factors greatly depend on the antecedent moisture. The larger the antecedent moisture, the lesser will be the initial abstraction, and vice versa. To meet these conditions, Mishra et al. (2006a) modified Eq. (2.8) to the following non-linear $I_a$ −S relation incorporating antecedent moisture M as:

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$$I_a = \frac{\lambda S^2}{S + M} \tag{2.14}$$

Here, for M = 0 or a completely dry condition, $I_a = \lambda S$, which is the same as Eq. (2.8). Thus, Eq. (2.8) is a specialized form of Eq. (2.14) and hence the latter is a generalized $I_a$-S relation.

### 2.2.4 Michel et al. (2005) model

Michel et al. (2005) remarked major inconsistencies in the soil moisture accounting (SMA) procedure used in the SCS-CN method and developed a procedure more consistent from the SMA viewpoint. They hypothesized that the SCS-CN model is valid not only at the end of a storm but also at any time along a storm, i.e. rainfall amount (P) and runoff amount (Q) are functions of time (t). They considered an SMA store which would absorb some portion of the rainfall that is not transformed into runoff by the SCS-CN equation (this amount is noted as $F + I_a$ in the existing SCS-CN method). Their SMA procedure is based on the notion that higher the moisture store level, higher the fraction of rainfall that is converted into runoff. If the moisture store level is full, i.e., if the soil is saturated, all rainfall will convert into runoff.

They finally suggested a one-parameter model to compute the surface runoff for the three AMCs, which are as follows:

$$\text{For AMC I } (V_0 = 0.33\,S),\ \ Q = P\left(\frac{P}{S + P}\right) \tag{2.15}$$

$$\text{For AMC II } (V_0 = 0.61S),\ \ Q = P\left(\frac{0.48S + 0.72P}{S + 0.72P}\right) \tag{2.16}$$

$$\text{For AMC III } (V_0 = 0.87S),\ \ Q = P\left(\frac{0.79S + 0.46P}{S + 0.46P}\right) \tag{2.17}$$

### 2.2.5 Sahu et al. (2007) model

Sahu et al. (2007) pointed out the Michel et al. (2005) model does not have any expression for initial soil moisture store level ($V_0$). This $V_0$ is taken as AMC-dependent in the simplified version of the model. It leads to a quantum jump in $V_0$ and, in turn, runoff computations. Hence, Sahu et al. (2007) developed an expression for $V_0$ to make the model a continuous watershed model with the following assumptions:

- The pre-antecedent moisture level ($V_{00}$) 5 days before the onset of rainfall is zero or a fraction of S.
- The initial soil moisture store level ($V_0$) at the time of the beginning of rainfall storm is equal to the sum of pre-antecedent moisture level ($V_{00}$) and a fraction ($\beta$) of the part of rainfall that is not transformed into runoff ($P_5 - Q_5$) owing to rainfall of $P_5$ at the time, where $Q_5$ is the corresponding runoff. This assumption is based on the fact that only a fraction, in general, of moisture/water added to the soil will contribute to $V_0$ due to evapotranspiration losses in the previous 5 days.
- Michel et al. model is valid for $P = P_5$.

### 2.2.6 Geetha et al. (2007) model

Geetha et al. (2007) attempted to modify the existing SCS-CN model in two ways: (i) by varying the CN using antecedent moisture condition (AMC), and (ii) by varying the CN using antecedent moisture amount (AMA). The daily moisture storage is updated based on varying curve number and other hydrologic abstractions. The first allows for varying the CN between CN(I), CN(II), and CN(III) based on the cumulative rainfall over the previous five days. Prior to estimating the current day's runoff, the CN value is selected based on predetermined, discrete rainfall criteria, as given in Table 2.3. In the second method, daily CN values are not allowed to vary directly by prior rainfall but by antecedent soil moisture. The antecedent moisture amount is still based on the previous five days of rainfall, but available soil storage each day is tracked and utilized to directly estimate the CN value of the current day allowing for more of a continuous estimation of CN as opposed to the discrete method described above. The work of Geetha et al., (2007) describes the successful application of these modified methods for predicting long-term runoff employing long-term rainfall data.

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## 2.3 SEDIMENT YIELD

Another main objective of this study is to determine sediment yield using SCS-CN based sediment yield model derived from the coupling of the SCS-CN method with Universal Soil Loss Equation (USLE). Hence, in this section, the literature review related to soil erosion by water and sediment yield modeling has been carried out.

### 2.3.1 Factors affecting sediment yield

Sediment yield is not only the outcome of any single factor but the resultant of numerous variables within a watershed. As the sediment is the product of erosion, those factors which affect erosion also affect the sediment yield of a watershed; however, rates of sediment yield are much lower than rates of erosion. This indicates that some other factors in addition to erosion also affect the rates of sediment yield.

Glymph, Jr (1954) listed out some factors which affect the sediment yield as follows:

(a) Soils
    i) Parent material
    ii) Texture
    iii) Organic content
    iv) Chemical constituents
(b) Ground surface cover
    i) Permanent vegetation (type, age, density)
    ii) Non-permanent vegetation (kinds of crops, growth characteristics, age, density)
(c) Precipitation
    i) Form
    ii) Seasonal occurrence
    iii) Intensities
    iv) Amount
(d) Drainage area and topographic features
    i) Size
    ii) Shape
    iii) Drainage pattern and density
    iv) Length of land slope

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    - v) Degree of land slope
- (e) Channel types
    - i) Shape, size and cross-section
    - ii) Slope
    - iii) Erodibility of bed and bank
- (f) Runoff
    - i) Rate
    - ii) Duration
    - iii) Amount
- (g) Soil and cover management practices

  Kind and amount of soil and cover management practices, including crop rotations, fertility amendments, grazing rates, fire protection, etc.
- (h) Conservation practices and watershed treatment measures

  Kind and amount of conservation practices and watershed treatment measures, including tillage methods, terracing, waterways, channel stabilization, detention reservoirs, etc.

### 2.3.2 Sediment delivery ratio (DR)

The sediment yield is computed using the potential erosion (A) and delivery ratio (DR). DR is a dimensionless ratio (varying from 0 to 1) of the sediment yield (Y) to the total potential erosion (A). Mathematically,

$$\mathrm{DR} = \frac{\mathrm{Y}}{\mathrm{A}} \tag{2.18}$$

DR generally decreases with the size of watershed (Roehl, 1962). Values of DR for an area are found to be affected by catchment physiography, sediment sources, transport system, texture of eroded material, land cover, etc. (Walling, 1983, 1988; Richard, 1993). However, the variables such as catchment area, land slope and land cover have been used mainly as parameters in the empirical equations for DR (Walling, 1983; Hadley et al, 1985). These characteristics vary within the catchment, and therefore, to account for these variability, watersheds should be subdivided either into cells of a regular grid or into units of sub-areas having approximately homogeneous characteristics and rainfall distribution (Julien and Gonzales del Tanago, 1991; Wilson and Gallant, 1996; Jain and Kothyari, 2000; Jain et al., 2004). A grid- or cellbased discretization is the most commonly used procedure both in empirical and process-based models (Beven et al., 1984). The technique of Geographical Information System (GIS) is well suited for quantification of heterogeneity in the topographic and drainage features of a watershed (Jain and Kothyari, 2000; Jain et al., 2004, 2005).

Based on the work of Ferro & Minacapilli (1995), Ferro (1997), and Ferro et al. (1998), the following relationship was derived by Jain & Kothyari (2000) for the delivery ratio of a grid sized area:

$$\mathrm{DR_i} = \exp\left\{-\gamma \sum_{i=1}^{m} \frac{l_i}{a_i \theta_i^{0.5}}\right\} \tag{2.19}$$

where $l_i$ is the flow length of the $i^{th}$ grid, $\theta_i$ is the slope of the $i^{th}$ grid, $\gamma$ is a coefficient considered as constant for a given catchment, $m$ is the number of grids located in a flow path, and $a_i$ is a coefficient related to land use. Note that $l_i/\theta_i^{0.5}$ is the definition of travel time used by Ferro and Minacapilli (1995). Values of the coefficient $a_i$ for different land uses were adopted from Haan et al. (1994).

### 2.3.3 Detachment rates of soil particles

Nearing et al. (1991) found the detachment of soil particles by shallow flow is influenced by soil cohesion, soil particles properties, and hydraulic flow characteristics. They carried out a series of experiments in a hydraulic flume with different bed slope (ranged from 0.5 to 2%) and depth of flow (ranged from 0.5 to 2.0 cm) to evaluate relationships among soil detachment rates, flow depth, bed slope, soil particles size, soil tensile strength, flow shear stress, and flow stream power. They performed the experiment on three aggregate sizes of two soil types (Russell silt loam and Paulding clay) with small, statically compressed samples. They found that the detachment rates increased with both increasing of flow depth and bed slope. Furthermore, they successfully correlated the detachment rate with flow depth, bed slope, and mean weight diameter. The detachment rate for a given soil particles was however not a unique function of either shear stress or stream power of the flow, and the largest size class of soil was detached at a faster rate than the smaller size class of soil particles.

Zhang et al. (2002) conducted a series of experiments to find out the relationships between soil detachment rates and flow discharge, flow depth, bed slope, mean flow velocity, shear stress, unit stream power, and stream power. A 5.0 m long and 0.4 m wide hydraulic flume was used with flow discharge ranged from 0.25 to 2.0 l/s and bed slope varied from 3.5% to 46.6%. They concluded as follows:

i) Detachment rates increased with both increasing flow discharge and slope.
ii) Detachment rate was more affected by discharge than by bed slope. The influence of bed slope on detachment rate was greater at higher slopes. The effect of flow depth on soil detachment rate was also dependent on bed slope.
iii) Stepwise variable selection analyses showed that detachment rate could be determined by a power function of discharge and slope.
iv) Substituting flow depth for discharge gave a poorer prediction.
v) Mean flow velocity was more closely correlated to detachment than was any other hydraulic parameter.
vi) Flow detachment rates were better correlated to a power function of stream power than to functions of either shear stress or unit stream power.
vii) The results of this study suggest that soil detachment by shallow flow is more closely related to flow energy than to shear stress.

Again, Zhang et al. (2003) conducted a series of experiment to (a) evaluate the difference of using natural soil samples (undisturbed), compared with the use of disturbed samples as used in previous studies (Zhang et al., 2002) to know the mechanism of soil detachment by overland flow; and (b) evaluate the influence of flow discharge and slope gradient on detachment rate of natural undisturbed loess soil and to examine the relationships between detachment rate and commonly used hydraulic parameters. Natural undisturbed soil samples obtained in the field were placed in a flume located in a laboratory to obtain the soil loss and hydraulic measurements. They noticed a great difference between the detachment rates of disturbed and undisturbed soil samples. They found that the detachment rates of disturbed soil samples were 1 to 23 times greater than the detachment rates of natural (undisturbed) soil samples. They concluded that it is necessary to use natural undisturbed soil samples to simulate the detachment process and to evaluate the influence of hydraulic parameter on detachment rate, if the desire is to understand erosion rates on undisturbed soil mass.

### 2.3.4 Sediment graph model

Singh et al. (2008) developed a new conceptual sediment graph models based on coupling of popular and widely used methods, viz., Nash model based instantaneous unit sediment graph (IUSG), SCS-CN method, and Power law with the following assumptions:

(i) The bed load contributions to the total sediment yield are neglected since they are usually small, and therefore, the suspended sediment yield is considered as the total sediment yield of the watershed.

(ii) The rainfall, P, grows linearly with time t, i.e. $P = i_0t$, where $i_0$ is the uniform rainfall intensity.

(iii) The inflow is instantaneous and occurs uniformly over the entire watershed producing a unit of mobilized sediment.

(iv) The process is linear and time invariant.

## 2.4 SUMMARY

The SCS-CN method is a well accepted tool for estimation of surface runoff volume from small watersheds for a given rainfall event. The runoff curve number (CN) values for ungauged watersheds were derived from small experimental watersheds in USA and these CN values are used for watersheds all over the world. Many of the works carried out are based on the application of SCS-CN method and possibly little or no attempt has been made to verify the CN-values for different watershed slopes, especially in Indian watershed. Hence this study aimed at to determine the runoff CN for experimental agricultural plots.

Estimation of potential soil erosion and sediment yield are important for project planning. Methods for estimation of sediment yield can be grouped into two categories: (i) empirical methods and (ii) process-based methods. The universal soil loss equation (USLE) is one of the examples of empirical models, which is simple in application and widely used. Soil erosion starts with detachment of soil particles from soil mass, which is caused by raindrop impact and existing soil moisture content. Hence in this study, the relation of soil moisture content with surface runoff and sediment yield are aimed at to evaluate the performance of SCS-CN-based sediment yield model, which is coupling the SCS-CN method with USLE.

## CHAPTER 3

# METHODOLOGY AND DEVICES USED

The main objectives of this study is to determine the runoff curve number and sediment yield from the watershed having maize crop with varying slopes. To achieve more accurate results from the study, choice of related methods/models and devices has always been one of the most important tasks for the researchers. Here, the runoff curve number was derived for the existing SCS-CN method and SCS-CN based sediment yield model is used to determine the sediment yield from the watershed.

Measurement of runoff and soil losses from an area under controlled conditions is necessary to evaluate the influence of soil type, slope, and land management practices on runoff and, in turn, curve number and soil loss. Such studies help develop relations useful for soil loss estimation under given set of conditions. The experimental design includes three independent variables (soils, landuse, and slopes/gradients).

### 3.1 GENERAL PROCEDURE

In general, the methodology can be described in steps as follows:

i. Small agriculture plots (size 22m x 5m) of varying slopes (1%, 3% and 5%) with same soil types having maize crop were prepared.

ii. In a rainstorm, the rainfall (P), runoff (Q), and sediment yield (Y) were measured at the outlet of each plot on continuous basis at small time intervals. Such information for 5 sets of natural rainstorms and 5 sets of artificial (flooding water supply) systems were collected.

iii. The curve numbers for different slopes of plots were derived from the observed rainfall-runoff data and then derived a representative CN-value for a given land use, soil type, and slope of the plot.

iv. The CN-values for all watershed slopes having maize crop were compared with those of NEH-4 and discussed the effect of slope on curve number.

v. Using the collected data, the SCS-CN based sediment yield model was validated.

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## 3.2 SCS–CN METHODOLOGY

The SCS-CN method is based on the water balance equation and two fundamental hypotheses. Thus, the SCS-CN method consists of the following three equations (Mishra and Singh 2003a):

i) Water balance equation:

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

ii) Proportional equality (First hypothesis) (Fig. 3.1):

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

iii) $I_a - S$ Relationship (Second hypothesis) :

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

where, $P$ = total precipitation

$I_a$ = initial abstraction

$F$ = cumulative infiltration excluding $I_a$

$Q$ = direct runoff

$S$ = potential maximum retention or infiltration, and

$\lambda$ = initial abstraction coefficient (= 0.2, a standard value in usual practical applications).

All quantities in the above equations are in depth or volumetric units.

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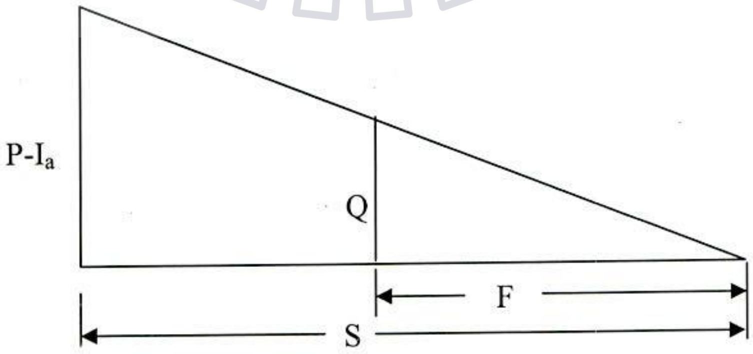

Fig. 3.1: Proportionality concept

The most commonly used form of SCS-CN rainfall runoff model can be derived by combining Eqs. (3.1) and (3.2) as follows:

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

Eq. (3.4) is valid for $P \geq I_a$; $Q = 0$ otherwise.

In order to eliminate the need of estimating the two variables $I_a$, and S in Eq. (3.4), a regression analysis was made on the basis of recorded rainfall and runoff data from small drainage basins. The data showed a large amount of scatter (SCS, 1972) and found the average value of $\lambda$ as 0.2, i.e. $I_a = 0.2\,S$

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

Eq. (3.5) is valid for $P \geq 0.2S$, which is the existing SCS – CN method and shows that S is the only parameter that determines the volume of direct runoff from daily storm rainfall, for the method was originally developed using daily rainfall-runoff data of annual extreme flows (Rallison and Cronshey, 1979). Mishra (1998) defined S as the maximum amount of space available in the soil profile under given antecedent moisture. Also Mockus (1964) described the physical significance of parameter S as: “S is that constant and is the maximum difference of (P – Q) that can occur for the given storm and watershed conditions. S is limited by either the rate of infiltration at the soil surface or the amount of water storage available in the soil profile, whichever gives the smaller S value. Since infiltration rates at the soil surface are strongly affected by the rainfall impact, they are strongly affected by the rainfall intensity.” The parameter potential maximum retention S is related to the CN value by the following relationship:

$$CN = \frac{25400}{S + 254} \tag{3.6}$$

where, S is in mm which can vary in the range of $0 \leq S \leq \infty$ and CN is dimensionless number varying in the range of $0 \leq CN \leq 100$. The curve number (CN) is derived from the NEH-4 tables for catchment characteristics, such as hydrologic soil group, land use, hydrologic condition, and initial soil moisture condition. The Eq. (3.6) shows that the CN decreases as the potential maximum retention S increases. Also, the equation shows the sensitivity of the change in water retention capacity to the CN range.

### 3.3 DETERMINATION OF CURVE NUMBER (CN)

In most cases, the curve numbers were developed using daily rainfall-runoff records corresponding to the maximum annual flows derived from gauged watersheds (SCS, 1985) for which information on their soils, cover, and hydrologic conditions was available (SCS, 1972). Rainfall – runoff data were plotted on the arithmetic paper having a grid of plotted curve numbers, as shown in Fig. (3.2). The curve number that represented the watershed was taken as the median curve number. Thus, the developed curve numbers represented the averages of median site values for soil groups, cover, and hydrologic conditions.

The upper enveloping curve was taken to correspond to AMC III, and the lower curve to AMC I. The average was later extended to imply the average soil moisture condition, i.e. AMC II (Miller and Cronshey, 1989). It is worth mentioning that not all soils, cover types, and hydrologic conditions were represented by rainfall-runoff data, rather these were interpolated to complete the information contained in NEH – 4 (SCS, 1971).

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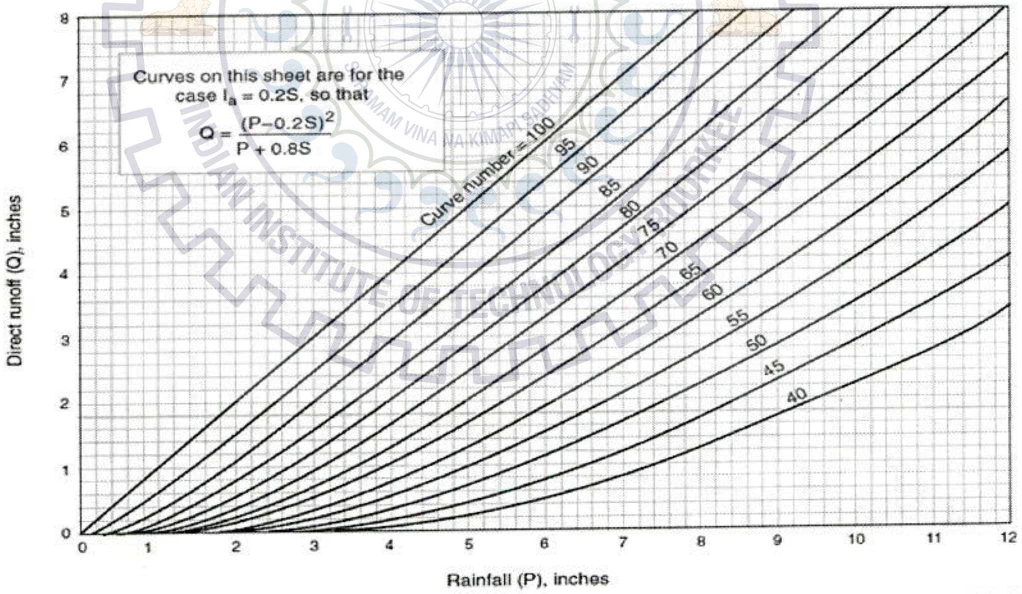

Fig. 3.2: Observed Rainfall-runoff Data and Estimated CN Curves (Source: TR-55, 1986)

To derive the average CN values for AMC II mathematically from the rainfall-runoff data of a gauged watershed, Hawkins (1993) suggested for computation of S (or CN) using the following equation:

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

The above Eq. (3.7) can be derived by solving Eq. (3.5) for S as a function of rainfall depth (P) and runoff depth (Q).

When the watershed consists of landuse with impervious cover (directly connected or unconnected impervious area), SCS (1986) (TR-55, June 1986) provides separate graphs for computing the composite curve number values depending on the percent of the impervious cover.

i) For directly connected impervious areas

An impervious area is said to be connected if runoff from the area goes directly into the drainage system. It is also considered connected if runoff from it occurs as concentrated shallow flow that runs over a pervious area and then into a drainage system.

CN values for urban area given in the NEH-4 table were developed for typical land use relationships based on specific assumed percentages of impervious area. These CN values were developed on the assumptions that (a) pervious urban areas are equivalent to pasture in good hydrologic condition and (b) impervious areas have a CN of 98 and are directly connected to the drainage system. If all of the impervious area is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in the NEH-4 table are not applicable, use the Fig. (3.3) to compute a composite CN.

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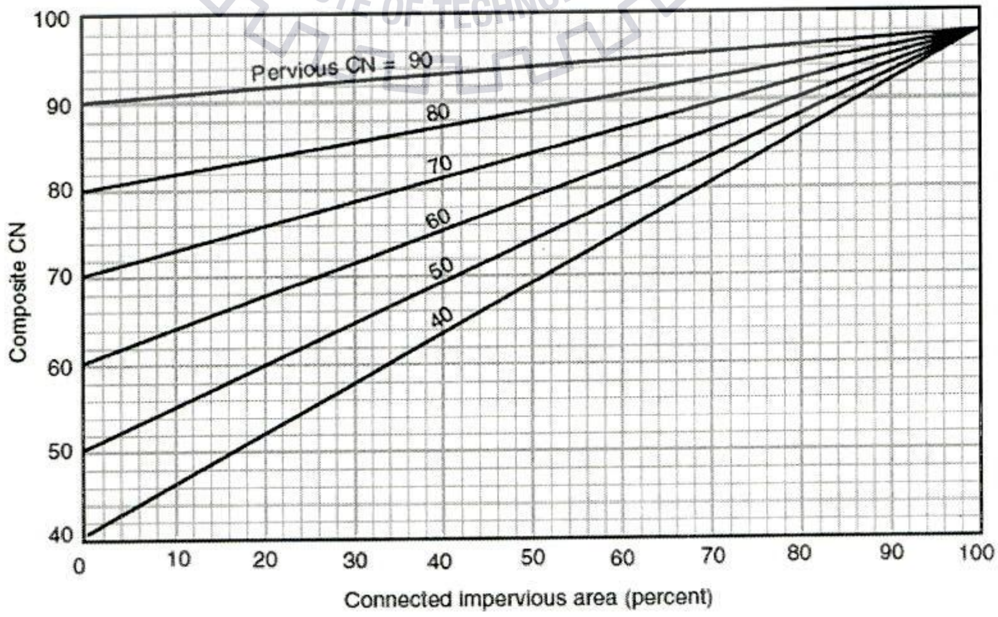

Fig. 3.3: Composite CN with Connected Impervious Area (Source: TR-55, 1986)

ii) For unconnected impervious area:

Runoff from these areas is spread over a pervious area as sheet flow. To determine CN when all or part of the impervious area is not directly connected to the drainage system, (a) use Fig. (3.4) if total impervious area is less than 30 percent or (b) use Fig.(3.3) if the total impervious area is equal to or greater than 30 percent, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff. When impervious area is less than 30 percent, obtain the composite CN by entering the right half of Fig.(3.4) with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN.

