Stormwater

Calculations

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SWMDR Training Day 1
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Presentation Goals

- Calculate the Time of Concentration (T_C)
- Calculate Peak Flow Rates Using the Rational Method
- Size a Basin Using the Modified Rational Method
- Use the NRCS Methodology (TR-55) (Peak Flow, Volume and Hydrographs)

Estimate Runoff with Models

N.J.A.C. 7:8-5.6(a)1: Stormwater runoff shall be calculated in accordance with the following:

i. NRCS Methodology

- **Section 4, National Engineering Handbook (NEH-4)** https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=43924.wba
- **Technical Release 55 ("TR-55")** https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

ii. The Rational Method for peak flow and the Modified Rational Method for hydrograph computations

Design Storms

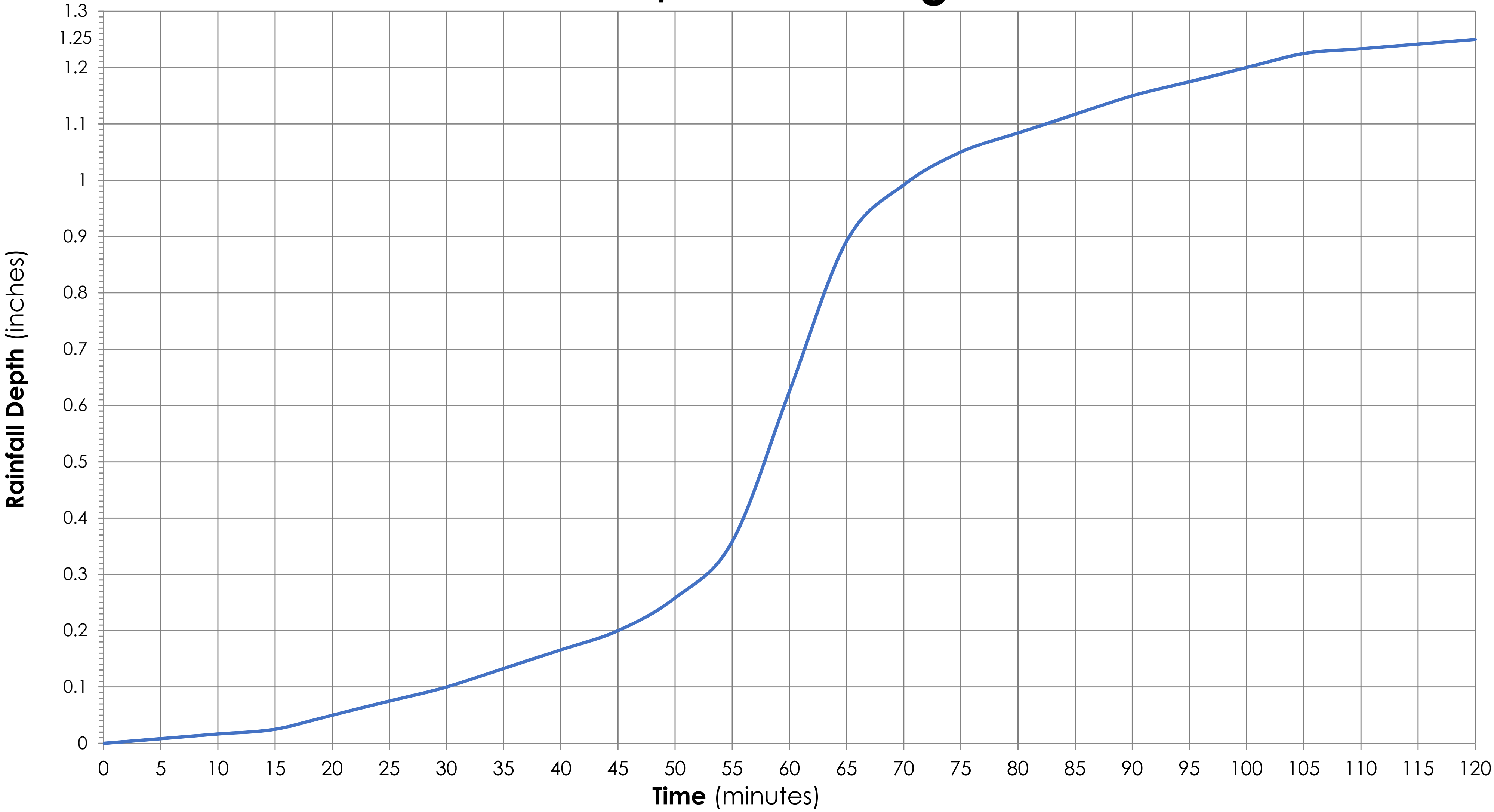
Compute stormwater runoff for:

1. Groundwater Recharge
2. Stormwater Quality
3. Stormwater Quantity

Design Storms

NJDEP Stormwater Water Quality Design Storm

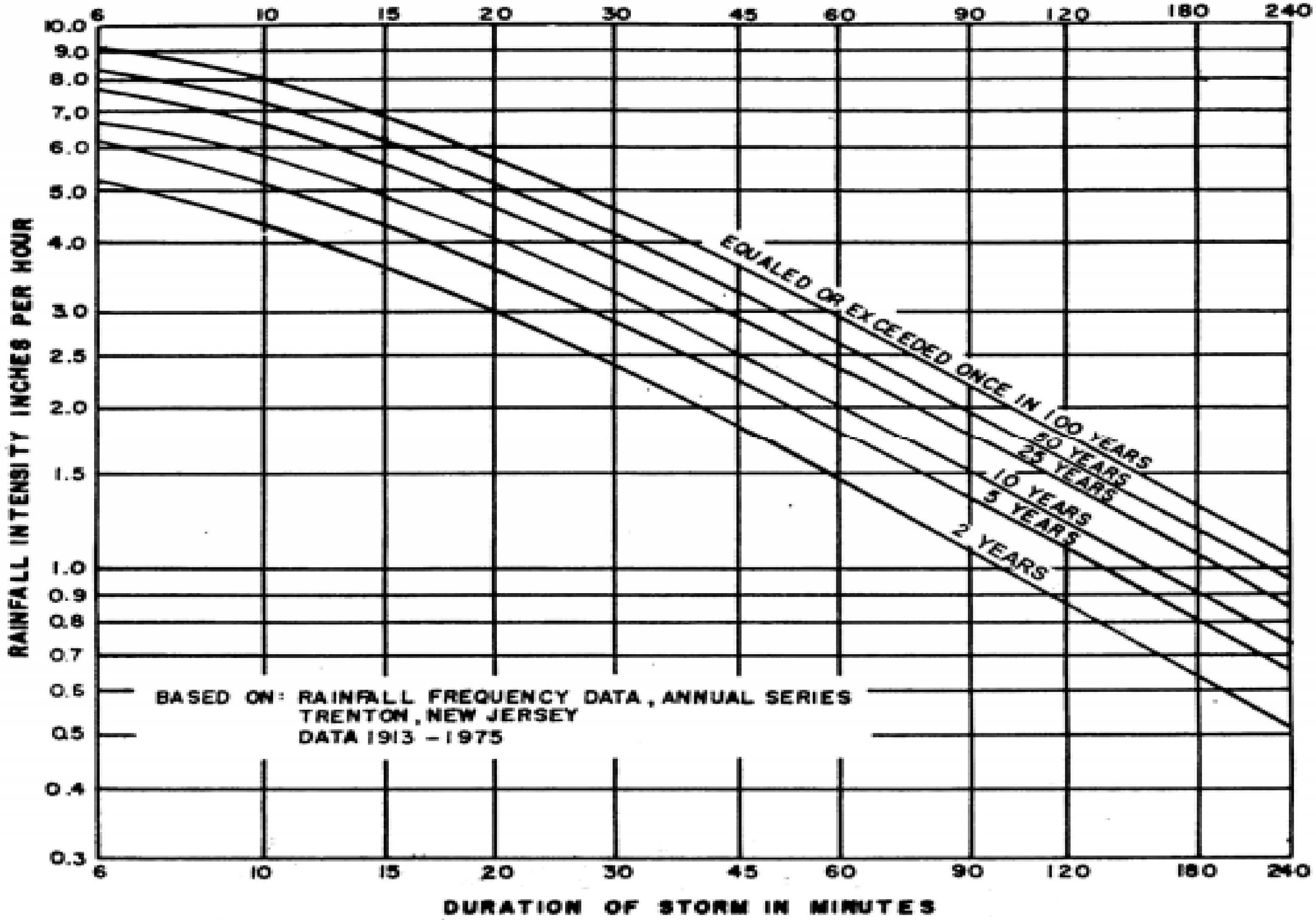
= 1.25-Inch/2-Hour Design Storm



Design Storms

Stormwater Quantity Control Design Storms

Intensity-Duration-Frequency (IDF) Curve



Design Storms

Stormwater Quantity Control Design Storms

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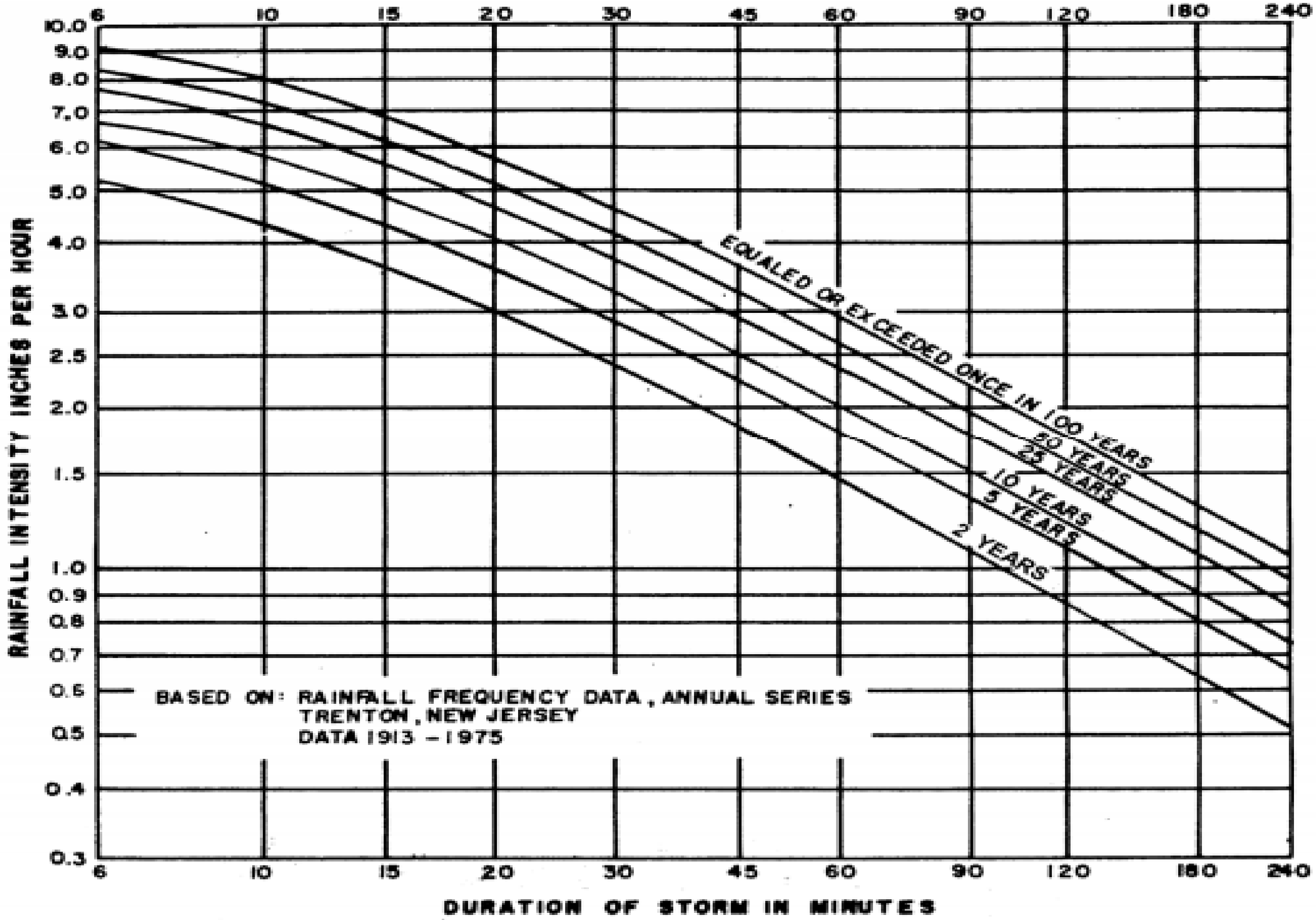
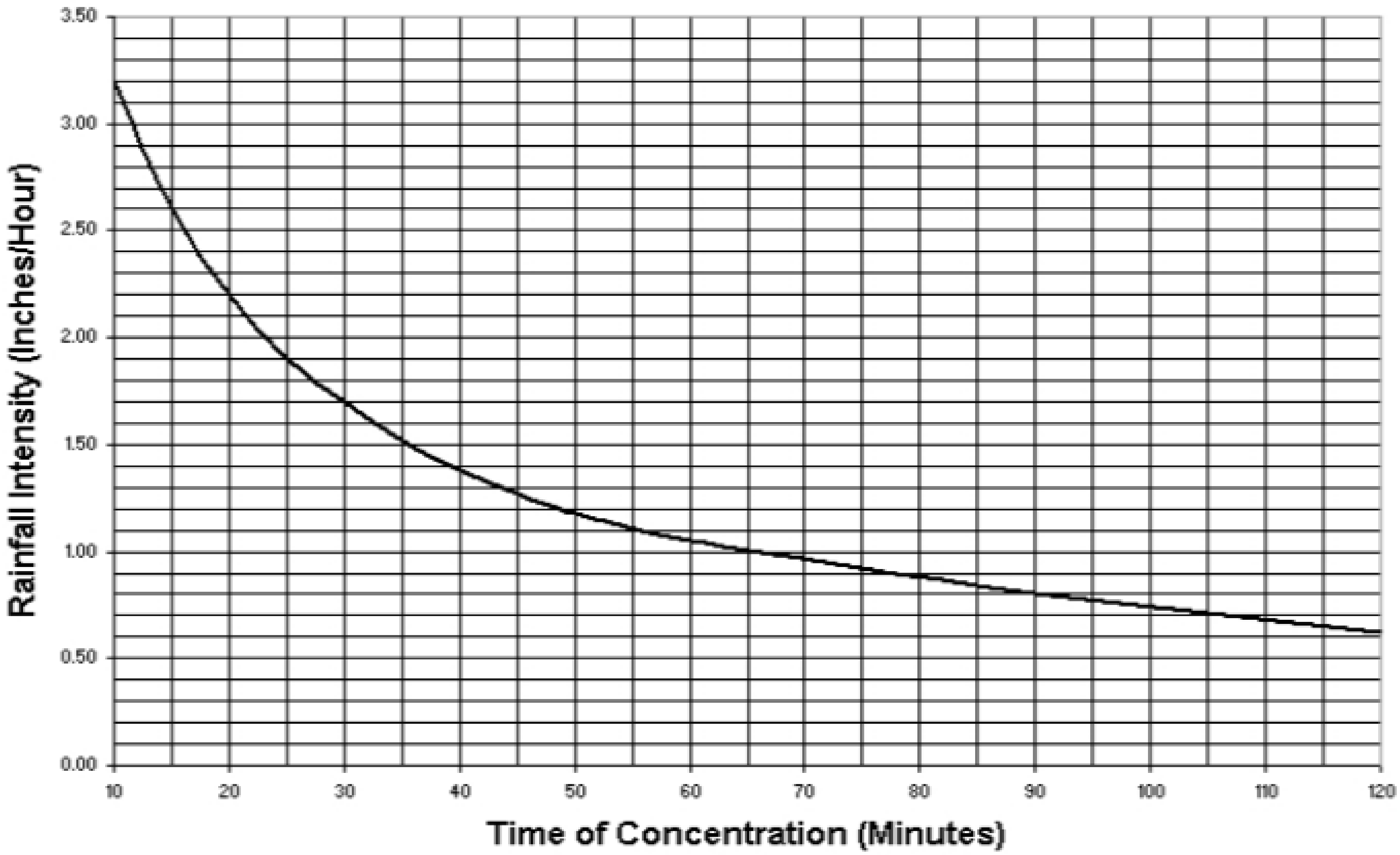


NJDEP WQDS

1.25-Inch/2-Hour Water Quality Design Storm Rainfall Intensity-Duration Curve



Design Storms – Rainfall Data

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs141p2_018235.pdf

For a specific county, rainfall depth from the New Jersey 24-hour Rainfall Frequency Data :

NEW JERSEY 24 HOUR RAINFALL FREQUENCY DATA

Rainfall amounts in Inches

County	1 year	2 year	5 year	10 year	25 year	50 year	100 year
Atlantic	2.72	3.31	4.30	5.16	6.46	7.61	8.90
Bergen	2.75	3.34	4.27	5.07	6.28	7.32	8.47
Burlington	2.77	3.36	4.34	5.18	6.45	7.56	8.81
Camden	2.73	3.31	4.25	5.06	6.28	7.34	8.52
Cape May	2.67	3.25	4.22	5.07	6.34	7.47	8.73
Cumberland	2.69	3.27	4.25	5.09	6.37	7.49	8.76
Essex	2.85	3.44	4.40	5.22	6.44	7.49	8.66
Gloucester	2.71	3.29	4.24	5.05	6.29	7.36	8.55
Hudson	2.73	3.31	4.23	5.02	6.19	7.20	8.31
Hunterdon	2.80	3.38	4.26	5.00	6.09	7.02	8.03
Mercer	2.74	3.31	4.23	5.01	6.19	7.20	8.33
Middlesex	2.76	3.35	4.30	5.12	6.36	7.43	8.63
Monmouth	2.79	3.38	4.38	5.23	6.53	7.66	8.94
Morris	2.94	3.54	4.47	5.24	6.37	7.32	8.35
Ocean	2.81	3.42	4.45	5.33	6.68	7.87	9.20
Passaic	2.87	3.47	4.42	5.23	6.43	7.47	8.62
Salem	2.69	3.26	4.20	5.00	6.22	7.28	8.45
Somerset	2.76	3.34	4.25	5.01	6.15	7.13	8.21
Sussex	2.68	3.22	4.02	4.70	5.72	6.60	7.58
Union	2.80	3.39	4.35	5.17	6.42	7.49	8.69
Warren	2.78	3.34	4.18	4.89	5.93	6.83	7.82

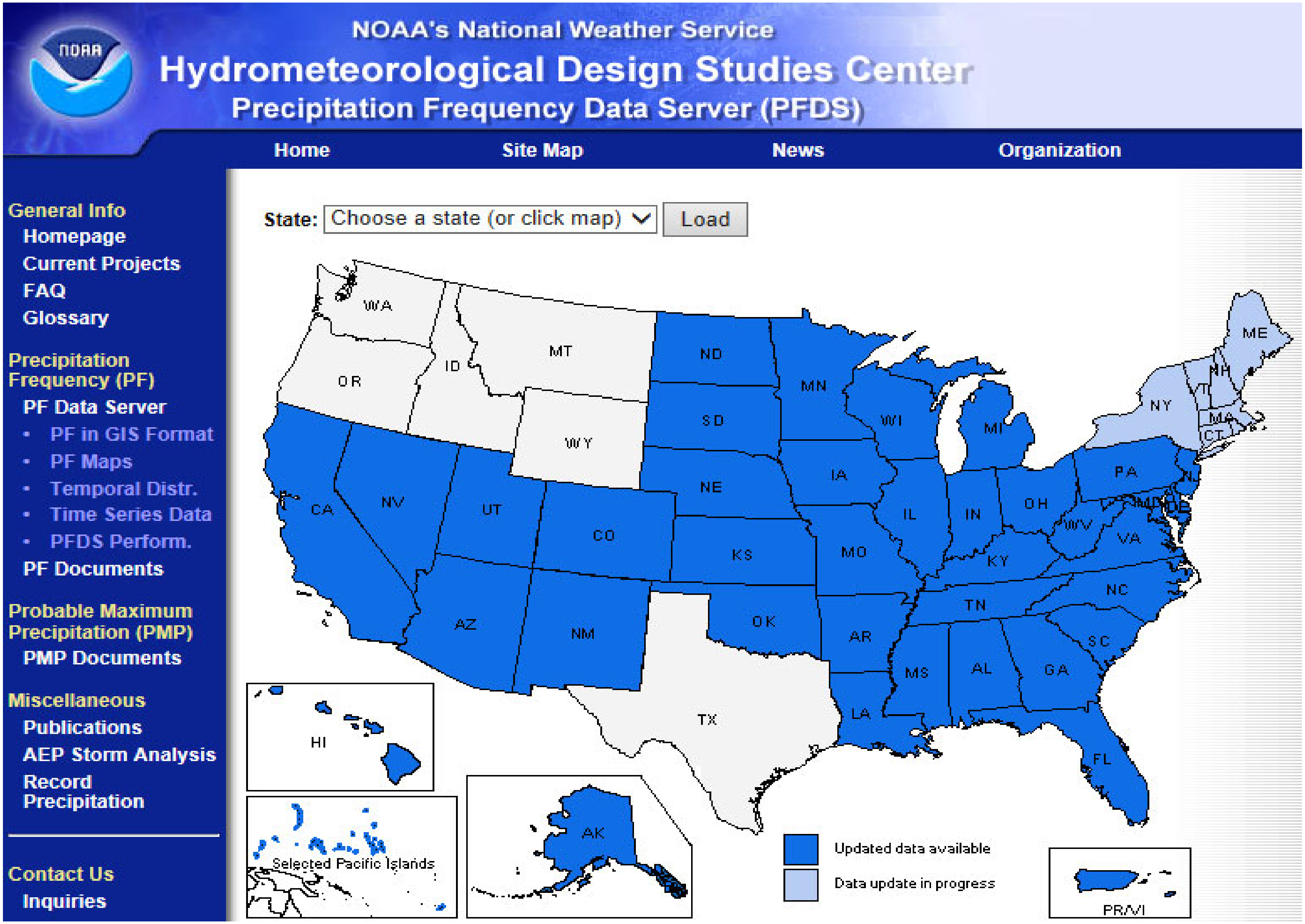
Notes: The average point rainfall amounts listed above were developed from data contained in NOAA Atlas 14 Volume 2.

Point rainfall estimates for specific locations may be obtained from the Precipitation Frequency Data Server located at http://www.nws.noaa.gov/ohd/hdsc/

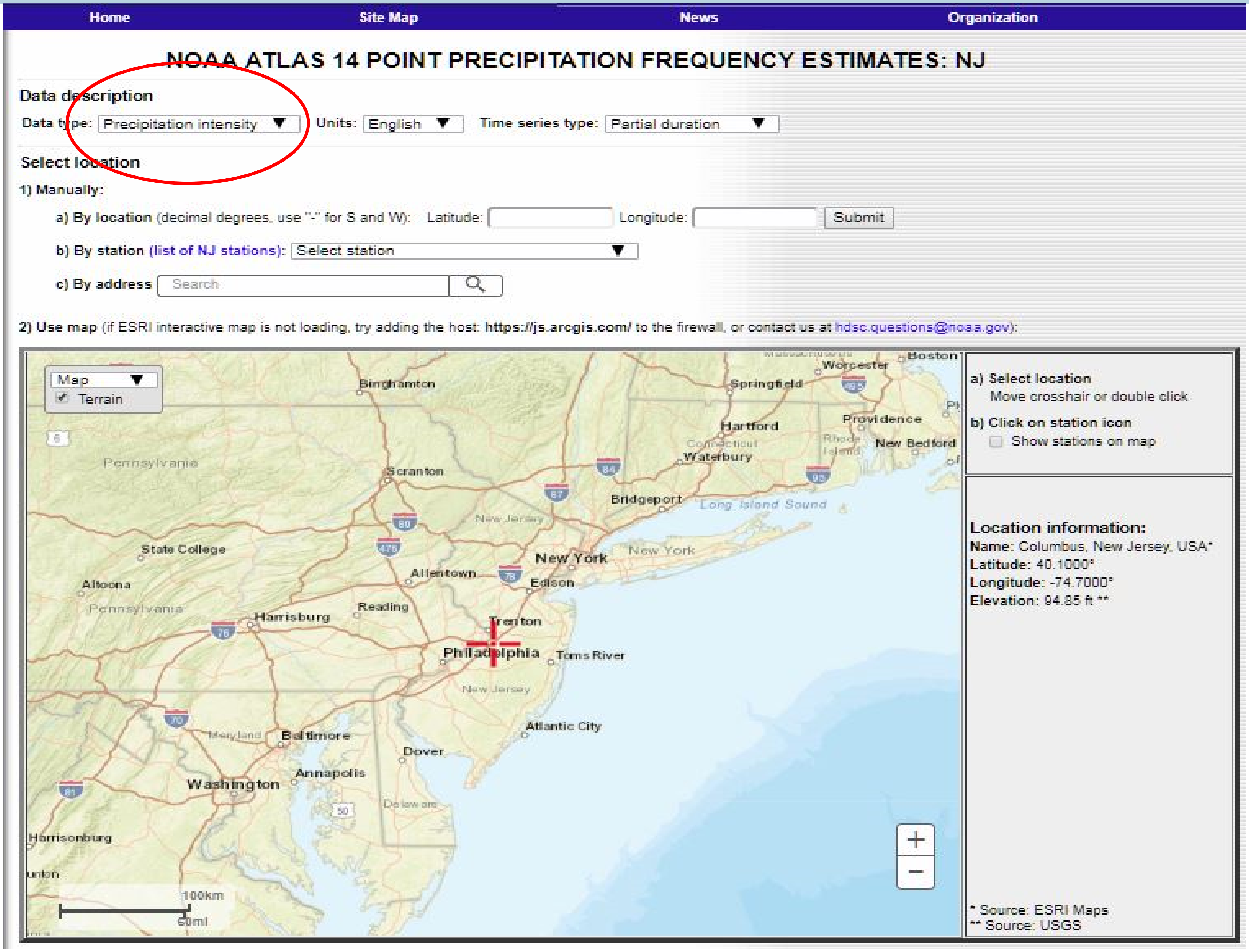
For most hydrologic design procedures, the rainfall amounts listed above may be rounded to the nearest tenth of an inch.

