Module 204

Runoff Curve Numbers

Module Description

Objectives

Upon completion of this module, participants will be able to:

. Explain the development of the runoff curve number procedure.

. Develop a CN for a unique or a specific soil-cover complex.

. Perform at ASK level 3 (perform with supervision).

Prerequisites

Module 103-Runoff Concepts; Module 104-Runoff Curve Numbers

References

Hydrology, Section 4, *National Engineering Handbook.*

Robert E. Rallison "Origin and Evolution of The NRCS Runoff Equation", Proceeding of the Symposium on Watershed Management 80 ASCE Boise, ID, July 1980.

Donald E Woodward "Runoff Curve Number for Semiarid Range and Forest Conditions" 1973 Annual Meeting ASAE Paper No. 73-209.

Who may take this course

All hydraulic engineers, area level engineers, technicians, and others who need to have an understanding of physical aspects pertaining to the prediction of runoff from precipitation.

Content

This module presents the history and development process of the runoff curve numbers and will allow the participants to develop a curve number for a unique soil-cover complex.

Introduction

This module allows the student to understand how a runoff curve number was developed for a given hydrologic soil-cover complex.
This module will allow the student to learn the history behind the development of curve numbers. This module will also allow the student to develop a runoff curve number for a unique soil-cover complex.

In 1954, the Soil Conservation Service (SCS) developed a unique procedure for estimating direct runoff from storm rainfall. This procedure was the end product of a major field investigation and the work of numerous early investigators such as Vic Mockus, L.K Sherman, RG. Andrews, and H.O. Orgosky. A major catalyst for getting this procedure to the field was the passage of the Watershed Protection and Flood Prevention Act (Public Law 83-566) in August, 1954.

According to Andrews, data from the experimental watersheds were meager and covered only a small fraction of the conditions encountered in any watershed. To obtain the basic data necessary to evaluate the effects of proposed conservation measures, extensive infiltrometer studies were made.

Runoff Curve Number Development

Thousands of infiltrometer runs were made during the late 1930s and early 1940s with the vast majority using the sprinkling-type infiltrometer.

Using primarily the data from infiltrometer plots and small watersheds, three private consultants-W.W. Homer, R.E. Horton, and L.K. Sherman-were employed by NRCS to aid in developing a logical and reasonable method for estimating runoff from any given plot of land under various cover conditions. Homer credited Horton with much of the pioneering work of characterizing infiltration capacity curves, while he concentrated on the development of infiltration capacity from small watershed data. The results of these studies were a series of rainfall retention rate curves. These curves were used with precipitation-excess and time-of-excess curves, to obtain the volume of runoff from any given land unit. Because this method required the availability of recording rain gauges, its use was limited in many areas. For this reason, NRCS never adopted this approach.

Other methods of estimating runoff, devised during the early 1940s, used infiltration data as background material. Andrews grouped the infiltrometer data from Texas, Oklahoma, Arkansas, and Louisiana and found texture class was the only soil characteristic that was consistent within each group.

From this data he developed a graphical procedure for estimating runoff from rainfall for combinations of soil texture, type and amount of cover, and conservation practices. This association of soils and cover variable was referred to as a soil-cover complex. This is the beginning of the concept of combining soil and cover data into a soil-cover complex.

Rainoff-Runoff Relationships

L. K. Sherman was one of the first to propose plotting direct runoff versus storm rainfall. Building on this idea, Mockus proposed that surface runoff could be estimated from the following information:

- Soils: types, areal extents, and locations
- Land use: kinds, areal extents, and locations
- Antecedent rainfall
- Duration of a storm and associated rainfall amount
- Average annual temperature and date of storm.

Mockus combined these parameters into an index value, b, which was solved from the following equation:

$$b = .\frac{374(10)^{.229m}C^{1.061}}{T^{1.990}D^{1.333}(10)^{2.271\left(\frac{S}{D}\right)}}$$

where:

M = 5-day antecedent rainfall, inches

C = cover practice index

T = seasonal index, which is a function of date and temperature (oF)

D = duration of storm, hours

S = soils index

Resulting b values were used as the second independent variable (P being the initial independent variable) in graph of P vs. Q, in which:

$Q = P[1 - 10^{-bP}]$

where:

Q = direct runoff, inches

P = storm rainfall, inches

The slope, b, in the above equation is related to watershed and storm characteristics, and it is possible to predict Q for any storm on any watershed when these characteristics are known for that watershed and storm. The form of this equation allows for the Q to become parallel to the equality line (450 slope line). This means that the loss tends to become a constant value after a large rainfall amount (fig. 1).

