DETERMINING RUNOFF FOR SMALL STORM EVENTS

1. Introduction

The following calculation guidance should be used during drainage design on all ALDOT projects requiring new development and re-development, as defined in the Guideline for Operation (GFO 3-73) (ALDOT 2014).

As stated in the GFO 3-73, designers should attempt to provide features and practices that cause post-development hydrology to mimic pre-development hydrology of the site to the maximum extent practicable for all small, frequent rain events, working within the constraints of the project, at all locations of discharge. While working toward this goal, consideration should first be given to the use of decentralized practices and features near the source of the runoff. Design elements that utilize natural materials and processes will be considered whenever possible (ALDOT 2014).

The purpose of this document is to provide calculation guidance for drainage design using small frequently occurring storms. The 95^{th} percentile rainfall event will be used for calculating runoff volume and peak discharge. Runoff volume (in inches) is calculated using the 95^{th} percentile rainfall event and a volumetric runoff coefficient. Peak discharge is calculated using the rainfall, basin area, modified curve number, and time of concentration. The modified curve number is determined using the rainfall and runoff volume. Peak discharge can be calculated by hand or through the use of various computer programs. Sample calculations for determining runoff and peak discharge have been included.

2. Design Storm

2.1. Design Storm

Small, frequently occurring storms account for a large proportion of the annual precipitation volume, and runoff from those storm events also significantly alter the discharge frequency, rate and temperature of the runoff (USEPA 2009). As indicated in the GFO 3-73, ALDOT will consider storm events with rainfall depths up to and including the 95^{th} percentile rainfall event, as defined by USEPA (2009), for a specific location as being such small storm events. In turn, for stormwater runoff calculation, the design storm to be used in the analysis will be the 95^{th} percentile rainfall event.

2.2. 95^{th} Percentile Rainfall Depths in Alabama

Estimation of the 95^{th} percentile rainfall depths for all locations throughout the State was performed by the ALDOT Design Bureau according to the approach detailed in the MS4 Stormwater Management Program Plan. Figure 1 is the isohyetal map for the 95^{th} percentile rainfall depths in Alabama generated using that approach.

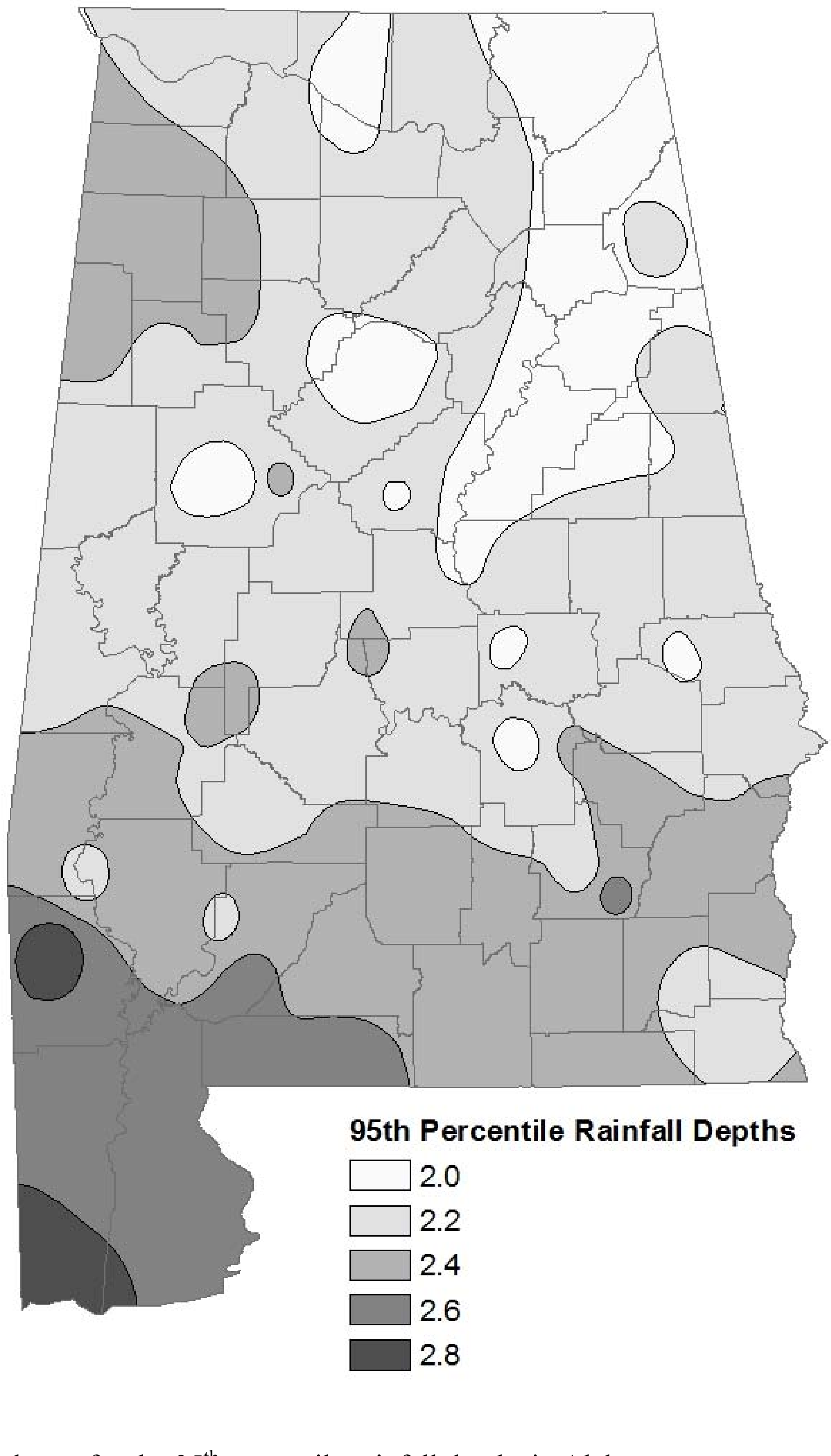


Figure 1 Isohyetal map for the 95th percentile rainfall depths in Alabama

3. Stormwater Runoff Volume and Peak Discharge Calculation

3.1. NRCS Curve Number Method

The curve number (CN) method is a commonly used tool for estimating runoff from rainfall excess. The method was developed by the USDA Natural Resources Conservation Service (NRCS, formerly SCS) and described in detail in Chapter 10 of the National Engineering Handbook, Part 630 - Hydrology (NEH 630) (USDA 2004). In this method, runoff is calculated based on precipitation, initial abstraction, and watershed storage. The curve number runoff equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad P > I_a \qquad (1)$$

$$Q = 0 \qquad P \leq I_a \qquad (2)$$

where, Q is runoff (in.), P is design storm (in.), I_a is initial abstraction (in.), and S is potential maximum retention (in.). Initial abstraction (I_a) consists mainly of interception, infiltration, and depression storage. I_a can be highly variable but NRCS (USDA 2004) found that it can be approximated in many cases by using the following formula:

$$I_a = 0.2\,S \qquad (3)$$

Therefore, the runoff equation becomes:

$$Q = \frac{(P - 0.2\,S)^2}{(P + 0.8\,S)} \qquad P > I_a \qquad (4)$$

where, S is a function of CN:

$$S = \frac{1000}{CN} - 10 \qquad (5)$$

Therefore, runoff can be calculated using only the curve number and rainfall. Curve numbers are determined by land cover type, hydrologic condition, antecedent moisture condition (AMC), and hydrologic soil group (HSG). Curve numbers for various land covers based on an average AMC for annual floods and I_a = 0.2 S can be found in NEH 630 (USDA 2004). For watersheds having multiple land cover types and HSGs, CN is weighted to get watershed CN, and the runoff is estimated using that weighted CN.

Despite its widespread use, the weighted CN method may not be appropriate for estimating runoff from smaller storm events because it can imply a significant initial loss that may not take place, as noted by Pitt (1999). Since all estimated 95th percentile storm events in Alabama are less than 3.0 inches (ranges from 2.0 to 2.8 inches), the design storm will be treated as a small storm. Therefore, the weighted CN will not be used to perform runoff volume and peak discharge calculations for the design storm. Instead, the CN will be modified using the methodology discussed in the following section.

3.2. Small Storm Hydrology Method

The Small Storm Hydrology Method (Pitt 1987) was developed to estimate the runoff volume from urban and suburban land uses for relatively small storm events. In this method, runoff is calculated using volumetric runoff coefficients. Pitt (2013) lists the runoff coefficients that are based on extensive field research conducted in the Midwestern U.S., the Southeastern U.S., and Ontario, Canada, over a wide range of land uses and storm events. Runoff coefficients for individual source areas generally vary with the rainfall amount. Larger storms have higher coefficients. The runoff coefficients for various source areas (Table 1) are derived using the original table from Pitt (2013).

Runoff is simply calculated by multiplying the rainfall amount by the appropriate runoff coefficient. Because the runoff relationship is linear for a given storm, a composite runoff coefficient (weighted average) can be computed for an area consisting of multiple land uses. Therefore, runoff is given by:

$$Q = P * R_{vc} \tag{6}$$

where, Q is runoff (in.), P is the 95th percentile rainfall (in.), and R_{vc} is the composite runoff coefficient.

The following equation is used to determine the stormwater runoff volume (V) in cubic feet:

$$V = \frac{P}{12} * R_{vc} * A * 43560 \tag{7}$$

where, V is runoff volume (ft^3) and A is drainage area (acres). Using the rainfall amount and runoff, a corresponding modified CN can be computed utilizing the following equation:

$$CN = \frac{1000}{10 + 5P + 10Q - 10\sqrt{Q^2 + 1.25\,Q\,P}} \tag{8}$$

Once the modified CN is computed, the time of concentration (t_c) can be computed based on methods identified in Chapter 15 of NEH 630 (USDA 2010) and peak discharge (Q_p) for the design storm can be computed. Procedures and sample calculations for stormwater runoff volume and peak discharge estimation are provided in the next subsection.

