Estimating Stormwater Runoff

An Online Continuing Education Course for Engineers

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1. Introduction

Stormwater runoff occurs when snowmelt or rain flow over the ground. Impervious surfaces like roofs, driveways, sidewalks, parking lots and streets prevent the rain or snowmelt from soaking into the ground. Some rain and snowmelt will soak into the ground, some will evaporate, some will be absorbed by plants, some will be retained in ponds but the rest becomes runoff. Evaporation is not typically considered important. Stormwater runoff ends in streams, rivers, lakes and oceans. Stormwater may cause flooding due to the volume and timing of the runoff. Stormwater may cause pollution due to the contaminants carried by the stormwater. Engineers design storm sewers, culverts, ditches and ponds to help solve some of these problems.

Rainfall data is very important in determining the amount of runoff. The *depth* or *volume* of rainfall during a specific time interval should be known. The total runoff volume is equal to the runoff depth multiplied by the watershed area. The current NWS precipitation-frequency documents by state can be found in the Hydrometeorological Design Studies Center of NOAA's National Weather Service. It looks something like this:

1.1 PF documents by state/territory and duration

State/Territory	Duration (D)		
	D < (≤) 1 hr	1 hr ≤ (<) D ≤ 24 hr	D > 24 hr
Contiguous U.S.			
Alabama	Tech Memo HYDRO-35 (1977)	Technical Paper 40 (1961)	Technical Paper 49 (1964)
Arizona	NOAA Atlas 14, Vol 1 (2004)	NOAA Atlas 14, Vol 1 (2004)	NOAA Atlas 14, Vol 1 (2004)
Arkansas	Tech Memo HYDRO-35 (1977)	Technical Paper 40 (1961)	Technical Paper 49 (1964)
California Southeast	NOAA Atlas 14, Vol 1 (2004)	NOAA Atlas 14, Vol 1 (2004)	NOAA Atlas 14, Vol 1 (2004)
California (remainder)	Frederick & Miller (1979)	NOAA Atlas 2, Vol 11 (1973)	Technical Paper 49 (1964)
Colorado	Arkell & Richards (1986)	NOAA Atlas 2, Vol 3 (1973)	Technical Paper 49 (1964)
Connecticut	Tech Memo HYDRO-35 (1977)	Technical Paper 40 (1961)	Technical Paper 49 (1964)
Delaware	NOAA Atlas 14, Vol 2 (2004)	NOAA Atlas 14, Vol 2 (2004)	NOAA Atlas 14, Vol 2 (2004)
District of Columbia	NOAA Atlas 14, Vol 2 (2004)	NOAA Atlas 14, Vol 2 (2004)	NOAA Atlas 14, Vol 2 (2004)
Florida	Tech Memo HYDRO-35 (1977)	Technical Paper 40 (1961)	Technical Paper 49 (1964)
Georgia	Tech Memo HYDRO-35 (1977)	Technical Paper 40 (1961)	Technical Paper 49 (1964)

As you can see from the table, for different durations, HYDRO-35, Technical Paper 40 and 49 are used in some states. Some states use Atlas 14 and Atlas 2 while other states use other documents.

The *area* of the watershed should be known as well as its shape and orientation. The *watershed* is the area of land that contributes runoff to a single point (culvert, inlet, or outfall). It is delineated and the area is determined from a contour map. Only a portion of the total rainfall will contribute to the runoff in the watershed or drainage area. In the United States, records have shown this to be from 30-50% of the precipitation depth. The *total precipitation depth* is equal to sum of the depth due to evaporation, the depth of runoff, the depth of depression storage, the depth of interception by plants and the depth of infiltration.

The *type of soil*, *land use* and *ground cover* should be known. There are three methods that use this data to derive total runoff volumes.

- Horton equation
- Runoff coefficients
- NRCS (SCS) Curve number

The *slopes* of the drainage paths and channels should be known to calculate the time of concentration.

The *intensity* (in/hr) over a time period should be know. The *frequency* of the storm should be known. The *duration* of the storm should be known. This type of data is often found in a rainfall *intensity-duration-frequency (IDF) curve*. Use the IDF curve for the area in question, which may be within a city or county IDF curve.