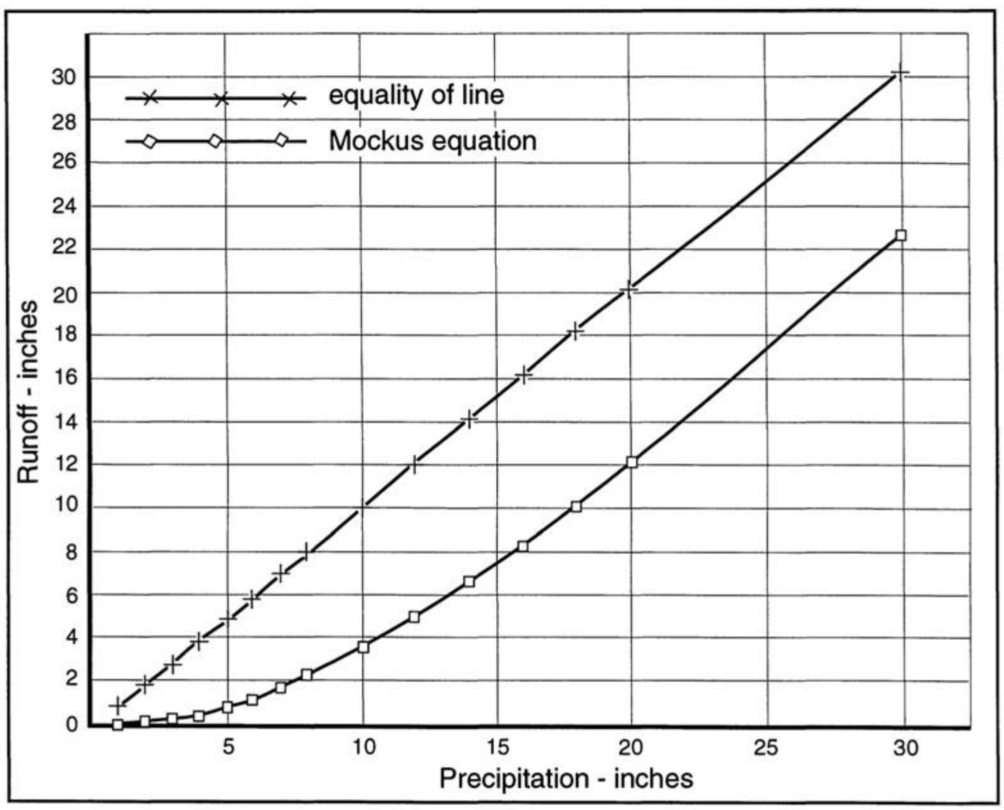


Figure 1. Graph of Mockus Equation.

Development of Curve Numbers

Curve numbers are developed from gauged watershed data where soils, cover, and hydrologic conditions were known. Daily rainfall and runoff volumes are used for the annual floods at a site. Table 1 shows the watersheds used to develop the initial curve numbers.

Data are plotted as rainfall versus runoff (P versus Q) on arithmetic graph paper. A grid of plotted curve numbers for la = 0.2S is laid over the graph paper, and the median CN selected. The curve number represents the average of median site values for hydrologic soils groups, cover, and hydrologic conditions. Not all soils, cover types and hydrologic conditions were represented by the available watershed data.

State	Town	State	Town
Arizona	Safford	New Mexico	Albuquerque
Arkansas	Bentonville	New Mexico	Mexican Springs
California	Watsonville	New York	Bath
Colorado	Colorado Springs	Ohio	Coshocton
Georgia	Americus	Ohio	Hamilton
Idaho	Emmett	Oklahoma	Muskogee
Illinois	Edwardsville	Oregon	Newberg
Maryland	Hagerstown	Texas	Garland
Montana	Culbertson	Texas	Vega
Nebraska	Hastings	Texas	Waco
New Jersey	Freehold	Virginia	Danville
		Wisconsin	Fennimore

Table 1. Watersheds used to develop initial curve numbers.