Table 1. Source areas and corresponding R_v values for different rainfall amounts

Source Areas	**Rainfall (inches)**				
	2.0	**2.2**	**2.4**	**2.6**	**2.8**
Roof Areas					
Flat, Connected	0.90	0.91	0.91	0.92	0.93
Pitched, Connected	0.99	0.99	0.99	0.99	0.99
Flat or Pitched, Unconnected, A Soil	0.07	0.09	0.10	0.12	0.13
Flat or Pitched, Unconnected, B Soil	0.16	0.18	0.19	0.21	0.22
Flat or Pitched, Unconnected, C or D Soil	0.26	0.28	0.29	0.31	0.32
Parking and Storage Areas					
Paved, Connected	0.99	0.99	0.99	0.99	0.99
Unpaved, Connected	0.89	0.90	0.91	0.92	0.92
Paved or Unpaved, Unconnected, A Soil	0.07	0.09	0.10	0.12	0.13
Paved or Unpaved, Unconnected, B Soil	0.16	0.18	0.19	0.21	0.22
Paved or Unpaved, Unconnected, C or D Soil	0.26	0.28	0.29	0.31	0.32
Driveways or Sidewalks					
Connected	0.99	0.99	0.99	0.99	0.99
Unconnected, A Soil	0.07	0.09	0.10	0.12	0.13
Unconnected, B Soil	0.16	0.18	0.19	0.21	0.22
Unconnected, C or D Soil	0.26	0.28	0.29	0.31	0.32
Streets or Alley Areas					
Smooth textured	0.88	0.89	0.90	0.91	0.91
Intermediate or Rough Textured	0.84	0.85	0.86	0.87	0.88
Highway Areas					
Paved Lane and Shoulder	0.88	0.89	0.90	0.91	0.91
Undeveloped or Pervious Areas					
Undeveloped or Pervious Areas, A Soil	0.07	0.09	0.10	0.12	0.13
Undeveloped or Pervious Areas, B Soil	0.16	0.18	0.19	0.21	0.22
Undeveloped or Pervious Areas, C or D Soil	0.26	0.28	0.29	0.31	0.32
Residential Areas*					
Low Density, < 2 units / acre	0.26	0.28	0.29	0.31	0.32
Medium Density, between 2 and 6 units / acre	0.55	0.58	0.60	0.61	0.62
High Density, > 6 units / acre	0.99	0.99	0.99	0.99	0.99
Other Areas					
Commercial / Industrial	0.99	0.99	0.99	0.99	0.99
High Traffic Urban Paved Areas	0.98	0.98	0.98	0.99	0.99
High Traffic Urban Pervious Areas	0.55	0.58	0.60	0.61	0.62
Excavation or Embankment Construction	0.26	0.28	0.29	0.31	0.32

Connected - flows directly into the drainage system, or occurs as concentrated shallow flow that runs over a pervious area and then into a drainage system.

Unconnected - drains over a pervious area as sheet flow, provided the impervious area is less than one-half the pervious area and the flow path through the pervious area is at least twice the impervious surface flow path. For unconnected flow use the R_v values associated with the appropriate soil type for pervious areas.

*Residential areas include buildings, driveways, yard and streets.

3.3. Calculation Procedures

Stormwater runoff volume and peak discharge can be estimated using the following procedure:

1. Determine the 95th percentile rainfall depth for the project location using the isohyetal map (Figure 1).
2. Delineate watershed boundaries and divide watershed into source areas based on its land use and soil type characteristics.
3. Assign runoff coefficients to source areas using Table 1 and compute the composite runoff coefficient (R_{vc}) by calculating a weighted average.
4. Compute runoff volume using Equations (6) and (7).
5. Compute modified CN using Equation (8).
6. Compute travel times and time of concentration using Velocity Method as described in Chapter 15 of NEH 630 (USDA 2010)
7. Calculate I_a/P using Equations (3) and (5).
8. Compute unit peak discharge (q_u) using Figure A.2 or A.3.
9. Calculate peak discharge using Graphical Peak Discharge Method as described in TR-55 (USDA 1986)

Land use and soil data can be obtained from various online sources. A few example websites are provided below:

Land Use Data:
National Land Cover Database 2011 (NLCD 2011) (http://www.mrlc.gov/nlcd2011.php): NLCD 2011 is the most recent national land cover product created by the Multi-Resolution Land Characteristics (MRLC) Consortium that has been applied consistently across the United States at a spatial resolution of 30 meters. Due to the coarser resolution of land use data for the purpose of this study, it is recommended that designers use recent aerial imagery to delineate land use for given location manually and/or using GIS tools.

Aerial Imagery:
Aerial imagery is available online in ArcGIS or it can be downloaded from different sources:
USGS EarthExplorer (http://earthexplorer.usgs.gov): Aerial imagery of different types (high resolution orthoimagery, NAIP JPG2000, etc.) are available to download depending on selected location.
USGS National Map Viewer (http://viewer.nationalmap.gov/viewer): 1-meter orthoimagery and other data can be downloaded from USGS National Map Viewer.

Soil Data:
The Soil Survey Geographic Database (SSURGO), operated by the USDA-NRCS, provides soil data and information produced by the National Cooperative Soil Survey. The information can be displayed in tables or as maps and is available for most areas in Alabama and other states. SSURGO map data can be viewed in the Web Soil Survey

(http://websoilsurvey.nrcs.usda.gov) or downloaded in ESRI Shapefile format. The coordinate systems are Geographic. Attribute data can be downloaded in text format that can be imported into a Microsoft Access database.

3.4. Sample Calculation (Example 1)

Using steps outlined in Section 3.3, the calculation of pre-development and post-development runoff volumes and peak discharges for the 95th percentile rainfall event in a watershed near Birmingham, Alabama is carried out below:

Pre-development Conditions

1. Determine the 95th percentile rainfall depth for the project location using the isohyetal map (Figure 1).

95th percentile rainfall (P) = 2.0 in.

2. Delineate watershed boundaries and divide watershed into source areas based on its land use and soil type characteristics.

Manual delineation or automatic delineation using GIS tools can delineate watershed boundaries for a given outlet and can divide a watershed into grouped areas based on its land use and soil type characteristics.

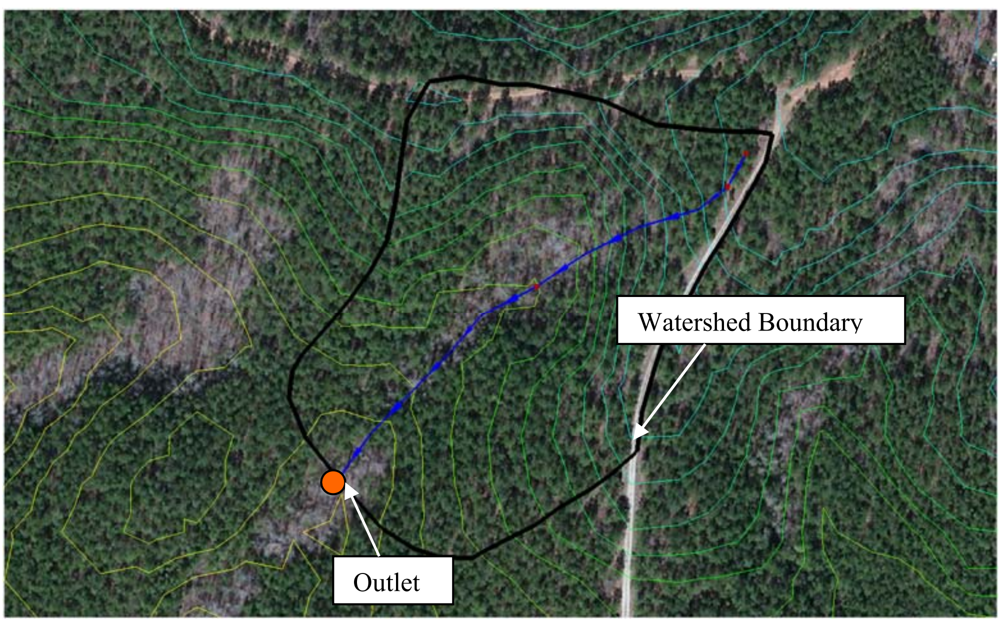


Figure 2. Aerial photograph indicating an outlet and drainage boundary

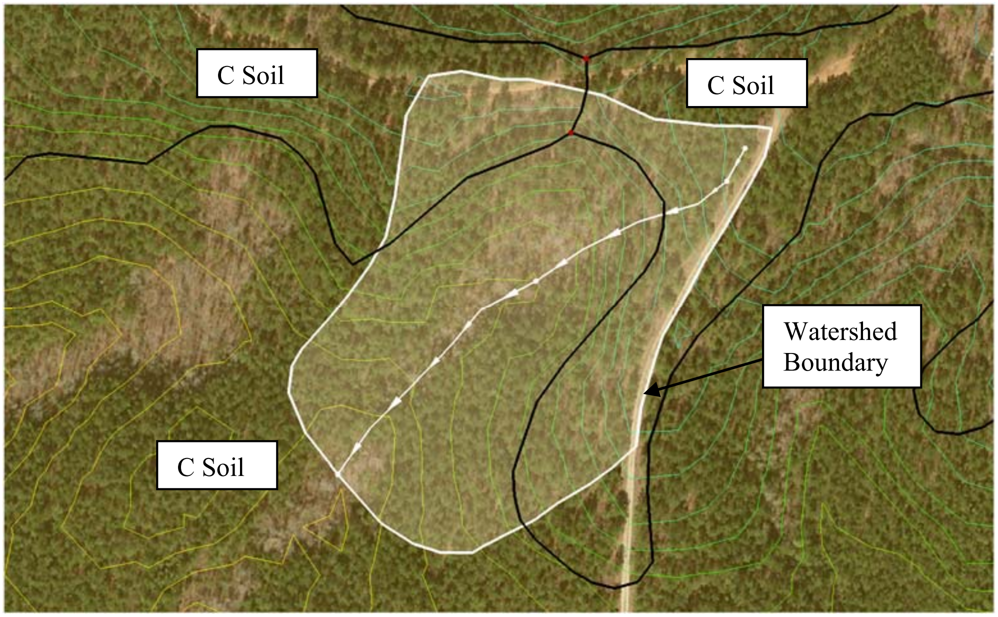


Figure 3. Aerial photograph indicating drainage boundary and soil types

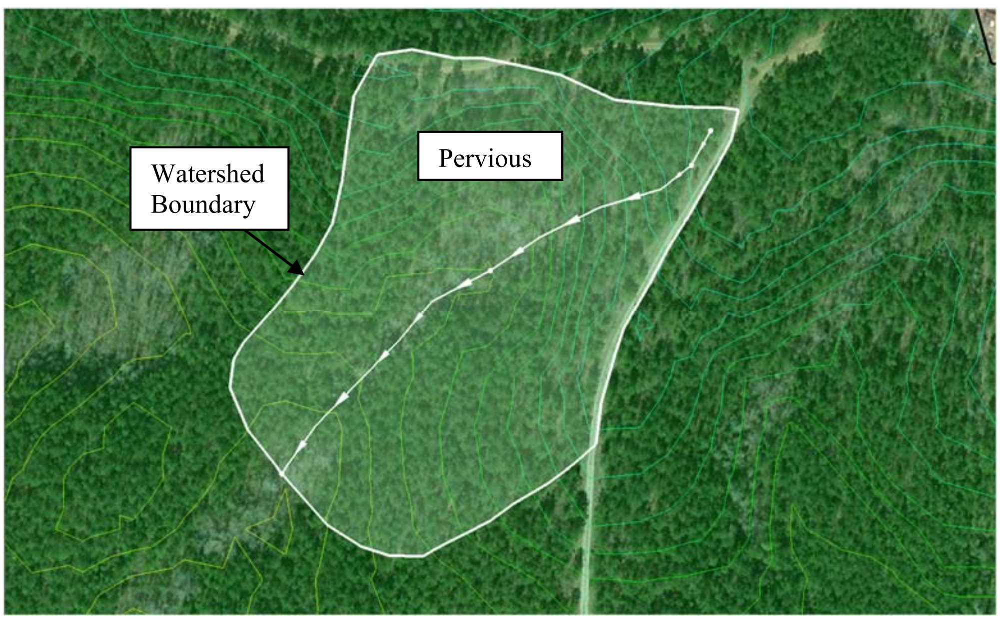


Figure 4. Aerial photograph indicating drainage boundary and pre-development source areas

Table 2. Land use and soil type distribution of sample watershed in Birmingham, Alabama

	Land Use	Soil Type	Area in acres
1	Woods- Good	Type C	5.9

3. Assign runoff coefficient to source areas using Table 1 and compute the composite runoff coefficient (R_{vc}) by calculating a weighted average.

