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A Comparison of Runoff Estimation Techniques

by

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Introduction:

This course presents an overview of and comparison of different methodologies for computing stormwater runoff. As explained in this course there are two widely used and accepted methods (the Rational Method and its derivatives and the SCS Method) as well as a number of lesser known methodologies. This course details both of the common methods and compares their use and also discusses the use of an alternate method.

When you complete this course you should be familiar with the basics of runoff estimation and should be able to use both the Rational Method and the SCS Method to calculate runoff. In addition, you should be able to make an educated decision as to which methodology to use and to be able to adjust both methodologies to fit a variety of real world situations.

Overview of Runoff Estimation Techniques:

The determination of the amount of stormwater runoff is considered by many to be a very inexact science. This view is supported by the fact that the design engineer modeling a watershed has to make several assumptions and has a variety of techniques to calculate the resulting runoff. To make matters worse, the different techniques often yield significantly different results and they even model different real-life situations. In fact, this is one branch of engineering where judgment, common sense, and feel are as important as the underlying equations and calculations. In order to estimate runoff, the engineer must reduce a series of complex, unique natural processes to a series of equations. These natural phenomena are often unique (such as the duration, intensity, and geographic area of a precipitation event) and changeable (such as the different features of a wheat field before and after harvest or the changes to a hardwood forest from summer to winter).

Despite these difficulties, it is very important to accurately calculate the peak rate and volume of stormwater runoff. This information is essential in designing drainage systems for roads and parking lots, in sizing culverts and storm drains, in designing stormwater control features such as drywells and detention basins, in sizing outlet structures for dams and in many other situations. To try to standardize the methodology and give the engineer an understanding of the underlying physical processes that are being modeled this course presents an overview of the situation.



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4. Decreasing groundwater recharge. Once again, rainfall has a chance to work its way into the ground through natural areas, but there is virtually no recharge taking place over impervious surfaces.
5. Reducing the amount of surface storage by regrading low points and eliminating wetlands.

In order to counteract these effects, the engineer needs to be able to design stormwater control devices. However, a pre-requisite to these designs is an understanding of the calculation procedures for the rate and quantity of runoff.

Design Storms:

One of the basic design parameters to consider in the determination of runoff is the design storm to be considered. Engineers routinely design stormwater management structures and conveyances for specific design storms. For example, a street drainage system might be designed for a 25 year storm and a detention basin can be designed for a 100 year storm. However, just what is a 25 year or a 100 year storm? The answer to this question is not as simple as it seems. Strictly speaking, a 100 year storm is a precipitation event that has a 1% chance of occurring in a particular year or, putting it another way, is expected to recur, on average, at intervals of 100 years. This definition, however, misses several key elements of the concept of a design storm. The more exact definition would be that a 100 year storm is a precipitation event that has a 1% chance of occurring in a particular year over a specified area and lasting a specific amount of time. For this reason, rainfall tables and graphs will have a series of 100 year storm events. For example the NY State Stormwater Design manual gives the 24 hour 100 year design storm as 8.0" in Ulster County, NY. However, approximately 2.3 inches of rain in 30 minutes is also considered a 100 year storm in this area. Why is this? Because they are defined in different ways. As indicated above, the design storm occurs for a specified amount of time. Therefore, there are published tables on design storms for durations ranging from 10 minutes (or less) to more than 24 hours. The engineer designing a specific stormwater facility for a 100 year event has to know beforehand exactly what the parameters of this design are to be. A design storm also implies that the storm occurs over the entire watershed at the same time for the same duration and at the same intensity. Obviously, this is a completely valid assumption for a small watershed of 1 acre, or less. It is also generally valid for somewhat larger watershed (say up to a few square miles) but it is not to be expected to be valid over a watershed that covers hundreds or thousands of square miles. In addition, as will be shown later, certain methodologies deal with specific rainfall distributions. Therefore, the SCS Method has four separate distributions representing idealized, average storm distributions in different parts of the country. Each of these storms has a duration of 24 hours but they differ in the intensity of the rainfall over this time period. Obviously, these are only average distributions



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and a real-life storm cannot be expected to last for exactly 24 hours or have the exact distribution modeled by the SCS Method. However, these models are based on years of data and can represent a typical storm for a specific area of the country.

Therefore, a 100 year storm can be 8 inches or 3 inches of rainfall and can last 24 hours or one half of an hour. The design engineer has to understand this and make sure that he or she is designing a particular stormwater facility for the appropriate rainfall event. Just how to accomplish this is the subject of this course.

The Rational Method

The Rational Method is a very easy to use, practical method for determining the peak runoff from any specific design storm. It is also a “common sense” type of approach because it assumes that the resulting runoff is directly related to the contributing drainage area, the intensity of the rainfall, and the land cover. However, there are several limitations that must be met if the rational Method is to be used. These include the following:

1. The rainfall intensity should be uniform throughout the duration of the storm.
2. The time of concentration must be less than the duration of the peak rainfall.
Time of concentration will be discussed in more detail later.
3. The rainfall is distributed uniformly over the drainage area.
4. There is no appreciable storage of water (e.g. reservoirs, impoundments, etc.) in the drainage area
5. The Rational method is generally used for relatively small drainage areas (i.e. less than 1 square mile).

The governing equation for the Rational Method is as follows:

$$Q = ciA,$$

Where Q is the peak runoff in cubic feet per second (CFS),

c is the runoff coefficient,

i is the rainfall intensity in inches per hour, and

A is the drainage area in acres.

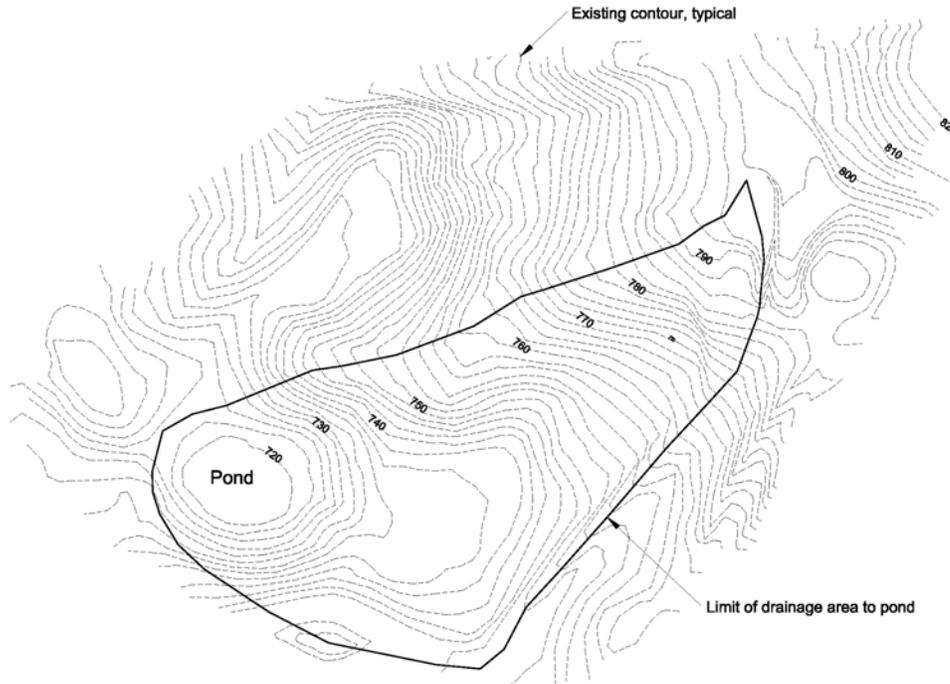
Therefore, the peak runoff can be found quite simply by finding the drainage area, determining the rainfall intensity, and applying the correct runoff coefficient. Each one of these is discussed in some detail below:

The drainage area is determined using topographic maps. In many cases it is important to field verify the topographic information, especially if roadways, or drainage conveyances are part of the drainage system. Features such as roadway crowns, curbs, or drainage inlets can dramatically alter the actual contributing drainage area.