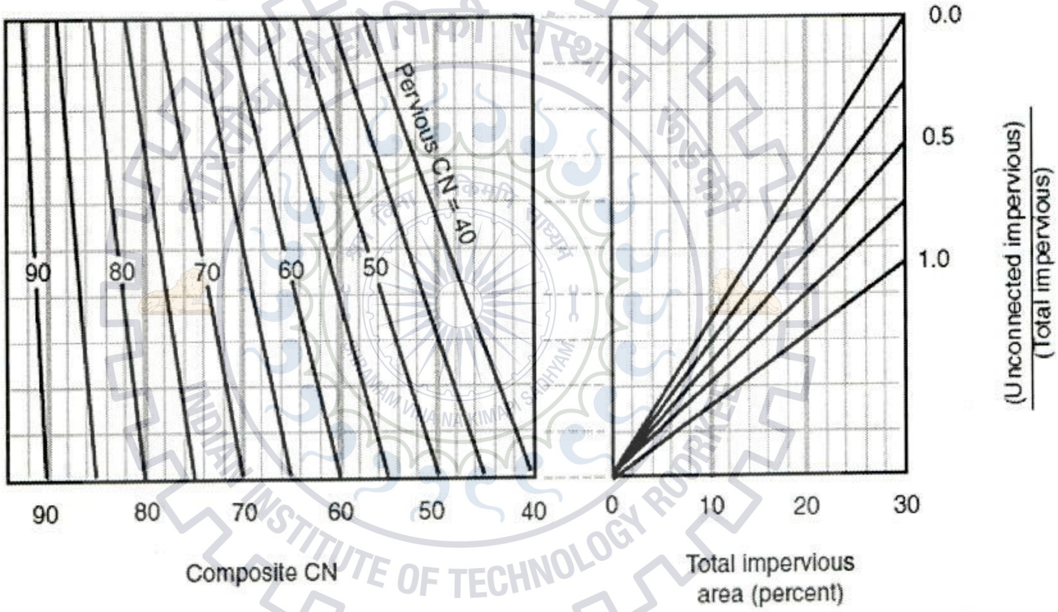

Fig. 3.4: Composite CN with Unconnected Impervious Areas and Total Impervious Areas less than 30% (Source: TR-55, 1986)

### 3.3.1 Frequency matching Curve Numbers

Many researchers have been worked to develop a better method to estimate an observed curve number for a watershed using rainfall and runoff data. Hawkins (1993) worked extensively with recorded rainfall and runoff data sets. Depending on the watershed responses to precipitation, the resulting plots fall into one of three categories. These three categories were identified as complacent, standard, and violent.

In the complacent behavior, observed CNs declines steadily with increasing rainfall depth as shown in the Fig. (3.5), but do not achieve a stable value. A consistent CN cannot be identified in this case.

In the standard behavior, the observed curve number declines with increasing rainfall depth, as in the complacent behavior. However, in standard behavior, the CNs approach and/or maintain a near-constant value with increasingly larger rainfall events. A large majority of watersheds analyzed show this tendency. An example of this behavior is shown in Fig. (3.6).

In the violent behavior, the observed CNs rise suddenly with increasing rainfall depth and asymptotically approach an apparent constant value as shown in Fig. (3.7). There is often accompanying complacent behavior at lower rainfalls.

According to Hawkins (1993), eighty percent of the watersheds fall into the standard and violent categories.

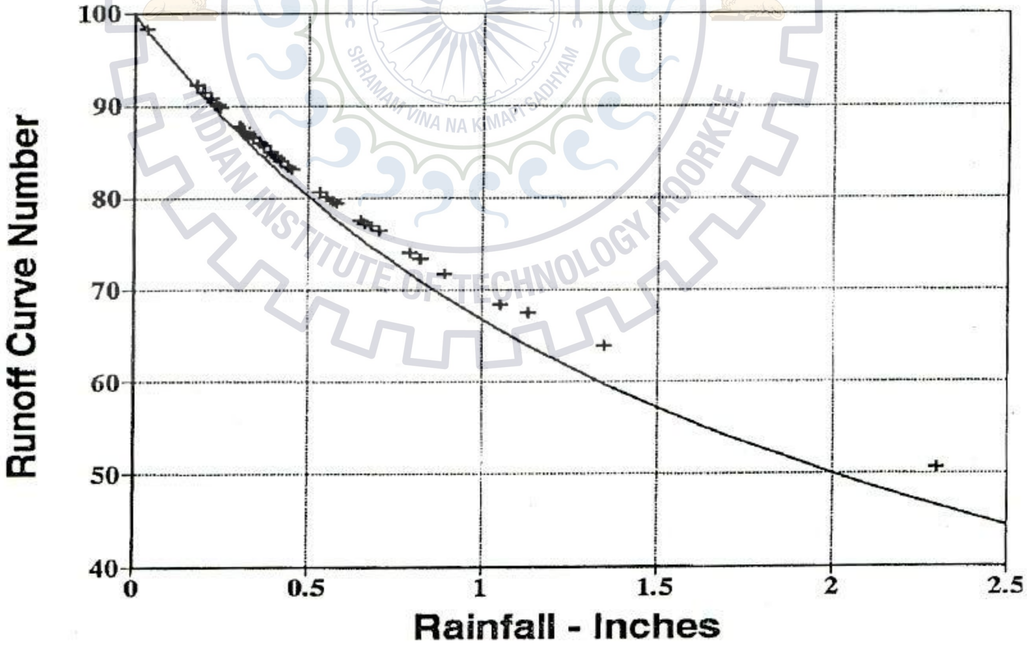

Fig. 3.5: Complacent Behavior (Source: Hawkins, 1993)

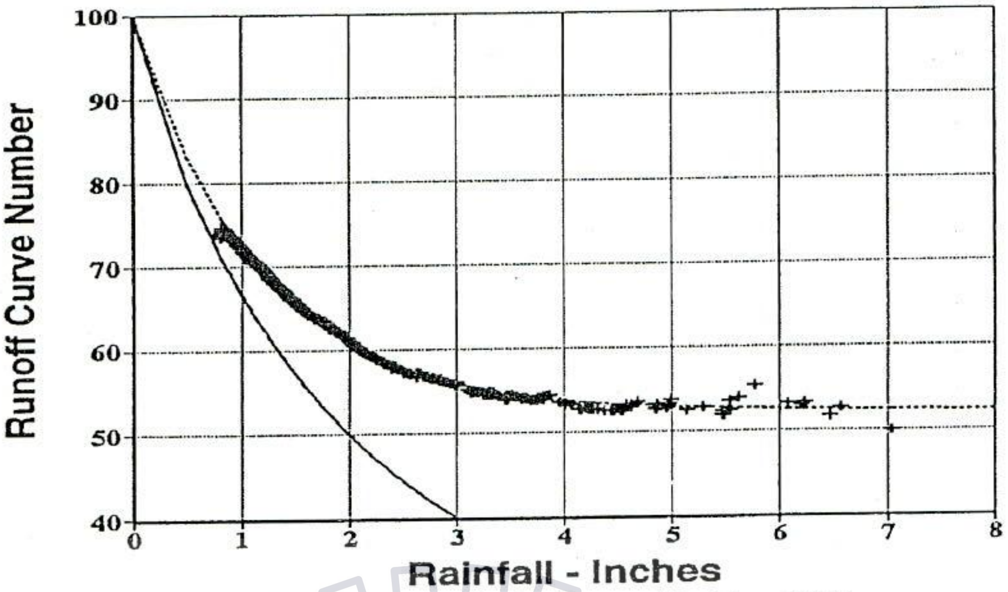

Fig. 3.6: Standard Behavior (Source: Hawkins, 1993)

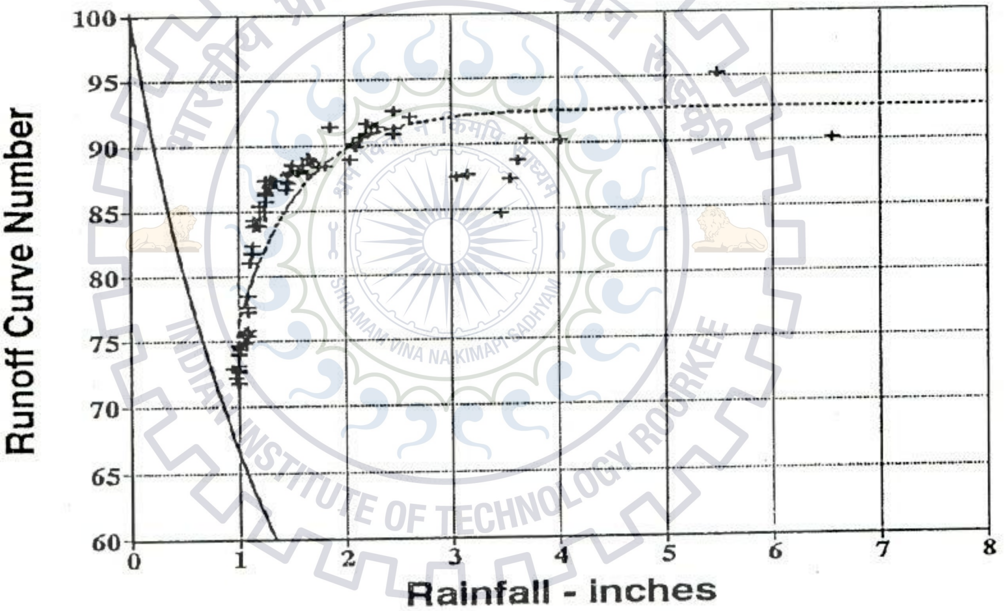

Fig. 3.7: Violent Behavior (Source: Hawkins, 1993)

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 for P > Q.
3. Plot the resulting curve numbers with respect to the corresponding rainfall depth.
4. Define the curve number from the asymptotic behavior as complacent, standard or violent.

The asymptotic constant value is used in identifying the CN for a watershed. Thus, where no constant value is approached, as in complacent behavior, no CN can be determined. The problem is then reduced to an objective determination of that asymptote for the standard and violent behaviors.

A standard asymptote occurs if there is a tendency for CN to decline and then approach a constant value with increasing rainfall depth (P); this asymptotic constant value $CN_\infty$ is used to identify the curve number for the watershed. The following equation has been found to fit P–CN data sets.

$$CN(P) = CN_\infty + (100 - CN_\infty) \exp(-k_1P) \tag{3.8}$$

where, $CN_\infty$ = constant value approached as $P \rightarrow \infty$; and $k_1$ = fitting constant. This equation may be fitted by a least-squares procedure for $CN_\infty$ and k (Sneller, 1985; Zevenbergen, 1985). Although this is an entirely curve-fitting approach, it has been found to be appropriate for a wide array of watershed data sets. The variable $CN\infty$ is the CN describing the data set for larger rainfall events.

The violent pattern applies to the observed CNs, that suddenly increases and approach a constant value with increasing rainfall depth. In this case, the following equation has been found to fit P-CN data set:

$$CN(P) = CN_\infty \{1 - \exp(-k_2P) \tag{3.9}$$

This pattern is sometimes preceded with a complacent pattern at lower rainfalls, but only the non-complacent data points should be used in Eq. (3.9)

## 3.4 UNIVERSAL SOIL LOSS EQUATION (USLE)

The universal soil loss equation (USLE) estimates the potential soil loss from upland (sheet and rill) erosion as (Wischmeier and Smith, 1965):

$$A = R\, K\, L_s\, V_c\, M_p \tag{3.10}$$

where,

A = potential soil loss (erosion) for a given storm (tones/ha)

R = rainfall factor

$K$ = soil erodibility factor, is a function of soil texture.

$L_s$ = slope-length factor

$V_c$ = vegetative cover factor, defines the protection of soil surface against the impact of raindrops and loss of soil particles.

$M_p$ = erosion control practice, defines the treatments that prevent further transportation of eroded particles.

The rainfall factor ( R) is computed using the following relation (Foster et al.,1977):

$$R = 0.5R_r + 7.5\ Q\ q^{1/3} \tag{3.11}$$

where,

$R_r$ = rainfall energy factor

$Q$ = runoff volume (cm)

$q$ = peak runoff rate (cm/hr)

Alternatively, the rainfall factor (R) can be computed using the following relation:

$$R = \sum[(2.29 + 1.15 \ln X_i)\, D_i]\, I \tag{3.12}$$

where,

$i$ = time interval of rainfall hyetograph

$X_i$ = rainfall intensity (cm/hr)

$D_i$ = rainfall volume during $i^{th}$ time interval (cm)

$I$ = maximum 30-min rainfall intensity of the storm (cm/hr)

The slope-length factor (Ls) is determined as follows (for slopes > 4%):

$$L_s = L^{1/2}(0.0138 + 0.00974\ Z + 0.00138\ Z^2) \tag{3.13}$$

where,

$L$ = length in meters from the point of origin of the overland flow to the point where the sedimentation begins

$Z$ = percent slope over the runoff length

The experimental derived values of $V_c$ and $M_p$ for various soil–vegetation–land use complexes are available elsewhere.

## 3.5 SCS-CN-BASED SEDIMENT YIELD MODEL

Coupling the Soil Conservation Service Curve Number (SCN-CN) method with the universal soil loss equation (USLE), Mishra et al. (2006c) developed a model for the estimation of the rainstorm-generated sediment yield from a watershed. The coupling is based on three hypotheses: (i) the runoff coefficient is equal to the degree of saturation, (ii) the potential maximum retention can be expressed in terms of the USLE parameters, and (iii) the sediment delivery ratio is equal to the runoff coefficient.

The relation developed coupling the SCN-CN method with the USLE is as follows:

$$Y = \frac{AP}{P + S} \tag{3.14}$$

Eq. (3.14) can be modified for various elements for the rainfall-runoff-erosion process as follows:

(i) Incorporation of initial abstraction ($I_a$)

The $I_a$ can be incorporated in Eq. (3.14) as:

$$Y = \frac{(P - I_a)A}{P - I_a + S} \tag{3.15}$$

Taking $I_a = 0.2S$, Eq. (3.15) can be written as:

$$Y = \frac{(P - 0.2S)A}{P + 0.8S} \tag{3.16}$$

Eq. (3.15) defines that the sediment yield increases with decreasing initial abstraction and vice versa.

(ii) Incorporation of Antecedent Moisture (M)

The antecedent moisture (M), which represents the amount of moisture in the soil prior to rainfall, can be incorporated in Eq. (3.15) as:

$$Y = \frac{(P - I_a + M)A}{P - I_a + S + M} \tag{3.17}$$

Taking $I_a = 0.2S$, Eq. (3.17) can be expressed as:

$$Y = \frac{(P - 0.2S + M)A}{P + 0.8S + M} \tag{3.18}$$

Eq. (3.17) defines that the sediment yield decreases with decreasing antecedent moisture amount and vice versa.

(iii) Incorporation of Initial Flush ($I_f$)

Initial flush ($I_f$) is the sediment which appears at the outlet of watershed. For simplicity, $I_f$ can also be related to the potential erosion (A) as:

$$I_f = \lambda_1 A \tag{3.19}$$

where $\lambda_1$ is the initial flush coefficient, similar to the initial abstraction coefficient. Eq. (3.18) can be further modified incorporating $I_f$ as follows:

$$Y = \left[\frac{(1-\lambda_1)(P-0.2S+M)}{P+0.8S+M} + \lambda_1\right]A \tag{3.20}$$

## 3.6 DEVICES USED

In the present study, the following devices were used.

### i) Raingauge

Two types of raingauges (self-recording and ordinary) (Fig. 3.8) were used to measure the rainfall on the farm. Self-recording raingauge was equipped with a data logger. Data logger is an electronic instrument designed to read and store information and the data can be transferred to computer. Event wise rainfall details as well as rainfall intensity can be obtained from self recording raingauge. The ordinary type (non-recording type) raingauge gives amount of rainfall by collecting rain water over a period of time.

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Fig. 3.8: Installation of Raingauges

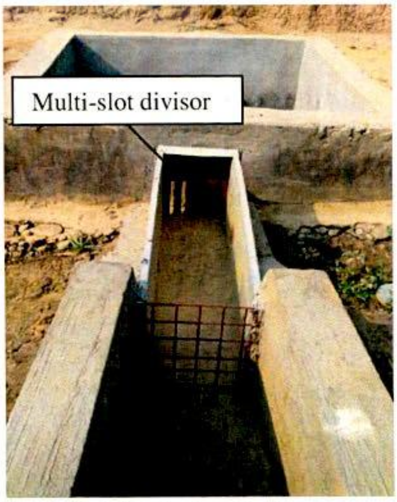

Fig. 3.9: Multi-slot divisor

### ii) Multi-slot divisor

The main function of multi-slot divisor (Fig. 3.9) is to reduce the volume of runoff to be collected in the chamber and hence reduce the size of chamber. It can be locally manufactured using steel plate with varying number of slots. Generally odd numbers of slot are made. The number and size of the slots are fixed according to the maximum intensity of rainfall occurred in the watershed. Initially Coshocton wheel was proposed to measure the runoff and sediment yield. But later this device was replaced by Multi-slot divisor because the Coshocton wheel does not give good result for the watershed having area less than 0.1 ha and runoff discharge less than 0.15 cumec.

### iii) Suspended solids analyzer

Suspended solid analyzer (Fig. 3.10) was used to measure the concentration of sediment in the surface runoff. The working principle of suspended solids analyzer is that a beam of light (infra-red) emitted by a source with constant intensity is scattered and/or absorbed by the suspended-sediment particles. The decrease of intensity of the beam, measured by an appropriate detector or sensor situated at constant distance from the source is proportional to the sediment concentration, provided other relevant characteristics of water and sediment (chemical, mineral composition, etc.) remain unchanged. The sensor utilizes an infra-red emitter to minimize colour effects and compensates for emitter variations due to temperature by measuring source brightness. It can measure 0 to 30,000 mg/lit in 0 to 65 $^{0}$C temperature. Its accuracy is 3% or 20mg/lit whichever is greater. It is mainly developed for wastewater treatment works and environmental field monitoring.

Fig. 3.10: Suspended Solids Analyzer

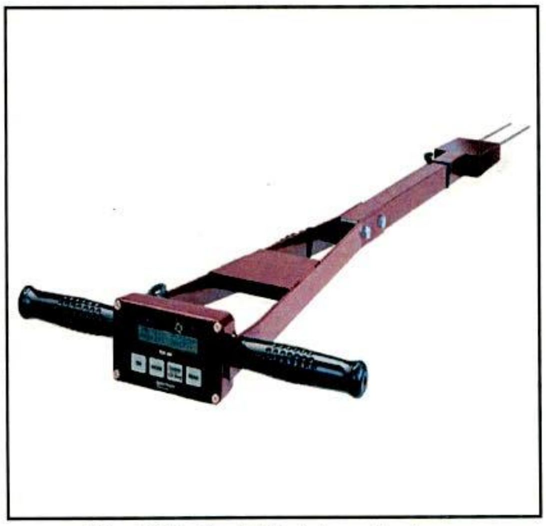

Fig. 3.11: Soil Moisture Tester

### iv) Soil moisture tester (Fieldscout TDR 300)

Soil moisture tester (Fieldscout TDR 300) having probe length 20cm (Fig. 3.11) is used to measure the antecedent soil moisture of the field plot. This instrument directly measures the soil moisture in volumetric water content (VWC) in percentage. The underlying principal of Time Domain Reflectometry (TDR) involves measuring the travel time of an electromagnetic wave along a waveguide. The speed of the wave in soil is dependent on the bulk dielectric permittivity ($\varepsilon$) of the soil matrix. The fact that water ($\varepsilon = 80$) has a much greater dielectric constant than air ($\varepsilon = 1$) or soil solids ($\varepsilon = 3\text{-}7$) 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 from the rods. The high frequency signal information is then converted to volumetric water content.

### v) Drying oven

Drying oven (Fig. 3.12) was used in the laboratory to determine the dry weight of sediment collected in the sediment samples. Samples were kept in the oven on $105^0$C for 24 hours to get the dry weight of sediment.

Fig. 3.12: Keeping sediment sample in Drying Oven

Fig. 3.13: Double Ring Infiltrometer

### vi) Double ring Infiltrometer

Double ring infltrometer (Fig. 3.13), having internal and external diameter as 20cm and 30cm respectively, was used to determine the minimum infiltration capacity of soils, and is used to classify hydrologic group of soil.

# CHAPTER 4

# EXPERIMENTAL SETUP AND DATA COLLECTION

## 4.1 LOCATION OF EXPERIMENTAL FARM

The experimental farm is located in Toda Kalyanpur, District Haridwar, Uttarakhand, India. It tentatively lies at latitude $29^0$ 50' 9" N and longitude $77^0$ 55' 21" E. The average elevation of the experimental farm is 266m above mean sea level (msl). This farm is near to the existing farm of the Department of Water Resources Development and Management, IIT Roorkee, which is about 6.0 km east south from the institute. Initially the farm was being used for agricultural purpose and it was of plain topography. The infiltration test and sieve analysis test carried out on this farm show that the farm has hydrologic soil group C and loamy sand.

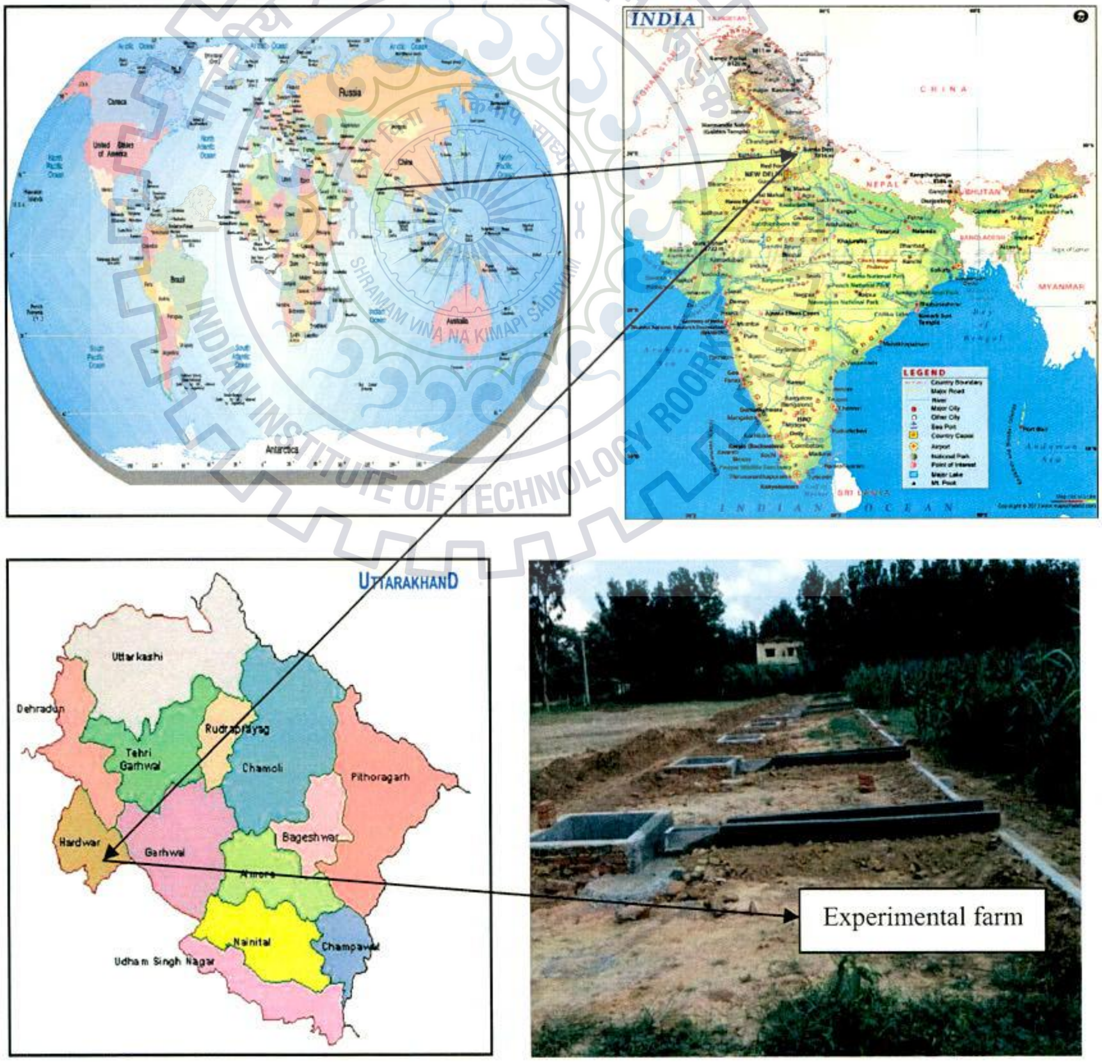

Fig. 4.1: Location of Experimental Farm

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## 4.2 ESTABLISHMENT OF EXPERIMENTAL FARM

### i) Preparation of Field

As the watershed according to our study requirement was not available as such, a plot of plain topography of size 70m x 50m was taken on lease and developed according to the requirement. Before its establishment, the farm was being used for agricultural purpose. The experimental design included three independent variables: soil type, land use, and slope. As a whole, the experimental farm was established for four different crops including maize on three different slopes of 1%, 3%, and 5% (Fig. 4.2). For this study, three plots (each of size 22m x 5m) with these slopes were prepared for maize crop.


(a) (b)

Fig. 4.2: Preparation of field

### ii) Excavation of Pond

As there was no natural drainage available, a pond of size 8m x 4m x 2.5m (length x breadth x depth) (Fig. 4.3) was excavated in one corner of the farm for collecting excess runoff which could be pumped out as and when required.