The data plotted are the largest annual daily runoff event and its associated daily precipitation. This means only one event per year is plotted. There should be at least 15 years of data used to develop a meaningful relationship between P and Q. It is hoped that the values cover a wide range of P and Q. The selected watershed should be as homogeneous as possible. It should be remembered that the selected curve number represents a single soil-cover complex. Figure 2 is an example of the P-Q relationship for a typical watershed used to determine the CN for a selected soil-cover complex.

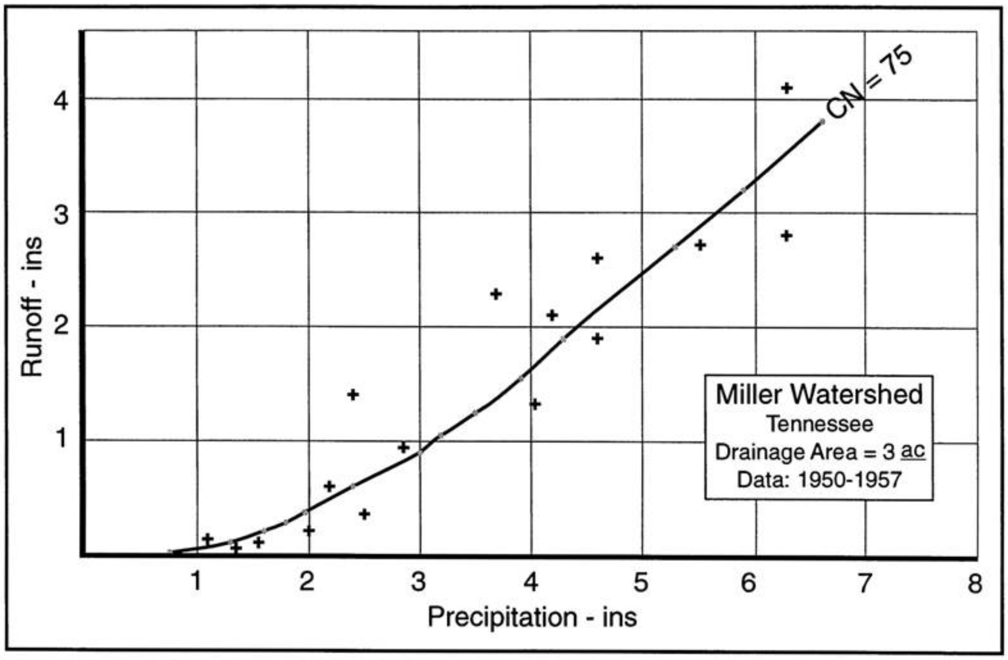


Figure 2. P-Q for a typical watershed.

8. To explain the rationale used to develop an individual curve number, Mockus wrote: "The curve number associated with the soil-cover complexes are median values, roughly representing average conditions on a watershed. We took the average condition to mean average soil moisture conditions because we had to ignore rainfall intensity." This concept has been clarified to mean the average soil moisture condition when the flood occurred. This means that the average soil moisture conditions when floods occur in Arizona are different than the soil moisture conditions when flood occur in New Jersey.

The sample variation in CN for a given watershed data set can be due to infiltration, evapotranspiration, soil moisture, lag time, rainfall intensity, temperature, etc. Antecedent runoff conditions are used to represent this variability. ARC I is the lower enveloping CN, ARC II the median CN, and ARC III the upper enveloping CN.

CN Development for a Unique or Special Soil-Cover Complex

Initially, the runoff curve number concept was to be used withsingle event models to estimate volumes of direct runoff. The peak flows associated with these direct runoff estimates were used to design conservation measures and make watershed evaluation studies.

Now curve numbers are being used in a wide range of conditions or uses outside the original development concept. For example, curve numbers are being used in various ARS continuous simulation watershed models to partition rainfall into runoff. These continuous simulation models include EPIC, SWRRB, GLEAMS, EPIC, and others. Each model is a continuous simulation model that operates on a daily time step. Each model was developed for a different purpose.

Curve Number Aligner

Mockus developed a technique to estimate curve numbers for the other hydrologic soil group with the same land use and hydrologic condition. This technique is known as the curve number Aligner. Use of the Aligner is shown in figure 3. The Aligner is to be used with land uses that do not involve mechanical treatment such as terraces, etc. Curve numbers that do not involve mechanical treatment will plot at a 45° slope on the graph. Urban and mechanical treatment land use curve numbers will plot a different slope on the graph.

