

SCSRunOf: A Spreadsheet Implementation of the SCS Runoff Method

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Abstract

A Microsoft Excel spreadsheet implementation of the SCS Curve Number Runoff Estimation Method for small watersheds allows the user to enter input and view output quickly and easily. The use of a spreadsheet provides both easy, powerful input-editing and a wide range of output graphing options, lets the user see results immediately and immediately check for spurious input, and avoids the difficulties of file import/export.

Required inputs are daily rainfall values, vegetation state (dormant/active), and a Curve Number, dependent upon soil properties and land cover and determined with look-up tables. The spreadsheet calculates the resulting depth of runoff on an areal basis, which can then be used to calculate total runoff volume. An example Excel workbook – SCSROXL1.XLS – includes sample data for some small drainage basins in south-central Kansas as well as the source code for calculating runoff.

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Explanation of SCS Method to Estimate Runoff

The SCS Runoff Method (Chow et al, 1988; SCS, 1975; SCS, 1985) is a widely-used method for calculating runoff from small watersheds based on minimal information: this section describes the SCS Method as presented in hydrology textbooks, and is based largely on Chow et al (1988).

The required input data are storm rainfall (here, daily rainfall), a Curve Number indicating runoff potential, and antecedent moisture condition, which is based on vegetation state and a summation of preceding rainfall. The resulting calculation gives the runoff as a distributed depth of runoff. (e.g., a rainfall event of 3.21 inches might produce a runoff of 1.17 inches equivalent runoff, meaning that each acre produces 1.17 acre-inches of water).

The Curve Number, used to calculate runoff, depends on a number of factors, including soil type, vegetation state, and degree and style of cultural features, particularly pavement and buildings. The SCS (1975, 1985) and most surface water hydrology books (e.g. Chow et al, 1988) provide tables to determine the Curve Number II based on these factors: The Curve Number is a surrogate for potential retention within the watershed. Depending on antecedent rainfall conditions and vegetation, one of three possible Curve Numbers may be used: Curve Number I for dry conditions; Curve Number II for normal conditions, and Curve Number III for wet conditions. Curve Number I and Curve Number III can be determined from Curve Number II with algebraic formulas. (See SCS (1985) and Chow et al (1988).) The spreadsheet automatically chooses the correct moisture condition and uses the appropriate Curve Number corresponding to the user's input of Curve Number II.

Traditionally, the SCS method is used with look-up curves giving the rainfall-runoff relationship for various curve numbers. This is a time-consuming, tedious, and error-prone process. The spreadsheet calculates the runoff based directly on the original formula.

Theoretical Basis of SCS Method

The theoretical basis for the SCS Method may be stated as

$$1a) \quad \frac{\text{Actual Retention Within Basin}}{\text{Potential Retention Within Basin}} = \frac{\text{Actual Runoff}}{\text{Potential Runoff}} \quad \text{or}$$

$$1b) \quad \frac{F}{S} = \frac{Q}{P_e} \quad , \text{ where}$$

F is infiltration occurring after runoff begins

S is potential maximum retention

Q is actual direct runoff

$P_e = \min(P - I_A, 0)$ is excess precipitation or potential maximum runoff

P is actual precipitation

$I_A = 0.2S$ is initial abstraction

The runoff Q may then be calculated as

$$2a) \quad Q = \frac{P_e^2}{P_e + S} \quad \text{or, more conveniently,}$$

$$2b) \quad Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad , \text{ if } P \geq 0.2S \text{ and}$$

$$Q = 0 \quad \text{if } P < 0.2S$$

SCS (1985) gives an explanation of these assumptions based on asymptotic behavior for large and small storms.

In order to express the soil water retention in a more convenient form, the Curve Number is introduced, which is

$$3) \quad CN = \frac{1000}{S + 10} \quad \text{and thus}$$

$$4) \quad S = \frac{1000}{CN} - 10$$

where S must be measured in inches.