(a) (b)

Fig. 4.3: Excavation of pond

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### iii) Construction of Collection Chambers

For the measurement of runoff discharge and sediment yield, collection chambers of size 1m x 1m x 1m were constructed at the end of each plot. Each chamber was connected to the respective plot by a conveyance channel (Fig. 4.4). Conveyance channels of 3m length were constructed with mild slope so that the runoff passes in equal quantity through all the slots without creating turbulence flow.


(a) (b)

Fig. 4.4: Construction of collection chambers

### iv) Installation of Multi-slot Divisor

To reduce the volume of runoff to be measured through collection chamber and hence its size, a multi-slot divisor (Fig. 4.5) was installed at the exit of channel and just before the entrance of collection chamber.

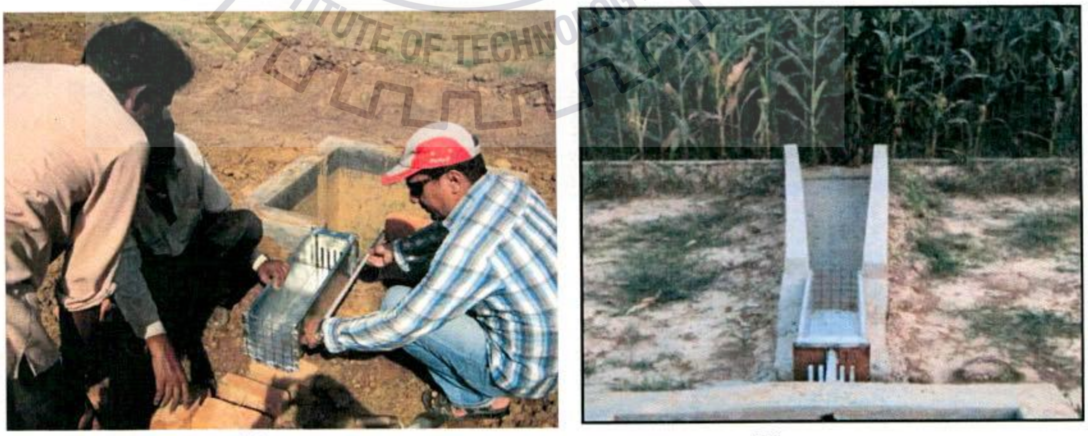
(a) (b)

Fig. 4.5: Installation of Multi-slot divisor.

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### v) Installation of Raingauge

To measure daily rainfall, self-recording type and ordinary type raingauges were installed on the farm (Fig. 4.6). The raingauges were installed in open space considering no obstruction in collecting the rainfall.

(a) (b)

Fig. 4.6: Installation of Raingauges

### vi) Construction of Shelter room and Fencing of farm

A single roomed temporary building (brick & mud mortar joint) of size 10' x 12' was constructed (Fig. 4.7a). This building is used to store instruments and other goods and for shelter. The farm was fenced with barbed wire and RCC pillar (Fig. 4.7b) for security point of view and to obstruct the movement of cattle.

(a) (b)

Fig. 4.7: (a) Construction of shelter room and (b) Fencing of farm

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## 4.3 OBSERVATION AND DATA COLLECTION

Following are the main data collected during the experimental study,

i) Rainfall
ii) Runoff
iii) Sediment yield
iv) Antecedent soil moisture ($\theta_0$)
v) Grain size analysis of soil
vi) Infiltration capacity of soil

In the present study, the runoff (Q) and sediment yield (Y) are the variable dependent on soil type, land use (presently maize), slope, and rainfall. Runoff and sediment yield data were collected for two systems, which are (a) natural rainfall system and (b) artificial (flooding water supply) system.

### i) Rainfall

Rainfall data were collected using two raingauges (self-recording type and ordinary type). Event wise rainfall details as well as rainfall intensity were recorded from self recording raingauge and total amount of rainfall were taken from ordinary type (non-recording type) rainguage for the verification of data as well.

After the rainy season, the experiment was continued with artificial (flooding water supply) event in which, underground water was supplied by pumping system. Discharge of water was supplied through six numbers of outlets covered with jute bags as shown in Fig. (4.8). This idea of supplying water helped to vary discharge and to distribute water uniformly over the plots. To know the amount of water supply, discharge rates of individual outlets were measured. Total volume of water supply was obtained by multiplying discharge rate with time of water supply. The observed natural rainfall and total volume of water supply for artificial system are presented in Tables (4.1) and (4.2).

Fig. 4.8: Application of water through artificial (Flooding system) event

Fig. 4.9: Runoff measurement

### ii) Runoff

The runoff generated from each plot of size 22m x 5m was collected in collection chambers. From multi-slot divisor, having 5 numbers of slots, runoff was collected only through one slot. The remaining runoff through other slots diverted out of the collection chamber. As the collection chamber and conveyance channel are open to sky, the amount of rainfall collected from the open spaces were deducted from the runoff. Then, the collected runoff from one slot (after deduction) was multiplied by 5 times to get actual runoff from the concerned plot (Appendix-A). Volumes of surface runoffs generated by one day natural rainfall event were measured from collection chamber using steel scale as shown in Fig. (4.9).

For artificial event, variations of runoff depth in collection chamber were measured at every minute for a set (Appendix-B). The surface runoff data of 5 sets for each plot with varying discharge were observed. The volume of water supply and measured surface runoff for both cases are given in Tables (4.1) and (4.2).

### iii) Sediment Yield

Concentration of sediment accumulated in the collection chambers was measured by two methods: (i) in-situ measurement by suspended solid analyzer, and (ii) by taking water-sediment sample in 1 liter bottle (Fig. 4.10) for oven drying method in the laboratory. Dry weights of sediment were determined in the laboratory (Fig. 4.11) after oven drying the sample at 105$^0$C for 24 hours (Appendix-C). The observed sediment yields (Y) for natural event are presented in Table (4.1).

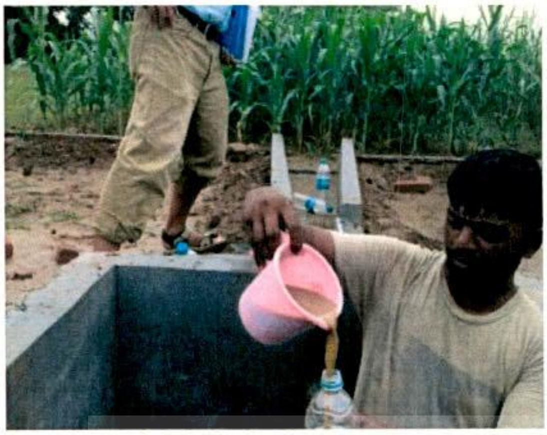

Fig. 4.10: Sample collection for sediment yield

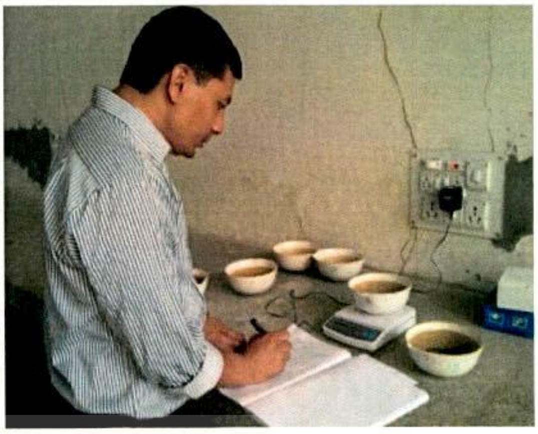

Fig. 4.11: Determination of sediment yield in the Laboratory

### iv) Antecedent soil moisture ($\theta_0$)

The antecedent soil moisture ($\theta_0$) of each plot was measured using soil moisture tester (Fieldscout TDR 300, having probes of length 20cm). The average value of in-situ moisture content measured in three to four points of a plot was adopted as antecedent soil moisture. These observations were taken before every natural rainfall event (i.e. one day rainfall event) and just before supplying water in case of artificial events (Fig. 4.12) and presented in Tables (4.1) and (4.2).

Fig. 4.12: Measurement of antecedent soil moisture of field plot

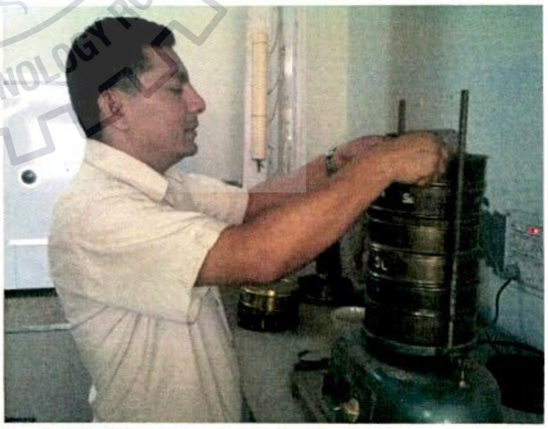

Fig. 4.13: Sieve analysis in the Laboratory

### v) Grain size analysis of soils

Soils are broadly classified as sand, silt and clay on the basis of grain size. To determine the size of soil particles, three soil samples from different plots were collected for grain size analysis (Fig. 4.13). From the result of sieve analysis found that plot of 1% slope had 81.52% of sand (2 - 0.05 mm) and 18.02% of fine particles (< 0.05mm); 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 (Appendix-D).

### vi) Infiltration capacity of soils

Infiltration tests were conducted using double ring infiltrometer (Fig. 4.14) to determine the hydrologic soil group of the plots. The minimum infiltration rates of three plots of 1%, 3%, and 5% slopes were found to be 3.69 mm/hr, 3.69 mm/hr, and 2.67 mm/hr, respectively (Fig. 4.15), which lie in the range (1.27 – 3.81) mm/hr, describing the soil to fall in hydrologic soil group 'C'. Computations are given in Appendix-E.


(a) (b)

Fig. 4.14: Testing infiltration rate of soil

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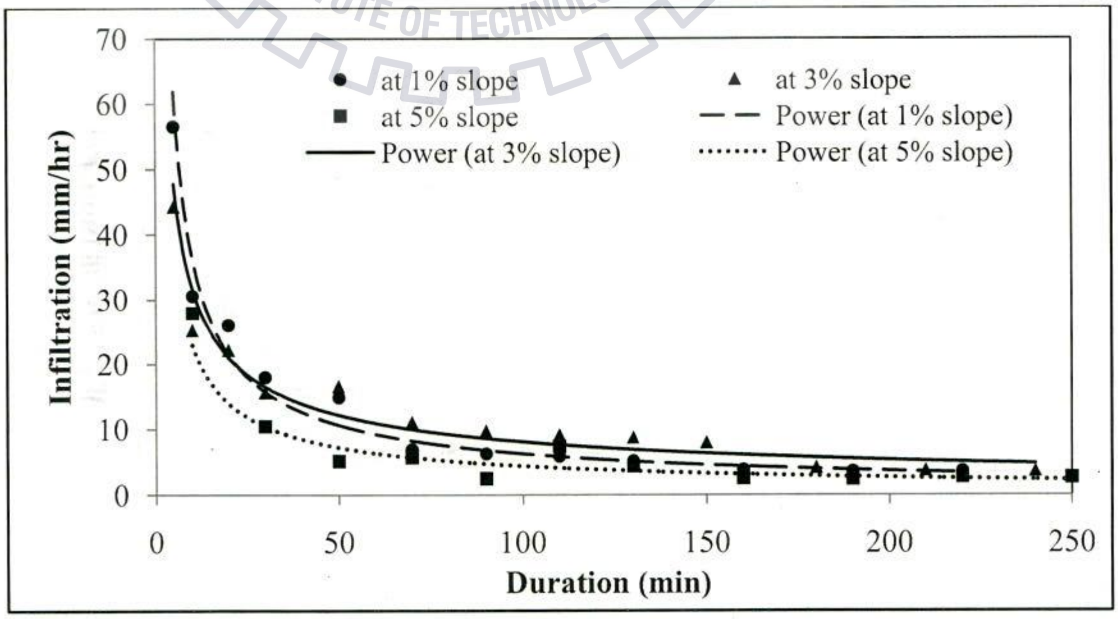

Fig. 4.15: Infiltration capacity curves for three different slopes

Table (4.1): Observed data - Rainfall (P), Runoff (Q), Antecedent soil moisture ($\theta_0$), and Sediment Yield ($Y_0$) (For Natural Rainfall Events)

| Event No. | Obs. date (Year 2012) | Rain-fall (P) (mm) | Observed Surface Runoff (Q) (mm) from the plot of slope | | | Observed Sediment Yield ($Y_0$) (kg) for the plot of slope | | | Antecedent Soil Moisture ($\theta_0$) (%) for the plot of slope | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1% | 3% | 5% | 1% | 3% | 5% | 1% | 3% | 5% |
| 1 | 12-Sep | 8.40 | 0.01 | 0.02 | 0.52 | 0.007 | 0.015 | 0.636 | 32.60 | 29.30 | 30.50 |
| 2 | 13-Sep | 22.20 | 2.85 | 7.94 | 14.67 | 0.630 | 2.715 | 16.466 | 29.80 | 30.00 | 32.60 |
| 3 | 14-Sep | 30.20 | 14.80 | 17.70 | 18.37 | 4.884 | 5.960 | 10.207 | 34.60 | 31.80 | 30.20 |
| 4 | 17-Sep | 42.10 | 14.66 | 20.80 | 24.06 | 3.225 | 5.720 | 11.910 | 31.10 | 31.10 | 28.10 |
| 5 | 18-Sep | 29.10 | 7.71 | 17.14 | 19.61 | 1.696 | 4.714 | 10.786 | 34.90 | 32.10 | 31.10 |

Table (4.2): Observed data – Water supply amount (P), Runoff (Q), and Antecedent soil moisture ($\theta_0$) (For Artificial Events)

| Event No. | Observation date | Discharge rate (Lit/sec) | Water supply amount (P) (mm) | Surface Runoff ($Q_0$) (mm) | Antecedent soil moisture ($\theta_0$) (%) |
|---|---|---|---|---|---|
| For plot @ 1% slope | | | | | |
| 1.1 | 27-Nov-012 | 2.84 | 54.28 | 35.14 | 26.30 |
| 1.2 | 28-Nov-012 | 3.28 | 62.60 | 34.45 | 23.40 |
| 1.3 | 29-Nov-012 | 3.73 | 50.93 | 37.55 | 27.40 |
| 1.4 | 30-Nov-012 | 2.24 | 48.93 | 28.27 | 28.10 |
| 1.5 | 07-Dec-012 | 4.06 | 58.64 | 42.82 | 25.20 |
| For plot @ 3% slope | | | | | |
| 3.1 | 26-Nov-012 | 3.77 | 46.85 | 36.09 | 24.50 |
| 3.2 | 27-Nov-012 | 2.77 | 34.81 | 23.36 | 27.40 |
| 3.3 | 29-Nov-012 | 2.24 | 42.20 | 25.18 | 21.00 |
| 3.4 | 07-Dec-012 | 4.06 | 49.79 | 36.95 | 23.20 |
| 3.5 | 08-Dec-012 | 3.28 | 48.29 | 34.91 | 25.40 |
| For plot @ 5% slope | | | | | |
| 5.1 | 26-Nov-012 | 4.06 | 42.05 | 30.73 | 18.10 |
| 5.2 | 28-Nov-012 | 4.06 | 37.62 | 30.68 | 21.08 |
| 5.3 | 30-Nov-012 | 2.24 | 30.58 | 23.82 | 23.30 |
| 5.4 | 07-Dec-012 | 3.73 | 36.67 | 31.95 | 22.00 |
| 5.5 | 08-Dec-012 | 3.28 | 32.20 | 29.45 | 25.30 |

# CHAPTER 5

# RESULTS AND DISCUSSION

## 5.1 DATA ANALYSIS

As mentioned earlier, the SCS-CN methodology is the most popular and simplest technique for determination of storm runoff from small agricultural watersheds. For the analysis of runoff curve number and sediment yield, the SCS-CN method and SCS-CN based sediment yield model were used. Here it is noted that it took about two months for establishing the experimental farm, therefore, in spite of best effort, only a few natural rainfall-runoff-sediment yield data only could be captured as the monsoon season had already passed. Notably, the maize is a kharif (monsoon) crop.

### 5.1.1 Data analysis for runoff CN

**i) Determination of CN value from NEH-4 table:**

Watershed characteristics were determined as follows:

*Hydrologic soil group*: It was determined according to the minimum infiltration capacity of soil. Conducting double ring infiltrometer test, the minimum infiltration rates of three plots were found in the range (1.27 – 3.81) mm/hr, describing the soil to fall in hydrologic soil group 'C'.

*Land use and treatment:* Maize crop with straight row.

*Hydrologic condition:* It was assumed that the plot was lightly grazed and plant cover on more than 75% of the area which describes as 'Good' hydrologic condition.

Based on the above watershed characteristics, the curve number for AMC II was taken from the NEH-4 table as 85. Accordingly, corresponding CNs for AMC I and AMC III are 70 and 94, respectively.

**ii) Determination of runoff CN value from rainfall-runoff data:**

For a given rainfall (P) and runoff (Q) pair, the potential maximum retention (S) and corresponding CN value were determined using following equations:

$$S = 5\left\{P + 2Q - \sqrt{Q(4Q + 5P)}\right\} \quad \text{and} \quad CN = \frac{25400}{S+254}$$

The computed S and CN values are presented in Tables (5.1) and (5.2).

Table 5.1: Computation of Potential Maximum Retention (S) and Curve number (CN) (for natural events)

| Event No. | Rainfall (P) mm | Observed Runoff (Q) (mm) from the plot of slope | | | S=5{P+2Q-√(Q(4Q+5P) )} for the plot of slope | | | CN= 25400/(S+254) for the plot of slope | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1% | 3% | 5% | 1% | 3% | 5% | 1% | 3% | 5% |
| 1 | 8.4 | 0.01 | 0.02 | 0.52 | 38.86 | 37.61 | 23.26 | 86.73 | 87.10 | 91.61 |
| 2 | 22.2 | 2.85 | 7.94 | 14.67 | 46.11 | 22.06 | 8.24 | 84.63 | 92.01 | 96.86 |
| 3 | 30.2 | 14.80 | 17.70 | 18.37 | 20.12 | 14.72 | 13.62 | 92.66 | 94.52 | 94.91 |
| 4 | 42.1 | 14.66 | 20.80 | 24.06 | 43.03 | 27.70 | 21.56 | 85.51 | 90.17 | 92.18 |
| 5 | 29.1 | 7.71 | 17.14 | 19.61 | 38.24 | 14.04 | 10.26 | 86.92 | 94.76 | 96.12 |

Table 5.2: Computation of Potential Maximum Retention (S) and Curve Number (CN) (for artificial events)

| Event No. | Observation date | Water supply amount (P)(mm) | Observed Runoff, $Q_0$ (mm) | S = 5[P+2Q-{Q(4Q+5P)}^0.5] | CN= 25400/(S+254) |
|---|---|---|---|---|---|
| For 1% slope of plot | | | | | |
| 1.1 | 27-Nov-012 | 54.28 | 35.14 | 21.22 | 92.29 |
| 1.2 | 28-Nov-012 | 62.60 | 34.45 | 34.40 | 88.07 |
| 1.3 | 29-Nov-012 | 50.93 | 37.55 | 13.67 | 94.89 |
| 1.4 | 30-Nov-012 | 48.93 | 28.27 | 24.52 | 91.20 |
| 1.5 | 07-Dec-012 | 58.64 | 42.82 | 16.27 | 93.98 |
| For 3% slope of plot | | | | | |
| 3.1 | 26-Nov-012 | 46.85 | 36.09 | 10.69 | 95.96 |
| 3.2 | 27-Nov-012 | 34.81 | 23.36 | 12.40 | 95.34 |
| 3.3 | 29-Nov-012 | 42.20 | 25.18 | 19.82 | 92.76 |
| 3.4 | 07-Dec-012 | 49.79 | 36.95 | 13.06 | 95.11 |
| 3.5 | 08-Dec-012 | 48.29 | 34.91 | 13.84 | 94.83 |
| For 5% slope of plot | | | | | |
| 5.1 | 26-Nov-012 | 42.05 | 30.73 | 11.63 | 95.62 |
| 5.2 | 28-Nov-012 | 37.62 | 30.68 | 6.64 | 97.45 |
| 5.3 | 30-Nov-012 | 30.58 | 23.82 | 6.67 | 97.44 |
| 5.4 | 07-Dec-012 | 36.67 | 31.95 | 4.31 | 98.33 |
| 5.5 | 08-Dec-012 | 32.20 | 29.45 | 2.43 | 99.05 |

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CN values for three AMC levels (AMC I, AMC II, and AMC III) were statistically determined to correspond, respectively, to 90%, 50%, and 10% cumulative probability of exceedance of runoff depth for a given rainfall according to Hjelmfelt et al., 1982 (Tables 5.3 and 5.4) . Though these percentage values were not achieved due to insufficient data, the nearest percentage values were taken for further analysis.

Table (5.3): Statistical derivation of CNs with different AMCs (for Natural event)

| Rank (m) | CN-values (in descending order) for the plot of slope | | | % Rank =(m/(n+1))*100 | AMC |
|---|---|---|---|---|---|
| | 1% | 3% | 5% | | |
| 1 | 92.66 | 94.76 | 96.86 | 16.67 | III |
| 2 | 86.92 | 94.52 | 96.12 | 33.33 | |
| 3 | 86.73 | 92.01 | 94.91 | 50.00 | II |
| 4 | 85.51 | 90.17 | 92.18 | 66.67 | |
| 5 | 84.63 | 87.10 | 91.61 | 83.33 | I |

Table (5.4) : Statistical derivation of CNs with different AMCs (for Artificial event)

| Rank (m) | CN–values (in descending order) for the plot of slope | | | % Rank =(m/(n+1))*100 | AMC |
|---|---|---|---|---|---|
| | 1% | 3% | 5% | | |
| 1 | 94.89 | 95.96 | 99.05 | 16.67 | III |
| 2 | 93.98 | 95.34 | 98.33 | 33.33 | |
| 3 | 92.29 | 95.11 | 97.45 | 50.00 | II |
| 4 | 91.20 | 94.83 | 97.44 | 66.67 | |
| 5 | 88.07 | 92.76 | 95.62 | 83.33 | I |

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### iii) Determination of Frequency Matching CN values

In this method, the observed rainfall and runoff were arranged, independently, in descending order. CN values were calculated from each ordered pair and are presented in Tables (5.5) and (5.6) for both natural rainfall and artificial events.

Table 5.5:Frequency Matching Curve Numbers (for Natural rainfall Event)

| Rainfall P(mm) in descending order | Runoff Q (mm) in descending order (from the plot of slope) | | | S = 5 [P + 2Q - {Q (4Q + 5P)}^0.5] for the plot of slope | | | CN = 25400/(S + 254) for the plot of slope | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1% | 3% | 5% | 1% | 3% | 5% | 1% | 3% | 5% |
| 42.10 | 14.8 | 20.8 | 24.06 | 42.61 | 27.70 | 21.56 | 85.64 | 90.17 | 92.18 |
| 30.20 | 14.66 | 17.7 | 19.61 | 20.41 | 14.72 | 11.72 | 92.56 | 94.52 | 95.59 |
| 29.10 | 7.71 | 17.14 | 18.37 | 38.24 | 14.04 | 12.08 | 86.92 | 94.76 | 95.46 |
| 22.20 | 2.85 | 7.94 | 14.67 | 46.11 | 22.06 | 8.24 | 84.63 | 92.01 | 96.86 |
| 8.40 | 0.01 | 0.02 | 0.52 | 38.86 | 37.61 | 23.26 | 86.73 | 87.10 | 91.61 |

Table 5.6: Frequency Matching Curve Numbers (for Artificial Event)

| Rainfall P (mm) in descending order | Runoff Q(mm) in descending order | S = 5 [P + 2Q - {Q(4Q + 5P)}^0.5] | CN = 25400/(S + 254) |
|---|---|---|---|
| For 1% slope of plot | | | |
| 62.60 | 42.82 | 21.19 | 92.30 |
| 58.64 | 37.55 | 23.54 | 91.52 |
| 54.28 | 35.14 | 21.22 | 92.29 |
| 50.93 | 34.45 | 17.76 | 93.46 |
| 48.93 | 28.27 | 24.52 | 91.20 |
| For 3% slope of plot | | | |
| 49.79 | 36.95 | 13.06 | 95.11 |
| 48.29 | 36.09 | 12.36 | 95.36 |
| 46.85 | 34.91 | 12.12 | 95.45 |
| 42.20 | 25.18 | 19.82 | 92.76 |
| 34.81 | 23.36 | 12.40 | 95.34 |
| For 5% slope of plot | | | |
| 42.05 | 31.95 | 10.11 | 96.17 |
| 37.62 | 30.73 | 6.59 | 97.47 |
| 36.67 | 30.68 | 5.63 | 97.83 |
| 32.20 | 29.45 | 2.43 | 99.05 |
| 30.58 | 23.82 | 6.67 | 97.44 |

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### 5.1.2 Data Analysis for sediment yield

- Observed 5 sets of in-situ data of natural rainfall events from the plots of varying slopes having maize crop were used for the analysis of sediment yield. The sediment yield obtained from oven drying was converted in kilogram with respect to the observed runoff data as presented in Table (5.7).