Design Storms – Rainfall Data

https://hdsc.nws.noaa.gov/hdsc/pfds/



Design Storms



Design Storms

POINT PRECIPITATION FREQUENCY (PF) ESTIMATES

WITH 90% CONFIDENCE INTERVALS AND SUPPLEMENTARY INFORMATION
NOAA Atlas 14, Volume 2, Version 3

PF tabular | PF graphical | Supplementary information

PDS-based precipitation frequency estimates with 90% confidence interval

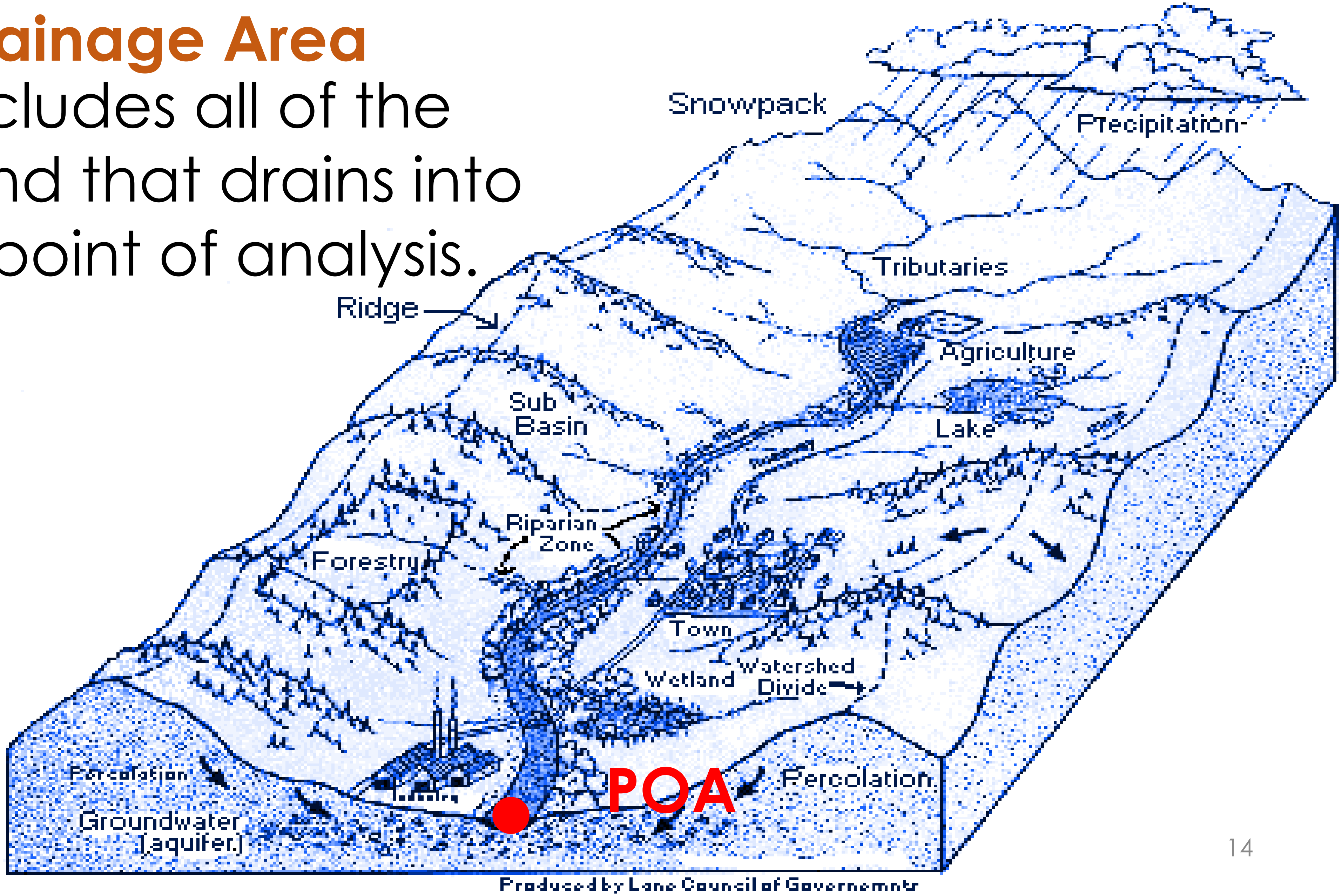
Duration	Average recurrence interval (years)						
	1	2	5	10	25	50	100
5-min	**4.16** (3.79-4.57)	**4.97** (4.52-5.46)	**5.90** (5.36-6.48)	**6.59** (5.96-7.24)	**7.43** (6.70-8.15)	**8.05** (7.21-8.84)	**8.66** (7.74-9.54)
10-min	**3.33** (3.03-3.65)	**3.98** (3.62-4.37)	**4.73** (4.30-5.19)	**5.27** (4.77-5.78)	**5.92** (5.34-6.50)	**6.41** (5.75-7.04)	**6.89** (6.14-7.58)
15-min	**2.77** (2.52-3.04)	**3.33** (3.04-3.66)	**3.99** (3.62-4.38)	**4.44** (4.02-4.88)	**5.00** (4.51-5.49)	**5.41** (4.85-5.94)	**5.80** (5.18-6.39)
30-min	**1.90** (1.73-2.09)	**2.30** (2.10-2.53)	**2.83** (2.57-3.11)	**3.22** (2.92-3.53)	**3.71** (3.34-4.07)	**4.07** (3.65-4.48)	**4.44** (3.97-4.89)
60-min	**1.19** (1.08-1.30)	**1.44** (1.32-1.59)	**1.82** (1.65-1.99)	**2.10** (1.90-2.30)	**2.47** (2.22-2.71)	**2.76** (2.48-3.03)	**3.06** (2.73-3.37)
2-hr	**0.718** (0.652-0.791)	**0.875** (0.794-0.964)	**1.11** (1.00-1.22)	**1.29** (1.16-1.41)	**1.53** (1.37-1.68)	**1.73** (1.54-1.90)	**1.93** (1.71-2.13)
3-hr	**0.524** (0.475-0.580)	**0.639** (0.580-0.707)	**0.810** (0.732-0.896)	**0.943** (0.850-1.04)	**1.13** (1.01-1.25)	**1.28** (1.14-1.41)	**1.44** (1.27-1.59)

Calculate the Time of Concentration (T_c)

Time of Concentration (T_c)

Drainage Area

Includes all of the land that drains into a point of analysis.



Time of Concentration (T_c)

What Affects the T_c?

- Surface Roughness
- Channel shape and flow patterns
- Slope

Time of Concentration (T_c)

Runoff moves through a watershed as:

1. Sheet Flow,
2. Shallow Concentrated Flow,
3. Channel Flow or

   A combination of these

Time of Concentration (T_c)

Sheet Flow

Depth:
about <0.1 ft

Shallow Concentrated Flow

Depth:
0.1 to 0.5 ft

Channel Flow

Visible
on Maps

Time of Concentration (T_c)

Velocity Method:

$$T_c = \sum_{i=1}^{n} \left(T_{t-\text{sheet flow}_i} + T_{t-\text{shallow conc flow}_i} + T_{t-\text{channel flow}_i}\right)$$

Time of Concentration (T_c)

Sheet Flow:

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

T_t = travel time (hr)

L = length of sheet flow (≤ 150 ft in length)

n = Manning's overland roughness coefficient

P_2 = 2-year, 24-hour rainfall
(NJ Depth: 3.2 – 3.5 in)

s = slope of hydraulic grade line (ft/ft)

Time of Concentration (T_c)

- TR-55, Chapter 3: Time of Concentration and Travel Time
- n = roughness coefficient for sheet flow
- 0.40 = max. roughness in NJ

Table 3-1 Roughness coefficients (Manning's n) for sheet flow

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

Time of Concentration (T_c)

P_2 = 2-year, 24-hour rainfall

- 3.2 – 3.5 in. in NJ
- NOAA's National Weather Service
  - Precipitation Frequency Data Server (PFDS)
- NRCS County Rainfall

Duration				
	1	2	5	10
5-min	**0.343** (0.311-0.378)	**0.409** (0.372-0.451)	**0.486** (0.440-0.535)	**0.542** (0.490-0.597)
10-min	**0.548** (0.497-0.603)	**0.654** (0.595-0.721)	**0.779** (0.705-0.857)	**0.867** (0.784-0.954)
15-min	**0.684** (0.622-0.754)	**0.822** (0.748-0.906)	**0.985** (0.892-1.08)	**1.10** (0.992-1.21)
30-min	**0.938** (0.853-1.03)	**1.14** (1.03-1.25)	**1.40** (1.27-1.54)	**1.59** (1.44-1.75)
60-min	**1.17** (1.06-1.29)	**1.43** (1.30-1.57)	**1.79** (1.63-1.98)	**2.07** (1.87-2.28)
2-hr	**1.41** (1.28-1.56)	**1.72** (1.56-1.90)	**2.18** (1.98-2.40)	**2.53** (2.29-2.79)
3-hr	**1.55** (1.40-1.72)	**1.89** (1.71-2.10)	**2.40** (2.16-2.66)	**2.79** (2.51-3.10)
6-hr	**1.96** (1.77-2.19)	**2.38** (2.15-2.65)	**3.01** (2.71-3.35)	**3.52** (3.16-3.91)
12-hr	**2.38** (2.15-2.67)	**2.88** (2.60-3.23)	**3.66** (3.30-4.10)	**4.33** (3.88-4.84)
24-hr	**2.76** (2.55-3.00)	**3.33** (3.08-3.63)	**4.24** (3.91-4.60)	**5.00** (4.60-5.42)
2-day	**3.19** (2.94-3.48)	**3.86** (3.56-4.22)	**4.91** (4.51-5.36)	**5.78** (5.29-6.31)

Time of Concentration (T_c)

Shallow Concentrated Flow:

$$T_t\ (\text{hr}) = \frac{L}{V * 3600}$$

T_t = travel time (hr)

L = flow length (ft)

V = estimated velocity (ft/sec)

Time of Concentration (T_c)