Curve Number II (CNII) is found from soil properties and cover type. Curve Number I, used under dry conditions, is calculated from Curve Number II as

$$5) \quad CNI = \frac{4.2CNII}{10 - 0.058CNII}$$

and Curve Number III, used under wet conditions, is found from Curve Number II as

$$6) \quad CN_{III} = \frac{23CN_{II}}{10 + 0.13CN_{II}}$$

Dry means 5-day antecedent rainfall less than 0.5" for dormant or 1.4" for active vegetation, and wet means more than 1.1" for dormant or 2.1" for active vegetation. Normal means 0.5-1.1" of antecedent rainfall for dormant vegetation or 1.4-2.1" antecedent rainfall for active vegetation. (SCS, 1985; Chow et al, 1988)

Spreadsheet to Calculate Runoff

Calculation of runoff using this spreadsheet requires 1) the spreadsheet and a copy of Excel; 2) knowledge of the soil properties and land cover to determine the Curve Number II from various SCS tables; and 3) daily rainfall and vegetation state (Active/Dormant). (Storm rainfall amounts could be used instead of daily rainfall and the calculations remain the same, but the layout of a spreadsheet becomes much more complicated.)

Once these data are available, the user can enter them into the spreadsheet and use the functions, described below, to calculate the runoff. Figure 1a shows a sample worksheet that uses these functions, as a user would normally see it. Figure 1b shows the formulas used to produce the worksheet in Figure 1a.

Runoff is most readily calculated directly, using the function `SCSRunoff()`, explained in Functions to Calculate Runoff. The formula for runoff in row 13, column D of Figure 1b shows a typical usage. The input values are current rainfall (`$B13`), five-day total rainfall (`SUM($B8:$B12)`), vegetation state (`$C13`), and Curve Number II (`D$3`). The dollar sign `$` is used to make absolute references rather than relative spreadsheet references: e.g., always use column B for rainfall, rather than the column two to the left. The user could easily have a column containing the Curve Number II if cover conditions are varying more rapidly, or get the five-day rainfall from a more complicated smoothing function using a more complicated formula or other column of data.

Figure 1 Sample Spreadsheet to Calculate Runoff by the SCS Method

	A	B	C	D	E	F	G	H
1		muname		PRATT-CARWILE COMPLEX	ALBION SANDY LOAM	WALDECK FINE SANDY LOAM	PLEVNA SOILS	Cement
2		Soil Runoff Letter		A	B	C	D	
3		Curve Number II		30	58	71	78	98
4								
5	Date	Rainfall	Vegetation State	Runoff A	Runoff B	Runoff C	Runoff D	Runoff Cement
6	850415	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
7	850416	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
8	850417	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
9	850418	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
10	850419	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
11	850420	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
12	850421	0.04	ACTIVE	0.00	0.00	0.00	0.00	0.00
13	850422	0.71	ACTIVE	0.00	0.00	0.00	0.00	0.34
14	850423	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
15	850424	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
16	850425	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
17	850426	0.39	ACTIVE	0.00	0.00	0.00	0.00	0.11
18	850427	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
19	850428	0.00	ACTIVE	0.00	0.00	0.00	0.00	0.00
20	850429	3.54	ACTIVE	0.00	0.00	0.22	0.54	3.02
21	850430	0.04	ACTIVE	0.00	0.00	0.00	0.00	0.00

Figure 1b Spreadsheet Formulas

	A	B	C	D
1		muname		PRATT-CARWILE COMPLEX
2		Soil Runoff Letter		A
3		Curve Number II		30
4				
5	Date	Rainfall	Vegetation State	RunoffA
6	31152	0	ACTIVE	=SCSRunoff(\$B6,SUM(\$B3:\$B5),\$C6,D\$3)
7	31153	0	ACTIVE	=SCSRunoff(\$B7,SUM(\$B4:\$B6),\$C7,D\$3)
8	31154	0	ACTIVE	=SCSRunoff(\$B8,SUM(\$B4:\$B7),\$C8,D\$3)
9	31155	0	ACTIVE	=SCSRunoff(\$B9,SUM(\$B4:\$B8),\$C9,D\$3)
10	31156	0	ACTIVE	=SCSRunoff(\$B10,SUM(\$B5:\$B9),\$C10,D\$3)
11	31157	0	ACTIVE	=SCSRunoff(\$B11,SUM(\$B6:\$B10),\$C11,D\$3)
12	31158	0.04	ACTIVE	=SCSRunoff(\$B12,SUM(\$B7:\$B11),\$C12,D\$3)
13	31159	0.71	ACTIVE	=SCSRunoff(\$B13,SUM(\$B8:\$B12),\$C13,D\$3)

FUNCTIONS TO CALCULATE RUNOFF

Listing 1 shows the Visual Basic Source Code for the function `SCSRunoff`, which allows one-step calculation of runoff by the SCS Method. `SCSRunoff` uses four input parameters (daily rainfall, five-day total rainfall, vegetation state (as text), and the Curve Number II) and returns that day's runoff.