Table 3. Source areas and corresponding R_v

Source areas	Area (acres)	R_v (2 in)	Area * R_v
Woods (Pervious areas – clayey soils, HSG - C)	5.9	0.26	1.534
∑ A =	5.9	∑ (A*R_v)=	1.534

Composite runoff coefficient

$$R_{vc} = \frac{\sum A * R_v}{\sum A} = \frac{1.534}{5.9} = \mathbf{0.26}$$

4. Compute runoff volume using Equations (6) and (7).

$$Q = P * R_{vc} = 2 * 0.26 = \mathbf{0.52\ in.}$$

$$V = \frac{P}{12} * R_{vc} * A * 43560 = \frac{2}{12} * 0.26 * 5.9 * 43560 = \mathbf{11137\ ft^3}$$

5. Compute modified CN using Equation (8)

$$CN = \frac{1000}{10 + 5P + 10Q - 10\sqrt{Q^2 + 1.25\ Q\ P}}$$

$$CN = \frac{1000}{10 + 5 * 2 + 10 * 0.52 - 10\sqrt{0.52^2 + 1.25 * 0.52 * 2}} = \mathbf{79}$$

6. Compute travel time and time of concentration (t_c) using Velocity Method

<u>Segment 1 – Sheet Flow</u>

Travel time for sheet flow

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} S^{0.4}} = \frac{0.007(0.4 * 50)^{0.8}}{(4.1)^{0.5}(0.029)^{0.4}} = 0.157\ hr = 9.4\ min$$

where, overland roughness coefficient (n) = 0.4 (Light Woods) (Appendix Table A.1),
flow length (L) = 50 ft,
2-year 24-hour rainfall (P_2) = 4.1 in., and
slope (S) = 0.029 ft/ft

Segment 2 – Shallow Concentrated Flow

From Figure A.1 (in Appendix) based on ground cover (Forest) and slope (0.204), average flow velocity (v)

$$v = 2.516(S)^{0.5} = 2.516 * 0.204^{0.5} = 1.14\ ft/s$$

Travel time for shallow concentrated flow

$$T_t = \frac{L}{60\ v} = \frac{300}{60 * 1.14} = 4.4\ min$$

Segment 3 – Open Channel Flow

For trapezoidal channel of width = 4 feet, flow depth = 0.4 feet (Grassed waterways, shallow concentrated flow, Figure A.1), and side slope (H:V)=3:1,
Area, $A = \frac{1}{2} * 0.4 * (6.4 + 4) = 2.08\ ft^2$

Wetted Perimeter, $P = 1.265 * 2 + 4 = 6.53\ ft$

Hydraulic Radius, $R = {}^{A}\!/_{P} = {}^{2.08}\!/_{6.53} = 0.319$

For open channel flow, velocity is estimated using Manning's equation:

$$v = \frac{1.49(R)^{\frac{2}{3}}(S)^{\frac{1}{2}}}{n} = \frac{1.49(0.319)^{\frac{2}{3}}(0.051)^{\frac{1}{2}}}{0.06} = 2.62\ \frac{ft}{s}$$

where, channel roughness (n) = 0.06 and
slope (S) = 0.051 ft/ft

Travel time for open channel flow

$$T_t = \frac{L}{60\ v} = \frac{380}{60 * 2.62} = 2.4\ min$$

Time of Concentration

Table 4. Time of concentration calculation

Segment	**Type of Flow**	**Length (ft)**	**Slope (ft/ft)**	**T_t (min)**
1	Sheet	50	0.029	9.4
2	Shallow concentrated	300	0.204	4.4
3	Open channel	380	0.051	2.4

$$t_c = 9.4 + 4.4 + 2.4 = 16.2\ min = \mathbf{0.27\ hr}$$

7. Calculate I_a/P using Equations (3) and (5).

$$I_a = 0.2\,S = 0.2 * \left({}^{1000}/_{CN} - 10\right) = 0.2 * \left({}^{1000}/_{79} - 10\right) = 0.532$$

$$\frac{I_a}{P} = \frac{0.532}{2} = \mathbf{0.27}$$

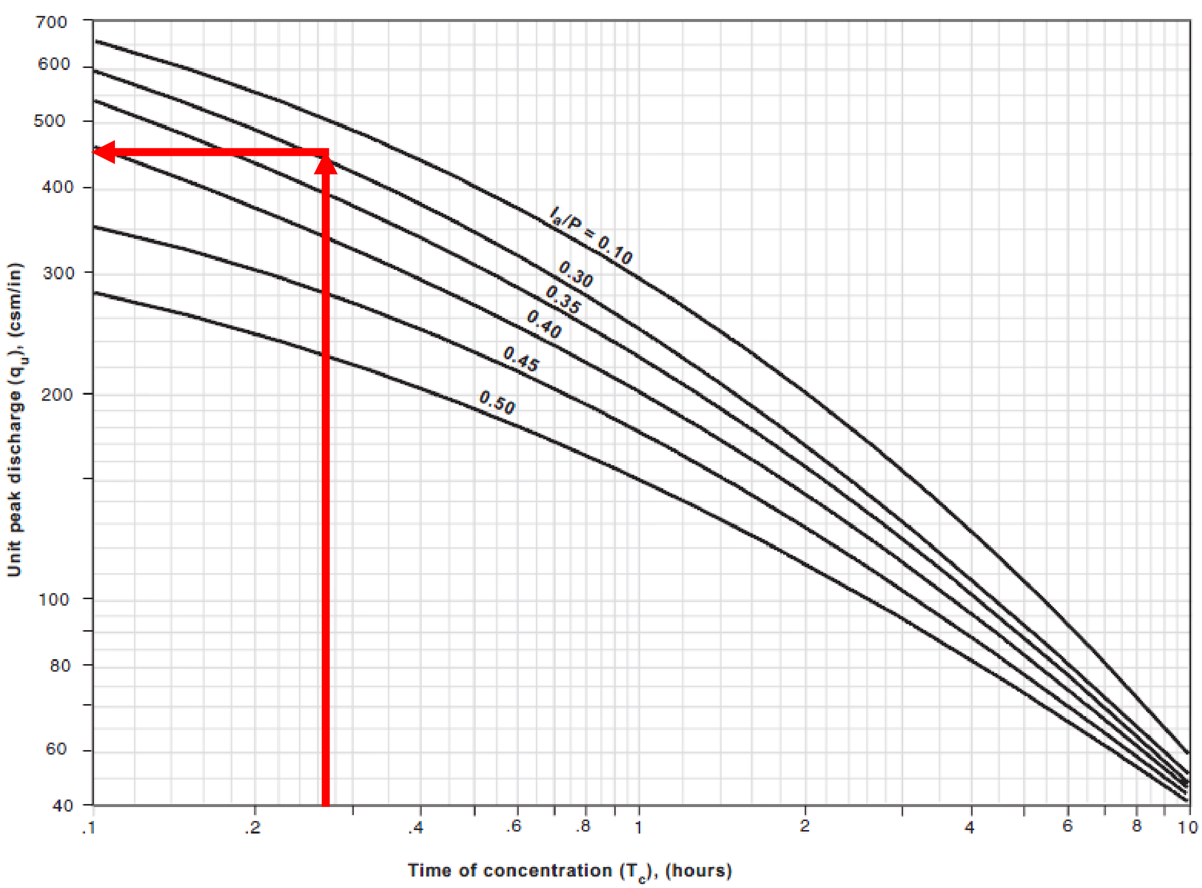
8. Compute unit peak discharge (q_u) using Figure A.2 or A.3.

q_u = 450 csm/in (From Appendix Figure A.3 for t_c = 0.27 hr and I_a/P = 0.27)

9. Calculate peak discharge (Q_p) using Graphical Peak Discharge Method for pre-development conditions

$$Q_p = q_u\,A\,Q\,F_p = 450 * 0.0092 * 0.52 * 1 = \mathbf{2.2\ cfs}$$

where, drainage area (A) = 0.0092 mi^2,
runoff volume (Q) = 0.52 in., and
F_p = 1 (From Appendix Table A.2, no pond and swamp areas)



Estimating unit peak discharge for type III rainfall distribution using Figure A.3

Post-development Conditions

1. Determine the 95th percentile rainfall depth for the project location using the isohyetal map (Figure 1).

95th percentile rainfall (P) = 2.0 in.

2. Delineate watershed boundaries and divide watershed into source areas based on its land use and soil type characteristics.

Manual delineation or automatic delineation using GIS tools can delineate watershed boundaries for a given outlet and can divide a watershed into grouped areas based on its land use and soil type characteristics.