V = estimated velocity,

= $16.1345(s)^{0.5}$ for unpaved conditions

= $20.3282(s)^{0.5}$ for paved conditions,

where:

s = slope of the hydraulic grade line or watercourse slope, ft/ft

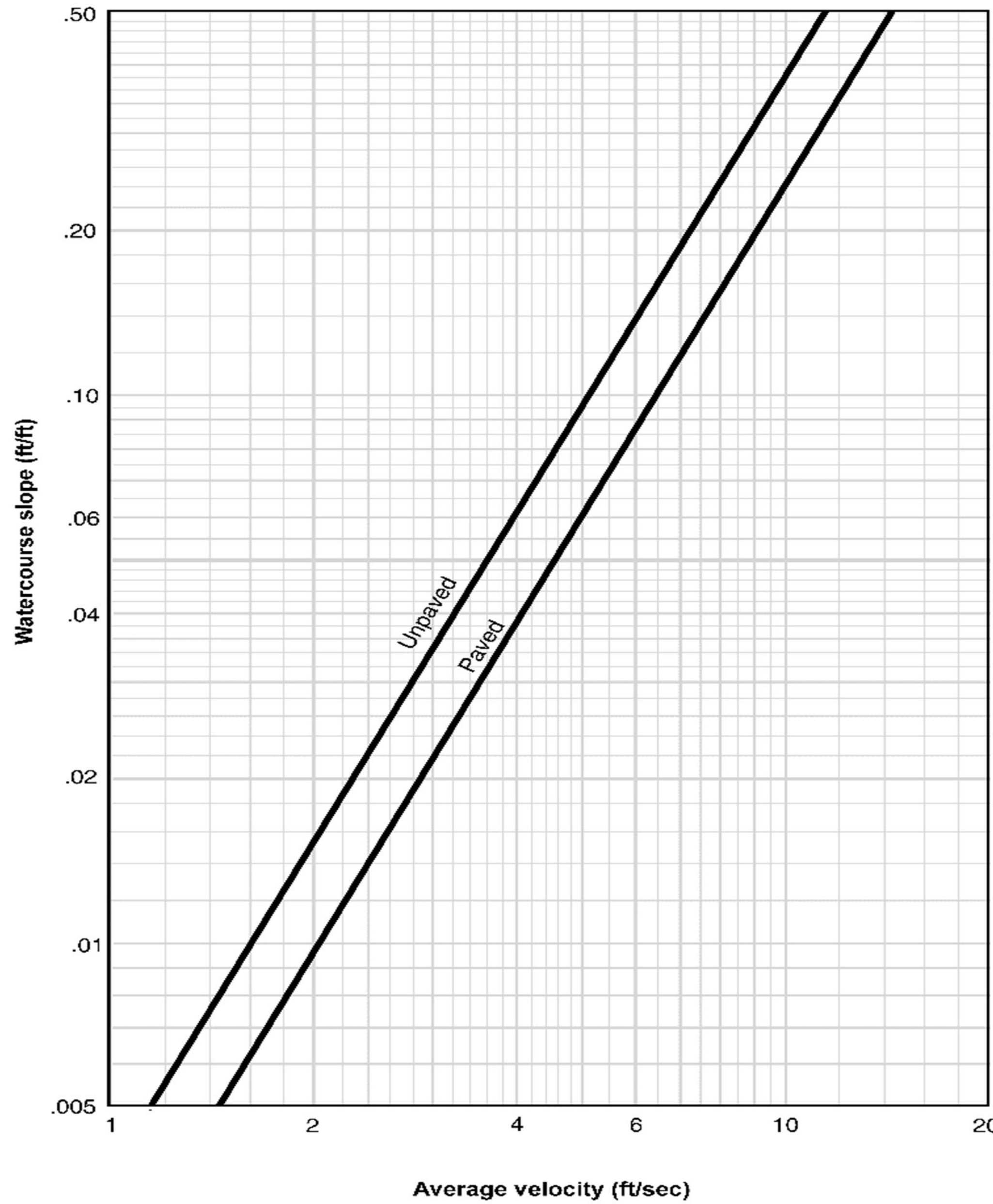


Figure 3-1: Average velocities for estimating travel time for shallow concentrated flow

Time of Concentration (T_c)

Figure 15–4 Velocity versus slope for shallow concentrated flow

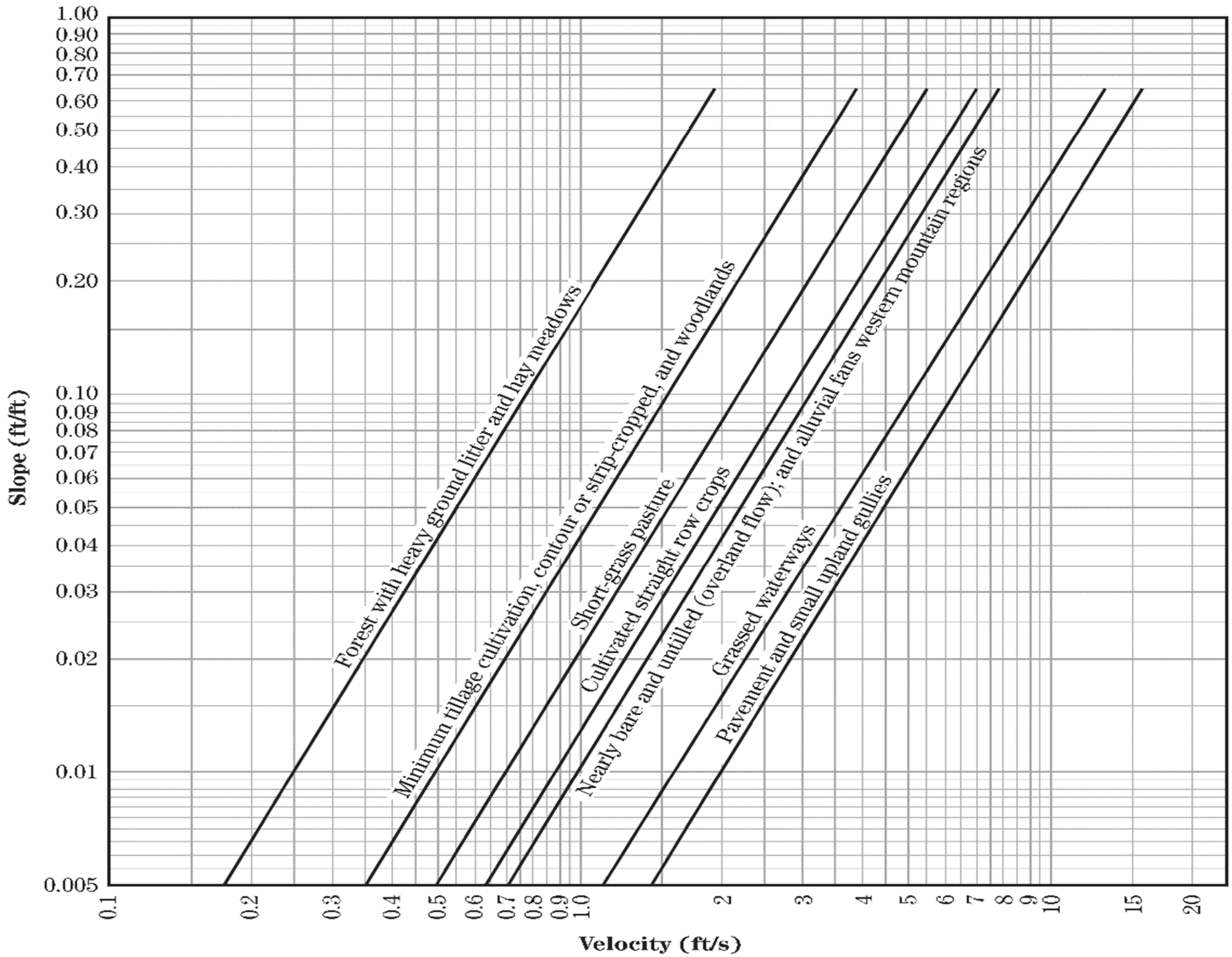


Figure 15-4: Velocity versus slope for shallow concentrated flow

Time of Concentration (T_c)

Channel Flow:

$$T_t(\text{hr}) = \frac{L(n)}{3600(1.49R^{\frac{2}{3}}s^{0.5})}$$

n = roughness coefficient for open channel flow

L = length (ft)

R = hydraulic radius of channel (ft)

$= \frac{a}{p_w}$, where a = cross sectional flow area (sf)

p_w = wetted perimeter (ft)

s = channel slope (ft/ft)

Example Project

Developer wants to develop a 20 acre site:

Existing:

- Forested
- HSG 'A' soils
- 50 ft of sheet flow over an area with a 0.5% slope
- 1000 ft of shallow concentrated flow over an area with a 1% slope
- No channel flow occurs

Proposed:

- 100% impervious surfaces
- HSG 'A' soils
- 50 ft of sheet flow over an area with a 0.5% slope
- 1000 ft of shallow concentrated flow over an area with a 1% slope
- No channel flow occurs

What are the times of concentration of both the existing and proposed conditions on the site?

Calculate Existing T_c

= Sum of all Travel Times for each Segment:

- Sheet Flow:

$$T_t(\text{hr}) = \frac{0.007\,(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}}$$

- Shallow Concentrated Flow:

$$T_t(\text{hr}) = \frac{L}{V * 3600}$$

- Channel Flow:

$$T_t(\text{hr}) = \text{N.A.}$$

Existing Sheet Flow T_t

$$T_t(\text{hr}) = \frac{0.007\,(50n)^{0.8}}{(P_2)^{0.5}(0.005)^{0.4}}$$

L = 50 ft

n = ?

P_2 = ?

s = 0.5% = 0.005 ft/ft

Existing roughness coefficient (n)

n = 0.40

(max. for woods)

Table 3-1 Roughness coefficients (Manning's n) for sheet flow

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

P_2 = 2-year, 24-hour rainfall

P_2 = 3.33 inches

Duration				
	1	2	5	10
5-min	**0.343** (0.311-0.378)	**0.409** (0.372-0.451)	**0.486** (0.440-0.535)	**0.542** (0.490-0.597)
10-min	**0.548** (0.497-0.603)	**0.654** (0.595-0.721)	**0.779** (0.705-0.857)	**0.867** (0.784-0.954)
15-min	**0.684** (0.622-0.754)	**0.822** (0.748-0.906)	**0.985** (0.892-1.08)	**1.10** (0.992-1.21)
30-min	**0.938** (0.853-1.03)	**1.14** (1.03-1.25)	**1.40** (1.27-1.54)	**1.59** (1.44-1.75)
60-min	**1.17** (1.06-1.29)	**1.43** (1.30-1.57)	**1.79** (1.63-1.98)	**2.07** (1.87-2.28)
2-hr	**1.41** (1.28-1.56)	**1.72** (1.56-1.90)	**2.18** (1.98-2.40)	**2.53** (2.29-2.79)
3-hr	**1.55** (1.40-1.72)	**1.89** (1.71-2.10)	**2.40** (2.16-2.66)	**2.79** (2.51-3.10)
6-hr	**1.96** (1.77-2.19)	**2.38** (2.15-2.65)	**3.01** (2.71-3.35)	**3.52** (3.16-3.91)
12-hr	**2.38** (2.15-2.67)	**2.88** (2.60-3.23)	**3.66** (3.30-4.10)	**4.33** (3.88-4.84)
24-hr	**2.76** (2.55-3.00)	**3.33** (3.08-3.63)	**4.24** (3.91-4.60)	**5.00** (4.60-5.42)
2-day	**3.19** (2.94-3.48)	**3.86** (3.56-4.22)	**4.91** (4.51-5.36)	**5.78** (5.29-6.31)

Existing Sheet Flow T_t

$$T_t(\mathrm{hr}) = \frac{0.007\,[50(0.40)]^{0.8}}{(3.33)^{0.5}(0.005)^{0.4}}$$

$$T_t(\mathrm{hr}) = .35\ \mathrm{hr} = 21\ \mathrm{minutes}$$

Existing Shallow Concentrated Flow T_t

$$T_t(\text{hr}) = \frac{1000}{V * 3600}$$

L = 1000 ft

V = ?