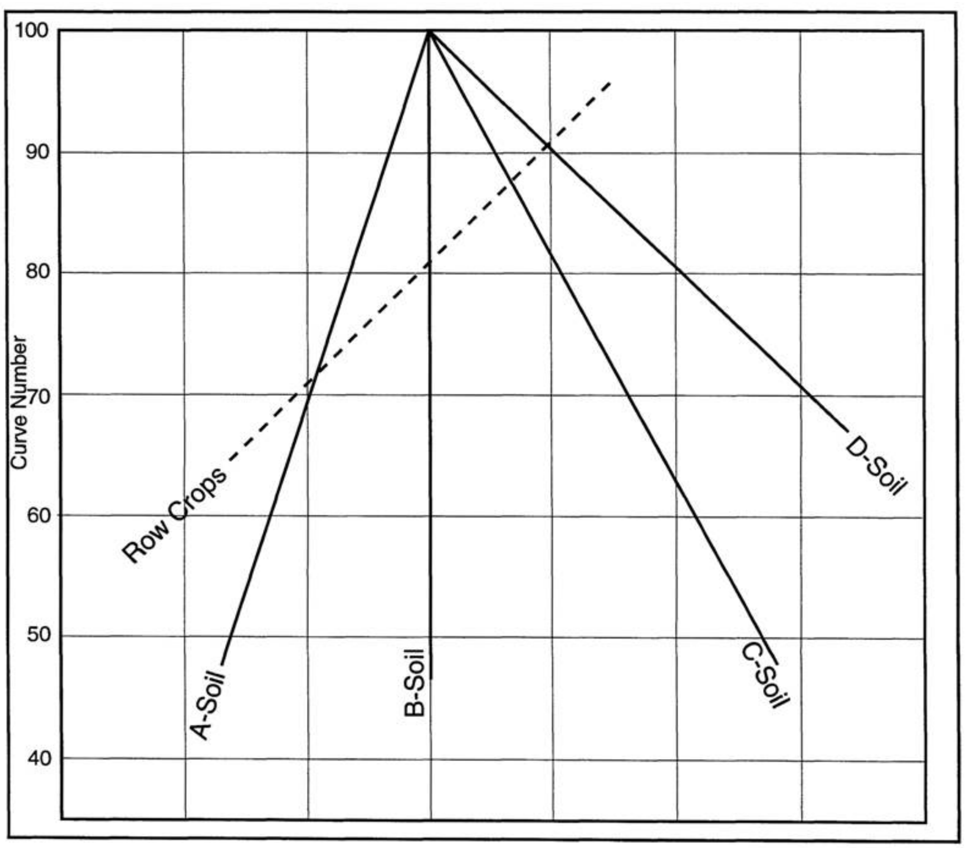


Figure 3. Curve number Aligner.

Urban Curve Numbers

The runoff curve numbers in Technical Release 55 (TR-55) "Hydrology for Small Urban Watersheds" were not developed from small plot rainfall runoff data. They were developed by weighting impervious soils and grass in good condition by percent area. The reason for this approach was that there was little or no urban watershed data available in the early 1970s. There has been limited checking of the urban curve numbers. The limited checks involved comparing actual storms curve numbers with the values in TR-55 or taking the average curve number for 3-5 years of data to compare with values in table 2-2 of TR-55. These limited checks indicate the values in TR-55 are reasonable.

Scientists with the Agriculture Research Service (ARS) have done extensive work on the runoff curve number system. Results indicate that, while the theory of the runoff curve number system is not the best, it works and should continue to be used. It was established that ARC! and ARCIII were equivalent to the mean value, plus or minus one standard deviation, which indicates there may be some statistical support for the upper and lower limits to the curve number for a specific soil-cover complex. This supports the idea that the CN is a random value developed from random events. Research also indicates that agricultural watersheds led to the most accurately estimated curve numbers. This was based on the analysis of 21 small agricultural watersheds.

Regional Curve Numbers

There are also efforts under way to reestablish the original documentation for the curve numbers in table 9.1, NEH-4. This effort is also being used to develop CN values for new and different soil-cover complexes, and to investigate if there are regional curve numbers for a single soil-cover complex. There are indications that the curve number for corn on a B soil in good hydrologic condition in Nebraska is different than the CN for the same soil-cover complex in Delaware. This effort is being lead by the ARS/NRCS Runoff Curve Number Work Group.