Table 5.7: Calculation of sediment yield ($Y_0$) in Kg. from the laboratory data (for Natural event)

| Event No. | Rain-fall (P) mm | Observed Runoff ($Q_0$) from the plot of (22m x 5m) | | Observed Sediment Yield ($Y_0$) from the plot of (22m x 5m) | |
|---|---|---|---|---|---|
| | | (mm) | (Liters) | mg/lit | Kg |
| For 1% slope of plot | | | | | |
| 1 | 8.40 | 0.01 | 1.1 | 6061 | 0.007 |
| 2 | 22.20 | 2.85 | 313.5 | 2010 | 0.630 |
| 3 | 30.20 | 14.80 | 1628.0 | 3000 | 4.884 |
| 4 | 42.10 | 14.66 | 1612.6 | 2000 | 3.225 |
| 5 | 29.10 | 7.71 | 848.1 | 2000 | 1.696 |
| For 3% slope of plot | | | | | |
| 1 | 8.40 | 0.02 | 2.2 | 7000 | 0.015 |
| 2 | 22.20 | 7.94 | 873.4 | 3109 | 2.715 |
| 3 | 30.20 | 17.70 | 1947.0 | 3061 | 5.960 |
| 4 | 42.10 | 20.80 | 2288.0 | 2500 | 5.720 |
| 5 | 29.10 | 17.14 | 1885.4 | 2500 | 4.714 |
| For 5% slope of plot | | | | | |
| 1 | 8.40 | 0.52 | 57.2 | 11111 | 0.636 |
| 2 | 22.20 | 14.67 | 1613.7 | 10204 | 16.466 |
| 3 | 30.20 | 18.37 | 2020.7 | 5051 | 10.207 |
| 4 | 42.10 | 24.06 | 2646.6 | 4500 | 11.910 |
| 5 | 29.10 | 19.61 | 2157.1 | 5000 | 10.786 |

- Potential maximum retention (S) and Potential soil erosion (A) were calculated from the observed data of rainfall (P), runoff (Q) and sediment yield ($Y_0$), using following formulae,

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

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

The computed value of S and A are presented in Table (5.8).

Table 5.8: Computations of potential maximum retention (S) and potential soil erosion (A) (for natural rainfall event)

| Event No. | Rainfall (P) (mm) | Observed Runoff (Q) (mm) | Observed Sediment Yield ($Y_0$), (kg) | Soil moisture content ($\theta_0$) (%) | $S = 5[P+2Q-\sqrt{Q(4Q+5P)}]$ (mm) | $A = Y_0(P+0.8S)/(P-0.2S)$ (kg) |
|---|---|---|---|---|---|---|
| For plot of 1% slope | | | | | | |
| 1 | 8.4 | 0.01 | 0.007 | 32.6 | 38.86 | 0.419 |
| 2 | 22.2 | 2.85 | 0.630 | 29.8 | 46.11 | 2.869 |
| 3 | 30.2 | 14.80 | 4.884 | 34.6 | 20.12 | 8.638 |
| 4 | 42.1 | 14.66 | 3.225 | 31.1 | 43.03 | 7.369 |
| 5 | 29.1 | 7.71 | 1.696 | 34.9 | 38.24 | 4.720 |
| For plot of 3% slope | | | | | | |
| 1 | 8.4 | 0.02 | 0.015 | 29.3 | 37.61 | 0.676 |
| 2 | 22.2 | 7.94 | 2.715 | 30.0 | 22.06 | 6.083 |
| 3 | 30.2 | 17.70 | 5.960 | 31.8 | 14.72 | 9.178 |
| 4 | 42.1 | 20.80 | 5.720 | 31.1 | 27.70 | 10.054 |
| 5 | 29.1 | 17.14 | 4.714 | 32.1 | 14.04 | 7.230 |
| For plot of 5% slope | | | | | | |
| 1 | 8.4 | 0.52 | 0.636 | 30.5 | 23.26 | 4.580 |
| 2 | 22.2 | 14.67 | 16.466 | 32.6 | 8.24 | 23.068 |
| 3 | 30.2 | 18.37 | 10.207 | 30.2 | 13.62 | 15.266 |
| 4 | 42.1 | 24.06 | 11.910 | 28.1 | 21.56 | 18.705 |
| 5 | 29.1 | 19.61 | 10.786 | 31.1 | 10.26 | 14.876 |

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## 5.2 DISCUSSION OF RESULTS OF CN

### 5.2.1 Comparison of computed CN with NEH-4 Table

The CN–values directly taken from the NEH-4 table based on the watershed characteristics (hydrologic soil group 'C', straight row crop, and good hydrologic condition) and the CN–values for the respective plots computed from the observed rainfall-runoff data sets of natural and artificial events for three plots having different slope are tabulated in the Table (5.9).

Table 5.9: Comparison of CN-values

| AMC Level | NEH-4 table | Natural rainfall events | | | Artificial (Flooding water supply) events | | |
|---|---|---|---|---|---|---|---|
| | | 1% slope | 3% slope | 5% slope | 1% slope | 3% slope | 5% slope |
| I | 70 | 84.63 | 87.10 | 91.61 | 88.07 | 92.76 | 95.62 |
| II | 85 | 86.73 | 92.01 | 94.91 | 92.29 | 95.11 | 97.45 |
| III | 94 | 92.66 | 94.76 | 96.86 | 94.89 | 95.96 | 99.05 |

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From Table (5.9), it can seen that the CN values obtained from natural rainfall event are quite close to the NEH-4 table, which supports the applicability of CN values (documented in NEH-4 table) to Indian watersheds, which is one of the objectives of this study. However, the CN values obtained from the artificial event data sets are in higher side. This is due to less initial abstraction loss, because of no vegetative interception loss in flooding water supply event as in the natural rainfall event and flow velocity was also more due to application of greater intensity of discharge which provides lesser opportunity time for water to stay over the land surface leading to less infiltration, and consequently, more direct runoff and, in turn, CN.

### 5.2.2 Effect of watershed slope on runoff

The rainfall and runoff data, observed from different slope of plots for both natural and artificial events, were plotted as shown in Figs. (5.1) and (5.2). From these figures, the surface runoff is seen to be higher in steeper slope of the plot, and vice versa, for the given land use, soil type, and rainfall. The increase in surface runoff due to steeper slopes can be explained by (a) reduction in initial abstraction (Huang, 1995;

Fox et al., 1997; Chaplot and Bissonnais, 2003), (b) decrease in infiltration (Philip, 1991), and (c) reduction in recession time of overland flow (Evett and Dutt, 1985). In case of artificial (flooding water supply) event, as amount of water supply is not same for each plot for an event, it was not appropriate for the comparison of runoff among the different slope of plots as in Fig. (5.1). However, linearly increasing trends of runoff according to watershed slope can be seen in Fig.(5.2) for artificial events.

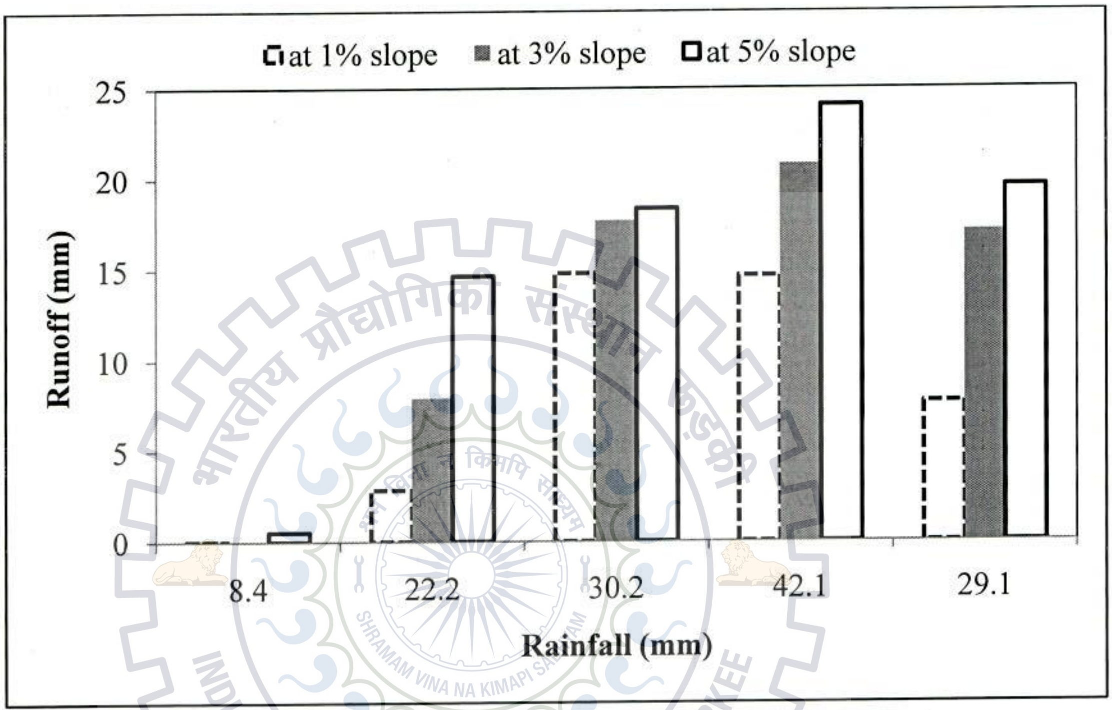

Fig. 5.1: Effect of watershed slope on runoff (for natural events)

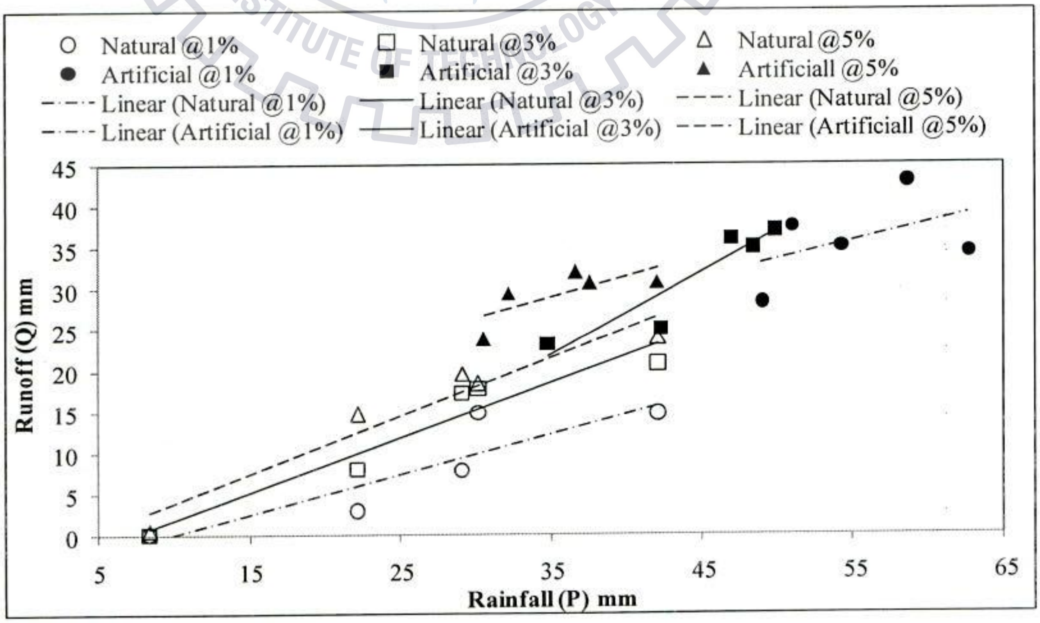

Fig. 5.2: Effect of watershed slope on runoff (for both natural and artificial events)

### 5.2.3 Effect of watershed slope on CN

The CN-values, computed by using Eq. (3.6) and (3.7) for natural and artificial events (Table 5.1 and 5.2), when plotted (Fig. 5.3 and 5.4) indicate higher CN for steeper plot, and vice versa, similar to runoff as described above. In case of artificial (flooding water supply) event as described in the runoff case, as amount of water supply is not same for each plot for an event, it was not appropriate for the comparison of CN among the different slopes of plots as in Fig. (5.3). However, data points of CN for steeper plots can be seen in upper side of the graph (Fig. 5.4).

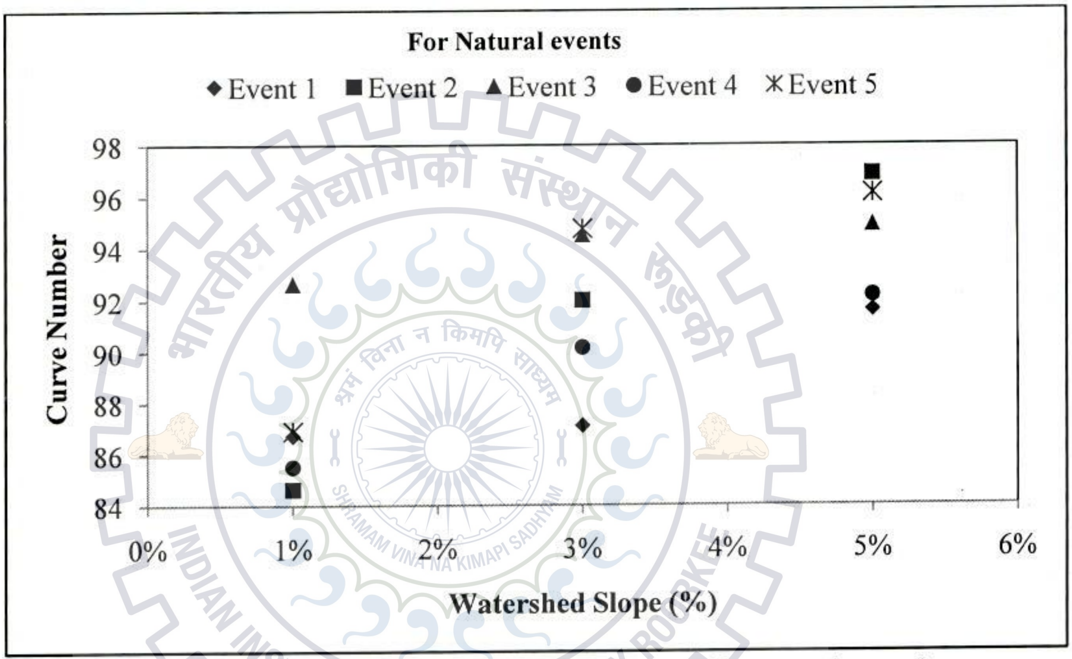

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Fig. 5.3: Variation of CN with watershed slope (for natural events)

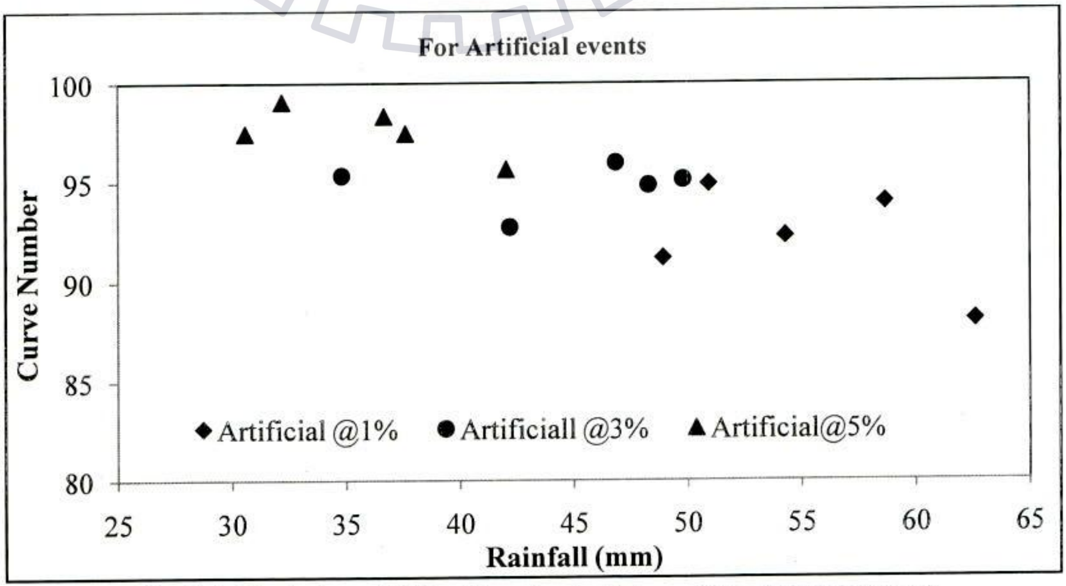

Fig. 5.4: Variation of CN with watershed slope (for artificial events)

### 5.2.4 Relation between CN and AMC

CN values for three AMC levels (AMC I to AMC III) were statistically related, respectively, to 90%, 50%, and 10% cumulative probability of exceedance of runoff depth for a rainfall (Table 5.9). CN vs watershed slope for three AMC levels, for both natural and artificial events, were plotted in a graph as shown in Fig. (5.5). The figure shows that for a given AMC, CN increases as the watershed slope increases, and vice versa. Similarly, as AMC increases from I (dry condition) to III (wet condition), CN also increases for a watershed, and vice versa.

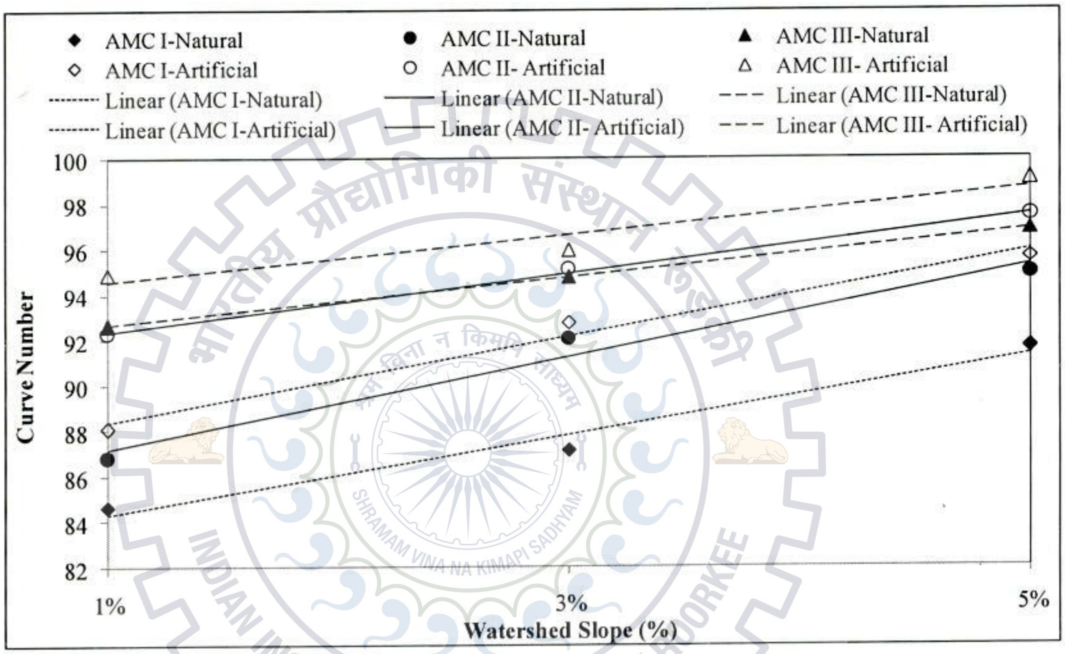

Fig. 5.5: Effect of watershed slope on CN for a given AMC (for natural and artificial events)

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### 5.2.5 Relation between S (or CN) and antecedent soil moisture ($\theta_0$)

The potential maximum retention (S) (mm), calculated from Eq. (3.7), were plotted against the corresponding observed antecedent soil moisture ($\theta_0$) (%) for both natural and artificial events, as shown in Fig. (5.6), for all three plots. As expected, S decreases with increasing $\theta_0$, and vice versa. In other words, CN increases with $\theta_0$, and vice versa.

Also, from the figure, it can be seen that the data points of plot having flatter slope are on the upper side than the plot having steeper slope. This means the flatter slope watersheds have more S-values than watershed having steeper slope, provided other parameters remain the same, which is consistent with the expectation and is valid for both natural and artificial events.

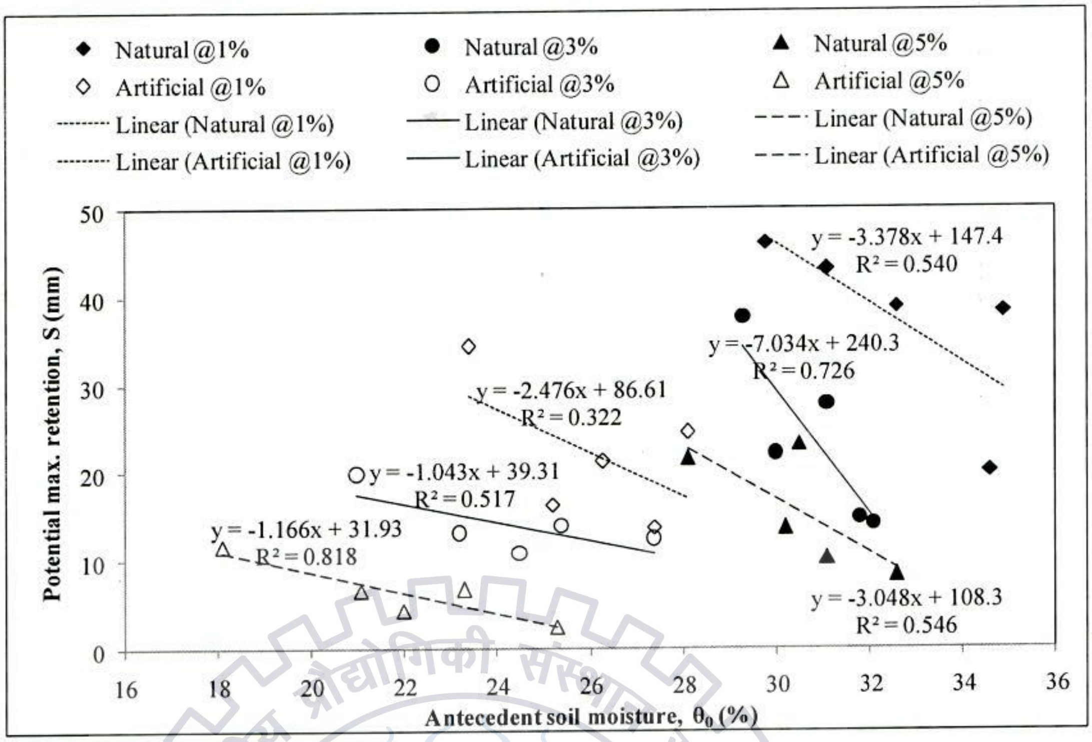

Fig. 5.6: Relationship between S and $\theta_0$ (for natural and artificial events)

### 5.2.6 Validation of CN-$\theta_0$ relationship

Runoff is computed using the above derived S- $\theta_0$ relationships (Fig. 5.6), which are presented in Tables (5.10) and (5.11) for natural and artificial events, respectively. The computed runoff was plotted against the respective observed runoff (Fig. 5.7), which reveals that the data points lie over and above, but near the line of perfect fit (LPF). The closeness of data points to LPF indicate satisfactory performance of the proposed S (or CN) – $\theta_0$ relationship for both natural and artificial events.