Existing estimated velocity (V)

V = 1.6 ft./sec

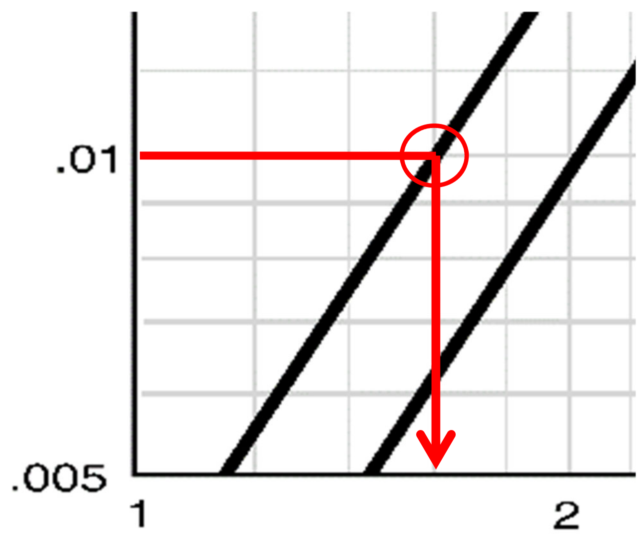
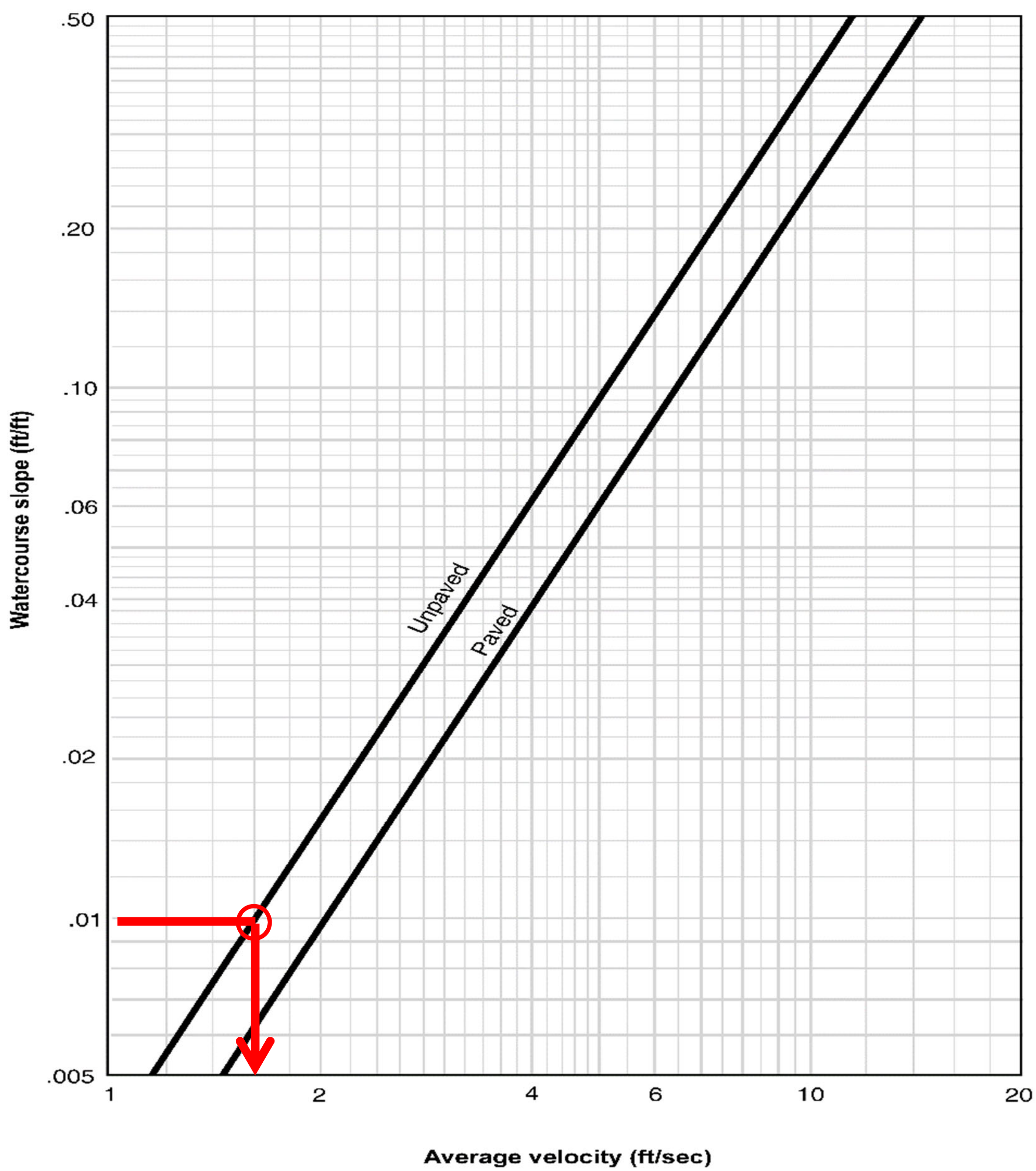


Figure 3-1 Average velocities for estimating travel time for shallow concentrated flow



Existing Shallow Concentrated Flow T_t

$$T_t(hr) = \frac{1000}{1.6 * 3600}$$

$$T_t(hr) = .17 \text{ hr} = 10.5 \text{ min}$$

Existing T_C

$$T_C(\text{min}) = 21 + 10.5$$

$$= \mathbf{31.5\ min}$$

Proposed Sheet Flow T_t

$$T_t(hr) = \frac{0.007\,(50(.011))^{0.8}}{(3.33)^{0.5}(0.005)^{0.4}} = .02\text{ hr} = 1.2\text{ min}$$

L = 50 ft

n = 0.011

P_2 = 3.33 in

s = 0.5% = 0.005 ft/ft

Proposed Shallow Concentrated Flow T_t

$$T_t(\text{hr}) = \frac{1000}{2.05 * 3600}$$

$$T_t(\text{hr}) = .14 \text{ hr} = 8.5 \text{ min}$$

L = 1000 ft

V = 2.05 ft/sec

Proposed T_C

$$T_c(\text{min}) = 1.2 + 8.5$$
$$= 9.7 \text{ min}$$

Minimum T_c Allowed:

- Rational method = 10 min
- NRCS method = 6 min

TR 55 Worksheet 3: Time of Concentration (T_c) or Travel Time (T_t)

Project: MS4 Reviewer Training | Designed By: AA | Date: 1/1/17

Location: New Jersey | Checked By: | Date:

Check one: ✔ Present ☐ Developed

Check one: ✔ T_c ☐ T_t ☐ through subarea

NOTES: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.

Sheet Flow (Applicable to T_c only)

Segment ID	AB			
1. Surface description (Table 3-1)				
2. Manning's roughness coeff., n (Table 3-1)	0.40			
3. Flow length, L (total L ≤ 100 ft) ... ft	50			
4. Two-year 24-hour rainfall, P_2 ... in	3.3			
5. Land slope, s ... ft/ft	0.005			
6. $T_t = \frac{0.007 (nL)^{0.8}}{P_2^{0.5} s^{0.4}}$ Compute T_t ... hr	0.35	+	=	0.35

Sheet Flow T_t

Shallow Concetrated Flow

Segment ID	BC			
7. Surface description (paved or unpaved)	unpaved			
8. Flow length, L ... ft	1,000			
9. Watercourse slope, s ... ft/ft	0.010			
10. Average velocity, V (Figure 3-1) ... ft/s	1.6			
11. $T_t = \frac{L}{3600\ V}$ Compute T_t ... hr	0.17	+	=	0.17

Shallow Concentrated Flow T_t

Channel Flow

Segment ID				
12. Cross sectional flow area, a ... ft^2				
13. Wetted perimeter, P_w ... ft				
14. Hydraulic radius, $r = \frac{a}{P_w}$ Compute r ... ft				
15. Channel Slope, s ... ft/ft				
16. Manning's Roughness Coeff., n				
17. $V = \frac{1.49\ r^{2/3}\ s^{1/2}}{n}$ Compute V ... ft/s				
18. Flow length, L ... ft				
19. $T_t = \frac{L}{3600\ V}$ Compute T_t ... hr		+	=	
20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19 ... hr				0.52

T_C

TR 55 Worksheet 3: Time of Concentration (T_c) or Travel Time (T_t)

Project: MS4 Reviewer Training Designed By: AA Date: 1/1/17

Location: New Jersey Checked By: ____ Date: ____

Check one: ☐ Present ✔ Developed

Check one: ✔ T_c ☐ T_t ☐ through subarea ____

NOTES: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.

Sheet Flow (Applicable to T_c only)

		Segment 1	Segment 2	Total
Segment ID		AB		
1. Surface description (Table 3-1)				
2. Manning's roughness coeff., n (Table 3-1)		0.01		
3. Flow length, L (total L ≤ 100 ft)	ft	50		
4. Two-year 24-hour rainfall, P_2	in	3.3		
5. Land slope, s	ft/ft	0.005		
6. $T_t = \frac{0.007\,(nL)^{0.8}}{P_2^{0.5}\, s^{0.4}}$ Compute T_t	hr	0.02	+	= 0.02

Sheet Flow T_t

Shallow Concetrated Flow

		Segment 1	Segment 2	Total
Segment ID		BC		
7. Surface description (paved or unpaved)		paved		
8. Flow length, L	ft	1,000		
9. Watercourse slope, s	ft/ft	0.010		
10. Average velocity, V (Figure 3-1)	ft/s	2.1		
11. $T_t = \frac{L}{3600\,V}$ Compute T_t	hr	0.14	+	= 0.14

Shallow Concentrated Flow T_t

Channel Flow

		Segment 1	Segment 2	Total
Segment ID				
12. Cross sectional flow area, a	ft^2			
13. Wetted perimeter, P_w	ft			
14. Hydraulic radius, $r = \frac{a}{P_w}$ Compute r	ft			
15. Channel Slope, s	ft/ft			
16. Manning's Roughness Coeff., n				
17. $V = \frac{1.49\, r^{2/3}\, s^{1/2}}{n}$ Compute V	ft/s			
18. Flow length, L	ft			
19. $T_t = \frac{L}{3600\,V}$ Compute T_t	hr		+	=
20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19)	hr			0.16

T_C

Calculate Peak Flow Rates Using the Rational Method

Rational Method

Assumptions:

- Rainfall intensity is uniform over the drainage basin during the duration of the rainfall
- Maximum runoff rate occurs when the rainfall lasts as long or longer than the time of concentration
- The frequency for rainfall and runoff are equal

Rational Method

General Use:

- Used for relatively small drainage areas with uniform surface cover (≤20 acres)
- Used for urban areas
- Not applicable if areas of ponding occur
- Used only to estimate the peak runoff rate

Rational Method

Equation: $$Q = ciA$$

Q = peak flow(cfs)

c = rational runoff coefficient (dimensionless)

i = average rainfall intensity (in/hr)

A = drainage area basin (acres)

- Rational method runoff coefficient (c) is a function of the soil type and drainage basin slope
- Table 10-4 in Section 10 of the Roadway Design Manual published by New Jersey Department of Transportation, available online at:

  https://www.state.nj.us/transportation/eng/documents/RDM/documents/2015RoadwayDesignManual.pdf

Rational Method Equation

c = rational runoff coefficient

	Runoff Coefficient, *c*					
	Soil Group A			Soil Group B		
Slope :	< 2%	2-6%	> 6%	< 2%	2-6%	> 6%
Forest	0.08	0.11	0.14	0.10	0.14	0.18
Meadow	0.14	0.22	0.30	0.20	0.28	0.37
Pasture	0.15	0.25	0.37	0.23	0.34	0.45
Farmland	0.14	0.18	0.22	0.16	0.21	0.28
Res. 1 acre	0.22	0.26	0.29	0.24	0.28	0.34
Res. 1/2 acre	0.25	0.29	0.32	0.28	0.32	0.36
Res. 1/3 acre	0.28	0.32	0.35	0.30	0.35	0.39
Res. 1/4 acre	0.30	0.34	0.37	0.33	0.37	0.42
Res. 1/8 acre	0.33	0.37	0.40	0.35	0.39	0.44
Industrial	0.85	0.85	0.86	0.85	0.86	0.86
Commercial	0.88	0.88	0.89	0.89	0.89	0.89
Streets: ROW	0.76	0.77	0.79	0.80	0.82	0.84
Parking	0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area	0.65	0.67	0.69	0.66	0.68	0.70