Climatic Index

There are additional adjustment techniques currently being used to account for regional variations in curve numbers. One technique is to use the Climatic Index from Chapter 21, NEH-4 to adjust curve numbers in table 9.1, NEH-4 for regional differences. This adjustment has been used in Texas, Oklahoma, and Kansas. The initial work was done in Texas using stream gage analysis to match rainfall volumes, curve numbers with runoff volumes. The climatic Index was a convenient parameter.

Duration

There are many factors that effect the variation of curve numbers with region. These factors include rainfall duration, rainfall intensity, and general soil moisture conditions. Some of the these factors have been investigated in the past by various groups and individuals. One study by Woodward (1973) indicated that there was a correlation between storm duration and curve number for semi-arid and arid conditions. The data for this study indicated that the storm duration was 1-2 hours for all original data used to determined arid and semi arid curve numbers. A careful review of selected storms suggested that, as the storm duration increased, the curve number decreased. The relationship reported by Woodward is being used in several Southwest states. You should check with your state conservation engineer to determine if the relationship can be used in your state.

Variation with Ground Cover

The former SCS Midwest National Technical Center studied the variation of CNs for conservation tillage practices with percent ground cover. The ARS reported in an unpublished paper that a definite relationship exists between curve number and residue on the ground surface.

With conservation tillage practices, the residue remaining on the ground surface provides additional surface storage not represented by original data sets. There is a definite need to account for effects of conservation tillage practices on curve numbers. The present conservation tillage curve numbers in NEH-4, Table 9.1, are for median conservation tillage conditions of the sample set. This means that a single CN represents the full range of residue remaining on the soil surface for that soil-cover complex.

The curve numbers in NEH-4, Chapter 9 apply to average crop conditions for a growing season. If variations in CN are desired, the stages of growth of the particular crop indicates how much and when to modify the average CN. There are studies under way to vary CN by the stage of crop growth. This variation in CN by stage of crop growth may play an important role in continuous simulation models. Most continuous simulation models use a daily time step, which suggests that the CN used should vary by the stage of growth. The significance of this variation on the model output has not been evaluated. Refinement of the curve number for stage of plant growth may not be justified by the sensitivity of the model results. The current adjustment for computing CN for the normal growing season is given by the following:

$$CN_{\text{normal peak growth}} = 2(CN_{\text{average}}) - (CN_{\text{fallow}})$$

Thus, if the average CN is 85 and the fallow CN is 91, the normal peak growth CN is 79. After harvest the CN varies between the values for fallow and normal peak growth, depending on the effectiveness of the plant residue as ground cover. In general, if 2/3 or more of the soil surface is exposed, the fallow CN applies; if 1/3 is exposed, the average CN applies; and if practically none is exposed, the normal peak growth CN applies.

For pasture, range, and meadow, the seasonal variation of CN can be estimated by means of NEH-4 tables 8.1 and 8.2; for woods or forest, the Forest Service method in NEH-4, Chapter 9 is applicable.

There are several published reports that correlated curve numbers with the c value for the Rational Equation. These studies were done to help obtain consistency in peak flow from several estimates. In some locations, storm water regulations require using the Rational Equation for small watersheds and TR-55 for larger watersheds. The use of correlated CN and c values helps obtain consistent peak flow estimates to the drainage area interface.

Summary

This module discussed the history of the runoff curve number system and how to develop an individual curve number from rainfall runoff data. The curve number concept was developed in the 1950s in response to the passage of the Watershed Protection and Flood Prevention Act of August, 1954.

An individual runoff curve number represents the average of median site values for hydrologic soil groups, cover, and hydrologic conditions. Several published papers indicate that the Curve Number method, while not perfect, does work and continues to be used.

An individual runoff curve number can be developed from plots of daily rainfall and runoff volumes as indicated in this module. You should check with your supervisor or the state conservation engineer before initiating an effort to determine a curve number.

There are several factors that effect the curve number for a given event. These include rainfall duration, rainfall intensity, soil moisture, stage of crop growth, amount of residue on the ground, and climatic factor.

Many efforts are underway to study the relationship of curve number with these variables. Tentative results from several studies are in use today. These include the Climatic Index adjustment in Texas, Oklahoma, and Kansas and the duration study for arid and semiarid runoff curve numbers. You should check with your supervisor or state conservation engineer before using these tentative studies.

You have proven that you can develop a curve number for a unique soil-cover complex. You also have demonstrated that you understand the history of the development of curve numbers.