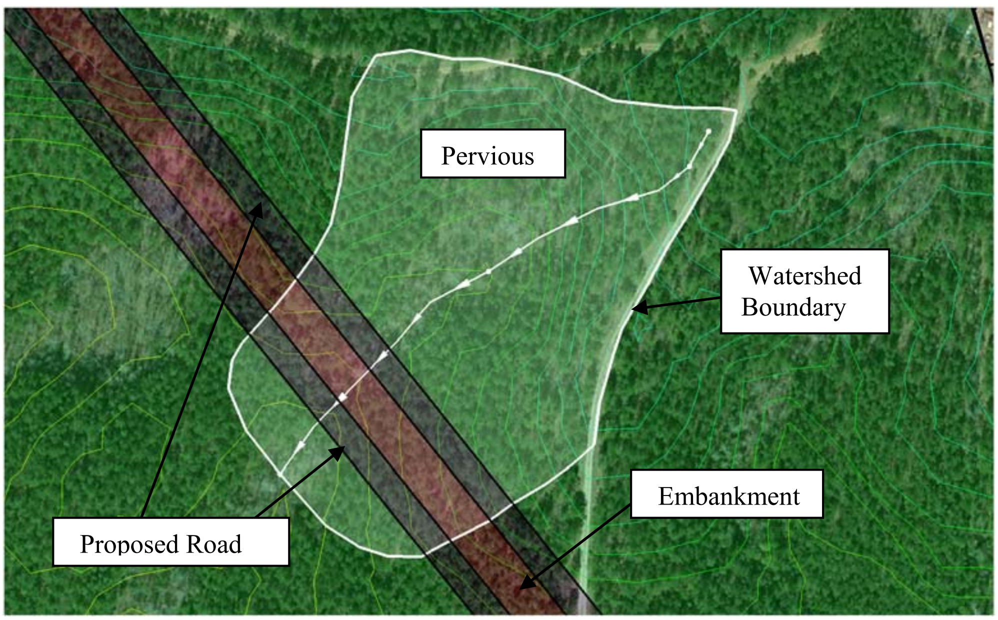


Figure 5. Aerial photograph indicating drainage boundary and post-development source areas

Table 5. Land use and soil type distribution of sample watershed in Birmingham, Alabama

	Land Use	Soil Type	Area in acres	
			Pre	Post
1	Woods- Good	Type C	5.9	4.8
2	Compacted Embankment	Type C		0.5
3	Road/Highway	Type C	-	0.6

3. Assign runoff coefficient to source areas using Table 1 and compute the composite runoff coefficient (R_{vc}) by calculating a weighted average.

Table 6. Source areas and corresponding R_v

Source areas	**Area (acres)**	**R_v (2 in)**	**Area * R_v**
Woods (Pervious areas – clayey soils, HSG - C)	4.8	0.26	1.248
Compacted Embankment (Pervious, HSG - D)	0.5	0.26	0.130
Road (Paved freeway & shoulder, smooth)	0.6	0.88	0.528
∑ A =	5.9	∑ (A*R_v)=	1.906

Composite runoff coefficient

$$R_{vc} = \frac{\sum(A * R_v)}{\sum A} = \frac{1.906}{5.9} = \mathbf{0.32}$$

4. Compute runoff volume using Equations (6) and (7).

$$Q = P * R_{vc} = 2 * 0.32 = \mathbf{0.64\ in.}$$

$$V = \frac{P}{12} * R_{vc} * A * 43560 = \frac{2}{12} * 0.33 * 5.9 * 43560 = \mathbf{13707\ ft^3}$$

5. Compute modified CN using Equation (8).

$$CN = \frac{1000}{10 + 5P + 10Q - 10\sqrt{Q^2 + 1.25\ Q\ P}}$$

$$CN = \frac{1000}{10 + 5 * 2 + 10 * 0.64 - 10\sqrt{0.64^2 + 1.25 * 0.64 * 2}} = \mathbf{82}$$

6. Compute travel time and time of concentration (t_c) using Velocity Method

<u>Segment 1 – Sheet Flow</u>

Travel time for sheet flow

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}S^{0.4}} = \frac{0.007(0.4 * 50)^{0.8}}{(4.1)^{0.5}(0.029)^{0.4}} = 0.157\ hr = 9.4\ min$$

where, overland roughness coefficient (n) = 0.4 (Light Woods) (Appendix Table A.1),
flow length (L) = 50 ft,
2-year 24-hour rainfall (P_2) = 4.1 in., and
slope (S) = 0.029

<u>Segment 2 – Shallow Concentrated Flow</u>

From Appendix Figure A.1 based on ground cover (Forest) and slope (0.204), average flow velocity (v)

$v = 2.516(S)^{0.5} = 2.516 * 0.204^{0.5} = 1.14\ ft/s$
Travel time for shallow concentrated flow

$$T_t = \frac{L}{60\ v} = \frac{300}{60 * 1.14} = 4.4\ min$$

Segment 3 – Open Channel Flow

For trapezoidal channel of width = 4 feet, flow depth = 0.4 feet (Grassed waterways, shallow concentrated flow, Figure A.1), and side slope(H:V)=3:1,
Area, $A = \frac{1}{2} * 0.4 * (6.4 + 4) = 2.08\ ft^2$

Wetted Perimeter, $P = 1.265 * 2 + 4 = 6.53\ ft$

Hydraulic Radius, $R = {}^{A}/_{P} = {}^{2.08}/_{6.53} = 0.319$

For open channel flow, velocity is estimated using Manning's equation:

$$v = \frac{1.49(R)^{\frac{2}{3}}(S)^{\frac{1}{2}}}{n} = \frac{1.49(0.319)^{\frac{2}{3}}(0.051)^{\frac{1}{2}}}{0.06} = 2.62\ \frac{ft}{s}$$

where, channel roughness (n) = 0.06 and
slope (S) = 0.051 ft/ft

Travel time for open channel flow

$$T_t = \frac{L}{60\ v} = \frac{380}{60 * 2.62} = 2.4\ min$$

Time of concentration

Table 7. Time of concentration calculation

Segment	Type of Flow	Length (ft)	Slope (ft/ft)	T_t (min)
1	Sheet	50	0.029	9.4
2	Shallow concentrated	300	0.204	4.4
3	Open channel	380	0.051	2.4

$t_c = 9.4 + 4.4 + 2.4 = 16.2\ min = \mathbf{0.27\ hr}$

7. Calculate I_a/P using Equations (3) and (5).

$I_a = 0.2\ S = 0.2 * \left({}^{1000}/_{CN} - 10\right) = 0.2 * \left({}^{1000}/_{82} - 10\right) = 0.439$

$$\frac{I_a}{P} = \frac{0.439}{2} = \mathbf{0.22}$$

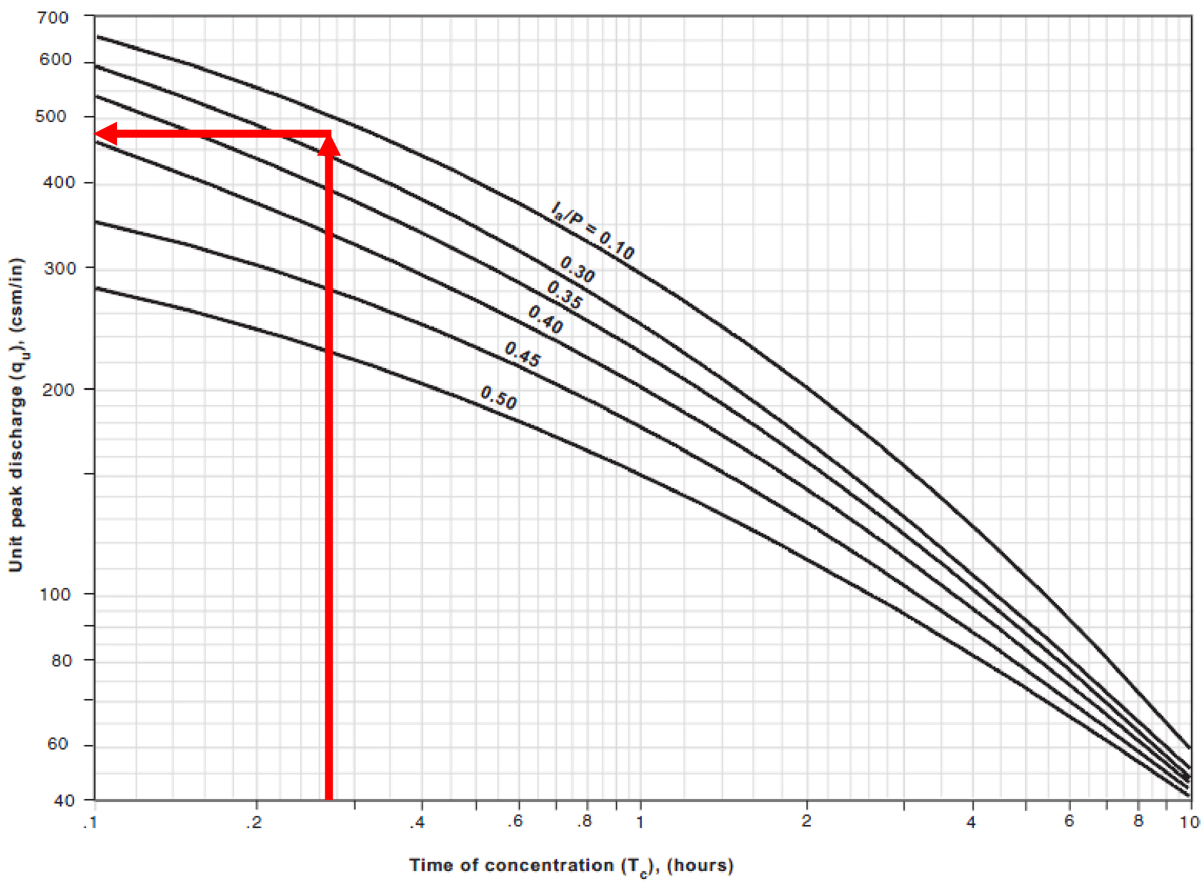
8. Compute unit peak discharge (q_u) using Figure A.2 or A.3.

q_u = 475 csm/in (From Appendix Figure A.3 for t_c = 0.27 hr and I_a/P = 0.22)

9. Calculate peak discharge (Q_p) using Graphical Peak Discharge Method for post-development conditions

$$Q_p = q_u\ A\ Q\ F_p = 475 * 0.0092 * 0.64 * 1 = \mathbf{2.8}\ \boldsymbol{cfs}$$

where, drainage area (A) = 0.0092 mi^2,
runoff volume (Q) = 0.66 in., and
F_p = 1 (From Appendix Table A.2, no pond and swamp areas)



Estimating unit peak discharge for type III rainfall distribution using Figure A.3

Summary of Results

Table 8. Comparison of pre-development and post-development runoff volumes and peak discharges

	Pre	Post
Runoff volume, Q (in.)	0.52	0.64
Runoff volume, V (ft^3)	11137	13707
Peak discharge, Q_p (cfs)	2.2	2.8

Post-development runoff volume has increased by 2570 ft^3 or 23% compared to pre-development runoff volume. Peak discharge has increased by 0.6 cfs or 27%. Since there is significant increase in runoff volume and peak discharge, runoff management practices will be required to maintain pre-development hydrology in accordance with GFO 3-73 (ALDOT 2014).