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A schematic drainage area reaching a pond in a mountainous terrain is shown below:



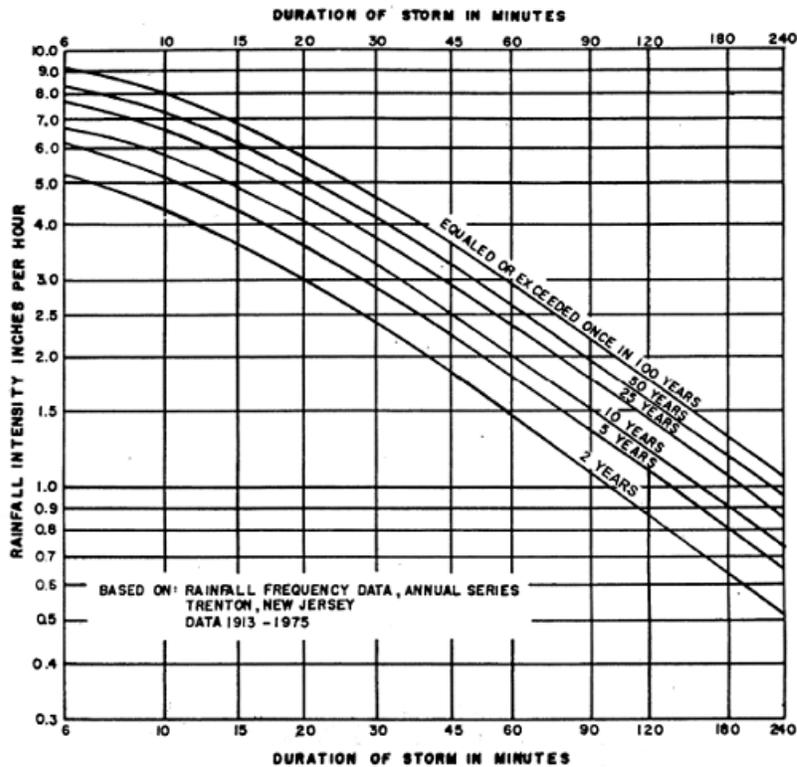
Schematic Drainage Area to Pond

The rainfall intensity is a function of the time of concentration and the design storm. The time of concentration (T_c) is defined as the time required for runoff to travel from the most hydraulically distant point in the watershed to the point of interest. One method for determining the time of concentration is discussed under the SCS Method below. However, there are a number of nomographs and “rule of thumb” approaches to this parameter.



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Once the design storm and the time of concentration are known, the rainfall intensity can be determined based on graphs such as the reprinted from the NJDEP “New Jersey Stormwater Best Management Practices Manual” reprinted below.



The runoff coefficient “c” can be thought of as the proportion of rainfall that is converted to runoff over a particular land cover. For impervious surfaces, it is assumed that virtually all of the rainfall will be converted to runoff and a ‘c’ value of 0.99 is commonly used. The actual determination of the runoff coefficient for a variety of other land cover types can be somewhat challenging and often requires a significant amount of engineering judgment or educated guesswork. A number of publications list various ‘c’ values for different land use types. Unfortunately, there is a lack of uniformity in these references. The Residential Site Improvement Standards in New Jersey includes a table of runoff coefficients for use in that state. However, many experts believe that the values in this table are unrealistically high, so it will not be used in this course.

The chart below is reprinted from information contained in a publication, dated 1967, entitled “Design and Construction of Sanitary and Storm Sewers”, prepared by a joint committee of the



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American Society of Civil Engineers and the Water Pollution Control Federation and provides c values for composite areas.

Land cover	Runoff Coefficient
Downtown Business Area	0.70 to 0.95
Neighborhood Business Area	0.50 to 0.70
Single-family Residential Area	0.30 to 0.50
Detached Multi-Family Residences	0.40 to 0.60
Attached Multi-Family Residences	0.60 to 0.75
Suburban Residential Area	0.25 to 0.40
Apartments	0.50 to 0.70
Industrial Area	0.50 to 0.90
Parks & Cemeteries	0.10 to 0.25
Playground	0.20 to 0.35
Railroad Yard	0.20 to 0.35
Unimproved Area	0,10 to 0.30

A review of the data in the chart above indicates that there is no single “right” c value to be assigned to most land uses and that the engineer must use his judgment in this matter. However, this table does give a useful range of c values for a variety of common land uses. Many of the areas shown in the table, however, are composite areas which include a mixture of pervious and impervious surfaces. For a variety of reasons it is probably better to break these composite areas into their component parts. This way, for example, a suburban residential area with 1 acre lots (which would be expected to have a fairly large proportion of green space) could be assigned a lower c value than a suburban residential area with lots averaging 1/8 acre. To accomplish this purpose, the same publication gives the following table:

Land Cover	Runoff Coefficient
Asphalt or Concrete Pavement	0.70 to 0.95
Brick Pavement	0.70 to 0.85
Roof	0.75 to 0.95
Lawns in sandy soil	0.05 to 0.20
Lawns in heavy soil	0.13 to 0,35

The table above can then be used to break up a composite area into its component parts and provide a more site-specific runoff curve number.



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It is interesting to note at this point that, despite appearances, the units in the equation, $Q = ciA$ actually do make sense. Assuming that the “c” is dimensionless, the product of i times A yields units of acre-inches per hour. However, 1 acre-inch per hour equals 1.008 CFS. Therefore, the resulting Q can be expressed in CFS without applying any conversion factor.

Example 1:

The following simple example will illustrate the use of the Rational Method:

A developer is planning to convert a two acre wooded property in Ocean County, NJ to a shopping center which will include 0.5 acres of rooftop, 1.0 acres of parking, and 0.5 acres of lawn. The time of concentration for both pre-development and post development conditions is assumed to be the minimum of 10 minutes. Using the following “c” values and the runoff intensity curves shown on page 6, determine the existing and proposed peak runoff values for a 25 year storm event.

Lawn “c” = 0.30

Woods “c” = 0.20

Impervious “c” = 0.99

Solution:

Using the runoff intensity curves on page 7 yields a 25 year rainfall of 6.6 inches per hour.

Under pre-developed conditions, the c value is 0.20 because the entire area is wooded.

Therefore the pre-developed peak runoff is:

$$Q_{25} = (0.20)(6.6)(2) = 2.64CFS$$

Under proposed conditions, the following table will be used to determine the “weighted” c value:

Land Use	Area (Ac)	c	Area X c
Lawn	0.5	0.3	0.15
Impervious*	1.5	0.99	1.485
Total	2.0	-----	1.635

*includes both rooftop & parking areas

Weighted c is calculated as: $c = 1.635 / 2.0 = 0.8175$ (This can be rounded to 0.82).

Therefore, the post developed peak 25 year runoff is:

$$Q_{25} = (0.82)(6.6)(2) = 10.82CFS$$

Therefore, the increase in the peak rate of runoff in a 25 year storm is $10.82 - 2.64 = 8.18CFS$.

This seems like a reasonable increase given the problem statement.



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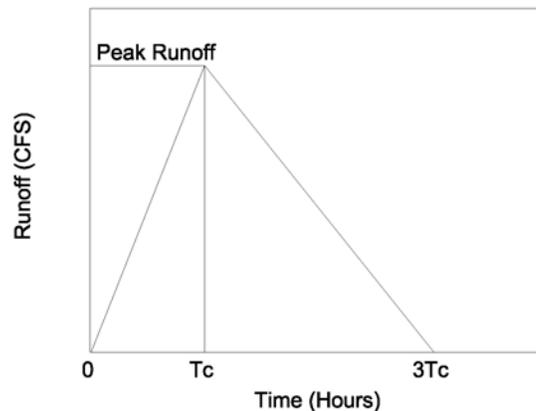
The Modified Rational Method

The Modified Rational Method builds on the standard Rational Method in that it gives the engineer a means of calculating not only the peak runoff amount but also the stormwater volume attributable to a specific design storm. This is invaluable because volume is a requisite parameter in the design of detention basins. The calculation of the peak runoff rate is accomplished in exactly the same manner as in the Rational Method. However, in the Modified Rational Method, the resulting hydrograph will generally either have a triangular or trapezoidal shape as shown below.

