Module 203

Runoff Concepts.EDC

Engineering Hydrology Training Series

Module 203-Runoff Concepts

Module Description

Objectives

Upon completion of this module, the participant will be able to:

- Explain the three types of runoff.
- List and explain the disposition of rainfall.
- Explain the NRCS Runoff Equation and future procedures.
- Perform at ASK level 3 (perform with supervision).

Prerequisites

Modules 101-Introduction to Hydrology; 102-Precipitation; 103-Runoff Concepts

Content

This module presents several important physical aspects pertaining to the prediction of runoff from rainfall and the important effects that soils and land use and management have upon runoff.

Introduction

Runoff is that portion of precipitation that makes its way toward stream channels, lakes, or oceans as surface flow. The intent of this module is to provide you with a basic understanding of the principal factors that pertain to the prediction of surface runoff from precipitation.

Surface runoff is the primary cause of soil erosion and is therefore an important item in SCS's goal of reducing soil erosion and improving water quality. Excess surface runoff causes flooding. Flood runoff amounts and peak discharges are required for the design of most conservation structural measures. Peak discharges are discussed in Hydrology Training Series Module 106.

In this module, you will cover the three types of runoff, disposition of rainfall, and go into some depth on the SCS Runoff Equation and future procedures.

Runoff

Key point

There are three major *types of runoff, depending* on *the source; surface flow, interflow, and base flow. These were discussed in Hydrology Training Series Modules 101 and 103.*

Runoff is that portion of precipitation that makes its way towards stream channels, lakes, or oceans as surface flow or subsurface flow. Before runoff can occur, precipitation must satisfy the demands of evaporation, interception, infiltration, and surface retention.

Surface Flow

Surface flow is water that has remained on the surface of the ground and moves as overland flow, shallow concentrated flow or channel flow.

Interflow

Interflow is water that infiltrates the upper soil profile and then moves laterally through the soil profile and, eventually, reappears as surface flow at a downstream point. Lateral flow is caused by a relatively impervious zone that prevents or restricts downward movement of water. Interflow may be a significant part of the total direct runoff under certain soil, geological, or land use conditions. It is common in forested areas on moderate or steep slopes with permeable soils over bedrock. Forest and ground litter provide high infiltration for water to enter the soil, and slopes provides energy for lateral flow.

Significant amounts of interflow are not common in cultivated soils on small watersheds and are not usually considered in SCS methods of estimating runoff. Interflow may return to the surface so quickly that it is not possible to separate surface flow and interflow. Interflow may have an impact on wetlands and water quality.

Base flow

Base flow is water from a saturated ground water zone that underlies most land areas. It usually appears at a downstream location in a watershed where the channel elevation is lower than the groundwater table. Groundwater provides stream flow during dry periods having minor or no precipitation. Groundwater may enter streams or channels as seepage along the lower banks of the channel or as spring flow. This type of flow is not normally a big contributor to flood runoff; however, it should be considered when designing structures or determining watershed yield.

Disposition of Rainfall

Key point

Principal climatic and physical factors that affect the disposition of rainfall are evaporation, interception, infiltration, and surface storage. These factors have a *varying effect during the rainfall event and are usually divided into two conditions:*

- *before runoff begins, and*
- *after runoff begins.*

Evaporation

Evaporation is the process by which water is changed from the liquid state into the gaseous state through the transfer of heat energy. While evaporation is the name usually given to this physical process, it includes:

1. Evaporation from free water surfaces,

2. Soil surface, moisture intercepted by plants, and

3. Transpiration by plants.

For convenience, evaporation (soil surface) and transpiration (plants) on land areas are often combined and referred to as evapotranspiration. Evapotranspiration is referred to as consumptive use.

The evaporation rate from soil or land surfaces is governed by the same factors that affect evaporation from water surfaces. The differences, however, are the nature of the surfaces, their ability to transmit water, and the availability of moisture.

Interception

Interception is precipitation which collects on the plant canopy. It ultimately evaporates back into the atmosphere and is generally lost as far as surface runoff is concerned. However, it is an abstraction from precipitation. The four primary factors which influence the amount of interception are:

1. Species of vegetation,

2. Growth stage of vegetation,

3. Season of the year, and

4. Wind velocity.

When the first drops of rain in any storm strike the leaves of vegetation, they are almost completely retained as droplets or as thin film over the surface of the leaves.