`SCSRunoff` works by first extracting the first letter of the Vegetation State, then uses the first letter to determine whether vegetation is dormant or active. Depending on vegetation and five-day total rainfall, it classifies the antecedent moisture conditions as wet, normal, or dry (Antecedent Moisture Class I, II, or III) and calculates the appropriate Curve Number from the input Curve Number II. It then calculates potential maximum retention S from the Curve Number. Finally, it calculates the runoff using Formula 2b.

FUNCTIONS TO CALCULATE INTERMEDIATE VALUES

To calculate runoff, only the function `SCSRunoff` is needed. For teaching and debugging purposes, it may be useful to examine partial solutions based on the SCS Method, such as the Antecedent Moisture Condition (`SCS_AMCClass()`) or the Curve Number to be used (`SCS_CurveNumber()`), or to use these to calculate the runoff with `SCSRunoffFromPrecipAndCurveNumber()`. These functions are listed in the Appendix and included in the spreadsheet for testing, teaching, and debugging purposes.

Listing 1 Visual Basic Code to Find Runoff by the SCS Method

```

Function SCSRunoff(RainToday As Single, Rain5DayTotal As Single, VegetationState As
String, CNii As Single) As Single

' CNii          the SCS Curve Number II
' RainToday     rainfall for the day to calculate runoff for
' Rain5DayTotal the total rainfall for the five preceding days
' VegetationState a string to indicate the state of vegetation. Only the first letter
will be used.
'Dormant Winter Fall Senescent Brown 0
'Growing Spring Summer Active Green 1

If RainToday <= 0 Then
'No precip means no rainfall, so leave immediately
'This is probably the most common case
  SCSRunoff = 0
  Exit Function
End If

Static CNUsed As Single, S As Single

'Choose Vegetation State based on first letter of word,
' then choose the Antecedent Moisture Condition, then
' calculate the Curve Number from CNii
Select Case UCase$(Left$(VegetationState, 1))
  Case "D", "W", "F", "S", "B", "0"
    If Rain5DayTotal < 0.5 Then
      'Use AMC I
      CNUsed = 4.2 * CNii / (10 - 0.058 * CNii)
    Else
      If Rain5DayTotal > 1.1 Then
        'Use AMC III
        CNUsed = 23 * CNii / (10 + 0.13 * CNii)
      Else
        'use AMCII
        CNUsed = CNii
      End If
    End If
  Case "G", "S", "A", "1"
    If Rain5DayTotal < 1.4 Then
      'Use AMC I
      CNUsed = 4.2 * CNii / (10 - 0.058 * CNii)
    Else
      If Rain5DayTotal > 2.1 Then
        'Use AMC III
        CNUsed = 23 * CNii / (10 + 0.13 * CNii)
      Else
        'use AMCII
        CNUsed = CNii
      End If
    End If
End Select
S = 1000 / CNUsed - 10
If RainToday < 0.2 * S Then
  SCSRunoff = 0
  Exit Function
End If

SCSRunoff = ((RainToday - 0.2 * S) ^ 2) / (RainToday + 0.8 * S)

End Function

```

Basin-wide Integration

Rarely does a watershed consist entirely of soils of one type. Prediction of runoff requires integration of the runoff from the constituent soils. Traditionally, SCS runoff has been calculated by looking up runoff with a chart or table with curves or columns for a set of Curve Numbers: because of the labor involved, the analyst usually calculated a single composite Curve Number for the whole basin and used that. The spreadsheet approach supports that method, but also includes the possibility of calculating the runoff for each soil and integrating to determine the total runoff, which is the recommended albeit tedious procedure in SCS (1985).