3.5. Sample Calculation (Example 2)

Using steps outlined in Section 3.3, the calculation of pre-development and post-development runoff volumes and peak discharges for the 95th percentile rainfall event for a watershed in Birmingham, Alabama is carried out below:

Pre-development Conditions

1. Determine the 95th percentile rainfall for project location using the isohyetal map.

95th percentile rainfall (P) = 2.0 in.

2. Delineate watershed boundaries and divide watershed into source areas based on its land use and soil type character. Manual delineation or automatic delineation using GIS tools can delineate watershed boundaries for a given outlet and can divide a watershed into grouped areas based on its land use and soil type characteristics.

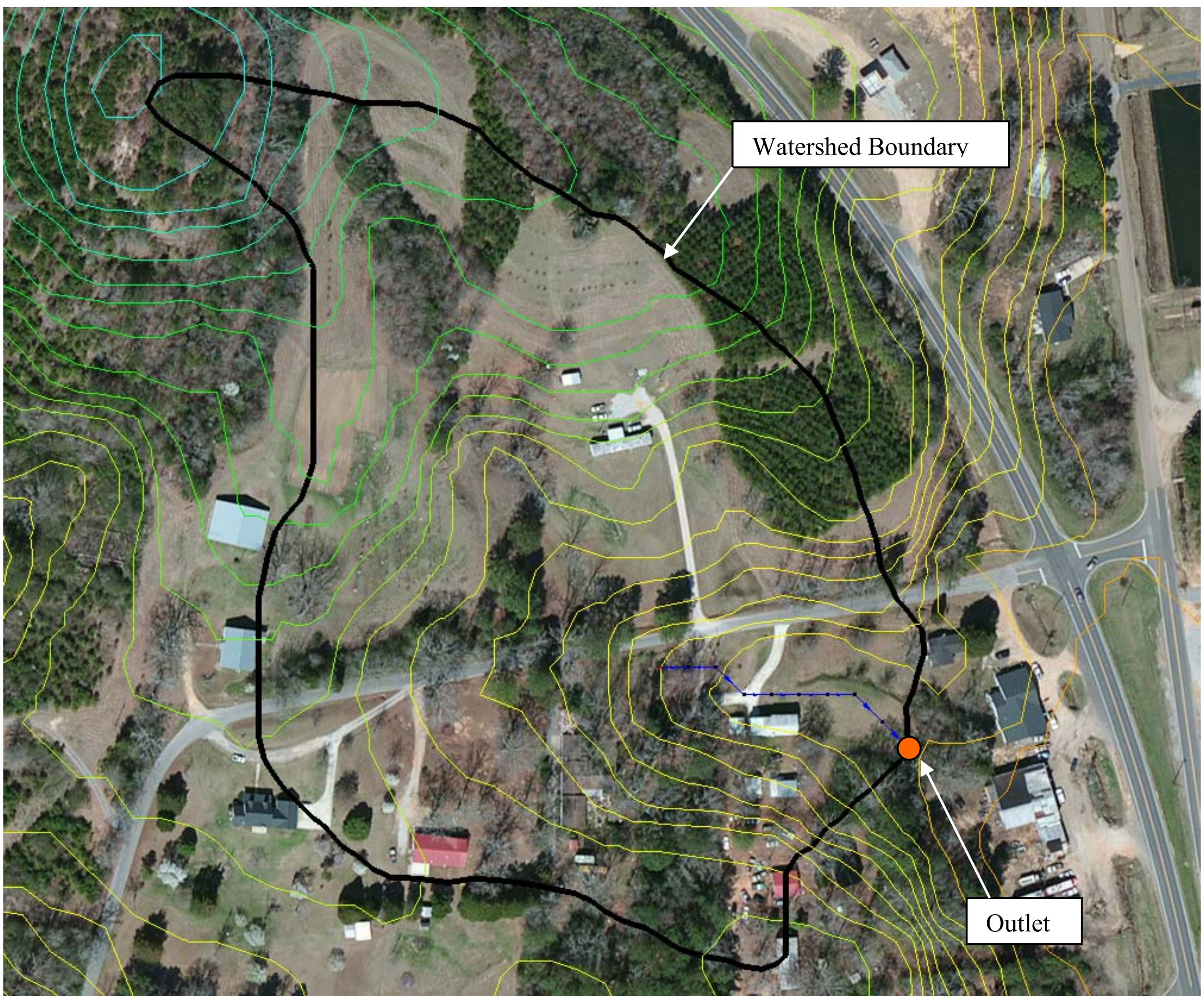


Figure 6. Aerial photograph indicating an outlet and drainage boundary

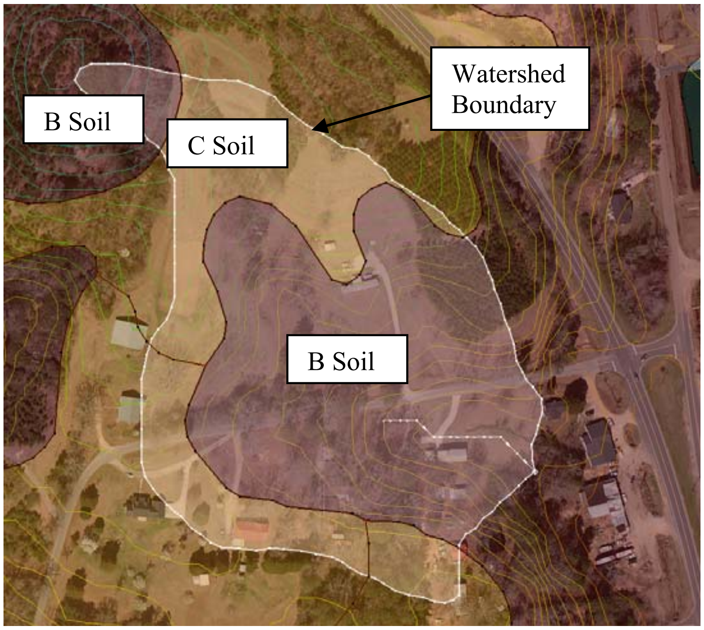


Figure 7. Aerial photograph indicating drainage boundary and soil types

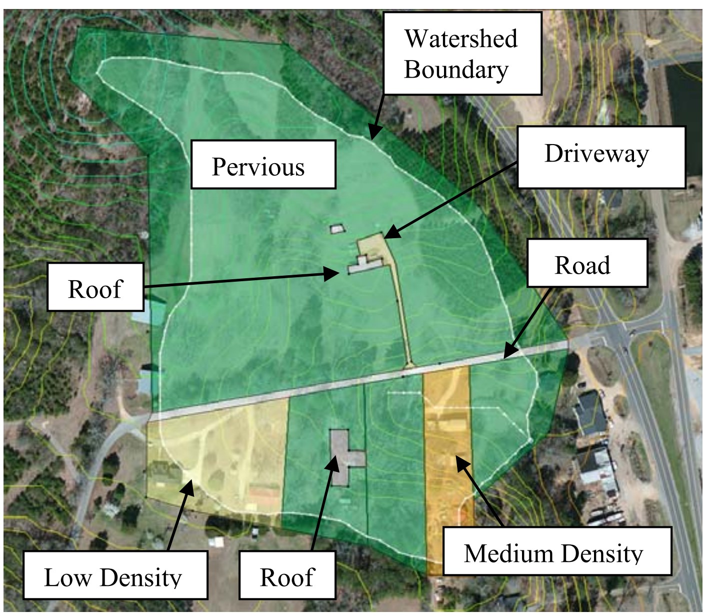


Figure 8. Aerial photograph indicating drainage boundary and pre-development source areas

3. Assign runoff coefficient to source areas using Table 1 and compute the composite runoff coefficient (R_{vc}) by calculating a weighted average.

Table 9. Source areas and corresponding R_v

Source areas	**Area (acres)**	**R_v (2 in)**	**Area * R_v**
Undeveloped or Pervious Areas, B Soil	7.13	0.16	1.141
Undeveloped or Pervious Areas, C or D Soil	4.00	0.26	1.040
Streets, Intermediate or Rough Textured	0.32	0.84	0.269
Low Density, < 2 units / acre	1.12	0.26	0.291
Roof, Flat or Pitched, Unconnected, B Soil	0.15	0.16	0.024
Roof, Flat or Pitched, Unconnected, C or D Soil	0.03	0.26	0.008
Driveway or Sidewalk, Unconnected, B Soil	0.13	0.16	0.021
Driveway or Sidewalk, Unconnected, C or D Soil	0.02	0.26	0.005
Medium Density, between 2 and 6 units / acre	0.87	0.55	0.479
$\sum$ A =	13.77	$\sum$ (A*R_v)=	3.277

Composite runoff coefficient

$$R_{vc} = \frac{\sum A * R_v}{\sum A} = \frac{3.277}{13.77} = \mathbf{0.24}$$

4. Compute runoff volume using Equations (6) and (7).

$$Q = P * R_{vc} = 2 * 0.24 = \mathbf{0.48\ \mathit{in}.}$$

$$V = \frac{P}{12} * R_{vc} * A * 43560 = \frac{2}{12} * 0.24 * 13.77 * 43560 = \mathbf{23{,}993\ \mathit{ft}^3}$$

5. Compute modified CN using Equation (8)

$$CN = \frac{1000}{10 + 5P + 10Q - 10\sqrt{Q^2 + 1.25\, Q\, P}}$$

$$CN = \frac{1000}{10 + 5 * 2 + 10 * 0.48 - 10\sqrt{0.48^2 + 1.25 * 0.48 * 2}} = \mathbf{78}$$

6. Compute travel time and time of concentration (t_c)

<u>Segment 1 – Sheet Flow</u>

Travel time for sheet flow

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}S^{0.4}} = \frac{0.007(0.4 * 43)^{0.8}}{(4.1)^{0.5}(0.026)^{0.4}} = 0.146\ hr = 8.8\ min$$

where, overland roughness coefficient (n) = 0.4 (Light Woods) (Appendix Table A.1),

flow length (L) = 43 ft,
2-year 24-hour rainfall (P_2) = 4.1 in., and
slope (S) = 0.026 ft/ft

Segment 2 – Shallow Concentrated Flow

From Figure A.1 based on ground cover (Forest) and slope (0.072), average flow velocity (v)

$$v = 2.516(S)^{0.5} = 2.516 * 0.072^{0.5} = 0.68\ ft/s$$

Travel time for shallow concentrated flow

$$T_t = \frac{L}{60\ v} = \frac{328}{60 * 0.68} = 8.0\ min$$

Segment 3 – Open Channel Flow

For trapezoidal channel of width = 5 feet, flow depth = 0.4 feet (Grassed waterways, shallow concentrated flow, Figure A.1), and side slope (H:V)=1:1,
Area, $A = \frac{1}{2} * 0.4 * (5.8 + 5) = 2.16\ ft^2$