The simplest form a Modified Rational Hydrograph has a triangular shape. The hydrograph has both a rising and a receding leg. The rising leg is equal in duration to the time of concentration (T_c) whereas the receding leg is assumed to be some multiple of T_c . Ordinarily, the duration of the receding leg is 1, 1.5, 2, or 3 times the T_c . The actual length of the receding leg is sometimes determined by the governmental reviewing agency.

This is shown schematically in the figure below:

Note: In this case the receding leg of the hydrograph is assumed to be equal to twice the T_c .



Rational Method Hydrograph

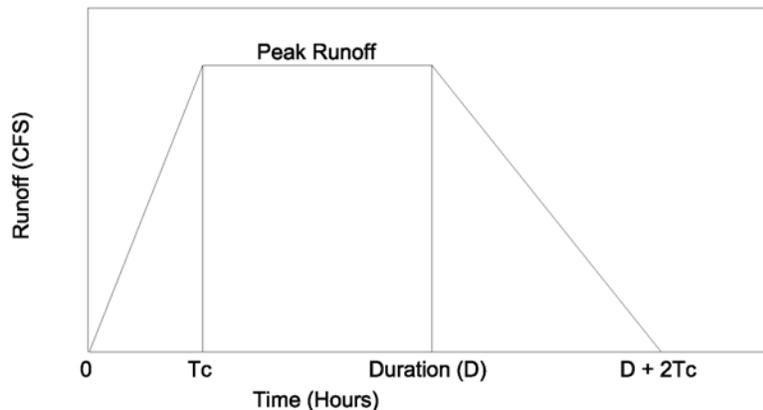
Time of Concentration = Storm Duration



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If the storm duration is greater than the time of concentration, then the hydrograph will take the form of a trapezoid, as shown below:

Note: In this case the receding leg of the hydrograph is assumed to be equal to twice the T_c .



Rational Method Hydrograph

Time of Concentration = Storm Duration

In either case, the area under the hydrograph represents the total volume of the stormwater.

When using the Modified Rational method for designing a detention basin it is imperative that the design engineer analyze storms with several different durations to determine the “critical” storm duration. This is the storm duration that will produce the maximum flood storage volume within the detention basin. To determine this critical volume it is necessary to analyze a number of different storms. Each of these storms must be routed through the detention basin using standard routing techniques (such as the Modified Puls method). A discussion of the routing through the basin is beyond the scope of this course but there are a number of commercially-available hydraulic programs that can perform these calculations. As the storm duration increases, the peak runoff will decrease (because the rainfall intensity (i) decreases with increasing time) but the volume will increase. Generally, the peak storage volume in the detention basin will increase until, at some storm duration, a peak is achieved. When this happens the critical storm duration is reached.



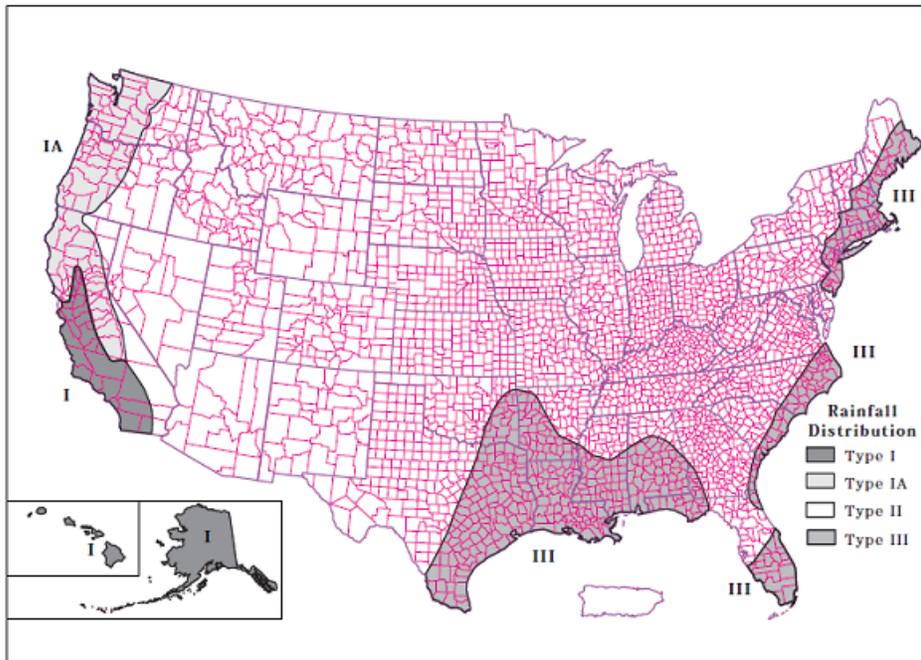
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The SCS Method

The main competitor of the Rational Method is the Soil Conservation District (SCS) Method. The SCS Method is described in great detail in the USDA publication “Urban Hydrology for Small Watersheds”, otherwise known as TR-55. Despite the title of this publication, the SCS Method can also be used to estimate runoff in agricultural or rural areas. In fact, this method is applicable to a wide variety of situations and can be adapted to a number of different situations. Like the Rational Method, however, it does have its limitations. However, it is a very robust model and can be used in almost any watershed.

The SCS Method has different storm distributions for use in the different regions of the country. TR-55 gives specifics on each of these storm distributions. For simplicity, this course will deal only with storm distribution Type III, which is applicable to much of the Atlantic and Gulf coasts. The geographic region covered by each storm type is shown below.

Figure B-2 Approximate geographic boundaries for NRCS (SCS) rainfall distributions



Like the Rational Method, the SCS Method makes use of a runoff coefficient. In this case it is called the runoff curve number (CN) and it is determined by the land cover and underlying soil type. Unlike the rational method, however, there is not a linear relationship between the curve number and the resulting runoff. Rather, this method uses the curve number to translate a rainfall depth into depth of direct runoff using the following equation:

$$Q = (P - 0.2S)^2 / (P + 0.8S), \text{ where}$$

Q is the direct runoff in inches,



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P is the rainfall in inches,

S is the potential maximum retention after runoff begins, in inches, and is related to the Runoff Curve Number (CN), as follows:

$$S = (1000 / CN) - 10$$

A concept that the SCS uses is the idea of initial abstraction (I_a). Initial abstraction represents all water lost to the downstream receiving waters before runoff begins. It includes water caught in surface depressions, water caught on the surface of vegetation, evaporation and transpiration (sometimes counted together and known as evapotranspiration). These features are shown schematically in the schematic hydrologic cycle diagram on page 3.

To determine the actual peak runoff the Graphical Peak Discharge Method is employed and the peak is calculated using the peak discharge equation, which is as follows:

$$q_p = q_u A_m QF_p, \text{ where}$$

q_p is the peak discharge (or runoff) in cubic feet per second (CFS).

