Hydrology Training Series

Module 103 - Runoff Concepts

Study Guide

Module Description

Objectives

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

1. List and define the three types of runoff.
2. List and explain the principal climatic factors that affect runoff.
3. Describe the major watershed factors that affect runoff.

The participant should be able to perform at ASK Level 3 (Perform with Supervision) after completing this module.

Prerequisites

Modules 101- Introduction to Hydrology and 102 - Precipitation

References

National Engineering Handbook, Section 4, Hydrology Engineering Field Manual
Technical Release 55-Urban Hydrology for Small Watersheds

Who May Take the Module

This module is intended for all NRCS personnel who use hydrology in their work.

Content

This module discusses runoff data, flood runoff, annual runoff, and three major types of runoff. The important climatic and watershed factors that affect the conversion of storm rainfall to runoff are also presented.

Introduction

Runoff is that portion of the 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 affect runoff. Surface runoff is the primary cause of soil erosion and is, therefore, an important item in NRCS's goals of reducing soil erosion and improving water quality. Surface runoff also causes flooding. Flood runoff amounts and peak discharges are also required for the design of most conservation structural measures. Peak discharge will be discussed in Module 106.

Runoff Data and Runoff

Surface runoff is the principal cause of soil erosion. Initial research studies on the relationship between runoff, rainfall, soils, vegetation, land slope, and other factors had the primary goal of finding effective and economical ways of reducing the amount and rate of runoff, which, in turn, would reduce erosion. NRCS has a broad and continuing need to improve our understanding of runoff and to find new methods to control or reduce runoff that are compatible with modem farming methods.

Measuring Runoff Rates

Our understanding and knowledge of runoff has been assisted by the continuous measurement of stream flow at gaging stations throughout the country. Most of these stations are operated by the U.S. Geological Survey, and the flow data are published in annual reports for each state. Many states have over 100 stations. The typical length of record may be 20 to 40 years.

For a given station, runoff data are reported in several ways, but usually as a rate of flow in cubic feet per second (cfs). In the Geological Survey reports, flow rates are reported as average daily values, and instantaneous peak flows are also reported for all peaks above a selected base value for that station

Runoff from a drainage area over a period of time is a volume and is usually expressed in acre-feet. For example, one acre-foot is the volume equal to a depth of one foot over one acre or 43,560 cubic feet. If we have an average rate of flow of 30 cfs during a 24 hour period, this will equal a volume of 2,592,000 cubic feet (24 hr x 60 min/hr x 60 see/min x 30 cfs), or 59.5 acre-feet (2,592,000/43,560).

Volume of runoff is also expressed as a depth in inches over the drainage area. In the above example, if the drainage area is 320 acres, the runoff volume of 59.5 acre-feet would equal 2.23 watershed inches.

*(*59.5 *ac-ft)(*12 *in/ft)/(*320 *ac)*=2.23 **watershed in.**

Flood Runoff

The most frequent use of runoff data by NRCS is for determining peak discharge for selected flood frequencies (for use in design of conservation measures).

Although there are a number of gaging stations in the country that provide a needed base of information on runoff, the majority of these gages involve drainage areas considerably larger than those of the typical conservation practice. Adjusting the gage data to apply to the smaller areas is difficult in most cases. Because we have adequate rainfall data for most sections of the country, ses has chosen to use rainfall data and factors obtained from extensive research studies to estimate flood runoff from rainfall.

The use of rainfall data also gives us the opportunity to consider a number of important factors that influence runoff in small watersheds. It also provides us with a means of estimating the effects of any land treatment or land use changes that are being considered.
In a few locations, surface runoff from snow melt may be the dominant cause of a flood, even for the smaller areas we are involved with. This occurs in some of the northern states and in the higher elevations of our mountain ranges. In these areas, flood runoff estimates are usually based on regional studies of measured stream flow data.

Water Yield

Another runoff data need of ses involves the design of structures with storage for beneficial use, such as rural water supply, irrigation, recreation, grade control, and livestock. For water supply studies, a seasonal duration of several months or an entire year is used. Because runoff is highly variable during a year and also from year to year, it is desirable to obtain data for a number of years. In order to make meaningful estimates of runoff on a frequency or probability basis, data for 20 to 30 years are desirable. Runoff studies for water supply storage are usually based on regional studies of stream gage data.

In higher rainfall areas of the country, the storage needed for certain uses may be small compared to the amount of available runoff. In these areas, small ponds for livestock or grade control are designed by general guidelines based on local experience.

Types of Runoff

There are three major types of runoff depending on the source: surface flow, interflow, and base flow. These were discussed in Module 101 and are expanded upon here.

Surface Flow

Surface flow is water that has remained on the surface and moves as overland or channel flow.

Interflow

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

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

Base flow

Base flow is water from a saturated ground water zone that underlies most land areas. It usually appears at a downstream location where the channel elevation is lower than the ground water table. Ground water provides the stream flow during dry periods having minor or no precipitation. Ground water may enter a channel as seepage along the lower banks of the channel. This type of flow is not normally a big contributor to flood runoff.

Climatic Factors That Affect Runoff

The principal climatic factors that affect the amount of runoff for a given watershed are rainfall duration and intensity, the season of the year, and the meteorologic and frozen soil conditions before the storm.

Rainfall Duration and Intensity

Total runoff for a storm is related to the rainfall duration and intensity. Duration is the length of the storm, and intensity is the rate at which it rains. Infiltration rate will usually decrease with time in the initial stages of a storm. Thus a storm of short duration may produce no runoff, whereas a storm of lesser intensity but of long duration could result in runoff.