Table 5.10: Computations of direct surface runoff ($Q_c$) using CN – $\theta_0$ relations (for natural events)

| Event No. | Rainfall (P) (mm) | Observed Runoff, $Q_0$ (mm) | Observed soil moisture, $\theta_0$ (%) | S(mm) (from Eq. 3.7) | S' (from Fig.5.6) | $Q_c$ (computed runoff using S') $Qc = (P-0.2S')^2/(P+0.8S')$ |
|---|---|---|---|---|---|---|
| For plot @ 1% slope; $S' = -3.378 * \theta_0 + 147.4$ | | | | | | |
| 1 | 8.40 | 0.01 | 32.6 | 38.86 | 37.28 | 0.023 |
| 2 | 22.20 | 2.85 | 29.8 | 46.11 | 46.74 | 2.772 |
| 3 | 30.20 | 14.80 | 34.6 | 20.12 | 30.52 | 10.631 |
| 4 | 42.10 | 14.66 | 31.1 | 43.03 | 42.34 | 14.887 |
| 5 | 29.10 | 7.71 | 34.9 | 38.24 | 29.51 | 10.211 |

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| Table 5.10: (Continued….) | | | | | | |
|---|---|---|---|---|---|---|
| Event No. | Rainfall (P) (mm) | Observed Runoff, $Q_0$ (mm) | Observed soil moisture, $\theta_0$ (%) | S(mm) (from Eq. 3.7) | S' (from Fig.5.6) | $Q_c$ (computed runoff using S') $Q_c = (P-0.2S')^2/(P+0.8S')$ |
| For plot @ 3% slope; $S' = -7.034 * \theta_0 + 240.3$ | | | | | | |
| 1 | 8.40 | 0.02 | 29.3 | 37.61 | 34.20 | 0.068 |
| 2 | 22.20 | 7.94 | 30.0 | 22.06 | 29.28 | 5.855 |
| 3 | 30.20 | 17.70 | 31.8 | 14.72 | 16.62 | 16.607 |
| 4 | 42.10 | 20.80 | 31.1 | 27.70 | 21.54 | 24.070 |
| 5 | 29.10 | 17.14 | 32.1 | 14.04 | 14.51 | 16.861 |
| For plot @ 5% slope; $S' = -3.048 * \theta_0 + 108.3$ | | | | | | |
| 1 | 8.40 | 0.52 | 30.5 | 23.26 | 15.34 | 1.376 |
| 2 | 22.20 | 14.67 | 32.6 | 8.24 | 8.94 | 14.198 |
| 3 | 30.20 | 18.37 | 30.2 | 13.62 | 16.25 | 16.812 |
| 4 | 42.10 | 24.06 | 28.1 | 21.56 | 22.65 | 23.438 |
| 5 | 29.10 | 19.61 | 31.1 | 10.26 | 13.51 | 17.463 |

Table 5.11: Computations of direct surface runoff ($Q_c$) using CN – $\theta_0$ relations (for artificial events)

| Event No. | Water supply amount (P)(mm) | Observed Runoff, $Q_0$ (mm) | Observed soil moisture, $\theta_0$ (%) | S(mm) (from Eq. 3.7) | S' (from Fig.5.6) | $Q_c$ (computed runoff using S') $Q_c = (P-0.2S')^2/(P+0.8S')$ |
|---|---|---|---|---|---|---|
| For plot @ 1% slope; $S' = -2.476 * \theta_0 + 86.61$ | | | | | | |
| 1.1 | 54.28 | 35.14 | 26.30 | 21.22 | 21.49 | 34.95 |
| 1.2 | 62.60 | 34.45 | 23.40 | 34.40 | 28.67 | 37.81 |
| 1.3 | 50.93 | 37.55 | 27.40 | 13.67 | 18.77 | 33.75 |
| 1.4 | 48.93 | 28.27 | 28.10 | 24.52 | 17.03 | 33.13 |
| 1.5 | 58.64 | 42.82 | 25.20 | 16.27 | 24.21 | 37.10 |
| For plot @ 3% slope; $S' = -1.043 * \theta_0 + 39.31$ | | | | | | |
| 3.1 | 46.85 | 36.09 | 24.50 | 10.69 | 13.76 | 33.62 |
| 3.2 | 34.81 | 23.36 | 27.40 | 12.40 | 10.73 | 24.59 |
| 3.3 | 42.20 | 25.18 | 21.00 | 19.82 | 17.41 | 26.71 |
| 3.4 | 49.79 | 36.95 | 23.20 | 13.06 | 15.11 | 35.35 |
| 3.5 | 48.29 | 34.91 | 25.40 | 13.84 | 12.82 | 35.72 |
| For plot @ 5% slope; $S' = -1.166 * \theta_0 + 31.93$ | | | | | | |
| 5.1 | 42.05 | 30.73 | 18.10 | 11.63 | 10.83 | 31.37 |
| 5.2 | 37.62 | 30.68 | 21.08 | 6.64 | 7.35 | 30.04 |
| 5.3 | 30.58 | 23.82 | 23.30 | 6.67 | 4.76 | 25.52 |
| 5.4 | 36.67 | 31.95 | 22.00 | 4.31 | 6.28 | 30.08 |
| 5.5 | 32.20 | 29.45 | 25.30 | 2.43 | 2.43 | 29.45 |

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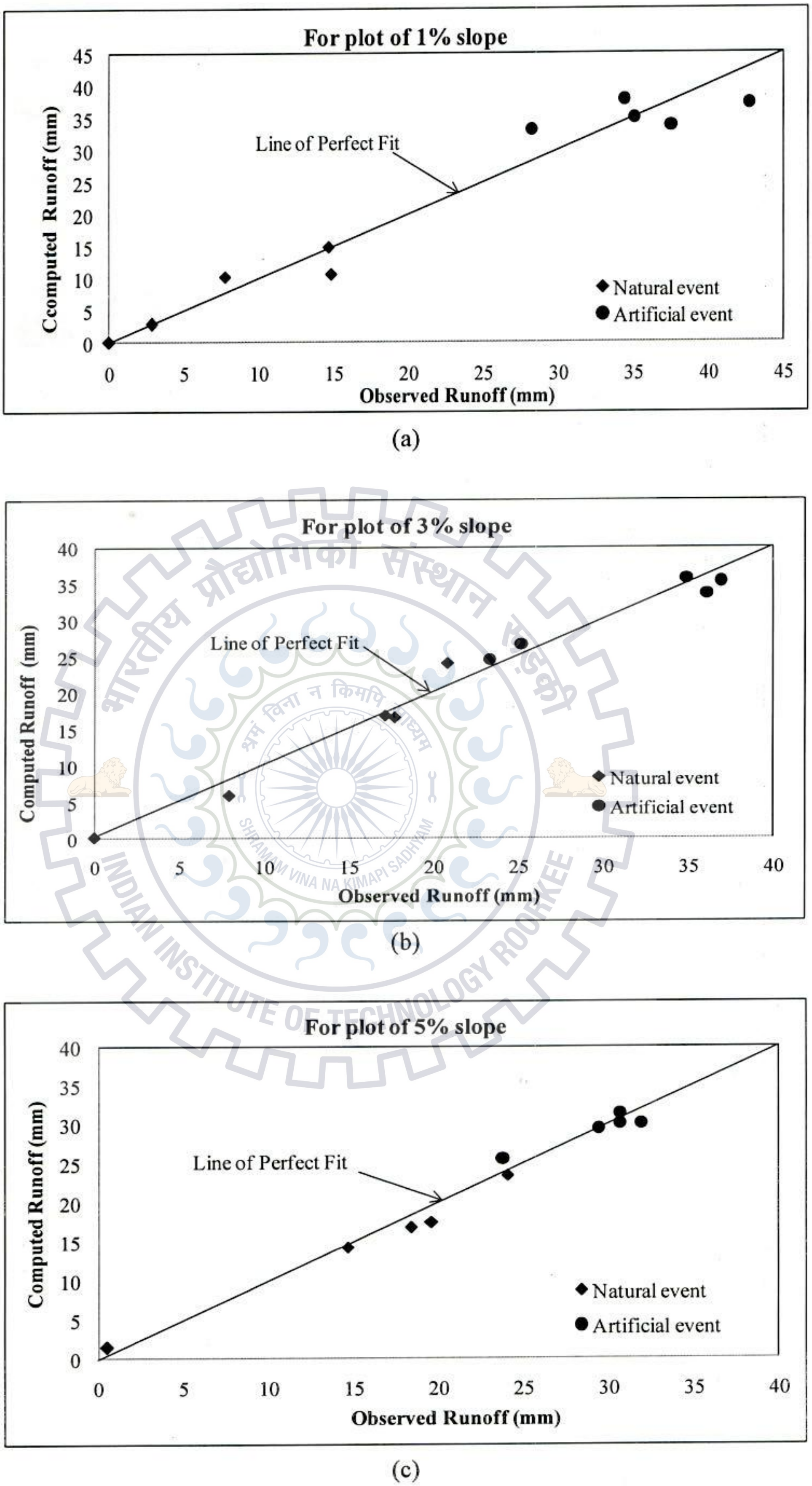

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Fig. 5.7: Comparison between observed and computed surface runoff.

### 5.2.7 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 the present study, behaviour of CN variation with respect to storm rainfall depth (Fig. 5.8), though the observed data are few, leads to identification of all three plots generally to be classified as violent as CNs are seen to be in increasing phase with rainfall depth.

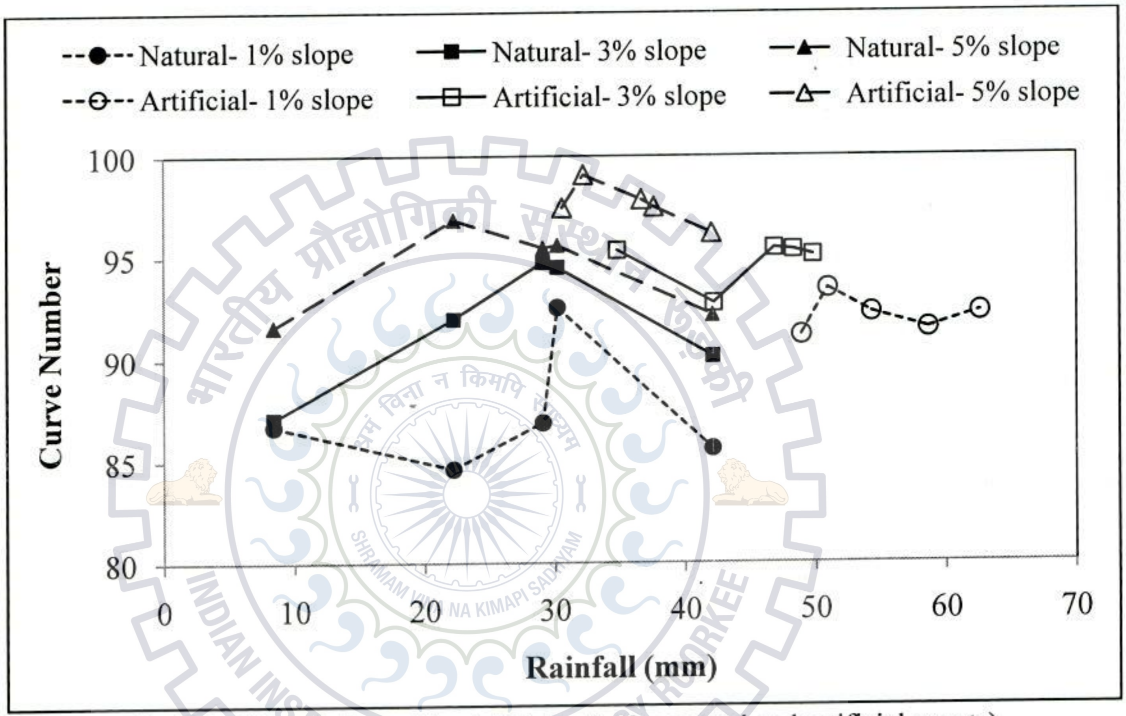

Fig. 5.8: CN variation with rainfall depth (for natural and artificial events)

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## 5.3 DISCUSSION OF RESULTS FOR SEDIMENT YIELD

### 5.3.1 Effect of watershed slope on sediment yield

The observed natural rainfall and corresponding sediment yield ($Y_0$) data were plotted for three different slopes of plots having same land use (here maize crop) and soil type as shown in Fig. (5.9). From the figure, the sediment yield is seen to be higher in steeper slope of the plot, and vice versa. When raindrops fall on the land surface, soil particles are detached due to impact of rain drops. Once a soil particle has been detached, sufficient energy must available to transport it. The movement of detached soil particles depends on the sediment load in the flow and the velocity of flow. Thus, the soil loss is influenced by watershed slope if other parameters (land use, soil type, and rainfall etc.) remain same.

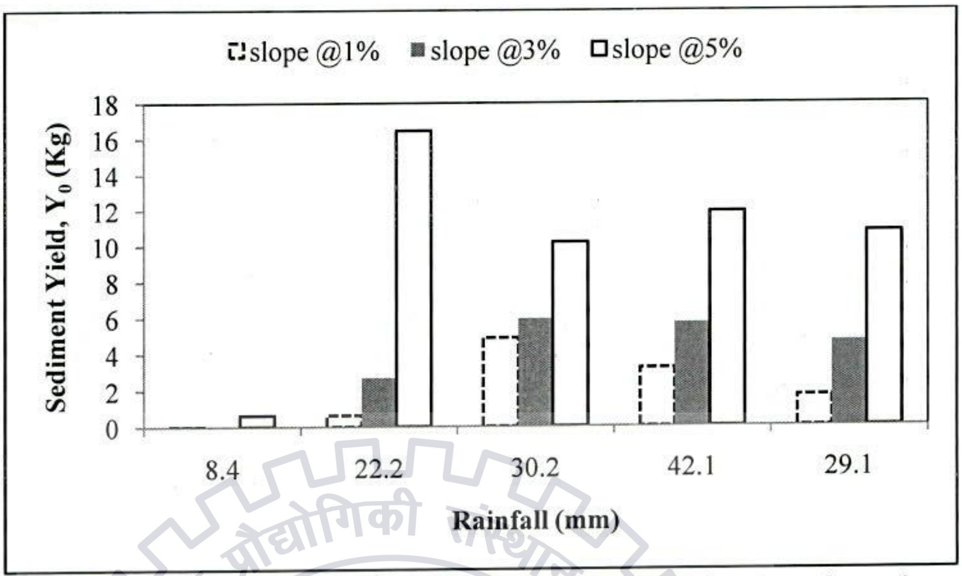

Fig. 5.9: Effect of watershed slope on Sediment Yield (for Natural event)

### 5.3.2 Effect of antecedent soil moisture ($\theta_0$) on sediment yield ($Y_0$)

The observed sediment yield ($Y_0$) from different slopes of plots were plotted against the antecedent soil moisture ($\theta_0$) (Fig. 5.10), which shows good correlation between the data of 3% slope of plot, however the data of 1% and 5% slope of plot do not have good correlation, which may be due to limited data. From the trend line (Fig. 5.10), we can conclude that sediment yield increases as antecedent soil moisture increases, and vice versa.

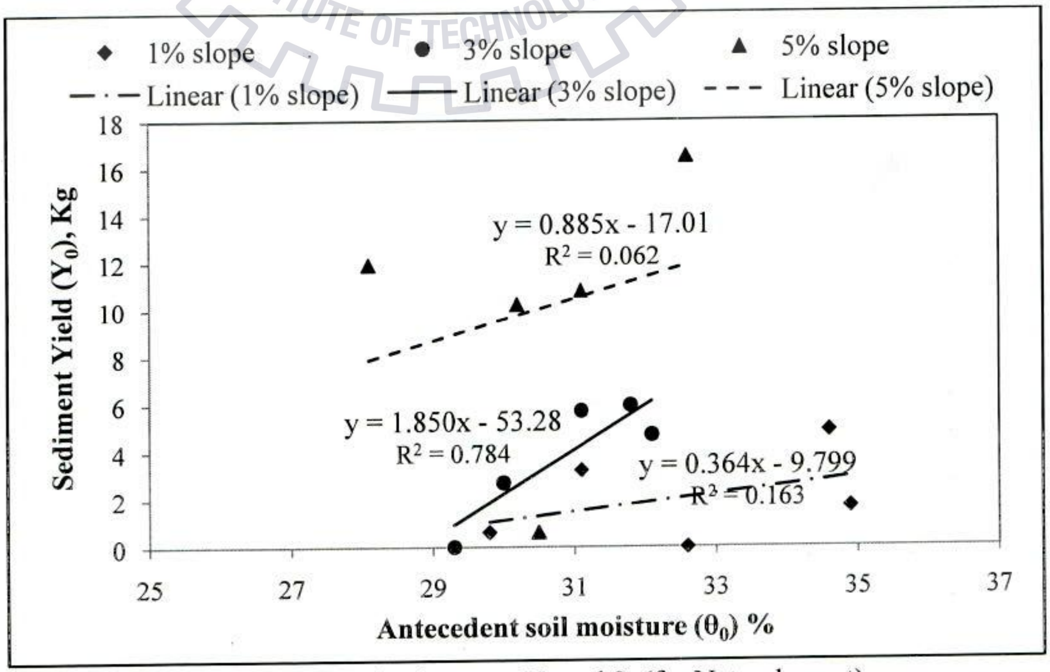

Fig. 5.10: Relation between $Y_0$ and $\theta_0$ (for Natural event)

### 5.3.3 Relation between S and $\theta_0$

The values of S (mm) calculated form Eq. (3.7) for natural rainfall event were plotted against the respective observed antecedent soil moisture ($\theta_0$) (%) for each slope of watershed (Fig. 5.11), which shows a linear relationship between them. The relations depict that as $\theta_0$ increases, S decreases linearly, which is consistent with the expectation.

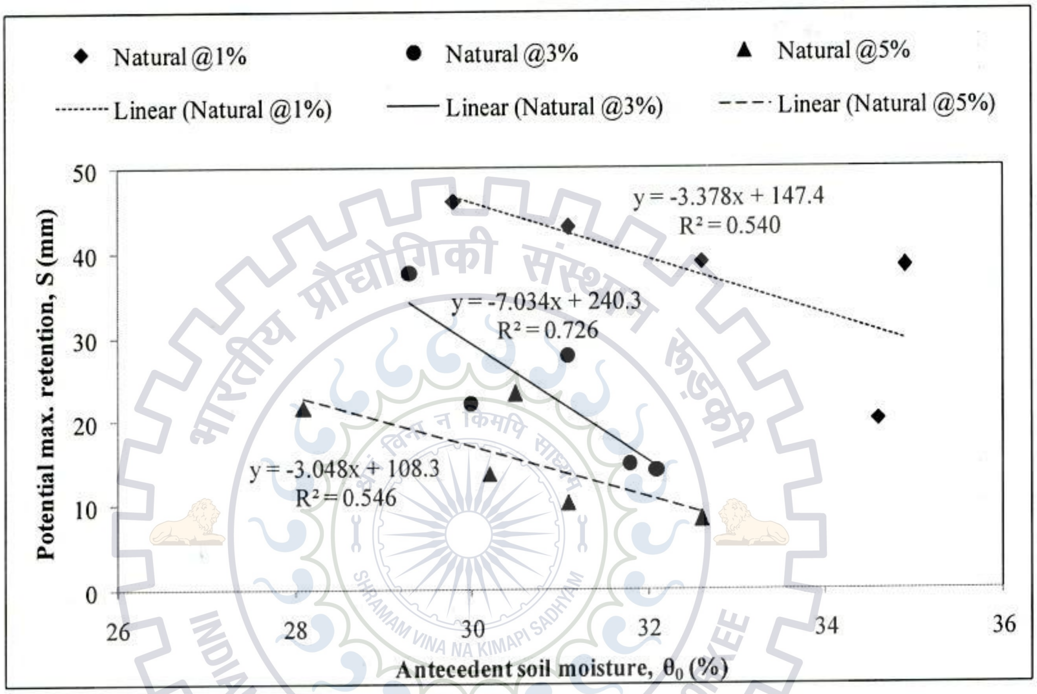

Fig. 5.11: Relationship between S and $\theta_0$ (for Natural events)

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### 5.3.4 Relation between A and $\theta_0$

The values of potential soil erosion A (kg) computed from Eq. (3.16) for natural rainfall event when plotted against the respective observed soil moisture content $\theta_0$ (%) for each slope of plot (Fig. 5.12) showed a linear relationship. It can be concluded from the trend line that A increases as $\theta_0$ increases, and vice versa, which supports the above relation of $Y_0 - \theta_0$.

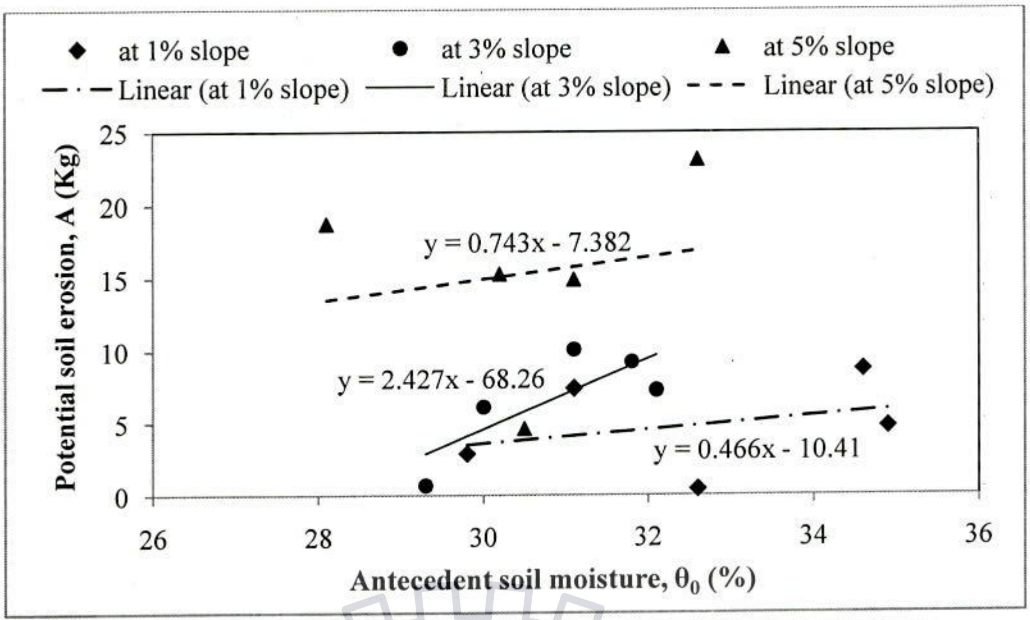

Fig. 5.12: Relation between A and $\theta_0$ (for Natural event)

### 5.3.5 Validation of $S - \theta_0$ and $A - \theta_0$ relations

The values of S and A were computed from the established linear relationships between $S - \theta_0$ (Fig. 5.11) and $A - \theta_0$ (Fig. 5.12); i.e. S and A were converted in the form of $\theta_0$. Using these S and A values, sediment yield ($Y_c$) were computed (Table 5.12) and plotted against the observed sediment yield ($Y_0$) for natural rainfall events, which are shown in Fig. (5.13). The figure reveals that the data points lie near the line of perfect fit (LPF). Computed data points falling close to the line of perfect fit indicate satisfactory performance of the proposed $S - \theta_0$ and $A - \theta_0$ relationship and validates in computation of sediment yield from the inputs of observed rainfall (P) and antecedent soil moisture ($\theta_0$).

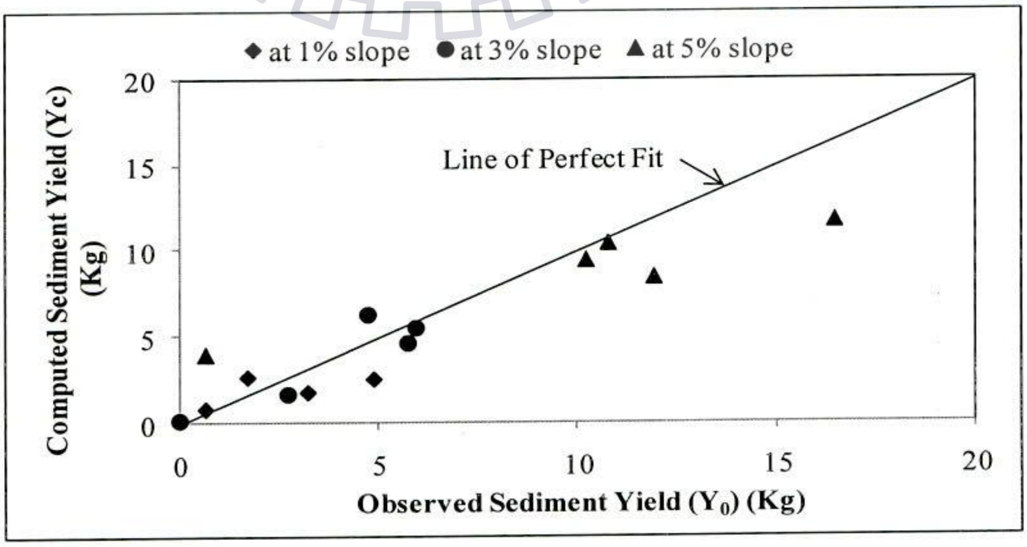

Fig. 5.13: Comparison between observed and computed sediment yield (Natural events)

Table 5.12: Computations of sediment yield using S-$\theta_o$ and A-$\theta_o$ relations (for natural events)

| Event No. | Rainfall (P), mm | Observed Runoff ($Q_0$), mm | Observed Sediment Yield ($Y_0$), Kg | $A_0 = Y_0(P+0.8S)/(P-0.2S)$ (kg) | Soil moisture content ($\theta_0$)% | $S = 5\{P+2Q-\sqrt{(Q(4Q+5P))}\}$ (mm) | S'(mm) From Fig.(5.11) | A' (Kg) From Fig.(5.12) | $Y_c = A'(P - 0.2S')/(P + 0.8S')$ (Kg) |
|---|---|---|---|---|---|---|---|---|---|
| For plot of 1% slope, $A' = 0.466 * \theta_0 - 10.41$; $S' = -3.378 * \theta_0 + 147.4$ | | | | | | | | | |
| 1 | 8.4 | 0.01 | 0.007 | 0.419 | 32.6 | 38.86 | 37.28 | 4.782 | 0.118 |
| 2 | 22.2 | 2.85 | 0.630 | 2.869 | 29.8 | 46.11 | 46.74 | 3.477 | 0.750 |
| 3 | 30.2 | 14.80 | 4.884 | 8.638 | 34.6 | 20.12 | 30.52 | 5.714 | 2.521 |
| 4 | 42.1 | 14.66 | 3.225 | 7.369 | 31.1 | 43.03 | 42.34 | 4.083 | 1.807 |
| 5 | 29.1 | 7.71 | 1.696 | 4.720 | 34.9 | 38.24 | 29.51 | 5.853 | 2.576 |
| For plot of 3% slope, $A' = 2.427 * \theta_0 - 68.26$; $S' = -7.034 * \theta_0 + 240.3$ | | | | | | | | | |
| 1 | 8.4 | 0.02 | 0.015 | 0.676 | 29.3 | 37.61 | 34.20 | 2.851 | 0.124 |
| 2 | 22.2 | 7.94 | 2.715 | 6.083 | 30.0 | 22.06 | 29.28 | 4.550 | 1.630 |
| 3 | 30.2 | 17.70 | 5.960 | 9.178 | 31.8 | 14.72 | 16.62 | 8.919 | 5.511 |
| 4 | 42.1 | 20.80 | 5.720 | 10.054 | 31.1 | 27.70 | 21.54 | 7.220 | 4.598 |
| 5 | 29.1 | 17.14 | 4.714 | 7.230 | 32.1 | 14.04 | 14.51 | 9.647 | 6.208 |
| For plot of 5% slope, $A' = 0.743 * \theta_0 - 7.382$; $S' = - 3.048 * \theta_0 + 108.3$ | | | | | | | | | |
| 1 | 8.4 | 0.52 | 0.636 | 4.580 | 30.5 | 23.26 | 15.34 | 15.280 | 3.942 |
| 2 | 22.2 | 14.67 | 16.466 | 23.068 | 32.6 | 8.24 | 8.94 | 16.840 | 11.713 |
| 3 | 30.2 | 18.37 | 10.207 | 15.266 | 30.2 | 13.62 | 16.25 | 15.057 | 9.393 |
| 4 | 42.1 | 24.06 | 11.910 | 18.705 | 28.1 | 21.56 | 22.65 | 13.496 | 8.420 |
| 5 | 29.1 | 19.61 | 10.786 | 14.876 | 31.1 | 10.26 | 13.51 | 15.725 | 10.403 |

## CHAPTER 6

# SUMMARY AND CONCLUSIONS

The following conclusions can be drawn from the in-situ data collected from the experimental farm consisting of three plots of different slopes (1%, 3% and 5%) having maize crop grown on a soil of hydrologic soil group C.