Rational Method Equation

i = rainfall intensity

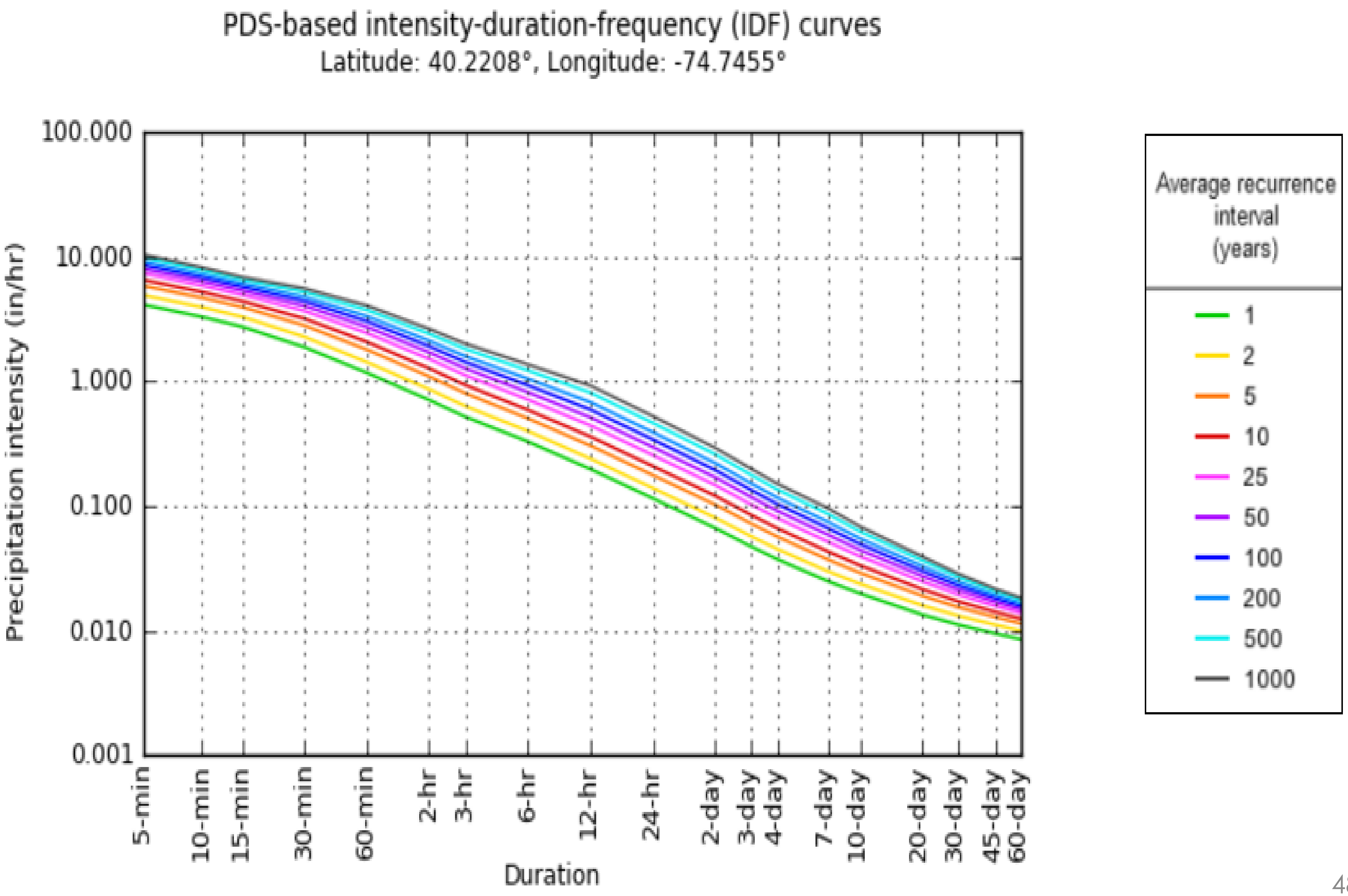
NOAA's National Weather Service

Precipitation Frequency Data Server (PFDS)

Duration	Average recurrence interval (years)						
	1	2	5	10	25	50	100
5-min	**4.12** (3.73-4.54)	**4.91** (4.46-5.41)	**5.83** (5.28-6.42)	**6.50** (5.88-7.16)	**7.34** (6.60-8.08)	**7.96** (7.12-8.75)	**8.56** (7.62-9.44)
10-min	**3.29** (2.98-3.62)	**3.92** (3.57-4.33)	**4.67** (4.23-5.14)	**5.20** (4.70-5.72)	**5.85** (5.26-6.43)	**6.34** (5.67-6.97)	**6.80** (6.06-7.51)
15-min	**2.74** (2.49-3.02)	**3.29** (2.99-3.62)	**3.94** (3.57-4.34)	**4.39** (3.97-4.83)	**4.94** (4.44-5.44)	**5.35** (4.78-5.88)	**5.73** (5.10-6.32)
30-min	**1.88** (1.71-2.07)	**2.27** (2.07-2.50)	**2.80** (2.54-3.08)	**3.18** (2.88-3.50)	**3.66** (3.29-4.03)	**4.03** (3.60-4.43)	**4.39** (3.91-4.84)
60-min	**1.17** (1.06-1.29)	**1.43** (1.30-1.57)	**1.79** (1.63-1.98)	**2.07** (1.87-2.28)	**2.44** (2.19-2.68)	**2.73** (2.44-3.00)	**3.02** (2.69-3.33)
2-hr	**0.707** (0.642-0.781)	**0.862** (0.782-0.950)	**1.09** (0.988-1.20)	**1.27** (1.14-1.39)	**1.51** (1.35-1.66)	**1.70** (1.52-1.87)	**1.90** (1.69-2.10)
3-hr	**0.517** (0.467-0.574)	**0.630** (0.570-0.699)	**0.798** (0.720-0.886)	**0.929** (0.836-1.03)	**1.11** (0.995-1.23)	**1.26** (1.12-1.40)	**1.42** (1.25-1.58)

Rational Method Equation
IDF Curve

i = rainfall intensity



Example Project

Developer wants to develop a 20 acre site:

Existing:

- Forested
- HSG 'A' soils
- 50 ft of sheet flow over an area with a 0.5% slope
- 1000 ft of shallow concentrated flow over an area with a 1% slope
- No channel flow occurs

Proposed:

- 100% impervious surfaces
- HSG 'A' soils
- 50 ft of sheet flow over an area with a 0.5% slope
- 1000 ft of shallow concentrated flow over an area with a 1% slope
- No channel flow occurs

1. **What is the existing peak runoff rate leaving the site for the 2-, 10- & 100-year storm events?**

2. **What is the proposed peak runoff rate leaving the site for the 2-, 10- & 100-year storm events?**

3. **What is the peak runoff rate that is allowed to discharge from the developed site for the 2-, 10-, & 100-year storm events?**

Rational Method

Use the Equation:

$$Q = ciA$$

c = ?

i = ?

A = 20 ac

T_C = 31.5 min

Rational Method

Existing conditions

rational runoff coefficient (c)

$c = 0.08$

	Runoff Coefficient, c					
	Soil Group A			Soil Group B		
Slope :	< 2%	2-6%	> 6%	< 2%	2-6%	> 6%
Forest	0.08	0.11	0.14	0.10	0.14	0.18
Meadow	0.14	0.22	0.30	0.20	0.28	0.37
Pasture	0.15	0.25	0.37	0.23	0.34	0.45
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Res. 1/4 acre	0.30	0.34	0.37	0.33	0.37	0.42
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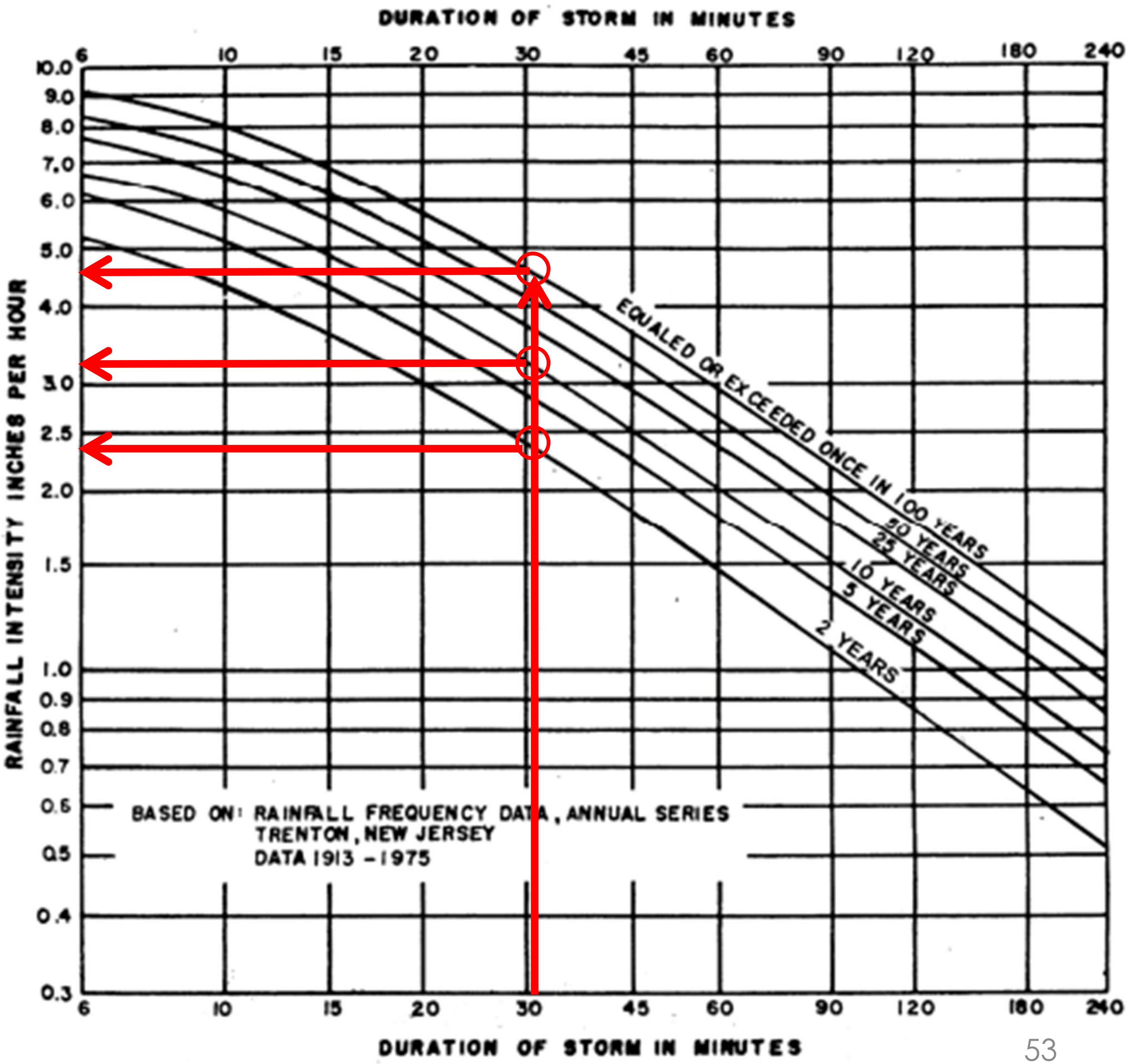
Commercial	0.88	0.88	0.89	0.89	0.89	0.89
Streets: ROW	0.76	0.77	0.79	0.80	0.82	0.84
Parking	0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area	0.65	0.67	0.69	0.66	0.68	0.70

Rational Method

Existing rainfall intensity (i)=

- 100-year = 4.5 in/hr
- 10-year = 3.2 in/hr
- 2-year = 2.4 in/hr



Rational Method

Existing rainfall intensity (i)= 2-year = 2.27 in/hr
10-year = 3.18 in/hr
100-year = 4.39 in/hr

Duration	Average recurrence interval (years)						
	1	2	5	10	25	50	100
5-min	**4.12** (3.73-4.54)	**4.91** (4.46-5.41)	**5.83** (5.28-6.42)	**6.50** (5.88-7.16)	**7.34** (6.60-8.08)	**7.96** (7.12-8.75)	**8.56** (7.62-9.44)
10-min	**3.29** (2.98-3.62)	**3.92** (3.57-4.33)	**4.67** (4.23-5.14)	**5.20** (4.70-5.72)	**5.85** (5.26-6.43)	**6.34** (5.67-6.97)	**6.80** (6.06-7.51)
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60-min	**1.17** (1.06-1.29)	**1.43** (1.30-1.57)	**1.79** (1.63-1.98)	**2.07** (1.87-2.28)	**2.44** (2.19-2.68)	**2.73** (2.44-3.00)	**3.02** (2.69-3.33)
2-hr	**0.707** (0.642-0.781)	**0.862** (0.782-0.950)	**1.09** (0.988-1.20)	**1.27** (1.14-1.39)	**1.51** (1.35-1.66)	**1.70** (1.52-1.87)	**1.90** (1.69-2.10)
3-hr	**0.517** (0.467-0.574)	**0.630** (0.570-0.699)	**0.798** (0.720-0.886)	**0.929** (0.836-1.03)	**1.11** (0.995-1.23)	**1.26** (1.12-1.40)	**1.42** (1.25-1.58)

Rational Method

Existing Peak Flow Rates (cfs):

$$Q = ciA$$

2-year storm: $Q = .08(2.27)(20) =$ **3.63 cfs**

10-year storm: $Q = .08(3.18)(20) =$ **5.08 cfs**

100-year storm: $Q = .08(4.39)(20) =$ **7.02 cfs**

Rational Method

Proposed Peak Flow Rates (cfs):

$$Q = ciA$$

2-year storm: $Q = .99(3.92)(20) =$ **78.2 cfs**

10-year storm: $Q = .99(5.20)(20) =$ **103.8 cfs**

100-year storm: $Q = .99(6.80)(20) =$ **135.7 cfs**

Rational Method

Peak Flow Rate Comparison (Q)

	Peak Flow Rate (cfs)	
Design Storm	**Existing Condition**	**Proposed Condition**
2-year	3.63	78
10-year	5.08	104
100-year	7.02	136

Water Quantity Standard

What is the peak flowrate allowed

to discharge from the developed site for the 2-, 10- and 100-year storms?