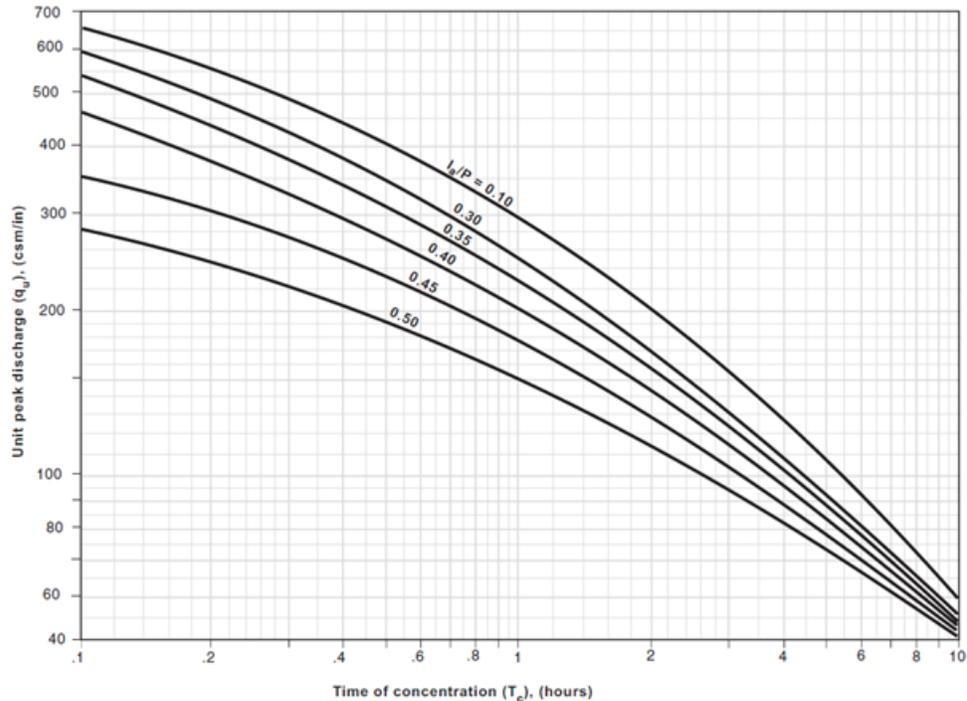
A is the contributing drainage area in square miles. (Recall that 1 square mile = 640 acres).

q_u is the unit peak discharge in csm/in. This value depends on several factors including the type of storm distribution, the initial abstraction, rainfall amount, and the time of concentration. TR-55 includes unit peak discharge curves for each of the storm distribution types. The curve for a Type III storm is included below:



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Exhibit 4-III Unit peak discharge (q_p) for NRCS (SCS) type III rainfall distribution



Q is the direct runoff, in inches, as calculated above.

F_p is the pond and swamp adjustment factor. Which can be determined based on the following table:

Percent of pond & swamp areas in watershed	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

As stated above, the CN value is based, in part, on the underlying soil types. For this purpose, all soils within the United States are assigned to one of four Hydrologic Soil Groups: A, B, C, or D. Published soils information, such as that contained in the National Resource Conservation Service (NRCS) web soil survey will show which soils are present on a site and what the hydrologic soil group is of each. Group A soils will absorb more rainfall (and, consequently, allow less runoff) than B soils, which will absorb more than C soils and so on. In some cases,



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the soil survey will show a split soil grouping such as B/D or C/D. In this case the lower value refers to the hydrologic soil group if the area has been treated with a sub-surface drainage system and the higher value refers to the area in pristine condition. If this is the case, it is prudent to use the lower value when dealing with agricultural fields, as farmers have historically been efficient in draining their land. TR-55 contains several pages of runoff curve numbers for a variety of land covers. A typical page is reprinted on the following page. This particular page deals with a number of man-made land types including residential areas, urban districts, and the like. However, TR-55 also includes similar graphs covering agricultural areas and more natural land covers.

Although the SCS Method is widely applicable, it does have some limitations. One of these is that it does not realistically model the runoff in cases when the CN values are very low (below about CN=40), especially when the rainfall amount is small. If this is the case, the Rational Method should be used to estimate the runoff.



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Chapter 2

Estimating Runoff

Technical Release 55
 Urban Hydrology for Small Watersheds

Table 2-2a Runoff curve numbers for urban areas ^{1/}

Cover description	Average percent impervious area ^{2/}	Curve numbers for hydrologic soil group			
		A	B	C	D
<i>Fully developed urban areas (vegetation established)</i>					
Open space (lawns, parks, golf courses, cemeteries, etc.) ^{3/} :					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) ^{4/}		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
<i>Developing urban areas</i>					
Newly graded areas					
(pervious areas only, no vegetation) ^{5/}	77	86	91	94	
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

¹ Average runoff condition, and $I_a = 0.2S$.

² The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

³ CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

⁴ Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

⁵ Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.



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Another page of runoff curve numbers, this one dealing with more “natural” areas is reprinted below.

Table 2-2c Runoff curve numbers for other agricultural lands ^{1/}

Cover description Cover type	Hydrologic condition	Curve numbers for hydrologic soil group			
		A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. ^{2/}	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. ^{3/}	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 ^{4/}	48	65	73
Woods—grass combination (orchard or tree farm). ^{5/}	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. ^{6/}	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 ^{4/}	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

¹ Average runoff condition, and $I_p = 0.2S$.

² *Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

³ *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

⁴ Actual curve number is less than 30; use CN = 30 for runoff computations.

⁵ CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

⁶ *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.



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A glance at the table above shows that the engineer must not only assign an area as a woods, meadow, etc, but must also determine the hydrologic condition of the area. The photographs below can be used as a guide in this regard.

The photograph below shows a meadow in “good” condition (using the SCS Method terminology) during the growing season. Based on the heavy growth, this area would be expected to convert relatively little of the rainfall into runoff. In the Rational Method a c value of 0.15 to 0.25 would be appropriate for this area.





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The woodland shown in the photograph below can be considered to be in “good” condition (using the SCS Method terminology) because it has adequate leaf litter and appears to be protected from both grazing and burning. In the Rational Method, a woods of this nature might be assigned a “c” value of 0.25 or 0.30.





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The photograph below is another meadow but this area would probably be more accurately modeled as a lawn or a pasture (Using the SCS Method) because the area is not heavily overgrown. Using the Rational Method, this area could be assigned a c value of 0.30 or 0.40.



In order to show how the runoff curve numbers are used to determine the peak runoff consider the following example:

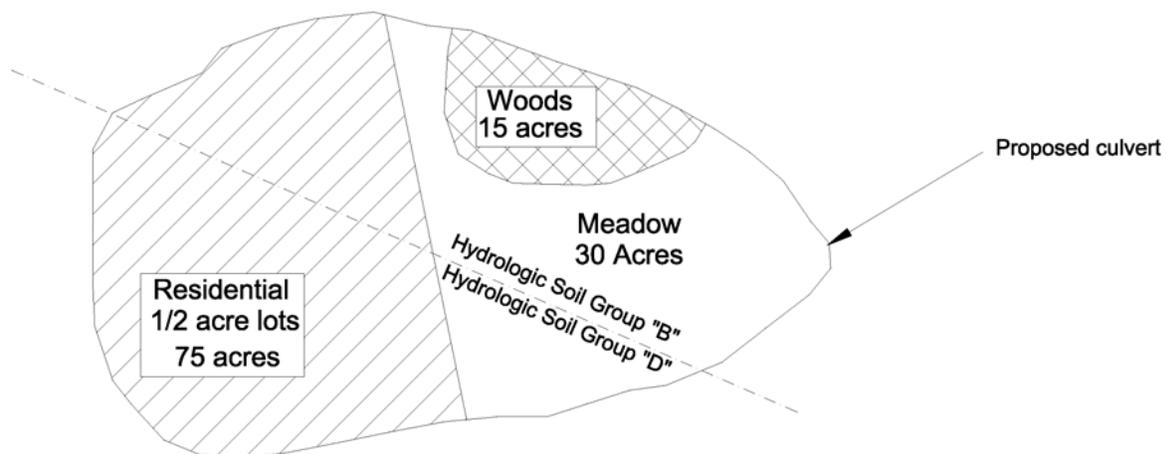


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Example 2:

A new roadway culvert is to be constructed under a roadway in Somerset County, New Jersey. The drainage area to the culvert has been determined to be 120 acres. A schematic of the drainage area showing current land uses and soil types is included below. (In order to obtain this data in a real life example, the engineer should rely on published soils information and available aerial photographs). The culvert will be designed to pass the 100 year storm, which in Somerset County is 8.2 inches in 24 hours. The 2 year storm is 3.3 inches in 24 hours. The time of concentration is assumed to be ½ hour. There are no appreciable swamps or ponds present in the watershed. Determine the peak 100 year runoff to the proposed culvert. It is assumed that the woods and meadows are in “good” hydrologic condition.

Note: 30 acres of the residential lots are on "B" soil and 45 acres are on "D" soil. 8 acres of the meadow are on "B" soil and 22 acres are on "D" soil.