### 6.1 RUNOFF CN

- The watershed having steeper slope generates more surface runoff for a given rainfall, land use and soil type than the watershed having flatter slope.
- CN increases (or S decreases) with increase in slope of watershed, and vice versa.
- For a given AMC, CN increases as the watershed slope increases, and vice versa. Similarly, as AMC increases from I (dry condition) to III (wet condition), CN also increases for a watershed, and vice versa.
- CN derived from natural rainfall-runoff data for 1% slope of plot were nearly equal to that derived from NEH-4 table whereas it was lower than those derived for the other 3% and 5% slopes.
- CN derived from artificial events data were in higher side than derived from NEH-4 table. The main reason of this is due to the supply of water with high intensity of discharge which causes decrease in initial abstraction and increase in surface runoff, in turn, CN.
- As expected, S decreases with increasing $\theta_0$, and vice versa. Alternatively, CN increases with increasing $\theta_0$, and vice versa.

### 6.2 SEDIMENT YIELD

- The steeper plots generate more sediment yield than flatter plots for a given rainfall, soil type, and land use. In other words, sediment yield increases as the watershed slope increases, and vice versa.
- As antecedent soil moisture ($\theta_0$) of a plot increases, potential maximum retention (S) decreases and potential soil erosion (A) increases linearly and, in turn, sediment yield (Y) increases. The resulting sediment yield values being close to the observed sediment yield supported the workability of the proposed $S - \theta_0$ and $A - \theta_0$ relationship.

- The sediment yield from a plot can be determined only with rainfall and moisture content as input data, with known $S - \theta_0$ and $A - \theta_0$ relationship of respective watershed.

## 6.3 MAJOR CONTRIBUTIONS OF THE STUDY

- As this experimental study shows, the CN derived from natural rainfall-runoff event is fairly close to the CN value documented in NEH-4 table, the further experimental work in this context is sought.
- This study also encourages further work to correlate the soil moisture content in determination of rainfall generated runoff and sediment yield, as $S - \theta_0$ and $A - \theta_0$ relationship were validated, but with limited data.

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# REFERENCES

1) Amutha, R. and Pochelvan, P. (2009), 'Estimation of Surface Runoff in Malattar Sub-watershed using SCS-CN method,' journal of Indian society of remote sensing, Vol. 37, pp. 291-304.

2) Andrews, R.G., (1954), 'The use of relative infiltration indices for computing runoff,' Paper presented at the meeting of the American Society of Agricultural Engineers (unpublished), Soil Conservation Service, Fort Worth, Texas.

3) Beasley, D. B., Huggins, L.F., and Monk, E.J. (1980), 'ANSWERS: A model for watershed planning,' Trans. ASCE, 23, 938-944.

4) Beven, K.j., Kirkby, M.J., Schofield, N. and Tagg, A.F. (1984), 'Testing a physically based flood forecasting model (TOPMODEL) for three UK catchments,' J. Hydrol., 49, 119-143.

5) Bhunya, P.K., Mishra, S.K., and Berndtsson, R. (2003), 'Discussion on estimation of confidence interval for curve numbers,' J. Hydrol. Engg., A.S.C.E., Vol. 8, No. 4, pp. 232-233.

6) Bonta, J.V. (1997), 'Determination of watershed curve number using derived distributions,' J. of Irrigation and Drainage Engg., A.S.C.E., Vol. 123, No. 1, pp. 28-36.

7) Brakensiek, D.L. and Rawls, W.J. (1988), 'Effects of agricultural and rangeland management systems on infiltration,' in Modeling Agricultural, Forest, and Rangeland Hydrology, Am. Soc. of Ag. Engrs., St. Joseph, Mich, p. 247.

8) Canters, F.; Chormanski, J.; Van de Voorde, T.; Batelaan, O. (2006), ' Effects of Different Methods for Estimating Impervious Surface cover on Runoff Estimation at Catchment Level,' In Proceedings of 7th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, Lisbon, Portugal, pp. 557–566.

9) Chaplot, V.A.M. and Bissonnais, Y.L. (2003), 'Runoff features for interrill erosion at different rainfall intensities, slope lengths, and gradients in an agricultural loessial hillslope,' Soil Science Society of America Journal 67: 844–851.

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

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11) Dutta, S.; Mishra, A.; Kar, S., and Panigrahy, S. (2006), 'Estimating spatial curve number for hydrologic response analysis of a small watershed,' J. Spat. Hydrol., 6, 57–67.

12) Ebrahimian, M., Nuruddin, A. A. B., Mohd Soom, M. A. B., Sood, A. M., and Neng, L. J. (2012), 'Runoff Estimation in Steep Slope Watershed with Standard and Slope-Adjusted Curve Number Methods,' Pol. J. Environ. Stud., Vol. 21, No. 5, pp. 1191-1202.

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

14) Evett S.R. and Dutt, G.R. (1985), 'Length and slope effects on runoff from sodium dispersed, compacted earth microcatchments,' Soil Science Society of America Journal 49: 734–738.

15) Fan, F., Deng, Y., Hu, X, and Weng, Q. (2013), 'Estimating Composite Curve Number Using an Improved SCS-CN Method with Remotely Sensed Variables in Guangzhou, China', Remote Sensing, 5, 1425-1438.

16) Ferro, V. (1997), 'Further remarks on a distributed approach to sediment delivery,' Hydrol. Sci. J., 42(5), 633-647.

17) Ferro, V. and Minacapilli, M. (1995), 'Sediment delivery processes at basin scale,' Hydrol. Sci. J., 40(6), 703-717.

18) Ferro, V., Porto, P., and Tusa, G. (1998), 'Testing a distributed approach for modeling sediment delivery,' Hydrol. Sci. J., 43(3), 425-442.

19) Foster, G.R., Meyer, L.D. and Onstad, C.A. (1977), 'An erosion equation devised from basic erosion principles,' Trans. A.S.A.E., 20, pp. 678-682.

20) Fox, D.M., Bryan, R.B., and Price, A.G. (1997), 'The influence of slope angle on final infiltration rate for interrill conditions,' Geoderma 80: 181–194.

21) Geetha, K., Mishra, S.K., Eldho, T.I., Rastogi, A.K., and Pandey, R.P. (2007), 'Modification to SCS-CN method for Long-Term Hydrologic Simulation,' Journal of Irrigation and Drainage Engineering, A.S.C.E., Vol. 133, No. 5, pp. 475-486.

22) Glymph, L.M., Jr., (1954), 'Studies of sediment yields from watersheds,' Tenth General Assembly of the International Union of Geodesy and Geophysics, Rome, Italy, pp. 178-191.

23) 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.

24) Haggard, B.E., Moore, P.A., Delaune, P.B., Smith, D.R., Formica, S., Kleinman, P.J., and Daniel, T.C. (2002), 'Effect of slope, grazing and aeration on pasture hydrology,' In ASAE Annual International Meeting/CIGR XVth World Congress, Hyatt Regency, Chicago, IL, USA.

25) Hann, C.T., Barfield, B.J., and Hayes, J.C. (1994), 'Design Hydrology and Sedimentology for Small Catchments,' Academic Press, New York, USA.

26) Hawkins, R.H. (1984), 'A comparison of predicted and observed curve numbers,' Proc., Irrigation and Drainage Division Special Conf., A.S.C.E., New York, N.Y., pp. 702-709.

27) Hawkins, R.H., Hejlmfelt, A.T., and Zevenbergen, A.W. (1985), 'Runoff probability, storm depth and curve numbers,' J. Irrig. and Drainage Engg., A.S.C.E., 111(4), pp. 330-339.

28) Hawkins, R.H. (1993), 'Asymptotic determination of runoff curve numbers from data,' J. Irrig. and Drain Engg., A.S.C.E., Vol. 119, No. 2, pp. 334-345.

29) Hejlmfelt, A.T. Jr. (1980), 'Empirical investigation of curve number technique,' Journal of Hydraulic Division, A.S.C.E., Vol. 106, No. HY9, pp. 1471-1476.

30) Hjelmfelt, A. T., Jr., Kramer, L. A., and Burwell, R. E. (1982), 'Curve number as random variables,' 'Proc. Int. Symp. on Rainfall-Runoff modeling, (Ed. V.P. Singh), Water Resources Publication, Littleton, Colo., pp. 365-373.

31) Hjelmfelt, A.T., Jr. (1991), 'Investigation of curve number procedure,' J. Hydraulic Eng., A.S.C.E., Vol. 117, No. 6, pp. 725-737.

32) Hong, Y. and Adler, R.F. (2008), 'Estimation of global SCS curve numbers using satellite remote sensing and geospatial data' Int. J. Remote Sens., 29, 471–477.

33) Huang, C.H. (1995), 'Empirical analysis of slope and runoff for sediment delivery from interrill areas,' Soil Science Society of America Journal 59: 982–990.

34) Huang, M., Gallichand, J., Wang, Z., and Goulet, M. (2006), 'A modification to the Soil Conservation Service curve number method for steep slope in the Loess Plateau of China,' Hydorl. Process. 20, 579-589.

35) Inayathulla, M., Paul, J.M., and Vijaya Kumar, H. (2013), 'SCS and GIS based runoff estimation for Jakkur Lake Catchment of Bangalore, Karnataka,' International Journal of Civil Engineering (IJCE), Vol. 2 (1), Feb 2013, pp. 13-20.

36) Jain, M.K. and Kothyari, U.C. (2000), 'Estimation of soil erosion and sediment yield using GIS,' Hydrol. Sci. J., 45(4), 771–786.

37) Jain, M.K., Kothyari, U.C., and Rangaraju, K.G. (2004), 'A GIS based distributed rainfall runoff model,' J. Hydrol., Elsevier Science, 299(1–2), 107–135.

38) Jain, M.K., Kothyari, U.C., and Rangaraju, K.G. (2005), 'Geographic information system based distributed model for soil erosion and rate of sediment outflow from catchments,' J. Hydraul. Eng., ASCE, 131(7), 755–769.

39) Jain, M.K., Mishra, S.K., Suresh Babu, P., Venugopal, K., and Singh, V.P. (2006b), 'Enhanced runoff curve number model incorporating storm duration and non-linear Ia-S Relation,' J. of Hydrologic Engineering, A.S.C.E., Vol. 11, No. 6, pp. 1-5.

40) Julien, P.Y., and Gonzales del Tanago M. (1991), 'Spatially varied soil erosion under different climates,' Hydrol. Sci. J., 36(5), 511–524.

41) Kinsel, W.G. (1980), 'CREAMS: A field scale model for chemicals, runoff, and erosion from agricultural management systems,' Cons. Res., Report No. 26, USDA-SEA, Washington, D.C., 643p.

42) Ludlow, C. (2009), 'Flood Modeling in a Data-Poor Region: A Satellite Data-supported Flood Model for Accra, Ghana,' In Proceeding of Annual Meeting of the Association for American Geographers, Las Vegas, NV, USA.

43) McCuen, R.H. (1982), 'A Guide to Hydrologic Analysis using SCS Methods,' Prentice Hall, Englewood Cliffs, New Jersey 07632.

44) McCuen, R.H. (2002), 'Approach to confidence interval estimation for curve numbers,' J. Hydrol. Engg., A.S.C.E., Vol. 7, No. 1, pp. 43-48.

45) 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.

46) Michel, C., V. Andreassian, and C. Perrin (2005), 'Soil Conservation Service Curve Number method: How to mend a wrong soil moisture accounting procedure?,' Water Resour. Res., 41, W02011, doi:10.1029/2004WR003191

47) Miller, N. and Cronshey, R.C. (1989), 'Runoff curve numbers, the next step,' Proc., Int. Conf., Channel Flow and Catchment Runoff, Uni. of Verginia, Charlottesville, Va.

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

49) Mishra, S.K. and Singh, V.P. (1999a), 'Another look at the SCS-CN method,' Lewos Publishers, A CRC Press Company, New York.

50) Mishra, S.K. and Singh, V.P. (2002a), 'SCS-CN-based hydrologic simulation package,' Mathematical Models in Small Watershed Hydrology, (eds.) V.P. Singh and D.K. Fervert, Water Resources Publications, P.O. Box 2841, Littleton, Colorado 80161.

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

52) 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.

53) Mishra, S.K., Sahu, R.K., Eldho, T.I. & Jain, M.K. (2006a), 'A generalized relation between initial abstraction and potential maximum retention in SCS-CN-based model,' Intl. J. River Basin Management, Vol.(4), No.(4), pp. 245-253.

54) Mishra, S.K., Tyagi, J.V., Singh, V.P., and Singh, R. (2006c), 'SCS-CN-based modeling of sediment yield,' Journal of Hydrology 324, 301–322.

55) Mishra, S.K., Jain, M.K., Suresh Babu, P., Venugopal, K., and Kaliappan, S. (2008), 'Comparison of AMC-dependent CN-conversion Formulae,' Water Resour Manage, 22 : 1409-1420.

56) 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, U.S.D.A., Dec. 1

57) Mockus, V. (1964), Letter to Orrin Ferris, March 5, 6p, In: Rallison, R.E, Origin and evolution of the SCS runoff equation, Proc., A.S.C.E. Symp. Watershed Management, Boise, Idaho, July, 1980.

58) Nearing, M.A., J.M. Bradford, and S.C. Parker (1991). Soil detachment by shallow flow at low slopes. Soil Sci. Soc. Am. J. 55:339–344.

59) 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 Institute, College Station, TX, TWRI Report TR-191

60) Neitsch, S. L., Arnold, J. G., Kiniry, J. R., and Williams, J. R. (2005), 'Soil and Water Assessment Tool – Theoretical Documentation,' Version 2005. Texas, USA.

61) Philip, J.R. (1991), 'Hillslope infiltration: planar slopes,' Water Resources Research 27: 109-117.

62) Ponce, V. M. and Hawkins, R.H. (1996), 'Runoff curve number: Has it reached maturity?,' J. Hydrol. Eng., A.S.C.E., Vol. 1, No. 1, pp. 11-19.

63) Pradhan, R., Pradhan, M.P., Ghose, M.K., Agarwal, V.S., and Agarwal, S. (2010), 'Estimation of Rainfall-Runoff using Remote Sensing and GIS in and around Singtam, East Sikkim,' International Journal of Geomatics and Geosciences, Vol. 1(3), pp. 466-476.

64) Rallison, R.E. and Cronshey, R.C. (1979), Discussion to 'Runoff curve numbers with varying soil moisture,' J. Irrig. and Drain. Div., A.S.C.E., 105(4), 439-441.

65) Rallison, R.E. (1980), 'Origin and Evolution of the SCS runoff equation,' Proc., Irrig. and Drain. Symp. on Watershed Management, A.S.C.E., New York, Vol II, 912-924.

66) Rawls, W.J. (1983), 'Estimation solid bulk density from particle size analysis and organic matter content,' Soil Sci., Vol. 135, No. 2, pp. 123-125.

67) Richards, K. (1993), 'Sediment delivery and the drainage network,' In: Channel Network Hydrology, ed. by K. Beven and M. J. Kirkby, 222-254. Wiley, Chichester, UK.

68) Roehl, J.W. (1962), 'Sediment source areas, delivery ratios, and influencing morphological factors,' Publication No.59, International Association Hydrology Science, pp. 202–213

69) 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,' Hydrol. Process. 21, 2872-2881.

70) Schneider, L.E., and McCuen, R.H. (2005), 'Statistical guidelines for curve number generation,' J. Irrigation and Drainage Engg., A.S.C.E., Vol. 131, No. 3, pp. 282-290.

71) SCS (1956, 1971, 1972, 1985, 1986), 'Hydrlogy,' National Engineering Handbook, Supplement A, Section 4, Soil Conservation Service, USDA, Washington, D.C.

72) Shafiq, M. and Ahmad, B. (2001), 'Surface runoff as affected by surface gradient and grass cover,' Journal of Engineering and Applied Sciences (Pakistan) 20: 88–92.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

73) Sharpley, A. N. and J. R. Williams (1990), 'EPIC- Erosion/Productivity Impact Calculator: 1. Model Documentation,' US Department of Agriculture Techecnical Bulletin No. 1768, US Government Printing Office: Washington, DC.

74) Sherman, L.K. (1942), 'Hydrographs of Runoff,' Physics of the Earth, IX, Hydrology, O.E. Meinzer, ed., McGraw Hill, New York.

75) Sherman, L.K. (1949), 'The unit hydrograph method,' In: O.E. Meinzer (ed.) Physics of the Earth, Dover Publications, Inc., New York, pp. 514-525.

76) Singh, P.K., Bhunya, P.K., Mishra, S.K. and Chaube, U.C. (2008), 'A sediment graph model based on SCS-CN method,' Journal of Hydrology 349, 244-255.

77) Sneller, J.A. (1985), 'Computation of runoff curve numbers for rangelands from landsat data,' Technical Rep. HL85-2, U.S. D. A., Agric Res. Service, Hydro. Lab., Beltsville, Md., 50.

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

79) Soulis, K.X., Valiantzas, J.D., Dercas, N., and Londra, P.A. (2009), 'Investigation of the direct runoff generation mechanism for the analysis of the SCS-CN method applicability to a partial area experimental watershed,' Hydrology and Earth System Sciences, Vol. 13, pp. 605-615.

80) Walling, D.E. (1983), 'The sediment delivery problem,' J. of Hydrology, 65: 209-237.

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

82) Wilson, J.P., Gallant, J.C. (1996), 'EROS: a grid-based program for estimating spatially distributed erosion indices,' Comp Geosci, 22(7), 707–712.

83) 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.

84) Woolhiser, D.A., Hanson, C.L., and Kuhlman, A.R. (1970), 'Overland flow on rangeland watersheds,' Journal of Hydrology 9: 336–356.

85) Wu, T.H., Hall, J.A., and Bonta, J.V. (1993), 'Evaluation of runoff and erosion models,' J. Irrig. Drain. Div., 119(4), 364-362.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

86) 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.

87) Yu, B. (1998), 'Theoretical Justification of SCS Method for Runoff Estimation,' Journal of Irrigation and Drainage Engineering, A.S.C.E., Vol. 124, No. 6, pp. 306-310.

88) Zevenbergen, A. T. (1985), 'Runoff curve numbers from rangeland from landsat data,' Technical Rep. HL85-1, U.S. D. A., Agric Res. Service, Hydro. Lab., Beltsville, Md.

89) Zhang,G.H., Liu, B.Y., Nearing, M., and Zhang, K.L. (2002), 'Soil detachment by shallow flow,' Trans. ASAE 45:351–357.

90) Zhang, G.H., Liu, B.Y., Liu, G.B., He, X.W., and Nearing, M. A. (2003), 'Detachment of Undisturbed Soil by Shallow Flow,' Soil Sci. Soc. Am. J. 67: 713–719.