The Composite Curve Number approach replaces the constituent soils with a homogeneous equivalent soil. The Areal Summation approach may require more calculation, but preserves the properties of each soil. The Areal Summation approach assumes that all runoff generated can reach streams: the Composite Curve Number approach assumes that runoff generated on one soil can infiltrate into another soil (i.e., runoff generated on soil A can infiltrate in an area of soil B). If the more impermeable soils are concentrated in bottom lands, the Areal Summation approach should more accurately predict the runoff. If the soils are distributed at random, the Composite Curve Number might be more realistic. Two worksheets in the sample workbook illustrate each of these approaches.

BY COMPOSITE CURVE NUMBER

In the Composite Curve Number approach, a single Curve Number II is calculated for the whole basin as a weighted average of the individual soils' Curve Number IIs. This Composite Curve Number is used for the whole basin to calculate runoff.

A spreadsheet allows easy calculation of the Composite Curve Number using matrix multiplication. The worksheet Runoff_CompositeCurveNumber shows an actual example. Figure 2 shows an example worksheet to calculate Composite Curve Number 2. The formula in cell E9 is a matrix multiplication of Curve Number IIs in row 2 by soil areas in column E divided by the total area.

Figure 2 Calculation of Composite Curve Number

E9 =MMULT(A2:D2,E4:E7)/SUM(E4:E7)						
	A	B	C	D	E	F
1	Foxtrot	Victor	Delta	Able		
2	30	30	72	58	Curve Number II	
3					Area	
4					12098	Foxtrot
5					1234	Victor
6					34756	Delta
7					98341	Able
8					146429	Total Area
9	Composite Curve Number				58.77	

BY AREAL SUMMATION

In the Areal Summation approach, the runoff from each soil is calculated using its own Curve Number II, then the total runoff is calculated using matrix multiplication. The worksheet Runoff_ArealSummation illustrates this approach.

Conclusions

The SCS Method to Estimate Direct Runoff is a popular and widely-accepted technique for estimating runoff from minimal information. Its implementation as an Excel spreadsheet provides many advantages over the traditional look-up curve and file-oriented program approaches, such as easy, powerful input-editing and easy and powerful graphing.

The computational power of modern computers combined with the ease of use of a spreadsheet makes more detailed analysis, such as the Areal Summation approach, more available than before. Because the necessary parameters are input for each day, the use of spreadsheets makes it easy to use either constant values for land cover conditions or let them vary on a daily basis. The spreadsheet approach may be particularly useful for explaining runoff related concepts.

Acknowledgments

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References

- Chow, Ven Te, David R Maidment, and Larry W. Mays, 1988, *Applied Hydrology*, McGraw-Hill, 572 pages
- SCS , 1975, *Urban Hydrology for Small Watersheds*, Technical Release Number 55, USDA Soil Conservation Service.
- SCS, 1985, *National Engineering Handbook, Section 4: Hydrology*, USDA Soil Conservation Service. (Versions were published in 1964, 1969, and 1972.) Chapter 10 develops the theory and Chapters 7, 8, and 9 explain the various soil and land cover considerations.

Appendix 1 Complete Listing of Spreadsheet Functions for Runoff Calculation with the SCS Method

Option Explicit

```
' This is a simple Visual Basic implementation of the SCS curve number technique as
described
' in Applied Hydrology by Chow, Maidment, and Mays for estimating surface runoff
```

```
'The function parameters are laid out to be in order of most-rapidly varying to least
rapidly varying.
```

```
Function SCSRunoff(RainToday As Single, Rain5DayTotal As Single, VegetationState As
String, CNii As Single) As Single
```

```
' CNii           the SCS Curve Number II
' RainToday      rainfall for the day to calculate runoff for
' Rain5DayTotal  the total rainfall for the five preceding days
' VegetationState a string to indicate the state of vegetation. Only the first letter
will be used.
'Dormant Winter Fall Senescent Brown 0
'Growing Spring Summer Active Green 1
```

```
If RainToday <= 0 Then
'No precip means no rainfall, so leave immediately
'This is probably the most common case
  SCSRunoff = 0
  Exit Function
End If
```

```
Static CNUsed As Single, S As Single
```

```
Select Case UCase$(Left$(VegetationState, 1))
  Case "D", "W", "F", "S", "B", "0"
    If Rain5DayTotal < 0.5 Then
      'Use AMC I
      CNUsed = 4.2 * CNii / (10 - 0.058 * CNii)
    Else
      If Rain5DayTotal > 1.1 Then
        'Use AMC III
        CNUsed = 23 * CNii / (10 + 0.13 * CNii)
      Else
        'use AMCII
        CNUsed = CNii
      End If
    End If
  Case "G", "S", "A", "1"
    If Rain5DayTotal < 1.4 Then
      'Use AMC I
      CNUsed = 4.2 * CNii / (10 - 0.058 * CNii)
    Else
      If Rain5DayTotal > 2.1 Then
        'Use AMC III
        CNUsed = 23 * CNii / (10 + 0.13 * CNii)
      Else
        'use AMCII
        CNUsed = CNii
      End If
    End If
End Select
S = 1000 / CNUsed - 10
If RainToday < 0.2 * S Then
  SCSRunoff = 0
  Exit Function
End If
```

```
SCSRunoff = ((RainToday - 0.2 * S) ^ 2) / (RainToday + 0.8 * S)
```