Wetted Perimeter, $P = 0.57 * 2 + 5 = 6.13\ ft$

Hydraulic Radius, $R = {}^{A}\!/_{P} = {}^{2.16}\!/_{6.13} = 0.352$

For open channel flow, velocity is estimated using Manning's equation:

$$v = \frac{1.49(R)^{\frac{2}{3}}(S)^{\frac{1}{2}}}{n} = \frac{1.49(0.352)^{\frac{2}{3}}(0.056)^{\frac{1}{2}}}{0.05} = 3.52\ \frac{ft}{s}$$

where, channel roughness (n) = 0.05 and
slope (S) = 0.056 ft/ft

Travel time for open channel flow

$$T_t = \frac{L}{60\ v} = \frac{971}{60 * 3.52} = 4.6\ min$$

Time of Concentration

Table 10. Time of concentration calculation

Segment	Type of Flow	Length (ft)	Slope (ft/ft)	T_t (min)
1	Sheet	43	0.026	8.8
2	Shallow concentrated	328	0.072	8.0
3	Open channel	971	0.056	4.6

$$t_c = 8.8 + 8.0 + 4.6 = 21.4\ min = \mathbf{0.36\ hr}$$

7. Calculate I_a/P using Equations (3) and (5).

$$I_a = 0.2\ S = 0.2 * \left({}^{1000}\!/_{CN} - 10\right) = 0.2 * \left({}^{1000}\!/_{78} - 10\right) = 0.564$$

$$\frac{I_a}{P} = \frac{0.564}{2} = \mathbf{0.28}$$

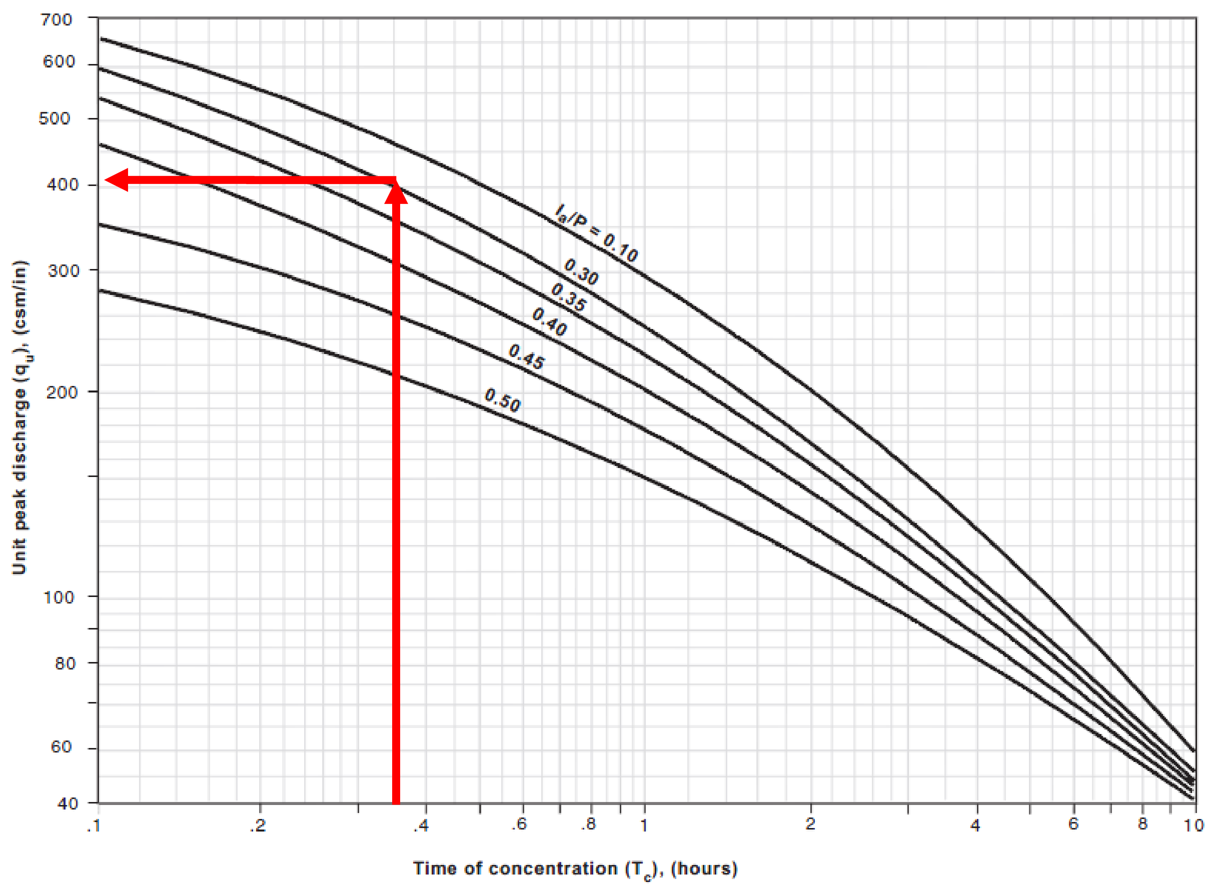
8. Compute unit peak discharge (q_u) using Figure A.2 or A.3.

q_u = 405 csm/in (From Figure A.3 for t_c = 0.36 hr and I_a/P = 0.28)

9. Calculate peak discharge (Q_p) using Graphical Peak Discharge Method for pre-development conditions

$$Q_p = q_u\, A\, Q\, F_p = 405 * 0.0215 * 0.48 * 1 = \mathbf{4.2\ cfs}$$

where, drainage area (A) = 0.0215 mi^2,
runoff volume (Q) = 0.48 in., and
F_p = 1 (From Table A.2, no pond and swamp areas)



Estimating unit peak discharge for type III rainfall distribution using Figure A.3

Post-development Conditions

1. Determine the 95th percentile rainfall for project location using the computer program described in Section 2.

95th percentile rainfall (P) = 2.0 in.

2. Delineate watershed boundaries and divide watershed into source areas based on its land use and soil type characteristics.

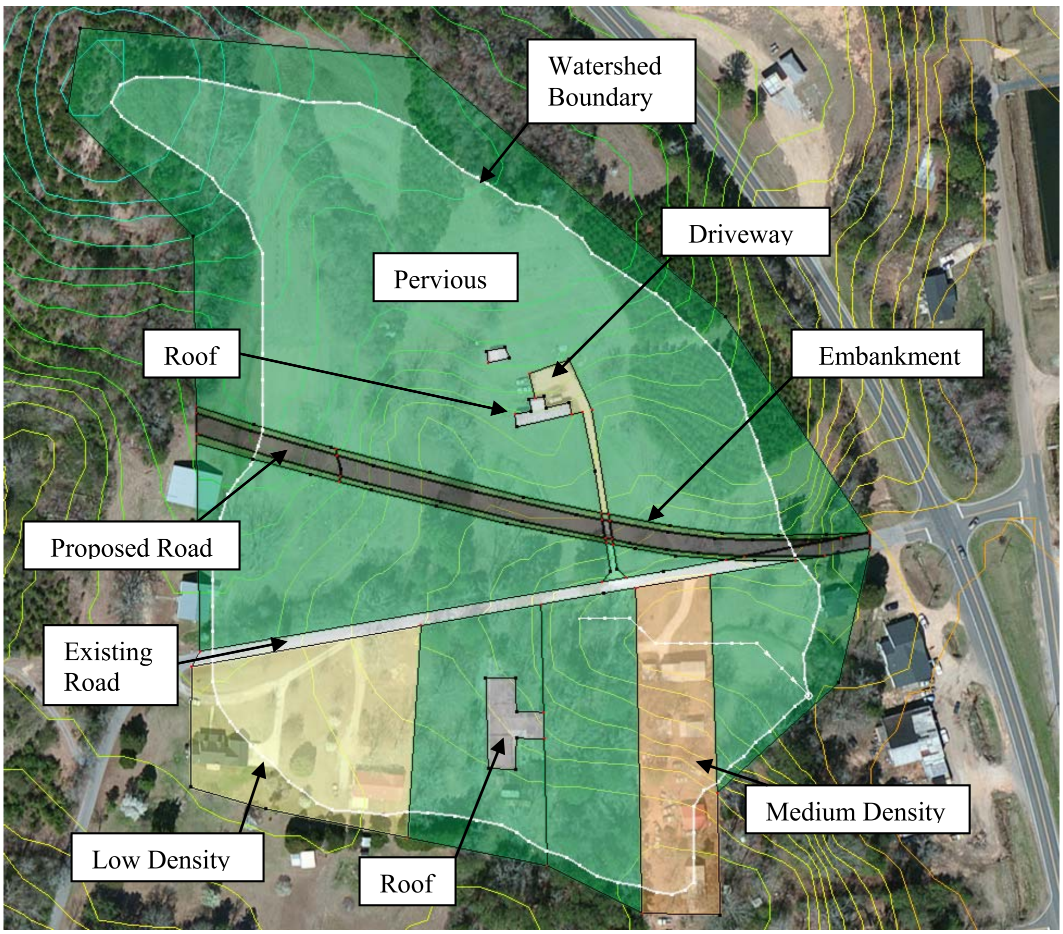


Figure 9. Aerial photograph indicating drainage boundary and post-development source areas

3. Assign runoff coefficient to source areas using Table 1 and compute the composite runoff coefficient (R_{vc}) by calculating a weighted average.