Watershed Schematic



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Solution:

First determine the weighted CN value. A table like the one below helps to organize the data:

Land Use	Soil Type	CN	Area(Ac)	CN X Area
Residential ½ acre lots	B	70	30	2100
Residential ½ acre lots	D	85	45	3825
Meadow	B	78	22	1716
Meadow	B	58	8	464
Woods	B	55	15	825
Total:			120	8930

Weighted CN=8930/120 = 74.4 (Use CN =74)

Next, determine the direct runoff. In order to do this we must calculate the S value as follows:

$$S = (1000 / CN) - 10 = (1000 / 75) - 10 = 3.333$$

Using this S value, determine the direct runoff (Q).

Note that 0.2S = 0.667 and 0.8S =2.666

$$Q = (P - 0.2S)^2 / (P + 0.8S) = (8.2 - 0.667)^2 / (8.2 + 2.666) = 5.22 \text{ inches}$$

Now, we can determine the actual 100 year peak runoff to the proposed culvert using the peak discharge equation which is repeated below:

$$q_p = q_u A_m Q F_p$$

In this example, the following parameters are known:

$A_m = 120 \text{ acres} = 0.1875 \text{ sq. miles}$

$Q = 5.22 \text{ inches}$

$F_p = 1.0$ (it is stated in the problem that there are no swamps or ponds, and this translates to an F_p value of 1.0 according to the table above).

This leaves only q_u to be determined. In order to use the unit peak discharge graph on page 12, we need the time of concentration (0.5 hours as stated in the problem), the rainfall, P (8.3 inches) and the initial abstraction, I_a). The I_a is equal to 0.2S and has been calculated above as 0.667.

Therefore, the quantity I_a/P is equal to 0.667/8.3 or 0.08. The curve closest to this value is the top curve ($I_a/P=0.10$) on the unit peak discharge graph. Using this curve and the time of concentration of 0.5 hours yields a unit peak discharge (q_u) of 400. Substituting all of these values into the peak discharge equation yields:

$$q_p = (400)(0.1875)(5.22)(1.00) = 391.5 \text{ CFS}$$

This is the 100 year peak design flow reaching the culvert.



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Time of concentration:

The determination of the time of concentration (Tc) is a critical component in calculating the peak rate of runoff. The SCS Method provides a relatively simple methodology for calculating the Tc. The total travel time is broken into component parts and each is calculated separately as described below:

Overland flow or sheet flow (Tt₁) represents the time it takes for runoff at the top of the watershed to form into small rivulets. It is calculated by the equation:

$$Tt_1 = (0.007)(nL)^{0.8} / (P_2^{0.5} s^{0.4}) \quad , \text{ where:}$$

n is the Manning's roughness coefficient (taken from the following table):

Surface Description	n
Smooth surfaces (concrete, asphalt, gravel, bare soil)	0.011
Fallow field (no crop residue)	0.05
Cultivated soils with <20% residue cover	0.06
Cultivated soils with >20% residue cover	0.17
Short grass prairie	0.15
Dense grasses	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods with light underbrush	0.40
Woods with heavy underbrush	0.80

L is the flow length, in feet

P₂ is the 2 year, 24 hour rainfall

s is the slope of the hydraulic grade line in feet per foot.



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The dense underbrush shown in the photograph below should probably be modeled as a “woods with heavy underbrush” and assigned an n value of 0.80. In assigning a CN value, this area might best be modeled as “brush”. For use in the Rational Method, an area like this should be assigned a very low runoff coefficient (e.g. $c = 0.10$).





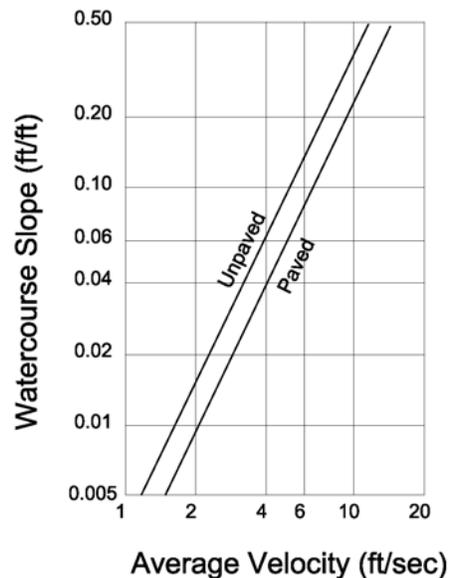
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This equation should only be used for flows lengths of 300 feet (some authorities would use 150 feet as the maximum length) because, after this length, the runoff will generally consolidate and change from overland sheet flow to shallow concentrated flow. The equation for shallow concentrated flow is simply:

$$Tt = L/V, \text{ where}$$

Tt is the time required to flow through a reach

V is the velocity (which can be taken from the graph below)



After a while the flow regime will ordinarily change again, as the runoff enters a stream or other watercourse; this time from shallow concentrated flow to channel flow. The same equation can be used as that shown on the previous page. However, in this case the Manning's Equation, shown below, can be used to calculate the velocity.

$$v = (1.486/n)R^{2/3}s^{1/2}, \text{ where:}$$

v is the velocity in the channel in feet per second,

n is the Manning's roughness coefficient, which can be estimated from the table below (which is adapted from the United States Geological Survey water Supply paper 2339 entitled "Guide for



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Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" and other sources):

Channel Characteristics	n
Concrete pipe	0.013
Plastic pipe	0.013
Grass waterway	0.030
Concrete waterway	0.015
Earth channel	0.025
Channel with weeds	0.050
Rock cut waterway	0.025
Gravel waterway	0.026

R is the hydraulic radius, which is defined as the cross sectional area of the channel divided by the wetted perimeter. It will have units of square feet divided by feet, or simply feet.

s is the channel slope in feet per foot.

As a short-cut, many engineers will simply assume a velocity of 5 or 6 FPS within the channel and use this for the calculation of the time of concentration. This is often done because detailed information on the cross-sectional geometry and physical characteristics of the channel may be lacking.

When calculating the time of concentration it is also important to take into account the flow of runoff through any pipe system. The Manning's Equation can be used for this type of flow as well. The minimum Tc used in the Rational Method should not be less than 10 minutes and the minimum Tc for use in the SCS method should not be less than 0.1 hour.

The example below will illustrate how the time of concentration is calculated using this method.

Example 3:

Determine the time of concentration for a large watershed located in Suffolk County, New York. The 2 year, 24 hour rainfall in this area is 3.3 inches. The drainage area is 120 acres and an analysis of the flow path reveals the following:

- The upper reach (overland flow) consists of 150 feet of lawn at a slope of 2%.
- The "shallow concentrated flow" is broken up into two components. For the first 600 feet it is comprised of lawn flow at a slope of 4%. It then flows across a parking lot for a distance of 300 feet at a slope of 1%.



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- After exiting the parking lot, runoff travels through a grassed waterway with an n value of 0.035, a cross sectional area of 10 SF and a wetted perimeter of 8 feet, and a slope of 0.5% for a distance of 1000 feet to the point of interest.

Solution:

In order to determine the time of concentration, each of the component travel times must be calculated separately. The overland sheet flow is calculated using the equation below. A value of 0.24 will be assigned to the lawn based on the table of n values shown above.

$$Tt_1 = (0.007)(0.24 \times 150)^{0.8} / ((3.3)^{0.5} (0.02)^{0.4}) = 0.32 \text{ hrs}$$

Next, the two reaches of shallow concentrated flow are calculated separately. Using the graph on page 24, find that the velocity for the lawn area is 3.2 FPS and the velocity in the parking lot is 2 FPS.

Therefore the two travel times are calculated as:

$$\text{Lawn Area: } Tt = 600 / 3.2 = 187. \text{ sec onds} \quad \text{and} \quad \text{Parking Lot: } Tt = 300 / 2.0 = 150 \text{ sec onds}$$

The total travel time for shallow concentrated flow is 337.5 seconds or 0.09 hours

Finally, compute the velocity in the watercourse using the Manning's Equation:

$$v = (1.486 / n) R^{2/3} S^{1/2}$$

In order to use this equation we must first determine the hydraulic radius of the channel which is 10/8 or 1.25 feet. Substituting all of the given values into the equation yields the following:

$$v = (1.486 / 0.035)(1.25)^{2/3} (0.005)^{1/2} = 3.5 \text{ FPS}$$

The resulting travel time in this reach is calculated as: $Tt = 1000 / 3.5 = 286 \text{ sec onds} = 0.08 \text{ hrs}$

Therefore, the time of concentration is calculated as:

0.32 hours + 0.09 hours + 0.08 hours = 0.49 hours. A time of concentration of 0.5 hours can be used in the calculations.