# APPENDICES

## Appendix - A

### Observed rainfall-runoff data of natural rainfall events

Area of Open spaces of collection chamber and conveyance channel = 1.9803 sq.m.

| Rainfall ( mm) | Measured Runoff Vol. (cm) collected from one slot for plot of slope | | | Measured Runoff Vol. (cu.m.) collected from one slot for plot of slope | | | Extra Runoff Vol. (cu.m.) = (open space x rainfall depth) | Actual Runoff Vol. (cum.) = (Runoff Vol. from one slot - Extra runoff) x 5 nos for plot of slope | | | Actual Runoff Vol. (mm. depth per area of plot) = (Runoff Vol. in cu.m./110) x 1000 for plot of slope | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1% | 3% | 5% | 1% | 3% | 5% | (for all plots) | 1% | 3% | 5% | 1% | 3% | 5% |
| 8.4 | 1.69 | 1.71 | 2.8 | 0.0169 | 0.0171 | 0.028 | 0.0166 | 0.0013 | 0.0023 | 0.0568 | 0.01 | 0.02 | 0.52 |
| 22.2 | 10.67 | 21.87 | 36.67 | 0.1067 | 0.2187 | 0.3667 | 0.0440 | 0.3137 | 0.8737 | 1.6137 | 2.85 | 7.94 | 14.67 |
| 30.2 | 38.53 | 44.93 | 46.4 | 0.3853 | 0.4493 | 0.464 | 0.0598 | 1.6275 | 1.9475 | 2.0210 | 14.80 | 17.70 | 18.37 |
| 42.1 | 40.58 | 54.1 | 61.27 | 0.4058 | 0.541 | 0.6127 | 0.0834 | 1.6121 | 2.2881 | 2.6466 | 14.66 | 20.80 | 24.06 |
| 29.1 | 22.73 | 43.47 | 48.9 | 0.2273 | 0.4347 | 0.489 | 0.0576 | 0.8484 | 1.8854 | 2.1569 | 7.71 | 17.14 | 19.61 |

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# Appendix - B

## 1. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 1 %
Area of plot = 110 sq.m.
Soil moisture content : (29.0, 23.4, 26.5, 29.8, 28.2) = 27.4% (average)
Discharge rate (pipe no. 2, 3, 4, & 6 = 3.73 lps) = 2.037 mm/min.(per 110 $m^2$)
Total duration of water supply = 25 minutes
Total volume of water supply = 50.93 mm.
Total vol. of runoff measured = 37.55 mm.
Date : 29 November 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 3.58.00 | 0 | | | | | supply start |
| 4.06.30 | 17.32 | | | | | (Runoff start) |
| 4.11.00 | 26.48 | 8.5 | 0.425 | 3.86 | 445 | |
| 4.12.00 | 28.52 | 12.1 | 0.605 | 5.50 | 437 | |
| 4.13.00 | 30.56 | 15.7 | 0.785 | 7.14 | 414 | |
| 4.14.00 | 32.59 | 19.8 | 0.99 | 9.00 | 402 | Sample no. 79 |
| 4.15.00 | 34.63 | 23.6 | 1.18 | 10.73 | 388 | |
| 4.16.00 | 36.67 | 27.7 | 1.385 | 12.59 | 383 | |
| 4.17.00 | 38.70 | 31.4 | 1.57 | 14.27 | 374 | |
| 4.18.00 | 40.74 | 35.9 | 1.795 | 16.32 | 372 | |
| 4.19.00 | 42.78 | 40.2 | 2.01 | 18.27 | 378 | |
| 4.20.00 | 44.82 | 44.3 | 2.215 | 20.14 | 378 | Sample no. 80 |
| 4.21.00 | 46.85 | 48.1 | 2.405 | 21.86 | 373 | |
| 4.22.00 | 48.89 | 52.5 | 2.625 | 23.86 | 371 | |
| 4.23.00 | 50.93 | 57 | 2.85 | 25.91 | 366 | No electricity |
| 4.24.00 | | 60.9 | 3.045 | 27.68 | 365 | |
| 4.25.00 | | 65 | 3.25 | 29.55 | 357 | |
| 4.26.00 | | 69.3 | 3.465 | 31.50 | 360 | |
| 4.27.00 | | 73.2 | 3.66 | 33.27 | 357 | |
| 4.28.00 | | 75.7 | 3.785 | 34.41 | 329 | |
| 4.29.00 | | 77.7 | 3.885 | 35.32 | 324 | |
| 4.30.00 | | 79.3 | 3.965 | 36.05 | 328 | Sample no. 81 |
| 4.31.00 | | 80.2 | 4.01 | 36.45 | 330 | |
| 4.32.00 | | 81.2 | 4.06 | 36.91 | 335 | |
| 4.33.00 | | 81.7 | 4.085 | 37.14 | 333 | |
| 4.35.00 | | 82.4 | 4.12 | 37.45 | 330 | |
| 4.36.00 | | 82.6 | 4.13 | 37.55 | 338 | No runoff |

## 2. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 1 % Area of plot = 110 sq.m.
Soil moisture content : (27.2, 27.9, 28.2, 28.4, 28.8) = 28.10 % (average)
Discharge rate (pipe no. 5 and 6 = 2.24 lps) = 1.223 mm/min.(per 110 $m^2$)
Total Duration and Vol. of water supply = 40 minutes and 48.93 mm
Total vol. of runoff measured = 28.27 mm. Date : 30 November 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 3.02.00 | 0 | 0 | 0 | 0 | | supply start |
| 3.09.00 | 8.56 | 0 | 0 | 0 | | No electricity |
| 3.13.00 | 8.56 | 0 | 0 | 0.00 | | |
| 3.41.00 | 8.56 | 0 | 0 | 0.00 | | again supply start |
| 3.49.00 | 18.35 | 0 | 0 | 0.00 | | (Runoff start) |
| 3.55.00 | 25.69 | 5.5 | 0.275 | 2.50 | 478 | |
| 3.56.00 | 26.91 | 7.3 | 0.365 | 3.32 | 451 | |
| 3.57.00 | 28.13 | 9.4 | 0.47 | 4.27 | 428 | |
| 3.58.00 | 29.36 | 11.5 | 0.575 | 5.23 | 415 | |
| 3.59.00 | 30.58 | 13.5 | 0.675 | 6.14 | 405 | |
| 4.00.00 | 31.80 | 15.5 | 0.775 | 7.05 | 396 | Sample no. 85 |
| 4.01.00 | 33.03 | 17.6 | 0.88 | 8.00 | 392 | |
| 4.02.00 | 34.25 | 19.9 | 0.995 | 9.05 | 387 | |
| 4.03.00 | 35.47 | 22 | 1.1 | 10.00 | 379 | |
| 4.04.00 | 36.70 | 24.1 | 1.205 | 10.95 | 382 | |
| 4.05.00 | 37.92 | 26.4 | 1.32 | 12.00 | 375 | |
| 4.06.00 | 39.14 | 28.3 | 1.415 | 12.86 | 381 | |
| 4.07.00 | 40.37 | 30.6 | 1.53 | 13.91 | 380 | |
| 4.08.00 | 41.59 | 32.8 | 1.64 | 14.91 | 369 | Sample no. 86 |
| 4.09.00 | 42.81 | 35.1 | 1.755 | 15.95 | 367 | |
| 4.10.00 | 44.03 | 37.4 | 1.87 | 17.00 | 373 | |
| 4.11.00 | 45.26 | 39.5 | 1.975 | 17.95 | 369 | |
| 4.12.00 | 46.48 | 41.7 | 2.085 | 18.95 | 361 | |
| 4.13.00 | 47.70 | 43.6 | 2.18 | 19.82 | 355 | |
| 4.14.00 | 48.93 | 46 | 2.3 | 20.91 | 355 | Supply stop |
| 4.15.00 | | 48.3 | 2.415 | 21.95 | 353 | |
| 4.16.00 | | 50.7 | 2.535 | 23.05 | 347 | |
| 4.17.00 | | 52.8 | 2.64 | 24.00 | 346 | |
| 4.18.00 | | 54.7 | 2.735 | 24.86 | 347 | |
| 4.19.00 | | 56.2 | 2.81 | 25.55 | 345 | |
| 4.20.00 | | 57.6 | 2.88 | 26.18 | 347 | |
| 4.21.00 | | 58.6 | 2.93 | 26.64 | 348 | |
| 4.22.00 | | 59.3 | 2.965 | 26.95 | 345 | |
| 4.23.00 | | 60.4 | 3.02 | 27.45 | 345 | |
| 4.24.00 | | 60.9 | 3.045 | 27.68 | 343 | |
| 4.25.00 | | 61.3 | 3.065 | 27.86 | 346 | |
| 4.27.00 | | 61.8 | 3.09 | 28.09 | 349 | |
| 4.29.00 | | 62.2 | 3.11 | 28.27 | 346 | No runoff |

## 3. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 1 %
Area of plot = 110 sq.m.
Soil moisture content : (26.2, 25.4, 25.1, 24.3) = 25.20 % (average)
Discharge rate (pipe no. 2, 3, 4, & 5 = 4.06 lps) = 2.213 mm/min.(per 110 m$^2$)
Total duration of water supply = 26.5 minutes
Total volume of water supply = 58.64 mm.
Total vol. of runoff measured = 42.82 mm.
Date : 07 December 2012

| Time | Cum. Vol. of water supply (mm)) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 4.16.30 | 0 | 0 | 0 | 0 | | supply start |
| 4.26.30 | 22.13 | 0 | 0 | 0 | | (Runoff start) |
| 4.31.00 | 32.09 | 9.8 | 0.49 | 4.45 | | |
| 4.32.00 | 34.30 | 13.5 | 0.675 | 6.14 | 904 | |
| 4.33.00 | 36.51 | 17.3 | 0.865 | 7.86 | 840 | |
| 4.34.00 | 38.73 | 22 | 1.1 | 10.00 | 786 | Sample no. 92 |
| 4.35.00 | 40.94 | 26.1 | 1.305 | 11.86 | 750 | |
| 4.36.00 | 43.15 | 30.9 | 1.545 | 14.05 | 706 | |
| 4.37.00 | 45.37 | 36.2 | 1.81 | 16.45 | 694 | |
| 4.38.00 | 47.58 | 40.7 | 2.035 | 18.50 | 669 | |
| 4.39.00 | 49.79 | 45.7 | 2.285 | 20.77 | 650 | Sample no. 93 |
| 4.40.00 | 52.01 | 50.3 | 2.515 | 22.86 | 630 | |
| 4.41.00 | 54.22 | 55.8 | 2.79 | 25.36 | 608 | |
| 4.42.00 | 56.43 | 60.1 | 3.005 | 27.32 | 594 | |
| 4.43.00 | 58.64 | 65.4 | 3.27 | 29.73 | 592 | Supply stop |
| 4.44.00 | | 70.2 | 3.51 | 31.91 | 584 | |
| 4.45.00 | | 75.4 | 3.77 | 34.27 | 578 | |
| 4.46.00 | | 79.5 | 3.975 | 36.14 | 574 | |
| 4.47.00 | | 83.8 | 4.19 | 38.09 | 590 | |
| 4.48.00 | | 86.4 | 4.32 | 39.27 | 578 | |
| 4.49.00 | | 88.6 | 4.43 | 40.27 | 571 | |
| 4.50.00 | | 90.5 | 4.525 | 41.14 | 579 | |
| 4.51.00 | | 91.3 | 4.565 | 41.50 | 584 | |
| 4.52.00 | | 92.3 | 4.615 | 41.95 | 583 | |
| 4.53.00 | | 92.6 | 4.63 | 42.09 | 588 | |
| 4.55.00 | | 93.8 | 4.69 | 42.64 | 582 | |
| 4.57.00 | | 94.2 | 4.71 | 42.82 | 596 | No runoff |

## 4. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 1 %    Area of plot = 110 sq.m.
Soil moisture content : (25.4, 20.4, 24.5, 23.4) = 23.40% (average)
Discharge rate (pipe no. 1, 5 and 6 = 3.28 lps) = 1.789 mm/min.(per 110 $m^2$)
Total duration of water supply = 35.00 minutes
Total volume of water supply = 62.60 mm
Total vol. of runoff measured = 34.45 mm.
Date : 28 November 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 1.38.00 | 0 | | | 0 | | supply start |
| 1.48.00 | 17.89 | | | | | (Runoff start) |
| 1.53.00 | 26.83 | 5.7 | 0.285 | 2.59 | | |
| 1.54.00 | 28.62 | 7.7 | 0.385 | 3.50 | 640 | |
| 1.55.00 | 30.41 | 9.9 | 0.495 | 4.50 | 592 | |
| 1.56.00 | 32.20 | 12.2 | 0.61 | 5.55 | 560 | |
| 1.57.00 | 33.98 | 14.8 | 0.74 | 6.73 | 533 | |
| 1.58.00 | 35.77 | 17.3 | 0.865 | 7.86 | 506 | Sample no. 71 |
| 1.59.00 | 37.56 | 19.5 | 0.975 | 8.86 | 488 | |
| 2.00.00 | 39.35 | 22.1 | 1.105 | 10.05 | 466 | |
| 2.01.00 | 41.14 | 24.6 | 1.23 | 11.18 | 449 | |
| 2.02.00 | 42.93 | 27.1 | 1.355 | 12.32 | 438 | |
| 2.03.00 | 44.72 | 29.5 | 1.475 | 13.41 | 415 | |
| 2.04.00 | 46.50 | 32 | 1.6 | 14.55 | 405 | |
| 2.05.00 | 48.29 | 34.7 | 1.735 | 15.77 | 390 | |
| 2.06.00 | 50.08 | 37.1 | 1.855 | 16.86 | 378 | |
| 2.07.00 | 51.87 | 39.8 | 1.99 | 18.09 | 375 | |
| 2.08.00 | 53.66 | 42.8 | 2.14 | 19.45 | 372 | Sample no. 72 |
| 2.09.00 | 55.45 | 45.0 | 2.25 | 20.45 | 375 | |
| 2.10.00 | 57.24 | 47.8 | 2.39 | 21.73 | 367 | |
| 2.11.00 | 59.03 | 50.3 | 2.515 | 22.86 | 370 | |
| 2.12.00 | 60.81 | 52.7 | 2.635 | 23.95 | 363 | |
| 2.13.00 | 62.60 | 55.4 | 2.77 | 25.18 | 354 | Supply stop |
| 2.14.00 | | 58.1 | 2.905 | 26.41 | 353 | |
| 2.15.00 | | 60.9 | 3.045 | 27.68 | 353 | |
| 2.16.00 | | 63.3 | 3.165 | 28.77 | 355 | |
| 2.17.00 | | 65.8 | 3.29 | 29.91 | 353 | |
| 2.18.00 | | 68.4 | 3.42 | 31.09 | 352 | |
| 2.19.00 | | 70.3 | 3.515 | 31.95 | 353 | |
| 2.20.00 | | 72.0 | 3.6 | 32.73 | 353 | |
| 2.21.00 | | 73.2 | 3.66 | 33.27 | 354 | Sample no. 73 |
| 2.22.00 | | 74.0 | 3.7 | 33.64 | 357 | |
| 2.23.00 | | 74.6 | 3.73 | 33.91 | 357 | |
| 2.25.00 | | 75.1 | 3.755 | 34.14 | 354 | |
| 2.27.00 | | 75.8 | 3.79 | 34.45 | 355 | No runoff |

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## 5. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 1 %
Area of plot = 110 sq.m.
Soil moisture content : (25.2, 26.6, 25.9, 27.5) = 26.3 % (average)
Discharge rate (pipe no. 1, 2, and 6 = 2.84 lps) = 1.551 mm/min.(per 110 $m^2$)
Total duration of water supply = 35.00 minutes
Total volume of water supply = 54.28 mm
Total vol. of runoff measured = 35.14 mm.
Date : 27 November 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 1.29.00 | 0 | 0 | 0 | 0 | 0 | supply start |
| 1.39.00 | 15.51 | 0 | 0 | 0 | 0 | (Runoff start) |
| 1.48.00 | 29.47 | 5.6 | 0.28 | 2.55 | | |
| 1.49.00 | 31.02 | 7.8 | 0.39 | 3.55 | 636 | |
| 1.50.00 | 32.57 | 10.6 | 0.53 | 4.82 | 612 | |
| 1.51.00 | 34.12 | 13.5 | 0.675 | 6.14 | 566 | |
| 1.52.00 | 35.67 | 16.6 | 0.83 | 7.55 | 527 | sample no |
| 1.53.00 | 37.22 | 19.1 | 0.955 | 8.68 | 498 | |
| 1.54.00 | 38.77 | 22.1 | 1.105 | 10.05 | 481 | |
| 1.55.00 | 40.32 | 24.8 | 1.24 | 11.27 | 462 | |
| 1.56.00 | 41.87 | 27.8 | 1.39 | 12.64 | 442 | |
| 1.57.00 | 43.43 | 30.9 | 1.545 | 14.05 | 431 | |
| 1.58.00 | 44.98 | 33.9 | 1.695 | 15.41 | 398 | |
| 1.59.00 | 46.53 | 37 | 1.85 | 16.82 | 386 | |
| 2.00.00 | 48.08 | 40.2 | 2.01 | 18.27 | 372 | |
| 2.01.00 | 49.63 | 43.4 | 2.17 | 19.73 | 361 | |
| 2.02.00 | 51.18 | 46.5 | 2.325 | 21.14 | 355 | sample no |
| 2.03.00 | 52.73 | 49.7 | 2.485 | 22.59 | 351 | |
| 2.04.00 | 54.28 | 52.7 | 2.635 | 23.95 | 350 | Supply stop |
| 2.05.00 | | 55.9 | 2.795 | 25.41 | 346 | |
| 2.06.00 | | 58.8 | 2.94 | 26.73 | 348 | |
| 2.07.00 | | 61.7 | 3.085 | 28.05 | 342 | |
| 2.08.00 | | 64.4 | 3.22 | 29.27 | 337 | |
| 2.09.00 | | 67.3 | 3.365 | 30.59 | 335 | |
| 2.10.00 | | 69.8 | 3.49 | 31.73 | 336 | |
| 2.11.00 | | 72.1 | 3.605 | 32.77 | 335 | |
| 2.12.00 | | 74 | 3.7 | 33.64 | 334 | |
| 2.13.00 | | 75.5 | 3.775 | 34.32 | 335 | |
| 2.14.00 | | 76.4 | 3.82 | 34.73 | 332 | sample no |
| 2.15.00 | | 77 | 3.85 | 35.00 | 332 | |
| 2.17.00 | | 77.3 | 3.865 | 35.14 | 331 | No runoff |

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## 6. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 3 %
Area of plot = 110 sq.m.
Soil moisture content : (24.3, 24.8, 24.2, 24.8) = 24.5 % (average)
Discharge rate (pipe no. 2, 3, 4 and 6 = 3.77 lps) = 2.037 mm/min.(per 110 $m^2$)
Total duration of water supply = 23 minutes
Total volume of water supply = 46.85 mm
Total vol. of runoff measured = 36.09 mm.
Date : 26 November 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 5.15.00 | 0 | 0 | 0 | 0 | | supply starts |
| 5.21.00 | 12.22 | | | 0 | | (Runoff start) |
| 5.25.00 | 20.37 | 7.5 | 0.375 | 3.41 | | |
| 5.26.00 | 22.41 | 11.5 | 0.575 | 5.23 | 202 | |
| 5.26.30 | 23.43 | 13.5 | 0.675 | 6.14 | 188 | |
| 5.28.00 | 26.48 | 19.2 | 0.96 | 8.73 | 166 | |
| 5.29.00 | 28.52 | 22.9 | 1.145 | 10.41 | 152 | Sample no. 58 |
| 5.30.00 | 30.56 | 26.8 | 1.34 | 12.18 | 136 | |
| 5.31.00 | 32.59 | 31 | 1.55 | 14.09 | 134 | |
| 5.32.00 | 34.63 | 34.8 | 1.74 | 15.82 | 127 | |
| 5.33.00 | 36.67 | 39.2 | 1.96 | 17.82 | 132 | |
| 5.34.00 | 38.70 | 43.3 | 2.165 | 19.68 | 129 | |
| 5.35.00 | 40.74 | 48 | 2.4 | 21.82 | 118 | |
| 5.36.00 | 42.78 | 52.3 | 2.615 | 23.77 | 115 | |
| 5.37.00 | 44.82 | 56.3 | 2.815 | 25.59 | 114 | |
| 5.38.00 | 46.85 | 60.6 | 3.03 | 27.55 | 110 | Supply stop |
| 5.39.00 | | 64.3 | 3.215 | 29.23 | 108 | |
| 5.40.00 | | 69 | 3.45 | 31.36 | 106 | |
| 5.41.00 | | 73 | 3.65 | 33.18 | 107 | |
| 5.42.00 | | 76 | 3.8 | 34.55 | 105 | |
| 5.43.00 | | 77.3 | 3.865 | 35.14 | 104 | |
| 5.43.30 | | 77.6 | 3.88 | 35.27 | 105 | |
| 5.44.00 | | 78.3 | 3.915 | 35.59 | 105 | |
| 5.44.30 | | 78.4 | 3.92 | 35.64 | 106 | Sample no. 59 |
| 5.47.00 | | 79.4 | 3.97 | 36.09 | 105 | No runoff |

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## 7. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 3 %
Area of plot = 110 sq.m.
Soil moisture content : (20.2, 20.9, 22.1, 20.8) = 21.00 % (average)
Discharge rate (pipe no. 5 and 6 = 2.24 lps) = 1.223 mm/min.(per 110 $m^2$)
Total duration of water supply = 34.50 minutes
Total volume of water supply = 42.20 mm
Total vol. of runoff measured = 25.18 mm.
Date : 29 November 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 4.25.30 | 0 | 0 | 0 | 0 | | supply start |
| 4.33.30 | 9.79 | 0 | 0 | 0 | | (Runoff start) |
| 4.39.00 | 16.51 | 4.8 | 0.24 | 2.18 | | |
| 4.40.00 | 17.74 | 6.4 | 0.32 | 2.91 | | |
| 4.41.00 | 18.96 | 7.7 | 0.385 | 3.50 | 326 | |
| 4.42.00 | 20.18 | 9.5 | 0.475 | 4.32 | 314 | |
| 4.43.00 | 21.41 | 11.4 | 0.57 | 5.18 | 305 | |
| 4.44.00 | 22.63 | 13 | 0.65 | 5.91 | 309 | |
| 4.45.00 | 23.85 | 15.3 | 0.765 | 6.95 | 308 | |
| 4.46.00 | 25.08 | 17.2 | 0.86 | 7.82 | 305 | |
| 4.47.00 | 26.30 | 19 | 0.95 | 8.64 | 309 | |
| 4.48.00 | 27.52 | 20.9 | 1.045 | 9.50 | 308 | |
| 4.49.00 | 28.74 | 23 | 1.15 | 10.45 | 304 | Sample no. 77 |
| 4.50.00 | 29.97 | 24.8 | 1.24 | 11.27 | 305 | |
| 4.51.00 | 31.19 | 26.8 | 1.34 | 12.18 | 303 | |
| 4.52.00 | 32.41 | 28.8 | 1.44 | 13.09 | 299 | |
| 4.53.00 | 33.64 | 30.8 | 1.54 | 14.00 | 306 | |
| 4.54.00 | 34.86 | 32.7 | 1.635 | 14.86 | 298 | |
| 4.55.00 | 36.08 | 34.7 | 1.735 | 15.77 | 305 | |
| 4.56.00 | 37.31 | 36.6 | 1.83 | 16.64 | 302 | |
| 4.57.00 | 38.53 | 38.6 | 1.93 | 17.55 | 299 | Sample no. 78 |
| 4.58.00 | 39.75 | 40.5 | 2.025 | 18.41 | 299 | |
| 4.59.00 | 40.98 | 42.4 | 2.12 | 19.27 | 291 | |
| 5.00.00 | 42.20 | 44.1 | 2.205 | 20.05 | 294 | Supply stop |
| 5.01.00 | | 46.1 | 2.305 | 20.95 | 292 | |
| 5.02.00 | | 47.9 | 2.395 | 21.77 | 290 | |
| 5.03.00 | | 49.9 | 2.495 | 22.68 | 287 | |
| 5.04.00 | | 52.3 | 2.615 | 23.77 | 287 | |
| 5.05.00 | | 53 | 2.65 | 24.09 | 286 | |
| 5.06.00 | | 54.1 | 2.705 | 24.59 | 284 | |
| 5.07.00 | | 54.8 | 2.74 | 24.91 | 288 | |
| 5.09.00 | | 55.4 | 2.77 | 25.18 | 290 | |
| 5.11.00 | | 55.4 | 2.77 | 25.18 | 290 | No runoff |

## 8. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 3 %
Area of plot = 110 sq.m.
Soil moisture content : (22.6, 24.3, 20.7, 25.4) = 23.20 % (average)
Discharge rate (pipe no. 2, 3, 4 and 5= 4.06 lps) = 2.213 mm/min.(per 110 $m^2$)
Total duration of water supply = 22.50 minutes
Total volume of water supply = 49.79 mm
Total vol. of runoff measured = 36.95 mm.
Date : 07 December 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 3.28.30 | 0 | 0 | 0 | 0 | | supply start |
| 3.34.30 | 13.28 | 0 | 0 | 0 | | (Runoff start) |
| 3.38.00 | 21.02 | 7 | 0.35 | 3.18 | | |
| 3.39.00 | 23.24 | 10.4 | 0.52 | 4.73 | 495 | |
| 3.40.00 | 25.45 | 13.9 | 0.695 | 6.32 | 471 | |
| 3.41.00 | 27.66 | 18.3 | 0.915 | 8.32 | 466 | |
| 3.42.00 | 29.88 | 22.4 | 1.12 | 10.18 | 447 | |
| 3.43.00 | 32.09 | 26.7 | 1.335 | 12.14 | 442 | Sample no. 90 |
| 3.44.00 | 34.30 | 30.3 | 1.515 | 13.77 | 437 | |
| 3.45.00 | 36.51 | 34.7 | 1.735 | 15.77 | 432 | |
| 3.46.00 | 38.73 | 38.5 | 1.925 | 17.50 | 437 | |
| 3.47.00 | 40.94 | 43.3 | 2.165 | 19.68 | 424 | Sample no. 91 |
| 3.48.00 | 43.15 | 47.8 | 2.39 | 21.73 | 421 | |
| 3.49.00 | 45.37 | 51.9 | 2.595 | 23.59 | 418 | |
| 3.50.00 | 47.58 | 56.2 | 2.81 | 25.55 | 417 | |
| 3.51.00 | 49.79 | 60.1 | 3.005 | 27.32 | 416 | Supply stop |
| 3.52.00 | | 64.7 | 3.235 | 29.41 | 415 | |
| 3.53.00 | | 68.9 | 3.445 | 31.32 | 414 | |
| 3.54.00 | | 72.8 | 3.64 | 33.09 | 414 | |
| 3.55.00 | | 75.9 | 3.795 | 34.50 | 409 | |
| 3.56.00 | | 78.7 | 3.935 | 35.77 | 410 | |
| 3.57.00 | | 79.2 | 3.96 | 36.00 | 411 | |
| 3.58.00 | | 80.1 | 4.005 | 36.41 | 411 | |
| 3.59.00 | | 80.4 | 4.02 | 36.55 | 414 | |
| 4.01.00 | | 81.2 | 4.06 | 36.91 | 417 | |
| 4.03.00 | | 81.3 | 4.065 | 36.95 | 416 | No runoff |