Table 11. Source areas and corresponding R_v

Source areas	**Area (acres)**	**R_v (2 in)**	**Area * R_v**
Undeveloped or Pervious Areas, B Soil	6.58	0.16	1.053
Undeveloped or Pervious Areas, C or D Soil	3.81	0.26	0.991
Streets, Intermediate or Rough Textured	0.26	0.84	0.218
Low Density, < 2 units / acre	1.12	0.26	0.291
Roof, Flat or Pitched, Unconnected, B Soil	0.15	0.16	0.024
Roof, Flat or Pitched, Unconnected, C or D Soil	0.03	0.26	0.008
Driveway or Sidewalk, Unconnected, B Soil	0.12	0.16	0.019
Driveway or Sidewalk, Unconnected, C or D Soil	0.02	0.26	0.005
Medium Density, between 2 and 6 units / acre	0.87	0.55	0.479
Paved Lane and Shoulder	0.50	0.88	0.440
Excavation or Embankment Construction	0.31	0.26	0.081
$\sum$ A =	13.77	$\sum$ (A*R_v)=	3.608

Composite runoff coefficient

$$R_{vc} = \frac{\sum(A * R_v)}{\sum A} = \frac{3.608}{13.77} = \mathbf{0.26}$$

4. Compute runoff volume using Equations (6) and (7).

$$Q = P * R_{vc} = 2 * 0.26 = \mathbf{0.52\ in.}$$

$$V = \frac{P}{12} * R_{vc} * A * 43560 = \frac{2}{12} * 0.26 * 13.77 * 43560 = \mathbf{25,992\ ft^3}$$

5. Compute modified CN using Equation (8).

$$CN = \frac{1000}{10 + 5P + 10Q - 10\sqrt{Q^2 + 1.25\ Q\ P}}$$

$$CN = \frac{1000}{10 + 5 * 2 + 10 * 0.52 - 10\sqrt{0.52^2 + 1.25 * 0.52 * 2}} = \mathbf{79}$$

6. Compute travel time and time of concentration (t_c)

<u>Segment 1 – Sheet Flow</u>

Travel time for sheet flow

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}S^{0.4}} = \frac{0.007(0.4 * 43)^{0.8}}{(4.1)^{0.5}(0.026)^{0.4}} = 0.146\ hr = 8.8\ min$$

where, overland roughness coefficient (n) = 0.4 (Light Woods) (Appendix Table A.1),
flow length (L) = 43 ft,
2-year 24-hour rainfall (P_2) = 4.1 in., and
slope (S) = 0.026

<u>Segment 2 – Shallow Concentrated Flow</u>

From Figure A.1 based on ground cover (Forest) and slope (0.204), average flow velocity (v)

$$v = 2.516(S)^{0.5} = 2.516 * 0.072^{0.5} = 0.68\ ft/s$$

Travel time for shallow concentrated flow

$$T_t = \frac{L}{60\ v} = \frac{328}{60 * 0.68} = 8.0\ min$$

<u>Segment 3 – Open Channel Flow</u>

For trapezoidal channel of width = 5 feet, flow depth = 0.4 feet (Grassed waterways, shallow concentrated flow, Figure A.1), and side slope (H:V)=1:1,

Area, $A = \frac{1}{2} * 0.4 * (5.8 + 5) = 2.16\ ft^2$

Wetted Perimeter, $P = 0.57 * 2 + 5 = 6.13\ ft$

Hydraulic Radius, $R = {}^{A}/_{P} = {}^{2.16}/_{6.13} = 0.352$

For open channel flow, velocity is estimated using Manning's equation:

$$v = \frac{1.49(R)^{\frac{2}{3}}(S)^{\frac{1}{2}}}{n} = \frac{1.49(0.352)^{\frac{2}{3}}(0.056)^{\frac{1}{2}}}{0.05} = 3.52\ \frac{ft}{s}$$

where, channel roughness (n) = 0.05 and
slope (S) = 0.056 ft/ft

Travel time for open channel flow

$$T_t = \frac{L}{60\ v} = \frac{971}{60 * 3.52} = 4.6\ min$$

<u>Time of concentration</u>

Table 12. Time of concentration calculation

Segment	Type of Flow	Length (ft)	Slope (ft/ft)	T_t (min)
1	Sheet	43	0.026	8.8
2	Shallow concentrated	328	0.072	8.0
3	Open channel	971	0.056	4.6

$$t_c = 8.8 + 8.0 + 4.6 = 21.4\ min = \mathbf{0.36\ hr}$$

7. Calculate I_a/P using Equations (3) and (5).

$$I_a = 0.2\,S = 0.2 * \left({}^{1000}/_{CN} - 10\right) = 0.2 * \left({}^{1000}/_{79} - 10\right) = 0.532$$

$$\frac{I_a}{P} = \frac{0.532}{2} = \mathbf{0.27}$$

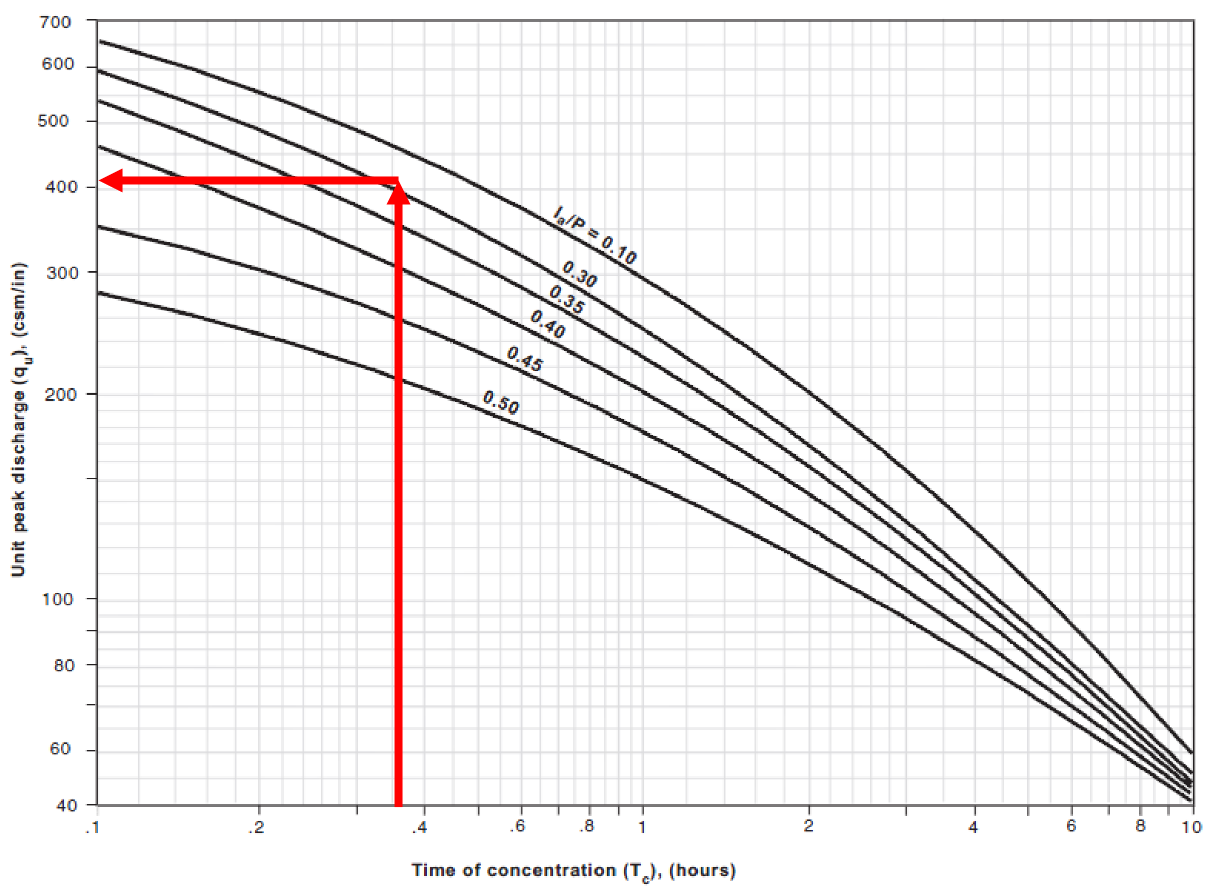
8. Compute unit peak discharge (q_u) using Figure A.2 or A.3.

q_u = 407 csm/in (From Figure A.3 for t_c = 0.36 hr and I_a/P = 0.27)

9. Calculate peak discharge (Q_p) using Graphical Peak Discharge Method for post-development conditions

$$Q_p = q_u\,A\,Q\,F_p = 407 * 0.0215 * 0.52 * 1 = \mathbf{4.6\ cfs}$$

where, drainage area (A) = 0.0215 mi^2,
runoff volume (Q) = 0.52 in., and
F_p = 1 (From Table A.2, no pond and swamp areas)



Estimating unit peak discharge for type III rainfall distribution using Figure A.3

Summary of Results

Table 13. Comparison of pre-development and post-development runoff volumes and peak discharges

	Pre	**Post**
Runoff volume, Q (in.)	0.24	0.26
Runoff volume, V (ft^3)	23,993	25,992
Peak discharge, Q_p (cfs)	4.2	4.6

Post-development runoff volume has increased by 1,999 ft^3 or 8.3% compared to pre-development runoff volume. Peak discharge has increased by 0.4 cfs or 9.5%. Since there is significant increase in runoff volume and peak discharge, runoff management practices will be required to maintain pre-development hydrology in accordance with GFO 3-72 (ALDOT 2014).

4. Acceptable Computer Models

There is a wide variety of both public and private domain computer models available for performing stormwater calculations. The computer models use one or more calculation methodologies to estimate runoff characteristics. Below is a list of few widely used public domain models that use NRCS CN method (Table 14). Once a modified curve number is calculated from R_v coefficients, it can be used in one of the listed models to generate peak discharge.

Table 14. List of acceptable public domain computer models

Program	**Developer**
HEC-1	U.S. Army Corps of Engineers
HEC-HMS	U.S. Army Corps of Engineers
SWMM	U.S. Environmental Protection Agency
WinTR-20	U.S. Department of Agriculture Natural Resources Conservation Service
WinTR-55	U.S. Department of Agriculture Natural Resources Conservation Service

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APPENDIX

1. Computation of Travel Time and Time of Concentration

Travel time (T_t) is the time it takes water to travel from one location to another in a watershed. T_t is a component of time of concentration (T_c), which is the time for runoff to travel from the hydraulically most distant point of the watershed to a given outlet point. T_c is sum of T_t values for the various consecutive flow segments. These segments can be sheet flow, shallow concentrated flow, open channel flow, or a combination of these.

Sheet Flow

Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams. Manning's kinematic solution can be used to compute T_t:

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}S^{0.4}}$$

where, T_t is travel time (hr),
n is Manning's roughness coefficient (Table A.1),
L is flow length (ft),
P_2 is 2 year, 24-hour rainfall (in), and
S is slope

Table A.1 Manning's n for sheet flow (USDA 2010)

Surface description	**n[1]**
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils: Residue cover ≤20% Residue cover >20%	 0.06 0.17
Grass: Short grass prairie Dense grasses [2] Bermuda grass	 0.15 0.24 0.41
Range (natural)	0.13
Woods:[3] Light underbrush Dense underbrush	 0.40 0.80

[1] The n values are a composite of information compiled by Engman (1986).
[2] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3] When selecting n , consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Shallow concentrated flow

Sheet flow becomes shallow concentrated flow after approximately 100 feet. The average velocity is function of watercourse slope and type of channel and can be determined from Figure A.1. After determining the velocity, travel time for the shallow concentrated flow can be estimated as follows:

$$T_t = \frac{L}{60\ v}$$

where, T_t is travel time (min),
L is flow length (ft), and
v is average velocity (ft/s).