Retain this Study Guide as a reference until you are satisfied that you have successfully mastered all the information discussed. 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 Certificate 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 Training Officer.

Activity 1

At this time, complete Activity 1 in your Study Guide to review the material just covered. When you have finished, compare your answers with the solutions provided. When you are satisfied that you understand the material, continue with Study Guide text.

In reviewing the plotted answer for Activity 1, it should be noted that there is a wide range in the plotted values. This is an indication of the range of expected runoff for this soil-cover complex. The median curve number of 73 represents the average watershed conditions when floods have occurred. As indicated earlier, the curve number could range from 87 to 54. It should be noted that the range in our example is from 93 to 58. This means there was more variability in the watershed conditions contributing to runoff in our example than in other watersheds. The median CN value of 73 compares favorably with the data from Agricultural Research Service (ARS) watersheds.

Year	Precipitation ins	Runoff ins
1951	1.00	0.10
1952	4.50	2.00
1953	2.10	1.30
1954	1.80	0.75
1955	3.50	0.60
1956	6.80	3.20
1957	5.20	2.10
1958	2.00	0.35
1959	4.00	1.20
1960	3.00	1.80
1961	2.00	0.40
1962	5.50	3.80
1963	4.20	1.10
1964	2.50	0.20
1965	4.90	2.50
1966	3.20	0.33
1967	6.00	1.60
1968	2.00	1.30

Activity 2

At this time, complete Activity 2 in your Study Guide to review the material just covered. When you have finished, compare your answers with the solutions provided. When you are satisfied that you understand the material, continue with Study Guide text.

Given

A curve number of 73 has been determined for a field with small grain grown on the contour in a hydraulic group B soil, in good hydrologic condition. Determine the curve numbers for hydrologic soil groups A, C, & D with the same land use and hydrologic condition.

Solution

Activity 3

At this time, complete Activity 3 in your Study Guide to review the material just covered. When you have finished, compare your answers with the solutions provided. When you are satisfied that you understand the material, continue with Study Guide text.

Given

In the Kluth watershed in Nebraska, the hydrologic soil group is C. The land use is corn in straight rows in good hydrologic condition. Determine the fallow condition CN, the average growing season CN, and the normal peak growth CN. Then, assuming that none of the ground is exposed, determine the curve number.