Only a small amount of rain reaches the ground until the vegetation has retained its maximum amount of stored water. After vegetation is completely saturated, the net interception would be zero were it not for considerable evaporation from the enormous wet surface of the foliage. Evaporation from plant surfaces continues during the entire rainfall event.

Wind affects interception in two distinct ways:

- It reduces the maximum storage by jarring free drops from the foliage; and,

- It increases the rate of evaporation from the plant surfaces.

These effects act in opposite directions. The net effect of wind during a storm may increase or decrease the total interception, depending upon wind velocity throughout the storm, duration of the storm, and humidity of the air.

Total interception during a storm consists of two parts:

- that required to satisfy the surface storage of vegetation; and

- That which evaporates during periods of rainfall.

- Seasonal variations of interception for crops result from growth stages and the resulting change in the surface area of foliage. The amount of interception by species of vegetation depends on the amount of foliage, storage area, and surface retention properties of the plant.

Surface Retention

Surface retention, also known as surface storage and initial abstraction, refers to that part of precipitation which does not appear as infiltration or surface runoff during or immediately after the storm event. Thus, surface retention includes:

- Interception by vegetation
- Depression storage
- Evaporation during precipitation.

Surface retention does not include water temporarily stored enroute to the stream system. This temporarily stored water is known as surface detention. After interception and the surface puddles of depression storage, the remaining precipitation forms a film of water over the soil surface. This film of water flows over land and is designated overland flow until it enters a channel system. It is then known as surface flow.

If large depression areas are present, the retention capacity of the depression must be determined to analyze the effect on the total surface runoff. Large depression areas may store a portion or all of the surface runoff from the contributing drainage area.

Normally, depression storage for cultivated fields, grassland, and forest, and the combined elements of surface retention may be sizeable in magnitude, ranging from 0.5 to 1.5 inches. The magnitude of the surface storage decreases as the surface slope increases.

Conservation Treatment Practices

Conservation treatment practices can increase the magnitude of depression storage on the land surface. These practices include, but are not limited to: conservation tillage, ridge tillage, contour farming, gradient terraces, and closed end level terraces. Closed end level terraces may be designed to hold in excess of 2 inches of surface runoff.

Infiltration

Infiltration is the passage of water through the soil surface and into the soil. It is to be distinguished from percolation which is the movement of water within the soil.

The two phenomena are closely related, however, in that infiltration cannot continue unimpeded unless percolation provides sufficient space in the surface layer for the infiltrated water. Infiltration capacity under specified conditions decreases with duration and rainfall. The total volume of infiltration for a specified duration varies from soil to soil and with initial conditions in the same soil.

Porosity determines the storage available for the infiltrated water and also affects resistance to flow. Higher porosity increases the available storage and decreases the resistance to flow. Therefore, infiltration increases with porosity.

The effect of rainfall drop size on infiltration capacity is mostly due to its effect on the rate of compaction of the soil surface layer, and breaking down of the soil structure. Therefore, excessively large rain drops tend to reduce the amount of infiltration during the first few minutes of rainfall until such time as a sheet of water collects over the soil surface. The rate of infiltration varies directly with the rainfall intensity when the intensity is less than the infiltration capacity. However, the rainfall intensity has little noticeable effect on rate of infiltration when it exceeds the capacity rate.

Land Slope

Observations show that variations in slope between 1 and 16 per cent have very little effect on infiltration rate. For zero slope, infiltration rates increased slightly due to the increased pressure head which builds upon the soil surface.

The effects of vegetation on infiltration capacity are difficult to determine directly, because vegetation also exerts an influence on interception. Nevertheless, vegetation does increase infiltration compared to that for barren soil because:

- It retards surface flow, thus giving the water additional time to enter the soil surface.
- The root system of the plant makes the soil more pervious to infiltrating water.
- It shields the soil from raindrop impact and hence reduces rain packing.
- It increases the organic matter content in the upper layer of the soil.