End Function

```
Function SCS_AMCClass(Rain5DayTotal As Single, VegetationState As String) As Integer
'Returns 1,2, or 3 for the SCS Antecedent Moisture Condition category

' Rain5DayTotal      the total rainfall for the five preceding days
' VegetationState    a string to indicate the state of vegetation. Only the first letter
                    will be used.
'Dormant Winter Fall Senescent Brown 0
'Growing Spring Summer Active Green 1

Select Case UCase$(Left$(VegetationState, 1))
Case "D", "W", "F", "S", "B", "0"
If Rain5DayTotal < 0.5 Then
'Use AMC I
SCS_AMCClass = 1
Else
If Rain5DayTotal > 1.1 Then
'Use AMC III
SCS_AMCClass = 3
Else
'Use AMCII
SCS_AMCClass = 2
End If
End If
Case "G", "S", "A", "1"
If Rain5DayTotal < 1.4 Then
'Use AMC I
SCS_AMCClass = 1
Else
If Rain5DayTotal > 2.1 Then
'Use AMC III
SCS_AMCClass = 3
Else
'Use AMCII
SCS_AMCClass = 2
End If
End If
End Select
End Function
```

```
Function SCS_CurveNumber(Rain5DayTotal As Single, VegetationState As String, CNii As
Single) As Single
'' This is a simple Visual Basic implementation of the SCS curve number technique as
described
'' in Applied Hydrology by Chow, Maidment, and Mays for estimating surface runoff

' CNii              the SCS Curve Number II
' Rain5DayTotal     the total rainfall for the five preceding days
' VegetationState   a string to indicate the state of vegetation. Only the first letter
                    will be used.
'Dormant Winter Fall Senescent Brown 0
'Growing Spring Summer Active Green 1
```

```
Static CNUsed As Single
Select Case UCase$(Left$(VegetationState, 1))
Case "D", "W", "F", "S", "B", "0"
If Rain5DayTotal < 0.5 Then
'Use AMC I
CNUsed = 4.2 * CNii / (10 - 0.058 * CNii)
Else
If Rain5DayTotal > 1.1 Then
'Use AMC III
CNUsed = 23 * CNii / (10 + 0.13 * CNii)
Else
'Use AMCII
CNUsed = CNii
End If
End If
Case "G", "S", "A", "1"
If Rain5DayTotal < 1.4 Then
'Use AMC I
```

```
        CNUsed = 4.2 * CNii / (10 - 0.058 * CNii)
    Else
        If Rain5DayTotal > 2.1 Then
            'Use AMC III
            CNUsed = 23 * CNii / (10 + 0.13 * CNii)
        Else
            'use AMCII
            CNUsed = CNii
        End If
    End If
End Select
SCS_CurveNumber = CNUsed

End Function

Function SCSRunoffFromPrecipAndCurveNumber(RainToday As Single, CurveNumberToUse As
Single) As Single

If RainToday <= 0 Then SCSRunoffFromPrecipAndCurveNumber = 0:      Exit Function

''This just accepts a curve number and precip and generates the runoff
Static S As Single
    S = 1000 / CurveNumberToUse - 10
    If RainToday < 0.2 * S Then
        SCSRunoffFromPrecipAndCurveNumber = 0
        Exit Function
    End If
    SCSRunoffFromPrecipAndCurveNumber = ((RainToday - 0.2 * S) ^ 2) / (RainToday + 0.8 * S)
End Function
```

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