Solution

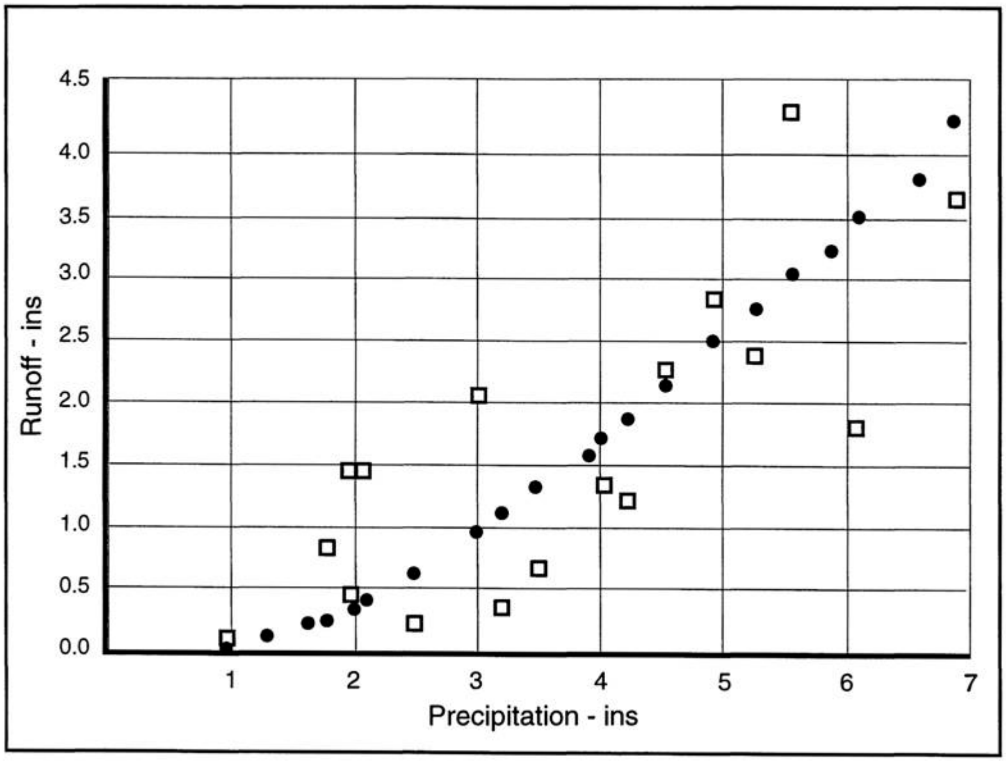
Activity Solutions

Activity 1

Development of a CN for a given set of P Q **data.**

The largest annual runoff event for each year and the associated precipitation are shown in the table below. Horse Creek Experimental Watershed in Montana has a drainage area of 2.5 acres. The soil name is Bozeman. The cover is herbaceous with a ground cover density of about 35 %. Bozeman soil is in hydrologic soil group B.

Solution



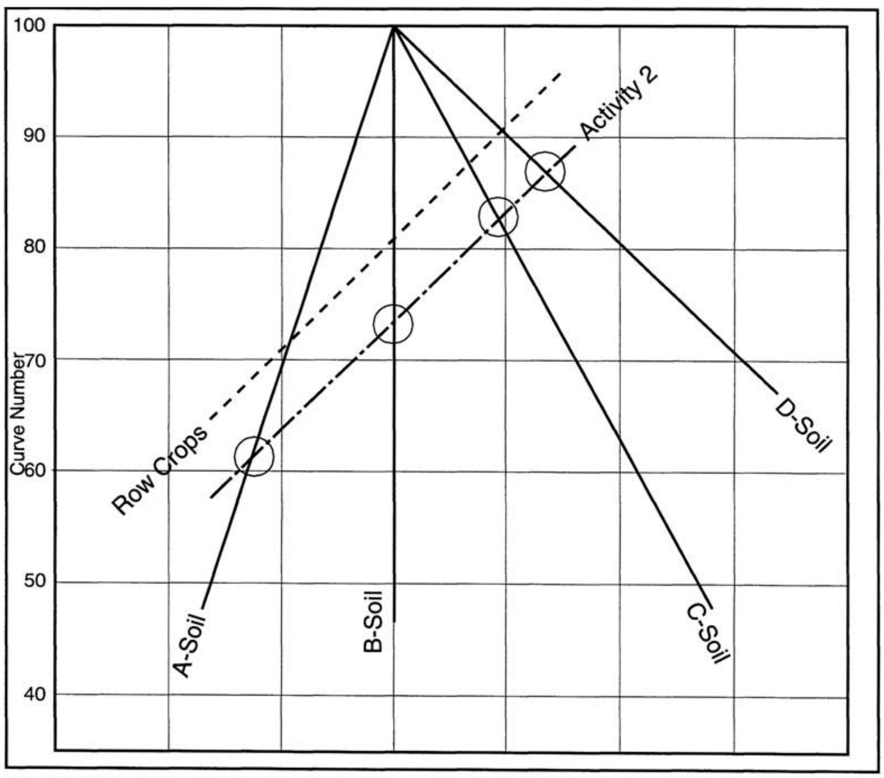
The CN *for herbaceous cover, hydrologic soil group* B, *and* 35 *percent ground cover* is 75.

Activity 2

A curve number of 73 has been determined for a field with small grain grown on the contour in a hydraulic group B soil, in good hydrologic condition. Determine the curve numbers for hydrologic soil groups A, C, & D with the same land use and hydrologic condition.

Solution

Plot the point for CN = 73 and B-soil. Draw a 45° line through the point.



The CN *for* a A *hydrologic soil* is 61.

The CN *for* a C *hydrologic soil* is 82.

The CN *for* a D *hydrologic soil* is 87.

Activity 3

In the Kluth watershed in Nebraska, the hydrologic soil group is C. The land use is corn in straight row in good hydrologic conditions. Determine the fallow condition CN, the av.erage growing season CN and the normal peak growth CN. Then assume that none of the ground is exposed, determine the curve number.

Solution

From table 9.1, *NEH-4, the average growing season curve number* is 85.

From table 9.1, *NEH-4, the fallow curve number* is 91.

The normal peak growth curve number is:

$2(CN_{average}) - CN_{fallow} = 2\,(85) - 91 = 79$

The curve number for the condition when none of the ground is exposed *equals the normal peak growth curve number.*
Therefore, CN = 79.