Rainfall intensity influences both the rate and the volume of runoff. An intense storm exceeds the infiltration rate of the soil by a greater margin than does a gentle rain; thus, the total volume of runoff is greater for the intense storm even though total precipitation for the two rains is the same. The intense storm may actually decrease the infiltration rate because of its destructive action on the structure of the soil surface.

Season of the Year

In many areas, there is a definite seasonal pattern when major storms are likely to occur. The major watershed factors that affect runoff on a seasonal basis are the extent of vegetative cover and the moisture content of the soil. During the dormant season, vegetative cover is significantly reduced for cultivated fields and deciduous woodlands or forests. Cultivated fields are bare or may be limited to surface residues for several weeks prior to and following planting. In humid and semi-humid areas, there is a gradual increase in soil moisture during the dormant season.

Meteorologic Conditions Before the Storm

The climate during a period of 5 to 10 days before a storm may affect the soil moisture level at the time of the storm. High temperatures, winds, low humidity, and high solar radiation increase evaporation and transpiration. This reduces the soil moisture content, provides more storage, and increases infiltration. Low temperatures, high humidity, and limited solar radiation have the opposite effect.

Frozen Soil Conditions Before the Storm

Frozen soil and frost depth have a major impact on infiltration. A soil and land use condition that would normally have moderate or high infiltration rates will have rates near zero under frozen conditions. We are fortunate that our climatic pattern is such that we do not usually have intense rain storms during the season when soils are frozen. However, there have been numerous cases where major floods have resulted from moderate rainfall on frozen soils.

Note that the climatic factors are governed by location and that any changes we can make are very limited.

Watershed Factors That Affect Runoff

Watershed factors affecting runoff are land slope, shape, soil, and land use.

Land Slope

The principal effect of land slope is on the rate of runoff. Runoff will flow faster on a steeper slope. This results in higher peaks at downstream locations. The effect of land slope on the volume is usually minor.

Shape

The shape of the watershed has an effect on the rate of runoff. The rate of runoff will be lower for a long narrow watershed than for a fan-shaped watershed.

Soil

The type of soil has a major effect on runoff due to its infiltration rate. Infiltration is the flow of water through the soil surface into the soil. Pore size and distribution are important. In sands, the pores are stable since sand' particles do not crumble or swell. Soils with silt or clay are subject to breakup of the crumbs during raindrop impact and wetting. There is a melting of aggregate, and the very small particles floating on the surface penetrate and clog existing pores, reducing infiltration.

As infiltration continues, some of the voids between soil particles are filled with water. The remaining water continues its downward movement. The flow of water downward through the soil and below the surface is called transmission or percolation. As the rainfall continues and the storage in the upper soil layer is filled, the infiltration rate will be limited by the percolation rate of a lower soil layer. When the rate of rainfall exceeds the infiltration rate, the excess water will start flowing over the soil surface, and runoff begins.

NRCS has a wealth of information on soils. We have classified all soils according to their infiltration rate after prolonged wetting with all vegetation removed. The soils are divided into four hydrologic groups:

Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission (greater than 0.30 in/hr).

Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15 - 0.30 in/hr).

Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05 - 0.15 in/hr).

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0.0 - 0.05 in/hr).

A list of soils and their hydrologic group may be found in the following references:

1. Engineering Field Manual, Chapter 2.
2. National Engineering Handbook, Section 4, Hydrology, Chapter 7.
3. Technical Release 55, Urban Hydrology for Small Watersheds, Second Edition, (June 1986), Appendix A

Land Use Vegetation

Vegetation has a significant influence on infiltration, and therefore, on runoff. Many studies have shown that for the same soils under the same conditions, infiltration is highest for forest and grassland, lower for cultivated field crops and lower still for fallow or bare soil. Root systems perforate the soil, keeping it unconsolidated and porous. Organic matter promotes a crumb structure and improves permeability. Vegetation and crop residues protect the soil surface from raindrop impact and reduce particle breakup. Vegetation provides surface roughness and obstruction to flow on the surface. This reduces the velocity of flow, providing additional time for infiltration.

NRCS uses the term "hydrologic condition" to describe or classify a given land use or vegetative cover. The condition may be rated as poor, fair, or good. This refers to the density of plant and residue cover, the amount of year-round cover, and the amount of surface roughness. The better the condition, the greater the infiltration and the less the volume runoff. This is discussed further in Module 104.

Summary

You should now be able to list and define three major types of runoff, list and explain the principal climatic factors that affect runoff, and describe the major watershed factors that affect runoff'.

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 should 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 sheet last page of the Study Guide), fill it out, and give it to your supervisor to submit, through channels, to your State or NTC Training Officer.

Activity 1

At this time, complete Activity 1 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. Which is *not* one of the three major types of runoff? Circle one.
    a. Surface flow
    b. Base flow
    c. Interflow
    d. Flood flow

2. List the principal climatic factors that affect runoff.

3. List the major watershed factors that affect runoff

Activity 1 Solution

At this time, complete Activity 1 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. Which is *not* one of the three major types of runoff? Circle one.
   a. Surface flow
   b. Base flow
   c. Interflow
   d. Flood flow
2. List the principal climatic factors that affect runoff.
   a. Rainfall duration and intensity.
   b. Season of the year of storm occurrence.
   c. Climatic conditions (temperature, wind, humidity, and solar radiation during a five to ten day period before the storm).
   d. Frozen soil and depth of frost at the time of the storm.

3. List the major watershed factors that affect runoff
   a. Land slope
   b. Soil
   c. Land Use – Vegetation
   d. Shape