2. Methods of runoff estimation

There are a number of empirical methods used to estimate stormwater runoff:

- Rational Method
- NRCS (SCS) Peak Flow Method
- USGS Regression Equations

The Rational Method is good for determining peak discharge for an area of up to about 200 acres or 0.31 mi^2. The USGS method is good from about 25 acres to 25 mi^2. The NRCS method is good for up to 2000 acres or 3.1 mi^2. These limits vary depending on your source. Some say the Rational Method is good for up to 25 acres. Peak flows are usually adequate for the designing of storm drains and open channels.

3. Rational Method

This is one of the most commonly used methods used to calculate peak flow.

$$Q = kCIA$$
$$k = unit\ conversion\ factor, 1.008\ for\ English\ units\ or\ .00278\ for\ metric\ units$$
$$C = dimensionless\ runoff\ coefficient$$
$$I = rainfall\ intensity, in/hr\ (mm/hr)$$
$$A = drainage\ area, acre, acres\ (ha)$$
$$Q = Flow\ or\ discharge, ft^3/s\ (m^3/s)$$

Notice if we leave off k, the units of flow would be in acre-in/hr. Now, to convert to ft^3/s, we multiply by 1.008 but most engineers just use 1.0.

Some of the assumptions for the rational method are:

- Rainfall intensity is the same over the entire drainage area
- Rainfall intensity is uniform over the duration time which is equal to the time of concentration, t_c. The *time of concentration* is the time required for water to travel from the most remote point of the drainage area to the point of interest.
- The frequency of rainfall intensity is assumed to produce the same frequency of peak flow
- The coefficient of runoff is the same for all storms
- Peak flow occurs when the entire drainage area is contributing to the flow

The runoff coefficient is a function of land use, ground cover and many other factors. If the drainage area has varying amounts of land use and ground cover, a composite runoff coefficient should be calculated and used. Typical values are listed in the following table:

In the Rational equation, Q=CAI, the runoff coefficient is good for storms 10 years frequency and less. The equation for other storm frequencies should be:

$$Q=C_fCIA$$

Storm (yr)	C_f
<=10	1
25	1.1
50	1.2
100	1.25

Table 3a

Runoff Coefficients

Type of Drainage area	Runoff Coefficient, C
Business:	
Downtown areas	0.70-0.95
Neighborhood area	0.50-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-unit, detached	0.40-0.60
Multi-unit, attached	0.60-0.75
Suburban	0.25-0.40
Apartment dwelling areas	0.50-0.70
Industrial:	
Light	0.50-0.80
Heavy	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.40
Railroad yards	0.20-0.40
Unimproved areas	0.10-0.30
Lawns:	
Sandy soil, flat, <2%	0.05-0.10
Sandy soil, average, 2-7%	0.10-0.15
Sandy soil, steep, >7%	0.15-0.20
Heavy soil, flat, <2%	0.13-0.17
Heavy soil, average, 2-7%	0.18-0.22
Heavy soil, steep, >7%	0.25-0.35
Streets:	
Asphalt	0.70-0.95
Concrete	0.80-0.95
Brick	0.70-0.85
Drives and sidewalks	0.75-0.85
Roofs	0.75-0.95

Table 3b

As you can see, there is a range of values for the runoff coefficient for different types of drainage areas.

You might like this table better:

Runoff Coefficients "C" for Rational Formula

Runoff Coefficients "C" for Rational Formula												
Soil Group	A			B			C			D		
Slope	0-2%	2-5%	5%+	0-2%	2-5%	5%+	0-2%	2-5%	5%+	0-2%	2-5%	5%+
Land Use												
Cultivated Land												
Winter conditions	.14	.23	.34	.21	.32	.41	.27	.37	.48	.34	.45	.56
Summer conditions	.10	.16	.22	.14	.20	.28	.19	.26	.33	.23	.29	.38
Fallowed Fields												
Poor conditions	.12	.19	.28	.17	.25	.34	.23	.33	.40	.27	.35	.45
Good conditions	.08	.13	.16	.11	.15	.21	.14	.19	.26	.18	.23	.31
Forest/Woodland	.08	.11	.14	.10	.14	.18	.12	.16	.20	.15	.20	.25
Grass Areas												
Good conditions	.10	.16	.20	.14	.19	.26	.18	.22	.30	.21	.25	.35
Average conditions	.12	.18	.22	.16	.21	.28	.20	.25	.34	.24	.29	.41
Poor conditions	.14	.21	.30	.18	.28	.37	.25	.35	.44	.30	.40	.50
Impervious Areas	.90	.91	.92	.91	.92	.93	.92	.93	.94	.93	.94	.95
Weighted Residential												
Lot size 1/5 acre	.29	.33	.36	.31	.35	.40	.34	.38	.44	.36	.41	.48
Lot size 1/4 acre	.26	.30	.34	.29	.33	.38	.32	.36	.42	.34	.38	.46
Lot size 1/3 acre	.24	.28	.31	.26	.32	.35	.29	.35	.40	.32	.36	.45
Lot size ½ acre	.21	.25	.28	.24	.27	.32	.27	.31	.37	.30	.34	.43
Lot size 1 acre	.18	.23	.26	.21	.24	.30	.24	.29	.36	.28	.32	.41

Table 3c

3.1 Hydrologic Soil Group Descriptions

The soil groups used in table 3c:

A -- Well-drained sand and gravel; high permeability.

B -- Moderate to well-drained; moderately fine to moderately coarse texture; moderate permeability.

C -- Poor to moderately well-drained; moderately fine to fine texture; slow permeability.

D -- Poorly drained, clay soils with high swelling potential, permanent high water table, clay pan, or shallow soils over nearly impervious layer(s).

3.1.1 Example

A 10 acre development has a Rational C value of 0.75 and the intensity is 0.63 in/hr.

Given:

C=0.75

I=0.63 in/hr

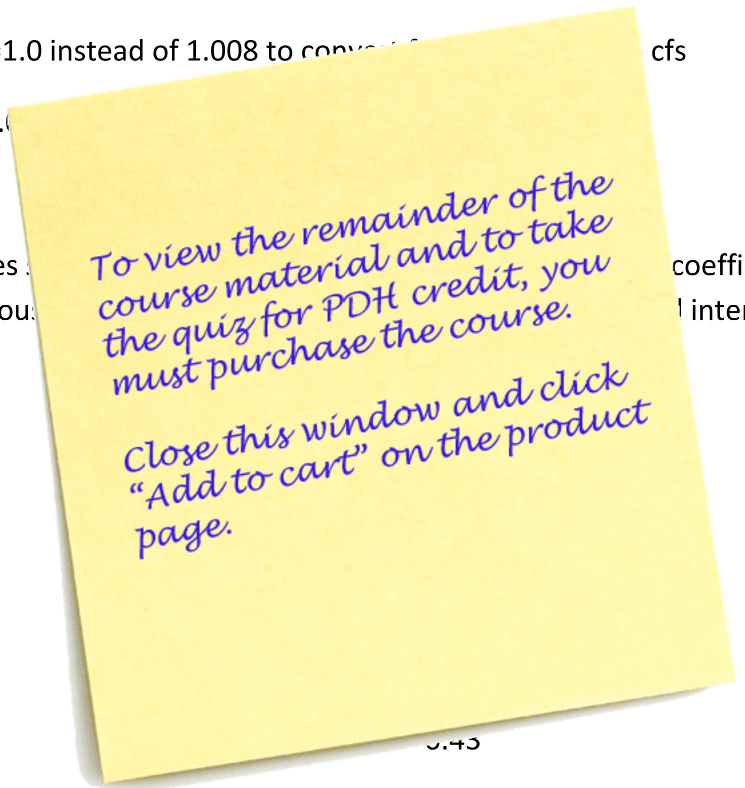
A=10 acres

Assume k=1.0 instead of 1.008 to conv… cfs

Q=kCIA= 1.…

3.1.2 Example

We have a 32 acres … coefficient is 0.88. About 23 acres are perviou… intensity is .72 in/hr.



…43

I= 0.72

CIA= 9.9 ft^3/s

$$Composite\ C = \frac{(0.88\times 9acres) + (0.26\times 23acres)}{32acres} = 0.43$$

To determine the intensity, we need to design for a certain year storm like the 2, 5 10, 25, 50 or 100 year storm. We would use and IDF curve like the one for Chattanooga, TN (Chart 3d).