The discussion of the SCS Method so far has only led to the calculation of a peak rate of runoff but has not constructed an entire hydrograph. However, the SCS Method allows for the calculation of the entire hydrograph (and the resulting volume of stormwater) by providing tables of hydrograph unit discharges for each of the storm distributions modeled. The resulting analysis is known as the Tabular Hydrograph Method.

The table below is taken from TR-55 and shows the unit hydrograph coordinates for a portion of the Type III Storm for $Tc = 1.0$ hrs.



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These tables are included in TR-55 for a variety of Tc values ranging from 0.1 hr to 1.5 hrs and for all four of the storm distributions.

Time (hours)	Tabular Hydrograph Unit Discharge	Time (hours)	Tabular Hydrograph Unit Discharge
11.0	15	13.6	164
11.3	19	13.8	128
11.6	24	14.0	103
11.9	32	14.3	78
12.0	37	14.6	64
12.1	44	15.0	52
12.2	54	15.5	43
12.3	71	16.0	36
12.4	98	16.5	31
12.5	136	17.0	26
12.6	181	17.5	23
12.7	227	18.0	21
12.8	264	19.0	16
13.0	297	20.0	14
13.2	270	22.0	12
13.4	215	26.0	0

In order to construct the hydrograph the engineer calculates the runoff at each time period using the coefficients contained in the following table. Of course, there are numerous commercially-available computer programs that will perform these calculations but it is instructive to go through the process at least part-way by hand to understand the underlying calculations. To use the table below, the engineer must determine the Tc value and calculate the value of Ia/P. The example below will illustrate how to construct the entire hydrograph using this data.

Example 4:

A detention basin has to be designed to control the runoff from a site in Putnam County, New York which is experiencing flooding. Hydrologic analysis of the upstream drainage area indicates that it has the following characteristics:

Area = 64 acres (0.10 sq. miles)

CN value = 63



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$T_c = 1.0$ hours

100 year, 24 hour rainfall, based on the “New York State Stormwater Design Manual” is 7.2 inches

Calculate the entire hydrograph so that a detention basin can be designed.

Solution:

Calculate the S value as follows:

$$S = (1000 / CN) - 10 = (1000 / 63) - 10 = 5.873$$

Using this S value, determine the direct runoff (Q).

Note that $0.2S = 1.175$ and $0.8S = 4.698$

$$Q = (P - 0.2S)^2 / (P + 0.8S) = (7.2 - 1.175)^2 / (7.2 + 4.698) = 3.05 \text{ inches}$$

Now, instead of determining a peak runoff, we will calculate a runoff value for each of the times given in the chart below. The governing equation is:

$$q = q_t A_m Q$$

In this case q is the runoff at time t, q_t is the tabular hydrograph unit discharge from Exhibit-III below at time, t, and A_m and Q are the area in square miles and the direct runoff in inches, as before.



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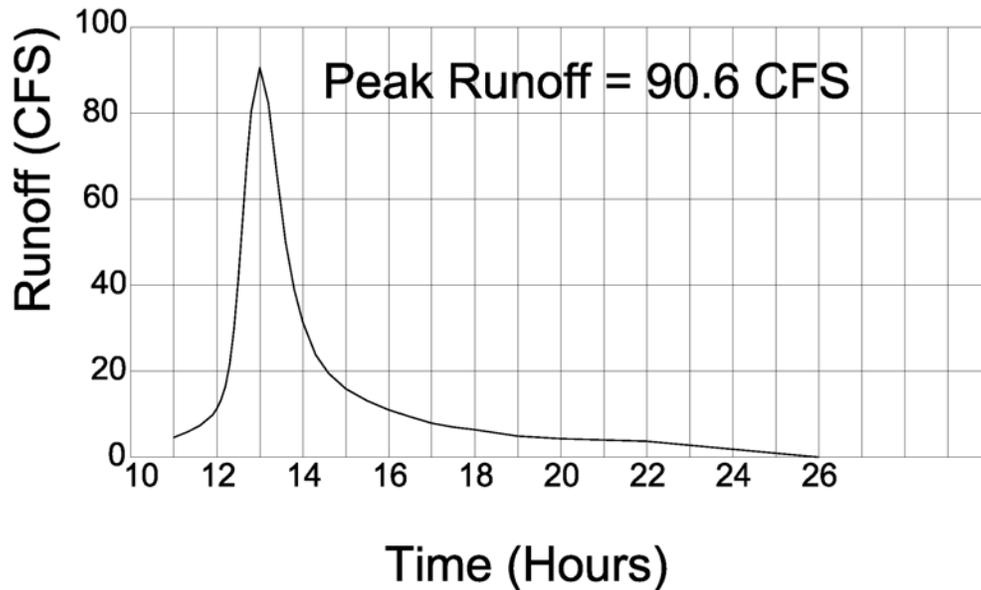
Calculating this for all of the hydrograph coordinates yields the following table:

Time (Hrs)	Tabular Hydrograph Unit Discharge (Taken from Exhibit 5-III of TR-55)	A_m (square miles)	Q (inches)	Q (CFS)
11.0	15	0.10	3.05	4.6
11.3	19	0.10	3.05	5.8
11.6	24	0.10	3.05	7.3
11.9	32	0.10	3.05	9.8
12.0	37	0.10	3.05	11.3
12.1	44	0.10	3.05	13.4
12.2	54	0.10	3.05	16.5
12.3	71	0.10	3.05	21.7
12.4	98	0.10	3.05	29.9
12.5	136	0.10	3.05	41.5
12.6	181	0.10	3.05	55.2
12.7	227	0.10	3.05	69.2
12.8	264	0.10	3.05	80.5
13.0	297	0.10	3.05	90.6
13.2	270	0.10	3.05	82.3
13.4	215	0.10	3.05	65.6
13.6	164	0.10	3.05	50.0
13.8	128	0.10	3.05	39.0
14.0	103	0.10	3.05	31.4
14.3	78	0.10	3.05	23.8
14.6	64	0.10	3.05	19.5
15.0	52	0.10	3.05	15.9
15.5	43	0.10	3.05	13.1
16.0	36	0.10	3.05	11.0
16.5	31	0.10	3.05	9.4
17.0	26	0.10	3.05	7.9
17.5	23	0.10	3.05	7.0
18.0	21	0.10	3.05	6.4
19.0	16	0.10	3.05	4.9
20.0	14	0.10	3.05	4.3
22.0	12	0.10	3.05	3.7
26.0	0	0.10	3.05	0



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The resulting hydrograph is shown graphically below. Note how much more complex this hydrograph is than the relatively simple hydrograph shapes obtained using the Modified Rational Method. Once again, the area under the hydrograph represents the total stormwater volume.



Before leaving the SCS Method, the following limitations should be noted.

1. As mentioned earlier, the SCS Method is not accurate for very low CN values and small rainfall amounts. As a general rule if the resulting direct runoff calculation yields a value of 0.5 inches or less, this method should not be used.
2. There is no provision in this method (or in the Rational Method, for that matter) for estimating snowmelt.
3. If the time of concentration is greater than 2 hours, the procedures described in TR-55 cannot be used. The SCS Method is still applicable, but a computer program must be used because the specific graphs and charts in TR-55 do not cover T_c values that are this large.