The SCS Runoff Equation and The Future

History

The SCS equation has been in use for more than 25 years. It has provided a uniform basis for estimating the effects of land use treatment and land use changes on volume of runoff under the wide range of climatic conditions found in the world.

The CN procedure continues to provide satisfactory answers for the type of hydrologic problems that it was developed to solve evaluating effects of land use changes and conservation practices on direct runoff. For situations in which continuous simulation of the hydrologic process is required, the lack of a time parameter in the curve number procedure is a significant restraint.

An alternative method for estimating runoff, based upon the development of infiltration curves, appears to offer the best opportunity for developing a more detailed procedure. The infiltration concept has been available for nearly 50 years; however, because of an inability to obtain quantitative information on many factors that affect infiltration, its use as a tool for evaluating the effects of land use changes has been limited.

Musgrave (1955) reviewed the major factors that affect infiltration. These include:

- Surface condition (of soil) and amount of protection against the impact of rain.
- Internal characteristics of soil mass, including pore size, depth or thickness of the permeable portion, degree of swelling of the clay and colloids, content of organic matter, degree of aggregation.
- Moisture content and degree of saturation.
- Duration of rainfall or application of water.
- Season of year and temperature of soil and water.

The continuing role of the Natural Resources Conservation Service is to provide technical assistance for application of natural resource conservation measures on the land. This requires that an infiltration-based model have the capability to reflect changes in infiltration resulting from changes in the land and soil characteristics that are due to conservation practices.

Green and Ampt

An infiltration model that appears to have this capability uses the Green and Ampt rate infiltration equation. Following Mein and Larson (1971) the Green and Ampt equation is:

$f = K\ (l + n¥_{1}/F)$

Where

f = Infiltration rate (cm/hr)

K = Hydraulic conductivity (cm/hr)

n = Available porosity

$¥_{1}$ = Wetting front capillary pressure head (cm) F = Infiltration amount (cm)

Brakensiek et al. (1980) have derived Green and Ampt infiltration equation parameters for 10 soil texture classes. They have indicated that the results can be used in sensitivity studies of the influence of soil variability on watershed hydrologic outputs. The Green and Ampt equation appears to have a wide applicability to modeling the infiltration process.

At present, SCS is better able to quantify many of the soil parameters that effect infiltration. An increasing amount of detailed data on soil characteristics are available, including unsaturated hydraulic conductivity, bulk density, and moisture content.

Two additional items that require attention before a workable field procedure can be developed using infiltration curves are:

- Prediction of the effects of management practices, tillage, rotation, and other factors on soil parameters such as bulk density and hydraulic conductivity.

- Development of a technique for estimating spatial variability of soil parameters. Measurements of soil parameters represent a point measurement, which can be useful for prediction only if it is made applicable for a significant area.

Future SCS Runoff Procedures

Future SCS runoff procedures will very likely include a hierarchy of processes. The lowest level may be a simplified curve number approach, ranging upward to an infiltration based storm runoff model where a detailed analysis is required.

Whether an infiltration based storm runoff model suitable for field use can be developed in the near future depends on:

- The amount of usable data available from research stations to determine the effects of management practice on soil parameters.
- Our success in identifying soil parameters for developing infiltration curves.
- The capability to handle the inherent spatial variability of the soil parameters and the effects of tillage practices, infiltration curves, and other factors.

Infiltration Approach/Curve Number Approach

The SCS Runoff Curve number procedure and concepts is explained in more detail in the National Engineering Handbook, Section 4, Hydrology, and in Hydrology Training Series Modules 104 and 204.

The CN technique was developed in SCS to solve an immediate problem-to predict the effects of proposed changes in land use and treatment on direct runoff. Several similar procedures
Preceded it during the 20 years before 1955, when the procedure was first described in a SCS handbook. **Since 1955, *however, the procedure has increasingly been used* in *applications that* its *author had not* intended. *This has generated substantial* criticism *regarding* its *perceived shortcomings.***

Although the procedure capably solves the type of problems for which it was developed, its wide use in the engineering profession, for a myriad of other types of problems, makes it almost mandatory that SCS and others thoroughly examine opportunities for improvement. Certain new data are available, particularly for soils that we expect will eliminate much of the subjective portion of the procedure. The Green and Ampt Infiltration equation is being examined by the U. S. Department of Agriculture, Agricultural Research Service, for application with parameters of saturated hydraulic conductivity, porosity, wetting front tension, and antecedent soil moisture. It may be difficult to determine changes in these parameters that reflect the runoff effects of changes in land use and treatment. Through current studies we hope to strengthen the curve number approach, and develop a hierarchy of procedures for estimating runoff from rainfall.