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## 9. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 3 %
Area of plot = 110 sq.m.
Soil moisture content : (26.8, 24.8, 25.7, 24.5) = 25.40 % (average)
Discharge rate (pipe no. 1, 5 and 6 = 3.28 lps) = 1.789 mm/min.(per 110 $m^2$)
Total duration of water supply = 27.00 minutes
Total volume of water supply = 48.29 mm
Total vol. of runoff measured = 34.91 mm.
Date : 8 December 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 11.00.00 | 0 | | | 0 | | supply starrt |
| 11.07.00 | 12.52 | | | | | (Runoff start) |
| 11.11.00 | 19.68 | 7.5 | 0.375 | 3.41 | | |
| 11.12.00 | 21.46 | 10.5 | 0.525 | 4.77 | 572 | |
| 11.13.00 | 23.25 | 13.4 | 0.67 | 6.09 | 548 | |
| 11.14.00 | 25.04 | 16.3 | 0.815 | 7.41 | 525 | |
| 11.15.00 | 26.83 | 19.7 | 0.985 | 8.95 | 511 | |
| 11.16.00 | 28.62 | 22.9 | 1.145 | 10.41 | 498 | |
| 11.17.00 | 30.41 | 26.1 | 1.305 | 11.86 | 512 | |
| 11.18.00 | 32.20 | 29.1 | 1.455 | 13.23 | 504 | |
| 11.19.00 | 33.98 | 32 | 1.6 | 14.55 | 479 | |
| 11.20.00 | 35.77 | 35.4 | 1.77 | 16.09 | 476 | |
| 11.21.00 | 37.56 | 39.2 | 1.96 | 17.82 | 467 | Sample no. 97 |
| 11.22.00 | 39.35 | 42 | 2.1 | 19.09 | 466 | |
| 11.23.00 | 41.14 | 45.7 | 2.285 | 20.77 | 461 | |
| 11.24.00 | 42.93 | 49.1 | 2.455 | 22.32 | 465 | |
| 11.25.00 | 44.72 | 52.3 | 2.615 | 23.77 | 465 | |
| 11.26.00 | 46.50 | 55.6 | 2.78 | 25.27 | 463 | Sample no. 98 |
| 11.27.00 | 48.29 | 58.9 | 2.945 | 26.77 | 465 | Supply stop |
| 11.28.00 | | 62.3 | 3.115 | 28.32 | 467 | |
| 11.29.00 | | 65.8 | 3.29 | 29.91 | 462 | |
| 11.30.00 | | 68.9 | 3.445 | 31.32 | 447 | |
| 11.31.00 | | 71.9 | 3.595 | 32.68 | 446 | |
| 11.32.00 | | 73.6 | 3.68 | 33.45 | 444 | |
| 11.33.00 | | 74.9 | 3.745 | 34.05 | 444 | |
| 11.34.00 | | 76 | 3.8 | 34.55 | 443 | |
| 11.35.00 | | 76.2 | 3.81 | 34.64 | 443 | |
| 11.37.00 | | 76.8 | 3.84 | 34.91 | 446 | No runoff |

## 10. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 3 %
Area of plot = 110 sq.m.
Soil moisture content : (28.7, 27.9, 27.3, 26.5, 26.5) = 27.40 % (average)
Discharge rate (pipe no. 2, 3 and 4 = 2.77 lps) = 1.513 mm/min.(per 110 $m^2$)
Total duration of water supply = 23.00 minutes
Total volume of water supply = 34.81 mm
Total vol. of runoff measured = 23.36 mm.
Date : 27 November 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 3.10.00 | 0 | 0 | 0 | 0 | | supply start |
| 3.18.00 | 12.11 | 0 | 0 | 0 | | (Runoff start) |
| 3.22.00 | 18.16 | 5.6 | 0.28 | 2.55 | | |
| 3.23.00 | 19.67 | 7.8 | 0.39 | 3.55 | 244 | |
| 3.24.00 | 21.19 | 10.2 | 0.51 | 4.64 | 218 | |
| 3.25.00 | 22.70 | 13.1 | 0.655 | 5.95 | 204 | |
| 3.26.00 | 24.22 | 15.8 | 0.79 | 7.18 | 199 | |
| 3.27.00 | 25.73 | 18.5 | 0.925 | 8.41 | 187 | |
| 3.28.00 | 27.24 | 21.3 | 1.065 | 9.68 | 187 | |
| 3.29.00 | 28.76 | 24.1 | 1.205 | 10.95 | 181 | Sample no. 60 |
| 3.30.00 | 30.27 | 26.8 | 1.34 | 12.18 | 182 | |
| 3.31.00 | 31.78 | 29.5 | 1.475 | 13.41 | 184 | |
| 3.32.00 | 33.30 | 32.7 | 1.635 | 14.86 | 181 | |
| 3.33.00 | 34.81 | 35.6 | 1.78 | 16.18 | 184 | Supply stop |
| 3.34.00 | | 38.4 | 1.92 | 17.45 | 182 | |
| 3.35.00 | | 41.3 | 2.065 | 18.77 | 177 | |
| 3.36.00 | | 44 | 2.2 | 20.00 | 176 | Sample no. 61 |
| 3.37.00 | | 46.3 | 2.315 | 21.05 | 177 | |
| 3.38.00 | | 48.6 | 2.43 | 22.09 | 176 | |
| 3.39.00 | | 49.7 | 2.485 | 22.59 | 176 | |
| 3.39.30 | | 50.2 | 2.51 | 22.82 | 177 | |
| 3.40.00 | | 50.3 | 2.515 | 22.86 | 177 | |
| 3.40.30 | | 50.8 | 2.54 | 23.09 | 177 | |
| 3.41.00 | | 51 | 2.55 | 23.18 | 181 | |
| 3.42.00 | | 51.2 | 2.56 | 23.27 | 178 | |
| 3.44.00 | | 51.3 | 2.565 | 23.32 | 185 | |
| 3.46.00 | | 51.4 | 2.57 | 23.36 | 186 | No runoff |

## 11. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 5 %
Area of plot = 110 sq.m.
Soil moisture content : (24.0, 25.1, 18.2, 20.7) = 22.00 % (average)
Discharge rate (pipe no. 2, 3, 4 and 6 = 3.73 lps) = 2.037 mm/min.(per 110 $m^2$)
Total duration of water supply = 18.00 minutes
Total volume of water supply = 36.67 mm
Total vol. of runoff measured = 31.95 mm.
Date : 7 December 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 2.54.00 | 0 | 0 | 0 | 0 | | supply start |
| 2.57.00 | 6.11 | | | 0 | | (Runoff start) |
| 3.00.00 | 12.22 | 7.8 | 0.39 | 3.55 | | |
| 3.01.00 | 14.26 | 12 | 0.6 | 5.45 | 20500 | |
| 3.02.00 | 16.30 | 16.4 | 0.82 | 7.45 | 19600 | |
| 3.03.00 | 18.33 | 21.3 | 1.065 | 9.68 | 18600 | Sample no. 87 |
| 3.04.00 | 20.37 | 25.4 | 1.27 | 11.55 | 18100 | |
| 3.05.00 | 22.41 | 29.9 | 1.495 | 13.59 | 18800 | |
| 3.06.00 | 24.45 | 34.2 | 1.71 | 15.55 | 18500 | |
| 3.07.00 | 26.48 | 38.8 | 1.94 | 17.64 | 18200 | |
| 3.08.00 | 28.52 | 43.6 | 2.18 | 19.82 | 17800 | |
| 3.09.00 | 30.56 | 47.9 | 2.395 | 21.77 | 17900 | Sample no. 88 |
| 3.10.00 | 32.59 | 52.7 | 2.635 | 23.95 | 17600 | |
| 3.11.00 | 34.63 | 57 | 2.85 | 25.91 | 17500 | |
| 3.12.00 | 36.67 | 61.8 | 3.09 | 28.09 | 17200 | Supply stop |
| 3.13.00 | | 66.6 | 3.33 | 30.27 | 16800 | |
| 3.14.00 | | 69.5 | 3.475 | 31.59 | 16500 | Sample no. 89 |
| 3.15.00 | | 70 | 3.5 | 31.82 | 15400 | |
| 3.17.00 | | 70.3 | 3.515 | 31.95 | 14100 | No runoff |

## 12. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 5 %
Area of plot = 110 sq.m.
Soil moisture content : (25.7, 24.3, 24.0, 20.4, 22.0) = 23.30 % (average)
Discharge rate (pipe no. 5 and 6 = 2.24 lps) = 1.223 mm/min.(per 110 $m^2$)
Total duration of water supply = 25.00 minutes
Total volume of water supply = 30.58 mm
Total vol. of runoff measured = 23.82 mm.
Date : 30 November 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 2.11.00 | 0 | 0 | 0 | 0 | | supply start |
| 2.14.30 | 4.28 | 0 | 0 | 0 | | (Runoff start) |
| 2.20.00 | 11.01 | 7 | 0.35 | 3.18 | | |
| 2.21.00 | 12.23 | 9.7 | 0.485 | 4.41 | 20900 | |
| 2.22.00 | 13.46 | 12.1 | 0.605 | 5.50 | 21300 | |
| 2.23.00 | 14.68 | 14.4 | 0.72 | 6.55 | 21200 | Sample no. 82 |
| 2.24.00 | 15.90 | 17 | 0.85 | 7.73 | 20700 | |
| 2.25.00 | 17.12 | 19.2 | 0.96 | 8.73 | 20400 | |
| 2.26.00 | 18.35 | 21.9 | 1.095 | 9.95 | 20400 | |
| 2.27.00 | 19.57 | 24.3 | 1.215 | 11.05 | 19800 | |
| 2.28.00 | 20.79 | 27 | 1.35 | 12.27 | 19700 | |
| 2.29.00 | 22.02 | 29.3 | 1.465 | 13.32 | 19300 | |
| 2.30.00 | 23.24 | 32.1 | 1.605 | 14.59 | 19100 | |
| 2.31.00 | 24.46 | 34.6 | 1.73 | 15.73 | 18600 | |
| 2.32.00 | 25.69 | 36.6 | 1.83 | 16.64 | 18000 | Sample no. 83 |
| 2.33.00 | 26.91 | 38.9 | 1.945 | 17.68 | 18400 | |
| 2.34.00 | 28.13 | 41.7 | 2.085 | 18.95 | 17800 | |
| 2.35.00 | 29.36 | 44.3 | 2.215 | 20.14 | 17700 | |
| 2.36.00 | 30.58 | 46.6 | 2.33 | 21.18 | 17300 | Supply stop |
| 2.37.00 | | 48.9 | 2.445 | 22.23 | 16700 | |
| 2.38.00 | | 50.8 | 2.54 | 23.09 | 16100 | |
| 2.39.00 | | 51.9 | 2.595 | 23.59 | 15600 | |
| 2.40.00 | | 52.1 | 2.605 | 23.68 | 14600 | |
| 2.41.00 | | 52.4 | 2.62 | 23.82 | 13700 | Sample no. 84 |

## 13. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 5 %
Area of plot = 110 sq.m.
Soil moisture content : (17.6, 22.0, 22.0, 20.9, 22.9) = 21.08 % (average)
Discharge rate (pipe no. 2, 3, 4 and 5= 4.06 lps) = 2.213 mm/min.(per 110 $m^2$)
Total duration of water supply = 17.00 minutes
Total volume of water supply = 37.62 mm
Total vol. of runoff measured = 30.68 mm.
Date : 28 November 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 12.03.00 | 0 | 0 | 0 | 0 | | supply start |
| 12.06.00 | 6.64 | 0 | 0 | 0 | | (Runoff start) |
| 12.10.00 | 15.49 | 11.2 | 0.56 | 5.09 | 19800 | |
| 12.11.00 | 17.70 | 15.7 | 0.785 | 7.14 | 20000 | Sample no. 65 |
| 12.12.00 | 19.92 | 19.6 | 0.98 | 8.91 | 19200 | |
| 12.13.00 | 22.13 | 25 | 1.25 | 11.36 | 18300 | |
| 12.14.00 | 24.34 | 28.3 | 1.415 | 12.86 | 18000 | |
| 12.15.00 | 26.56 | 32.9 | 1.645 | 14.95 | 17700 | |
| 12.16.00 | 28.77 | 37.3 | 1.865 | 16.95 | 17100 | Sample no. 66 |
| 12.17.00 | 30.98 | 42.4 | 2.12 | 19.27 | 17500 | |
| 12.18.00 | 33.20 | 47.2 | 2.36 | 21.45 | 16600 | |
| 12.19.00 | 35.41 | 51.3 | 2.565 | 23.32 | 16600 | |
| 12.20.00 | 37.62 | 56 | 2.8 | 25.45 | 16000 | Supply stop |
| 12.21.00 | | 60.8 | 3.04 | 27.64 | 15900 | Sample no. 67 |
| 12.22.00 | | 64.8 | 3.24 | 29.45 | 15100 | |
| 12.23.00 | | 66.9 | 3.345 | 30.41 | 15100 | |
| 12.24.00 | | 67.4 | 3.37 | 30.64 | 14900 | |
| 12.26.00 | | 67.5 | 3.375 | 30.68 | 13300 | No runoff |

## 14. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 5 %
Area of plot = 110 sq.m.
Soil moisture content : (21.2, 21.5, 19.5, 10.1) = 18.10 % (average)
Discharge rate (pipe no. 2, 3, 4 and 5= 4.06 lps) = 2.213 mm/min.(per 110 $m^2$)
Total duration of water supply = 19.00 minutes
Total volume of water supply = 42.05 mm
Total vol. of runoff measured = 30.73 mm.
Date : 26 November 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 2.30.00 | 0 | 0 | 0 | 0 | | supply start |
| 2.33.45 | 8.30 | 0 | 0 | 0 | | (Runoff start) |
| 2.37.00 | 15.49 | 6.7 | 0.335 | 3.05 | | |
| 2.38.00 | 17.70 | 9.8 | 0.49 | 4.45 | 25600 | |
| 2.39.00 | 19.92 | 12.8 | 0.64 | 5.82 | 24400 | |
| 2.40.00 | 22.13 | 15.7 | 0.785 | 7.14 | 28300 | |
| 2.41.00 | 24.34 | 19.7 | 0.985 | 8.95 | 30000 | |
| 2.43.00 | 28.77 | 27.8 | 1.39 | 12.64 | 28900 | Sample no. 53 |
| 2.44.00 | 30.98 | 32.2 | 1.61 | 14.64 | 27900 | |
| 2.45.00 | 33.20 | 35.3 | 1.765 | 16.05 | 27400 | |
| 2.46.00 | 35.41 | 40.1 | 2.005 | 18.23 | 27600 | |
| 2.47.00 | 37.62 | 44.5 | 2.225 | 20.23 | 27500 | |
| 2.48.00 | 39.83 | 48.7 | 2.435 | 22.14 | 28400 | |
| 2.49.00 | 42.05 | 53.6 | 2.68 | 24.36 | 28900 | Supply stop |
| 2.50.00 | | 58.4 | 2.92 | 26.55 | 28600 | |
| 2.51.00 | | 64 | 3.2 | 29.09 | 27700 | |
| 2.52.00 | | 66.8 | 3.34 | 30.36 | 25600 | |
| 2.52.30 | | 67.2 | 3.36 | 30.55 | 24200 | |
| 2.53.00 | | 67.5 | 3.375 | 30.68 | 23200 | |
| 2.54.00 | | 67.6 | 3.38 | 30.73 | 25100 | Sample no. 54 |
| 2.55.00 | | 67.6 | 3.38 | 30.73 | 24900 | No runoff |

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## 15. Observed data of Artificial (Flooding water supply) Events

Slope of plot = 5 %
Area of plot = 110 sq.m.
Soil moisture content : (24.5, 25.4, 25.7, 27.3, 23.4) = 25.30 % (average)
Discharge rate (pipe no. 1, 5 and 6 = 3.28 lps) = 1.789 mm/min.(per 110 $m^2$)
Total duration of water supply = 18.00 minutes
Total volume of water supply = 32.20 mm
Total vol. of runoff measured = 29.45 mm.
Date : 8 December 2012

| Time | Cum. Vol. of water supply (mm) | Measured Cumulative Runoff | | | Sediment (mg/lit) (measured from instrument) | Remarks |
|---|---|---|---|---|---|---|
| | | From 1 slot (cm.) (depth measured in tank) | From 5 slots (cum) | From 5 slots (mm) (Vol./Area) | | |
| 11.55.00 | 0 | | | 0 | | supply start |
| 11.57.00 | 3.58 | | | | | (Runoff start) |
| 12.00.00 | 8.94 | 7.1 | 0.355 | 3.23 | 18700 | |
| 12.01.00 | 10.73 | 10.6 | 0.53 | 4.82 | 16700 | |
| 12.02.00 | 12.52 | 14.4 | 0.72 | 6.55 | 15600 | |
| 12.03.00 | 14.31 | 18.5 | 0.925 | 8.41 | 14700 | |
| 12.04.00 | 16.10 | 22.7 | 1.135 | 10.32 | 13800 | Sample no. 99 |
| 12.05.00 | 17.89 | 26.2 | 1.31 | 11.91 | 13200 | |
| 12.06.00 | 19.68 | 30.4 | 1.52 | 13.82 | 12900 | |
| 12.07.00 | 21.46 | 34.2 | 1.71 | 15.55 | 12600 | |
| 12.08.00 | 23.25 | 37.9 | 1.895 | 17.23 | 12400 | |
| 12.09.00 | 25.04 | 41.7 | 2.085 | 18.95 | 12200 | Sample 100 |
| 12.10.00 | 26.83 | 45.5 | 2.275 | 20.68 | 12300 | |
| 12.11.00 | 28.62 | 49.1 | 2.455 | 22.32 | 12100 | |
| 12.12.00 | 30.41 | 52.9 | 2.645 | 24.05 | 12000 | |
| 12.13.00 | 32.20 | 56.4 | 2.82 | 25.64 | 11700 | Supply stop |
| 12.14.00 | | 60.5 | 3.025 | 27.50 | 11700 | |
| 12.15.00 | | 63.4 | 3.17 | 28.82 | 11200 | |
| 12.16.00 | | 64.1 | 3.205 | 29.14 | 11100 | |
| 12.17.00 | | 64.6 | 3.23 | 29.36 | 11000 | |
| 12.18.00 | | 64.8 | 3.24 | 29.45 | 10400 | Sample 101 |

## Appendix - C

**Calculation of Sediment Yield in the laboratory (For Natural rainfall events)**

| Sample/ Bottle No. | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Slope of plot (%) | 5% | 3% | 1% | 5% | 3% | 1% | 5% | 3% | 1% | 5% | 3% | 1% | 5% | 3% | 1% |
| Sample collection date (Year 2012) | 12-Sep | 12-Sep | 12-Sep | 13-Sep | 13-Sep | 13-Sep | 14-Sep | 14-Sep | 14-Sep | 17-Sep | 17-Sep | 17-Sep | 18-Sep | 18-Sep | 18-Sep |
| Volume of sample (ml.) | 990 | 1000 | 990 | 980 | 965 | 995 | 990 | 980 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| Weight of pan (gm.) | 620 | 581 | 578 | 626 | 581 | 627 | 583 | 626 | 581 | 626 | 581 | 626 | 581 | 626 | 581 |
| Dry wt. of sample + pan(gm.) | 631 | 588 | 584 | 636 | 584 | 629 | 588 | 629 | 584 | 630.5 | 583.5 | 628 | 586 | 628.5 | 583 |
| Dry wt. of sediment (gm) | 11 | 7 | 6 | 10 | 3 | 2 | 5 | 3 | 3 | 4.5 | 2.5 | 2 | 5 | 2.5 | 2 |
| Concentration of sediment (mg/lit) | 11111 | 7000 | 6061 | 10204 | 3109 | 2010 | 5051 | 3061 | 3000 | 4500 | 2500 | 2000 | 5000 | 2500 | 2000 |

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## Appendix - D

### (i) Grain Size Analysis

**Sieve Analysis**

Date Tested: October 9, 2012

Sample Number: **Plot of 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 (W) (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 gm

Weight Loss during Lab work = (Wd - Wr)/Wd x 100 = 0.47 % < 2 %    OK

Gravel = 0 %
Sand = 81.52 %
Fines = 18.02 %

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## (ii) Grain Size Analysis

**Sieve Analysis**

Date Tested: October 9, 2012

Sample Number: **Plot of 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 (W) (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 gm

Weight Loss during Lab work = (Wd - Wr)/Wd x 100 = 0.51 % < 2 % OK

Gravel = 0 %
Sand = 73.22 %
Fines = 26.27 %

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## (iii) Grain Size Analysis

**Sieve Analysis**

Date Tested: October 9, 2012

Sample Number: **Plot of 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 | |

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Total Weight (Wr) = 497.481 gm

Weight Loss during Lab work = (Wd - Wr)/Wd x 100 = 0.51 % < 2 %    OK

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

## Appendix - E

## (i) Infiltration Test (Double Ring Infiltrometer)

**Plot = 1% slope**

Place : Toda Kalyanpur

Diameter of inner circle, d = 20 cm

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

Date: 6th October 2012

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| S.No. | Time | Time Interval | Cumulative Time | Volume of Water Added | Infiltration (from col. 5) | Infiltration Capacity (from col. 3 & 6) |
| | | minute | minute | ml ($cm^3$) | mm | mm/hr |
| 1 | 10:35 am | 0 | Start = 0 | | | |
| 2 | 10:40 am | 5 | 5 | 148 | 4.71 | 56.53 |
| 3 | 10:45 am | 5 | 10 | 80 | 2.55 | 30.56 |
| 4 | 10:55 am | 10 | 20 | 136 | 4.33 | 25.97 |
| 5 | 11:05 am | 10 | 30 | 94 | 2.99 | 17.95 |
| 6 | 11:25 am | 20 | 50 | 156 | 4.97 | 14.90 |
| 7 | 11:45 am | 20 | 70 | 72 | 2.29 | 6.88 |
| 8 | 12:05 pm | 20 | 90 | 66 | 2.10 | 6.30 |
| 9 | 12:25 pm | 20 | 110 | 62 | 1.97 | 5.92 |
| 10 | 12:45 pm | 20 | 130 | 54 | 1.72 | 5.16 |
| 11 | 1:15 pm | 30 | 160 | 60 | 1.91 | 3.82 |
| 12 | 1:45 pm | 30 | 190 | 56 | 1.78 | 3.57 |
| 13 | 2:15 pm | 30 | 220 | 58 | 1.85 | **3.69** |

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## (ii) Infiltration Test (Double Ring Infiltrometer)

**Plot = 3% slope**

Place : Toda Kalyanpur

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

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

Date: 5th October 2012

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| S.No. | Time | Time Interval | Cumulative Time | Volume of Water Added | Infiltration (from col. 5) | Infiltration Capacity (from col. 3 & 6) |
| | | minute | minute | ml (cm$^3$) | mm | mm/hr |
| 1 | 3:25 pm | 0 | Start = 0 | | | |
| 2 | 3:30 pm | 5 | 5 | 116 | 3.69 | 44.31 |
| 3 | 3:35 pm | 5 | 10 | 66 | 2.10 | 25.21 |
| 4 | 3:45 pm | 10 | 20 | 116 | 3.69 | 22.15 |
| 5 | 3:55 pm | 10 | 30 | 82 | 2.61 | 15.66 |
| 6 | 4:15 pm | 20 | 50 | 174 | 5.54 | 16.62 |
| 7 | 4:35 pm | 20 | 70 | 116 | 3.69 | 11.08 |
| 8 | 4:55 pm | 20 | 90 | 102 | 3.25 | 9.74 |
| 9 | 5:15 pm | 20 | 110 | 96 | 3.06 | 9.17 |
| 10 | 5:35 pm | 20 | 130 | 92 | 2.93 | 8.79 |
| 11 | 5:55 pm | 20 | 150 | 84 | 2.67 | 8.02 |
| 12 | 6:25 pm | 30 | 180 | 66 | 2.10 | 4.20 |
| 13 | 6:55 pm | 30 | 210 | 60 | 1.91 | 3.82 |
| 14 | 7:25 pm | 30 | 240 | 58 | 1.85 | **3.69** |

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## (iii) Infiltration Test (Double Ring Infiltrometer)

**Plot = 5% slope**

Place : Toda Kalyanpur

Diameter of inner circle, d = 20.0 cm

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

Date: 5th October 2012

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| S.No. | Time | Time Interval | Cumulative Time | Volume of Water Added | Infiltration (from col. 5) | Infiltration Capacity (from col. 3 & 6) |
|  |  | minute | minute | ml ($cm^3$) | mm | mm/hr |
| 1 | 10:50 am | 0 | Start = 0 |  |  |  |
| 2 | 11:00 am | 10 | 10 | 146 | 4.65 | 27.88 |
| 3 | 11:20 am | 20 | 30 | 110 | 3.50 | 10.50 |
| 4 | 11:40 am | 20 | 50 | 54 | 1.72 | 5.16 |
| 5 | 12:00 pm | 20 | 70 | 60 | 1.91 | 5.73 |
| 6 | 12:20 pm | 20 | 90 | 26 | 0.83 | 2.48 |
| 7 | 12:40 pm | 20 | 110 | 78 | 2.48 | 7.45 |
| 8 | 1:00 pm | 20 | 130 | 46 | 1.46 | 4.39 |
| 9 | 1:30 pm | 30 | 160 | 40 | 1.27 | 2.55 |
| 10 | 2:00 pm | 30 | 190 | 38 | 1.21 | 2.42 |
| 11 | 2:30 pm | 30 | 220 | 44 | 1.40 | 2.80 |
| 12 | 3:00 pm | 30 | 250 | 42 | 1.34 | **2.67** |

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# LIST OF PUBLICATIONS

1. **Shrestha, R.K.**, Mishra, S.K., and Pandey, A. (2013), 'Curve number affected by slope of experimental plot having maize crop,' Journal of Indian Water Resources Society. (Manuscript ID – 1345) (Accepted)

2. Mishra, S.K., Chaudhary, A., **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)**. (Under Review)

3. Mishra, S.K., Chaudhary, A., **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).** (Under Review)

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