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Other Methods:

There are a number of other, less commonly employed ways to calculate runoff. Most of these are not in general use. However, one such method, the “Stankowski Method” will be discussed in this course. This method was developed in 1974 and published in the “Magnitude of Floods in New Jersey with Effects of Urbanization”, State of NJ Department of Environmental Protection Division of Water Resources Special Report 38 . The Stankowski Method is not as straightforward as the other methods discussed in this course and the equations are somewhat more cumbersome. However, it is based on a wealth of empirical data. It relies on a series of so-called regional equations which relate impervious cover, drainage area, land slope, and surface storage to a peak discharge for a variety of storm frequencies. The regional equation for a 100 year storm is as shown below:

$$Q_{100} = 136A^{0.84} S^{0.26} S_t^{-0.51} I^{0.14}, \text{ where:}$$

Q_{100} is the peak 100 year runoff in cubic feet per second (CFS).

A is the drainage area in square miles.

S is the main channel slope (in feet per mile) defined as the average slope of the main channel between points 10% and 85% of the distance from the runoff site to the watershed boundary.

S_t is the surface storage index, in percent, of the drainage area occupied by lakes and swamps plus 1%.

I is the index of manmade surface cover, in percent, which can be used for both existing and future conditions from population data and projections using the equation:

$$I = 0.117D^{0.792-0.039\log D}$$

Where D is the watershed population density in persons per square mile.

The Stankowski Method is something of a “black box” model, in that it is not clear what affect the specific parameters have on the final result. However, the results do appear to be realistic as the following example will illustrate.

Example 5:

Using the Stankowski Method determine the peak 100 year runoff from a watershed in Bergen County, New Jersey with the following characteristics:

Drainage area = 2.5 square miles

Main channel slope = 2% (105 feet per mile)

There are no ponds or swamps (i.e. surface storage index = 1%)

Population density (D) is 3500 persons per square mile (based on published sources)

Solution:

First, the index of manmade surface coverage (I) must be calculated using the population density.



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$$I = 0.117(3500)^{0.792-0.039\log 3500} = 24\%$$

Next, use the regional equation to determine the peak 100 year runoff rate:

$$Q_{100} = 136(2.5)^{0.84}(105)^{0.26}(1)^{-0.51}(24)^{0.14} = 3309\text{CFS}$$

This peak rate of runoff appears to be reasonable for a drainage area of 2.5 square miles.

As stated previously, there are Stankowski regional equations other design storm frequencies ranging from 2 years to 50 years. These are given below:

$$2 \text{ year: } Q_2 = 25.6A^{0.89}S^{0.25}St^{-0.56}I^{0.25}$$

$$5 \text{ year: } Q_5 = 39.7A^{0.88}S^{0.27}St^{-0.54}I^{0.22}$$

$$10 \text{ year: } Q_{10} = 54.0A^{0.88}S^{0.27}St^{-0.53}I^{0.20}$$

$$25 \text{ year: } Q_{25} = 78.2A^{0.86}S^{0.27}St^{-0.52}I^{0.18}$$

$$50 \text{ year: } Q_{50} = 104A^{0.85}S^{0.26}St^{-0.51}I^{0.16}$$

In all of these equations, the variables are as described above for the 100 year regional equation.

This is not the only alternate method for determining peak runoff values however. For example, the USGS has a publication entitled “Methods for Adjusting US Geological Survey Rural Regression Peak Discharges in an Urban Setting”. This publication provides a number of equations for estimating the peak runoff values for various regions of the United States based on an analysis of historic rain and river gauge readings. Like the Stankowski Method, these equations are perhaps best used in larger drainage areas. Also, like the Stankowski Method, these equations, while useful, tend to be cumbersome and not very user-friendly.

Conclusions:

It can be seen that there are a number of ways to estimate runoff. The Rational Method and the SCS Method are the most commonly used. In determining which method to use the engineer should consider the following factors:

1. The size of the drainage area. (The SCS Method can generally be applied to larger areas than the Rational Method).
2. The homogeneity of the drainage area. (The Rational Method works best on fairly homogenous areas and is less applicable to more complex areas. The SCS Method can be used on areas that are quite complex and varied).
3. The reason for the calculation (i.e. will a detention be designed based on the calculation or is it to size a road culvert. The Modified Rational method or the SCS Method must be used if a detention basin is being designed).
4. Any historical data which can be used as a check of the final result achieved.



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Often it is hard to obtain empirical data on a particular watershed and the engineer must rely on judgment as to which methodology to use. The same is true of the underlying assumptions. The engineer must decide if a woods is in “good” or “fair” hydrologic condition when applying a CN value or if the woods has “light underbrush” or “heavy underbrush” when calculation time of concentration. When using the Rational Method, should a particular lawn be assigned a c value of 0.20 or 0.30? These are questions that are very hard to answer definitively. However, the engineer can obtain a measure of certainty by applying the following logic:

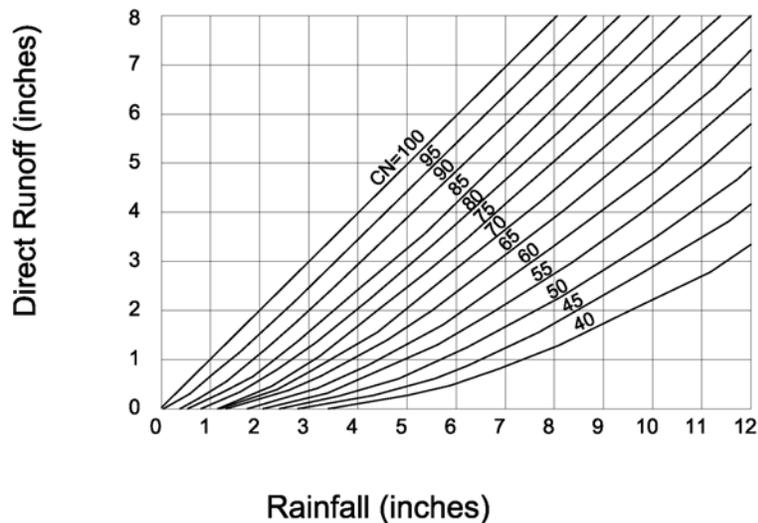
1. Try to be as consistent as possible throughout the calculations. For instance, if one area of open lawn is assigned a “c” value of 0.20, then a stand of dense woods (which would be expected to generate less runoff than the lawn) should be assigned a lower value.
2. Try running the calculations using alternate assumptions and see what effect they have on the results. For example, if the ‘n’ value of woods is assigned a value of 0.40, run the calculations again using $n=0.80$ and see how the resulting Tc value changes. Some engineers run one calculation using the Rational Method and then re-do the analysis using the SCS Method to see if they agree within reason.
3. Try to find any historic data on the watershed to see if there is information on flow rates for specific storms. This information is often available for larger streams but is, unfortunately, virtually never available for small drainage areas.
4. Check the final results against expected values. For instance if a 1 acre wooded parcel is being converted to a parking lot, one would expect a significant increase in both the peak rate and volume of runoff generated by the site. If this is not the case, then the underlying assumptions may be erroneous. Maybe the runoff coefficients under pre-developed conditions are too great or the reduction in the time of concentration is too small. Either of these would tend to reduce the calculated difference between the existing and peak runoff values. Checking the results in this way can often lead the engineer to find inconsistencies in the underlying assumptions. Correcting these can lead to more realistic results.
5. If possible, show the analysis to another experienced drainage engineer. There is nothing like experience in setting a design on the right path.

At this point a few additional differences between the Rational Method and the SCS Method should be discussed. One of these is that the runoff coefficients describe similar conditions but are not exactly analogous. The Rational Method ‘c’ value is directly proportional to the calculated peak rate of runoff and the relationship between them is linear. The SCS “CN” value, on the other hand, certainly contributes to the peak rate of runoff but their relationship is not linear. For this reason, one cannot directly compare the ‘c’ and ‘CN’ values. There is no CN value, for example, that corresponds to a c value of 0.30 for all design storms. The c value of



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0.30 means that 30% of the rainfall (as calculated by the peak storm intensity multiplied by the drainage area) will be converted to runoff. The chart below shows the relationship between the rainfall and runoff depths for a variety of CN values. Note that for 3" of rainfall, the direct runoff is 30% (or 0.9 inches) for a CN value of 75. For a 9" rainfall, however, the direct runoff is 30% (2.7 inches) for a CN value of 50. This illustrates the strong non-linear relationship between the CN value and runoff using the SCS Method. It also shows why a specific CN value cannot be directly correlated with a Rational Method c value.