Water Quantity Standard

3rd Option (N.J.A.C. 7:8-5.4(a)3.iii):

Design stormwater management measures so that the post-construction peak runoff rates for the 2-, 10-, and 100-year storm events are 50, 75, and 80 percent, respectively, of the pre-construction peak runoff rates.

Water Quantity Standard

Allowable peak flow rates:

Design Storm	Reduction Factor x Ex. Pk. Flow	=	Allowable Prop. Peak Flow Rate
2-year:	0.50 x 3.63	=	**1.82 cfs**
10-year:	0.75 x 5.08	=	**3.82 cfs**
100-year:	0.80 x 7.02	=	**5.62 cfs**

Size a Basin Using the Modified Rational Method

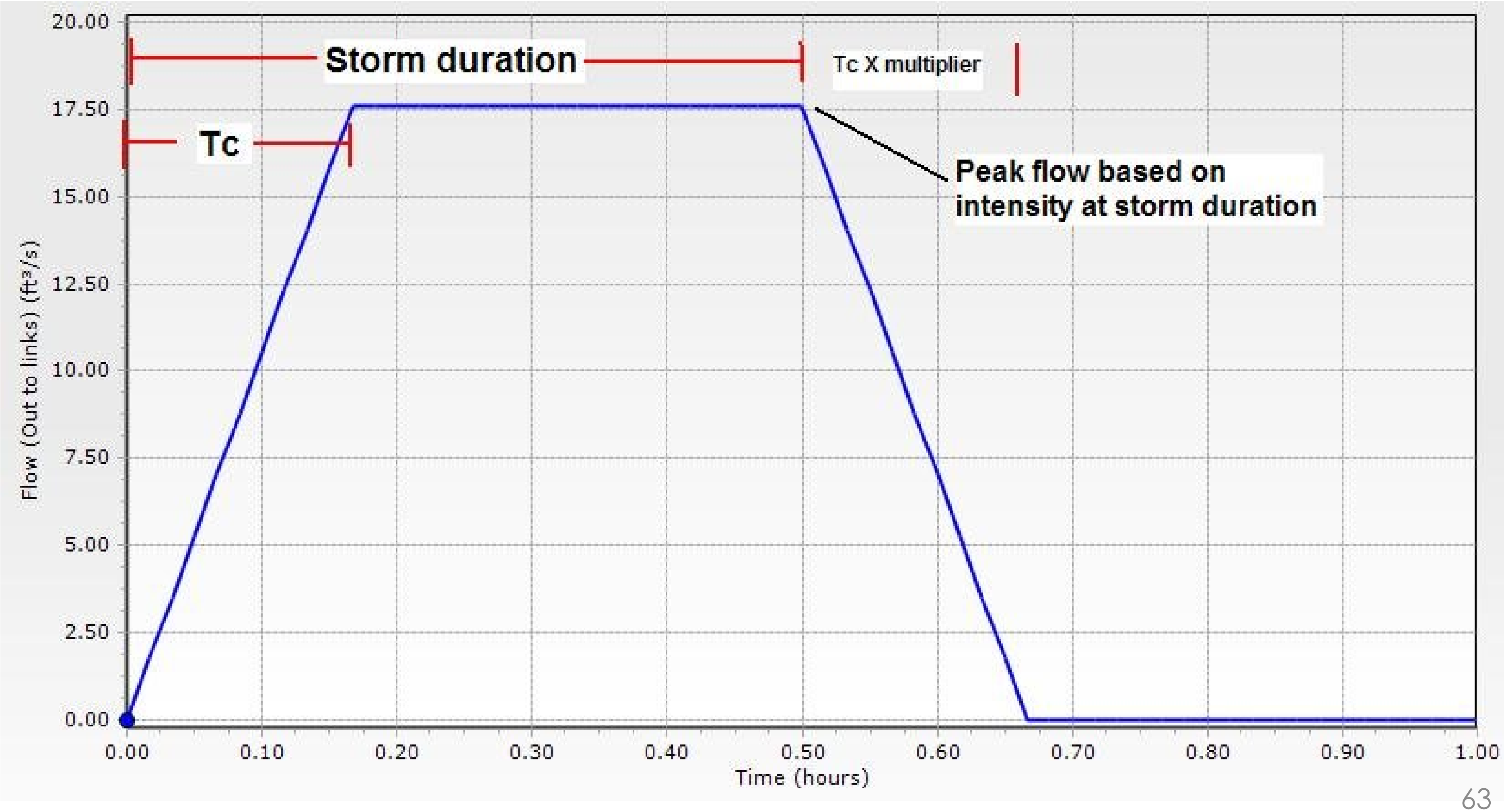
Modified Rational Method

Major Differences from Rational Method:

- Calculates volume
- No longer assumes the storm duration is equal to the T_C
- Requires a flowrate leaving the basin to calculate critical storage volume

Modified Rational Method

Hydrograph:



Modified Rational Method

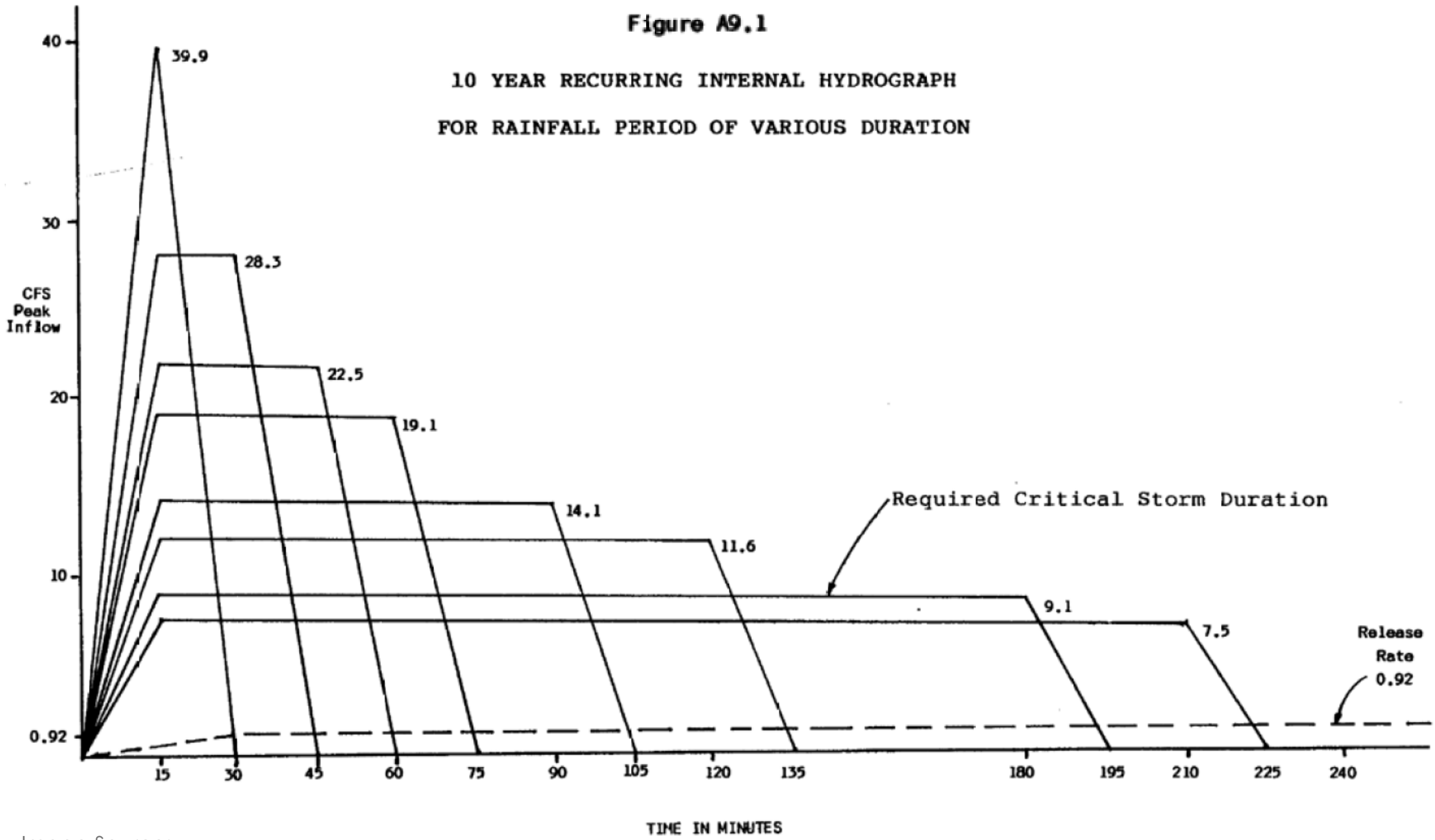


Image Source:
https://www.nj.gov/agriculture/divisions/anr/pdf/2014NJSoilErosionControlStandardsComplete.pdf

Example Project

Developer wants to develop a 20 acre site:

Existing:

- Forested
- HSG 'A' soils
- 50 ft of sheet flow over an area with a 0.5% slope
- 1000 ft of shallow concentrated flow over an area with a 1% slope
- No channel flow occurs

Proposed:

- 100% impervious surfaces
- HSG 'A' soils
- 50 ft of sheet flow over an area with a 0.5% slope
- 1000 ft of shallow concentrated flow over an area with a 1% slope
- No channel flow occurs

Use the Modified Rational Method to estimate the required detention volume (critical storage volume) to reduce the peak flow rate from the 100-year storm event to the allowable rate.

T_c = 10 minutes

c = 0.99

Existing 100-year Peak Flow Rate (Q) = 7.02 cfs

Allowable 100-year Peak Flow Rate (Q) = 5.62 cfs

Modified Rational Method

Develop a Table

A	B	C	D	E	F	G
Storm Duration (min)	Intensity (in/hr)	Inflow Rate (cfs)	Runoff Volume (cf)	Outflow Rate (cfs)	Outflow Volume (cf)	Storage Volume (cf)

Modified Rational Method

Column A: Storm Duration

- Lowest Storm Duration = T_C
- Storm Duration Selection

A
Storm Duration (min)
10
15
30
60
120
180
360
720

Modified Rational Method

Column B: Storm Intensity

- Storm Intensity Data using NOAA
- Intensities decrease with increased duration

A	B
Storm Duration (min)	**Storm Intensity (in/hr)**
10	6.80
15	5.73
30	4.39
60	3.02
120	1.90
180	1.42
360	0.925
720	0.592

Modified Rational Method

Column C: Inflow Rate

- Peak flow for each storm duration
- $Q = c i A$ (rational method)
- For this example:
  $c = 0.99$ &
  $A = 20$ acres
- $Q = (0.99 \times 3.02 \times 20) \times$
  = **59.8 cfs**

A	B	C
Storm Duration (min)	**Storm Intensity (in/hr)**	**Inflow Rate (cfs)**
10	6.80	134.6
15	5.73	113.5
30	4.39	86.9
60	**3.02**	**59.8**
120	1.90	37.6
180	1.42	28.1
360	0.925	18.3
720	0.592	11.7

Modified Rational Method

Column D: Runoff Volume

- Total runoff volume is area under the hydrograph

- Column D
  = Column A x Column C x 60
  = 10 x 134.6 x 60 = **80,760 cf**

A	C	D
Storm Duration (min)	**Inflow Rate (cfs)**	**Runoff Volume (cf)**
10	134.6	**80760**
15	113.5	102150
30	86.9	156420
60	**59.8**	215280
120	37.6	270720
180	28.1	303480
360	18.3	395280
720	11.7	505440