Comparison of Direct Runoff Prediction Approaches		
	Approach	
Factors	**Curve Number**	**Infiltration**
Precipitation	Rainfall Amount	Rainfall intensities or rainfall distribution and amount
Soil	Antecedent runoff condition (I, II, III) Hydrologic Soil Group HSG	Antecedent soil water storage (volume) by soil layer or soil depth Soil water properties by layers or soil depth, Le., bulk density, saturated conductivity, and water entry or bubbling pressure
Cover	**L**and use treatment or practice, hydrologic condition	Tillage influences on soil properties. Land use and treatment, practices' influences on surface properties. Ground cover (live or mulch), influences on surface properties.
Soil	Initial abstraction (I_a), assumed to be 0.2 (S)	Total infiltration prior to surface ponding
Surface	Included with initial abstraction (I_a)	Estimated soil surface storage as influenced by topography, land use, and tillage.
Interception	Included with initial abstraction I_a	Estimated interception storage by ground cover (live or mulch).

Table 1. Comparison of direct runoff prediction approaches.

Summary

You should now be able to list and define the three (3) major types of runoff and the four (4) factors that affect the disposition of rainfall. You should also have an understanding of the present SCS-CN runoff procedure and factors required for infiltration procedures; and know the differences between the CN and infiltration procedure.

Retain this Study Guide as a reference until you are satisfied that you have successfully mastered all the methods covered. It will provide an easy review at any time if you encounter a problem.

If you have had problems understanding the module or if you would like to take additional, related modules, contact your supervisor.

When you are satisfied that you have completed this module, remove the Certification of Completion (last page of the Study Guide), fill it out, and give it to your supervisor to submit, through channels, to your Training Officer.

Activity 1

At this time, complete Activity 1 in your study guide to review the material just covered. After finishing the Activity, compare your answers with the solution provided. When you are satisfied that you understand the material, continue with the study guide text.

1. List the three (3) major types of runoff.

a.

b.

c.

2. What are the four (4) elements that affect the disposition of rainfall?

a.

b.

c.

d.

3. List the three (3) elements that comprise surface retention.

a.

b.

c.

4. List the four (4) primary factors that influence interception.

a.

b.

c.

d.

Activity 2

At this time, complete Activity 2 in the study guide to review the material just covered. After finishing the Activity, compare your answers with the solution provided. When you are satisfied that you understand the material, continue with the Study Guide text.

1. In the SCS CN procedure, what is lacking that is a significant restraint when continuous simulation modeling is required?

2. What infiltration procedure is the SCS currently examining for use?

3. List the two (2) items that need additional development before an infiltration procedure can become a workable field procedure.

   a.

   b.

Activity 1

1. List the three (3) major types of runoff.

    a. *Surface runoff*

    b. *Interflow*

    c. *Baseflow*

2. What are the four (4) elements that affect the disposition of rainfall?

    a. *Evaporation*

    b. *Interception*

    c. *Surface retention*

    d. *Infiltration*

3. List the three (3) elements that comprise surface retention.

    a. *Interception* by *vegetation*

    b. Depression *storage*

    c. *Evaporation during* precipitation

4. List the four (4) primary factors that influence interception.
    a. Species *of vegetation*
    b. *Growth stage of vegetation*
    c. *Season of year*
    d. *Wind velocity*

Activity 2

1. In the NRCS CN procedure, what is lacking that is a significant restraint when continuous simulation modeling is required?

   CN procedure lacks a *time parameter for precipitation*.

2. What infiltration procedure is the NRCS currently examining for use?

   The Green *and Ampt infiltration procedure.*

3. List the two (2) items that need additional development before an infiltration procedure can become a workable field procedure.

   a. Prediction *of the effects of conservation practices.*

   b. *Development of* a *technique for estimating spatial variability of soil parameters.*