When using the SCS Method, some authorities require that runoff be calculated separately for pervious and impervious areas. This points out another difference between the two methods. Because there is a direct, linear relationship between the c value and the calculated peak runoff, averaging the c value over a variety of areas will not change the final results. However, calculating a weighted CN value (as was done in the example in this course and which is routinely done in real-life examples) can sometimes lead to misleading results. This is illustrated by the very simple example below.



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Example Showing the Effect of Averaging Runoff Coefficients:

In this case the total drainage area is 2 acres and 1 acre is impervious and 1 acre is woods in “good” condition on B soil. The time of concentration is assumed to be 0.1 hours. The 100 year, 24 hour runoff is 8.2 inches. Determine the peak 100 year runoff using the SCS Method.

Solution:

The problem will be worked out two different ways. First, a weighted CN value will be determine as shown in the table below:

First determine the weighted CN value. Once again, the table below will help to organize the data:

Land Use	Soil Type	CN	Area(Ac)	CN X Area
Impervious	B	98	1	98
Woods	B	55	1	55
Total:			2	143

Weighted CN=143/2 = 71.5 (Use CN =72)

Calculate the S value as follows:

$$S = (1000 / CN) - 10 = (1000 / 72) - 10 = 3.889$$

Using this S value, determine the direct runoff (Q).

Note that 0.2S = 0.778 and 0.8S =3.111

$$Q = (P - 0.2S)^2 / (P + 0.8S) = (8.2 - 0.778)^2 / (8.2 + 3.111) = 4.87inches$$

F_p=1.0 (it is stated in the problem that there are no swamps or ponds, and this translates to an F_p value of 1.0 according to the table above).

Determine q_u using the time of concentration (0.1 hours as stated in the problem), the rainfall, P (8.2 inches) and the initial abstraction, I_a, or 0.778/8.2=0.09) The curve closest to this value is the top curve (I_a/P=0.10) on the unit peak discharge graph. Using this curve and the time of concentration of 0.1 hours yields a unit peak discharge (q_u) of 660. Substituting all of these values into the peak discharge equation yields:

$$q_p = (660)(2 / 640)(4.87)(1.00) = 10.0CFS$$

Now, separate the pervious and impervious areas and re-solve the equations to determine the peak runoff. For the pervious area, CN =55 (woods in B soil).

$$S = (1000 / CN) - 10 = (1000 / 55) - 10 = 8.182$$

Using this S value, determine the direct runoff (Q).



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Note that $0.2S = 1.636$ and $0.8S = 6.545$

$$Q = (P - 0.2S)^2 / (P + 0.8S) = (8.2 - 1.636)^2 / (8.2 + 6.545) = 2.92 \text{ inches}$$

$F_p = 1.0$ (as above)

Determine q_u using the time of concentration (0.1 hours as stated in the problem), the rainfall, P (8.2 inches) and the initial abstraction, I_a , or $1.636/8.2 = 0.20$. This falls midway between the top two curves, so we will interpolate between them to obtain a unit peak discharge (q_u) of 630.

Substituting all of these values into the peak discharge equation yields:

$$q_p = (630)(1/640)(2.92)(1.00) = 2.87 \text{ CFS}$$

Now, perform the same analysis on then impervious surfaces using a CN value of 98.

$$S = (1000 / CN) - 10 = (1000 / 98) - 10 = 0.204$$

Using this S value, determine the direct runoff (Q).

Note that $0.2S = 0.041$ and $0.8S = 0.163$

$$Q = (P - 0.2S)^2 / (P + 0.8S) = (8.2 - 0.041)^2 / (8.2 + 0.163) = 7.96 \text{ inches}$$

$F_p = 1.0$ (as above)

Determine q_u using the time of concentration (0.1 hours as stated in the problem), the rainfall, P (8.2 inches) and the initial abstraction, I_a , or $0.041/8.2 = 0.005$. Use the top curve and obtain a unit peak discharge (q_u) of 660. Substituting all of these values into the peak discharge equation yields:

$$q_p = (660)(1/640)(7.96)(1.00) = 8.21 \text{ CFS}$$

Adding these two values obtains a final runoff value of 11.08. This is greater than 10.0 CFS obtained when the CN values were averaged. Note that the results are obtained are significantly different. If this same analysis was done using the Rational Method, separating the pervious and impervious areas would not have affected the resulting peak runoff value.

So, this brings us to two big questions: which method is more accurate and will the two yield similar results? The answer to the first question depends on a variety of factors as discussed in this course. It should be repeated that each of the methods has its uses and its limitations. The Rational Method should generally not be used if the drainage area is greater than 1 square mile or if it is very heterogeneous. The SCS Method, on the other hand is not applicable if its equations will yield a very low runoff amount (generally less than 0.5 inches). Alternate methods, like the Stankowski Method discussed in this course are generally only applicable in specific geographic areas and under a prescribed set of circumstances. Therefore, neither the Rational Method nor the SCS Method can be said to be more accurate in every particular



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situation. As to the second question, the Rational method and the SCS can Method yield very similar results in some cases. This is shown by the example discussed below.

Comparison example:

In this final example a very simple situation will be analyzed using both the Rational Method and the SCS Method to see if the two yield comparable results. The drainage area is a 2 acre lawn located in Morris County, New Jersey, that will drain into a lawn inlet. The underlying soil is in Hydrologic Soil Group B. The time of concentration is 30 minutes. A 10 year design storm is analyzed. The 10 year, 24 hour runoff in Morris County is 5.2 inches according to published sources.

Rational Method Solution:

A “C” value of 0.30 will be assigned to the lawn. The rainfall intensity is taken from the curve on page 10 is 3.2 inches per hour for a duration of 30 minutes. Therefore, the peak 10 year runoff is:

$$Q = (0.3)(3.2)(2) = 1.92 \text{ CFS}$$

SCS Method Solution:

The CN value for a lawn on “B” soil is 61 (assuming the lawn to be in “good” condition). The S value is calculated as: $S = (1000 / 61) - 10 = 6.39$

The direct runoff is calculated as:

$$Q = (5.2 - 0.2(6.39))^2 / (5.2 + 0.8(6.39)) = 1.49 \text{ inches}$$

Using the peak discharge equation,

$$q_p = q_u A_m Q F_p, \text{ input the following:}$$

q_u is taken from the unit peak discharge curve on page 10 of this course. The quantity Ia/P is $1.278/5.2 = 0.245$. Therefore, the curve for Ia/P of 0.30 will be used with $T_c = 0.5$ hours.

The resulting q_u value is 370.

A_m is the area in sq. miles (0.003125)

Q is the direct runoff (1.49 inches, calculated above)

$F_p = 1.0$ (There is no indication of ponds or swamps in the problem statement).

The peak 10 year storm runoff is calculated as:

$$q_p = (370)(0.003125)(1.49)(1.0) = 1.72 \text{ CFS}$$

Comparing these two results indicates that there is a difference of 0.20 CFS (or about 11%) in the final results. This indicates that the two methods can agree fairly well in some instances. It is obvious that tweaking some of the assumptions would affect these results. For example, using



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a c value of 0.25 for the lawn area instead of the 0.30 chosen would reduce the runoff calculated by the Rational Method to 1.60 CFS. Note that this would reduce the difference to 0.12 CFS (7.5%). This kind of analysis can help to relate the two methods. In other cases, the engineer may find that the two methodologies yield significantly different results. If this is the case, the engineer should study the underlying assumptions (as they relate to runoff coefficients, time of concentration, etc.) and decide if the values used are realistic.

In conclusion, no matter what method is employed, it is important to base all assumptions either on reliable published data or long-standing accepted engineering standards. It was said earlier that runoff estimation is considered to be an inexact science. This is certainly true and two engineers could analyze the same situation and come up with different results. However, as shown in this course applying sound engineering judgment to all aspects of the analysis should lead to sound results.