Open channel flow

Shallow concentrated flow occurs at shallow depths of 0.1 to 0.5 feet. Beyond that channel flow is assumed to occur. Manning's equation can be used to estimate average flow velocity for open channel flow:

$$v = \frac{1.49(R)^{\frac{2}{3}}(S)^{\frac{1}{2}}}{n}$$

where, v is average velocity (ft/s),
R is hydraulic radius (ft),
S is channel slope, and
n is Manning's n value for open channel flow

Manning's n value can be obtained from Chow (1959) and other references.

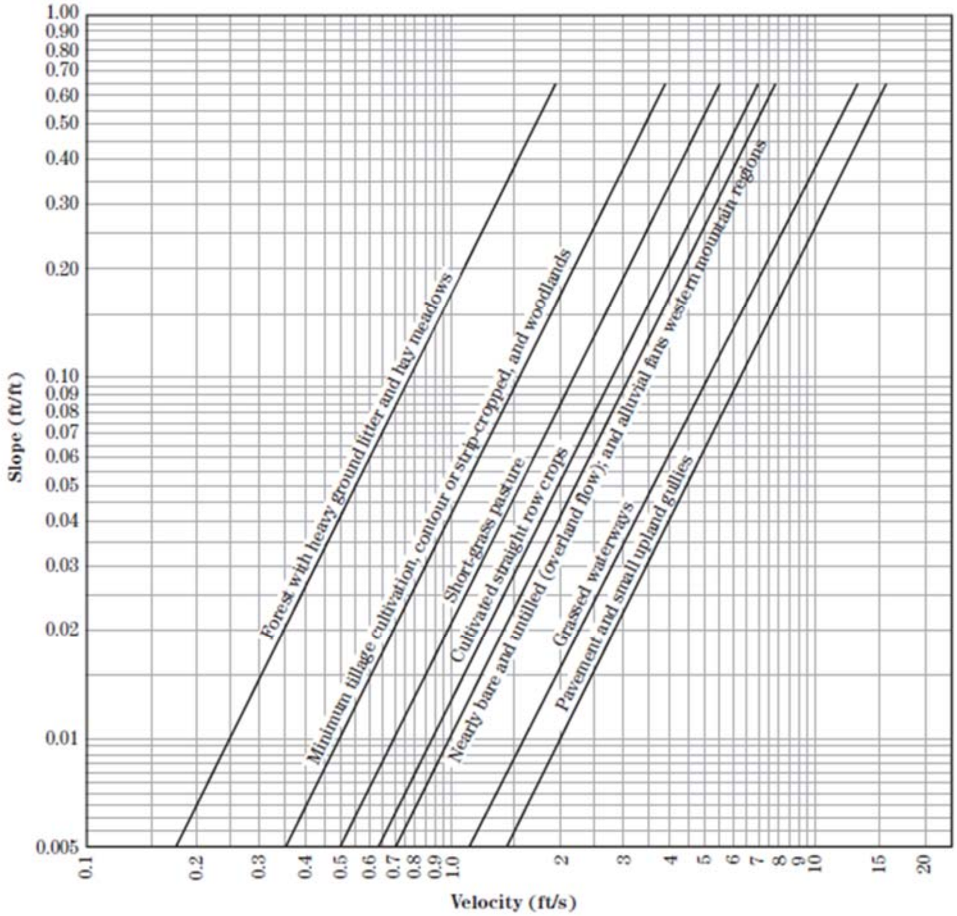
2. Graphical Peak Discharge Method

This method was developed from hydrograph analyses using TR-20, "Computer Program for Project Formulation - Hydrology" (SCS 1983). The peak discharge equation used is:

$$Q_p = q_u\ A\ Q\ F_p$$

where, Q_p is peak dischage (ft^3/s),
q_u is unit peak discharge (csm/in),
A is drainage area (mi^2),
Q is runoff volume (in), and
F_p is pond and swamp factor (Table A.2)

After modified CN and T_c is computed, peak discharge per square mile per inch of runoff (q_u) is obtained from Figure A.2 or A.3 by using rainfall distribution type and I_a/P ratio.



Flow type	Depth (ft)	Manning's *n*	Velocity equation (ft/s)
Pavement and small upland gullies	0.2	0.025	$V = 20.328(s)^{0.5}$
Grassed waterways	0.4	0.050	$V=16.135(s)^{0.5}$
Nearly bare and untilled (overland flow); and alluvial fans in western mountain regions	0.2	0.051	$V=9.965(s)^{0.5}$
Cultivated straight row crops	0.2	0.058	$V=8.762(s)^{0.5}$
Short-grass pasture	0.2	0.073	$V=6.962(s)^{0.5}$
Minimum tillage cultivation, contour or strip-cropped, and woodlands	0.2	0.101	$V=5.032(s)^{0.5}$
Forest with heavy ground litter and hay meadows	0.2	0.202	$V=2.516(s)^{0.5}$

Figure A.1 Average velocities for estimating travel time for shallow concentrated flow (USDA 2010)

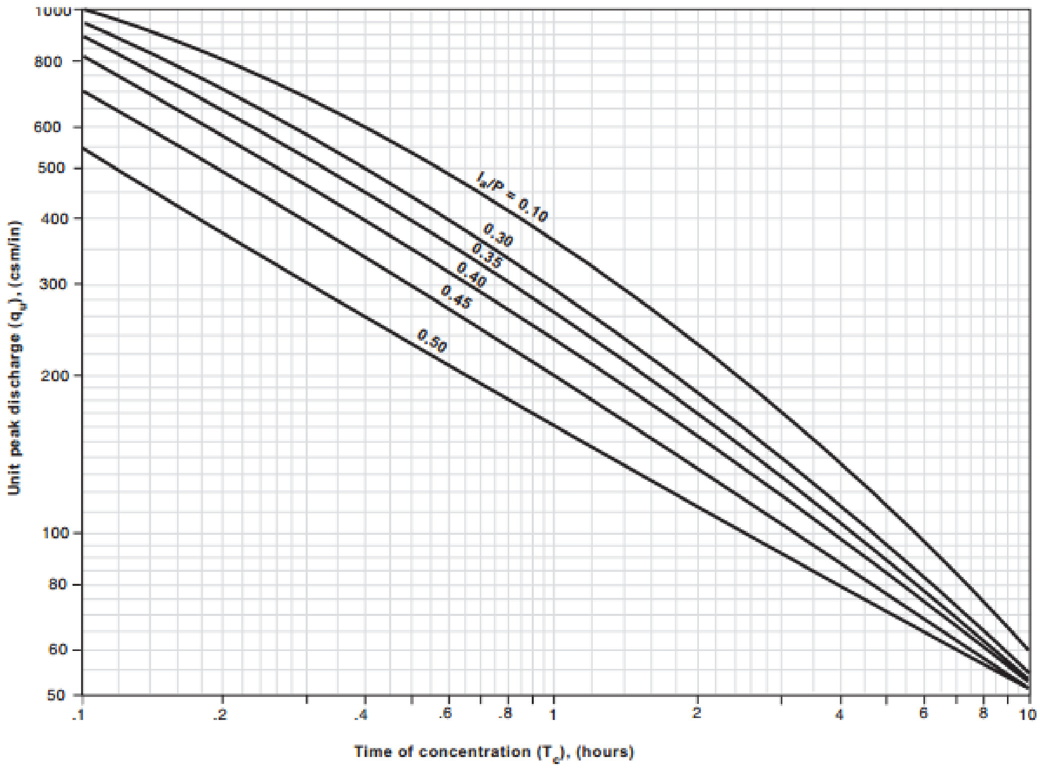


Figure A.2 Unit peak discharge (q_u) for Type II rainfall distribution (USDA 1986)

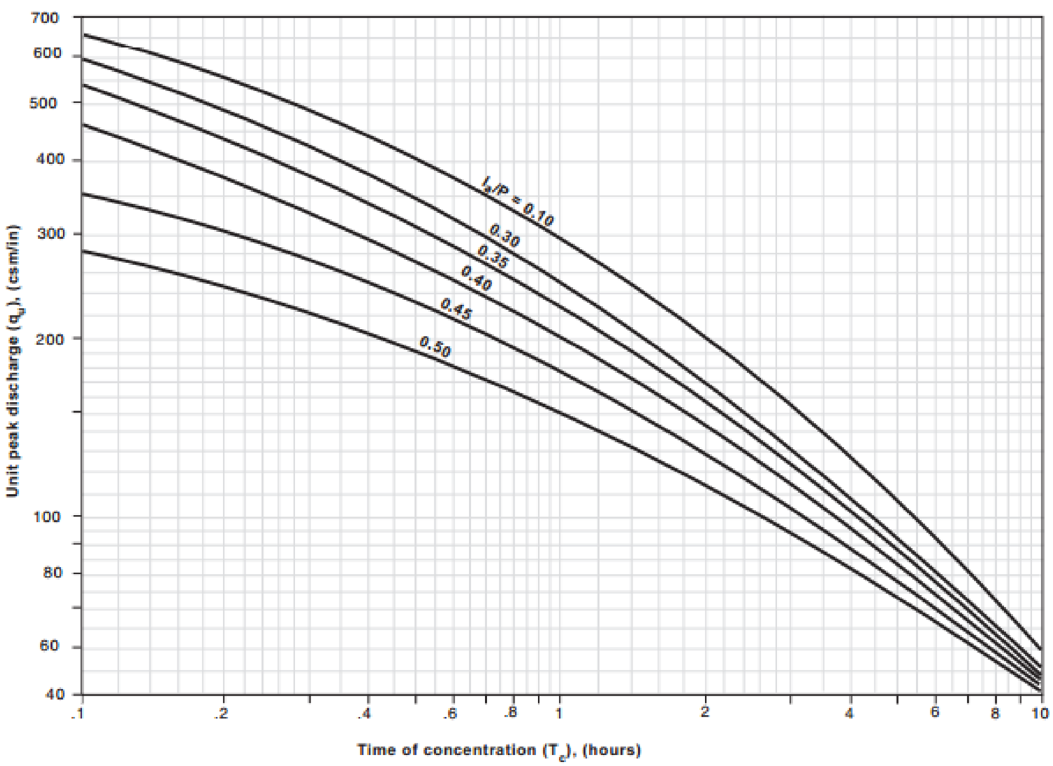


Figure A.3 Unit peak discharge (q_u) for Type III rainfall distribution (USDA 1986)

Table A.2 Factor for Pond and Swamp Areas (USDA, 1986)

Pond and Swamp Areas (%[1])	**F_p**
0	1.00
0.2	0.97
1	0.87
3	0.75
5 or greater	0.72

[1] Percent of entire drainage basin