Modified Rational Method

Column E: Outflow Rate

- 80% of the pre-development peak flow rate
- Outflow rate is constant

E
Outflow Rate (cfs)
5.62
5.62
5.62
5.62
5.62
5.62
5.62
5.62

Modified Rational Method

Column F: Outflow Volume

- At each storm duration how much volume is flowing out of the basin

- Column F
  = Column A x Column E x 60
  = 30 x 5.62 x 60 = **10,116 cf**

A	E	F
Storm Duration (min)	**Outflow Rate (cfs)**	**Outflow Volume (cf)**
10	5.620	3372
15	5.620	5058
30	5.620	**10116**
60	5.620	20232
120	5.620	40464
180	5.620	60696
360	5.620	121392
720	5.620	242784

Modified Rational Method

Column G: Storage Volume

- How much must be stored?
- Column G
  = Column D - Column F
  = 156,420 – 10,116= **146,304 cf**

D	F	G
Runoff Volume (cf)	**Outflow Volume (cf)**	**Storage Volume (cf)**
80760	3372	77388
102150	5058	97092
156420	**10116**	**146304**
215280	20232	195048
270720	40465	230255
303480	60696	242784
395280	121392	273888
505440	242784	262656

Modified Rational Method

Resulting Table:

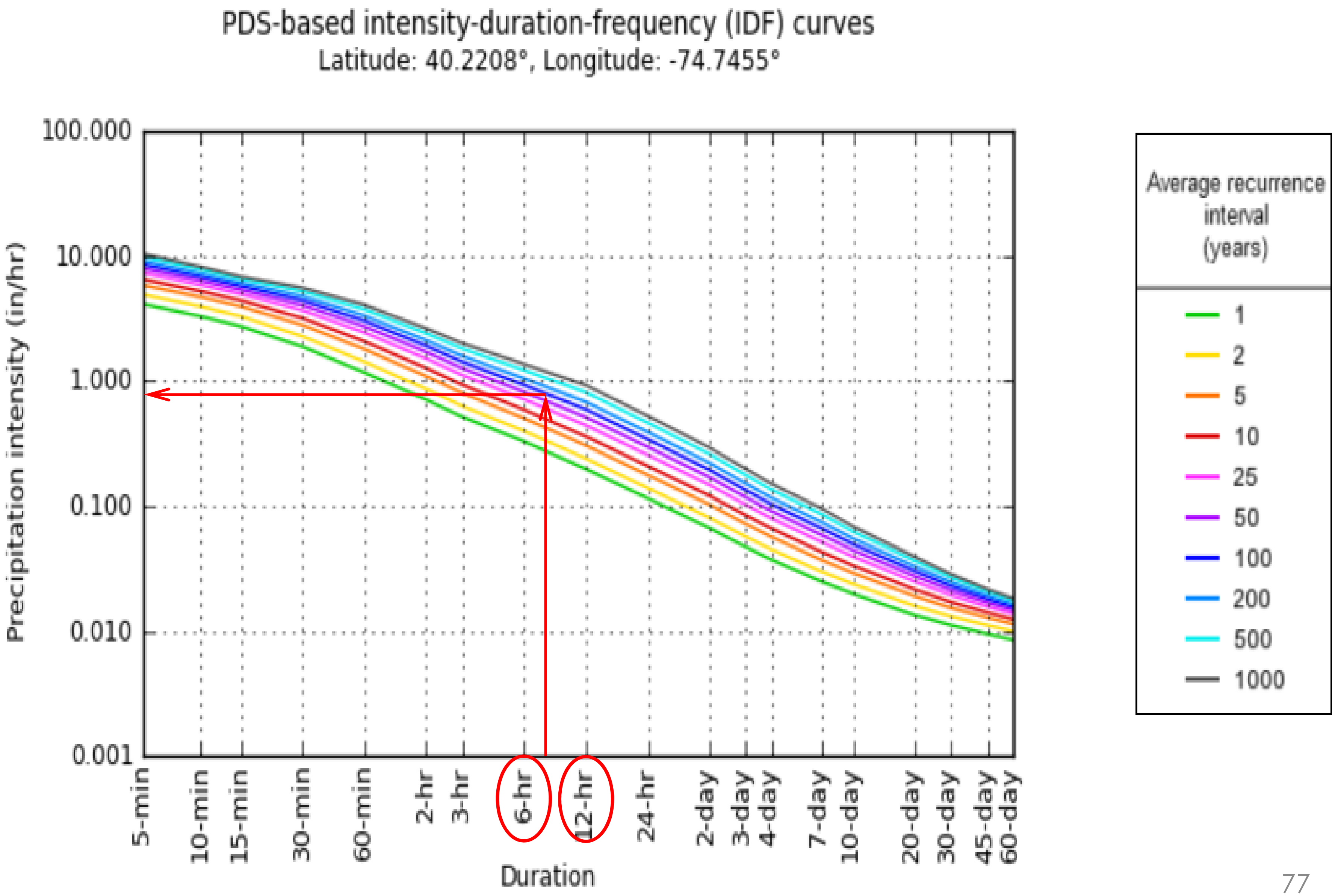
A	B	C	D	E	F	G
Storm Duration (min)	Storm Intensity (in/hr)	Inflow Rate (cfs)	Runoff Volume (cf)	Outflow Rate (cfs)	Outflow Volume (cf)	Storage Volume (cf)
10	6.80	134.6	80760	5.620	3372	77388
15	5.73	113.5	102150	5.620	5058	97092
30	4.39	86.9	156420	5.620	10116	146304
60	3.02	59.8	215280	5.620	20232	195048
120	1.90	37.6	270720	5.620	40465	230255
180	1.42	28.1	303480	5.620	60696	242784
360	0.925	18.3	395280	5.620	121392	273888
720	0.592	11.7	505440	5.620	242784	262656

Modified Rational Method

Design Storage Volume Required:

A	B	C	D	E	F	G
Storm Duration (min)	Storm Intensity (in/hr)	Inflow Rate (cfs)	Runoff Volume (cf)	Outflow Rate (cfs)	Outflow Volume (cf)	Storage Volume (cf)
10	6.80	134.6	80760	5.620	3372	77388
15	5.73	113.5	102150	5.620	5058	97092
30	4.39	86.9	156420	5.620	10116	146304
60	3.02	59.8	215280	5.620	20232	195048
120	1.90	37.6	270720	5.620	40465	230255
180	1.42	28.1	303480	5.620	60696	242784
360	0.925	18.3	395280	5.620	121392	273888
720	0.592	11.7	505440	5.620	242784	262656

Modified Rational Method – Further Evaluation:



Modified Rational Method

Final Table:

A	B	C	D	E	F	G
Storm Duration (min)	Storm Intensity (in/hr)	Inflow Rate (cfs)	Runoff Volume (cf)	Outflow Rate (cfs)	Outflow Volume (cf)	Storage Volume (cf)
360	0.925	18.3	395280	5.620	121392	273888
420	0.869	17.2	433440	5.620	141624	291816
480	0.813	16.1	463680	5.620	161856	301824
540	0.757	15.0	486000	5.620	182088	**303912**
600	0.701	13.9	500400	5.620	202320	298080
660	0.645	12.8	506880	5.620	222552	284328
720	0.592	11.7	505440	5.620	242784	262656

Use the NRCS Methodology (TR-55)

NRCS Methodology (TR-55)

What can it calculate?

- Peak Runoff Rates
- Runoff Volumes
- Runoff Hydrographs

NRCS Methodology (TR-55)

NRCS Runoff Equation (CN Equation):

$$Q \text{ (in)} = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Q = depth of runoff

P = rainfall depth (in)

I_a = initial abstraction (in), losses before runoff begins, where $I_a = 0.2S$

S = potential maximum retention after runoff begins, where $S = \frac{1000}{CN} - 10$

Simplified,

$$Q \text{ (in)} = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

NRCS Methodology (TR-55)

Curve Numbers (CN):

- Hydrologic Soil Group (HSG)
- Land Cover

NRCS Methodology (TR-55)

Hydrologic Soil Groups (HSG):*

- ‘A’ = Low runoff and high infiltration
- ‘B’ = Moderately low runoff and infiltration
- ‘C’ = Moderately high runoff and low infiltration
- ‘D’ = High runoff and very low infiltration

*When thoroughly saturated

Curve Number (CN)

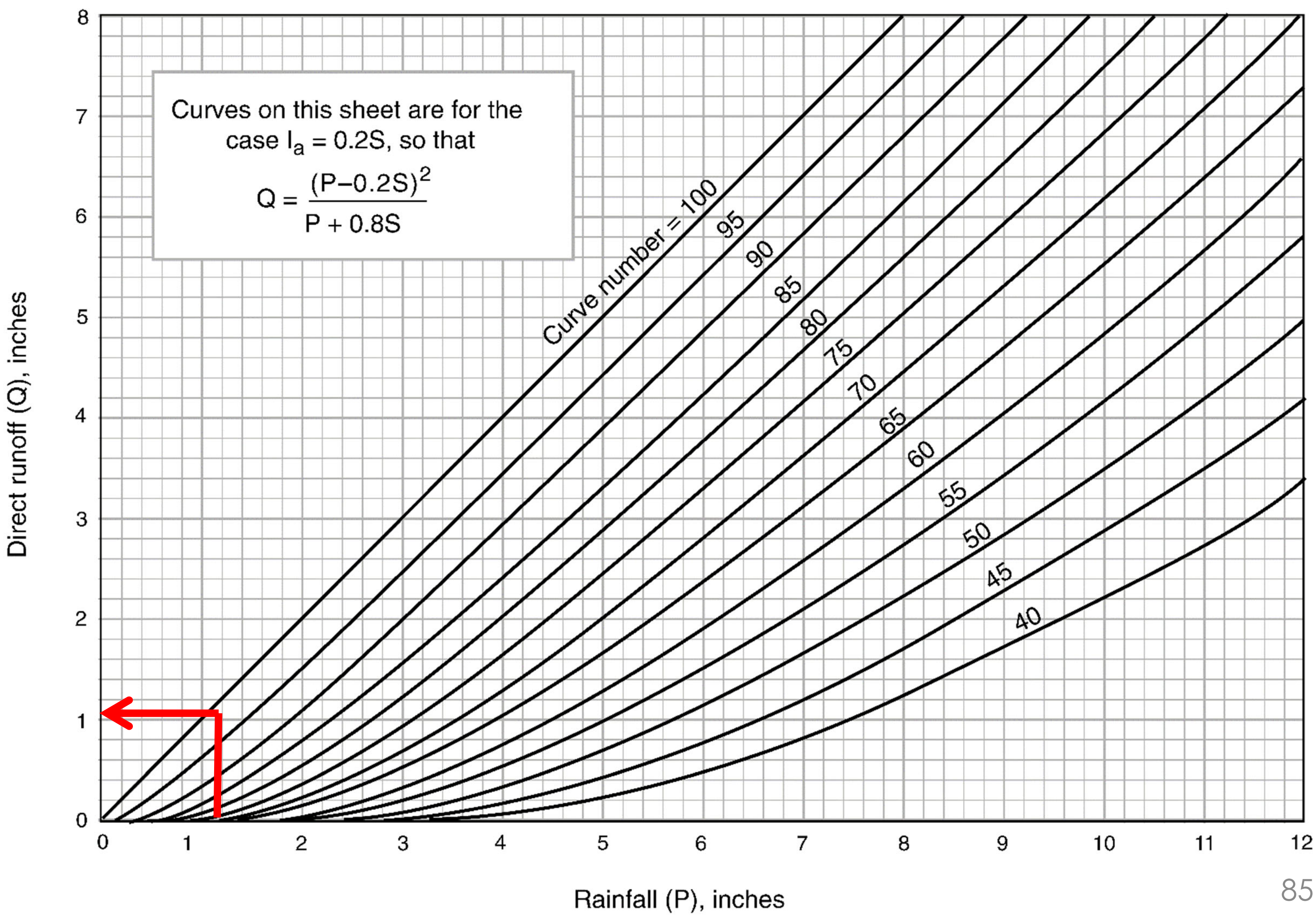
Table 2-2a Runoff curve numbers for urban areas [1/]

Cover description: Cover type and hydrologic condition	Average percent impervious area [2/]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
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

N.J.A.C. 7:8-5.6(a)2: *Presume that the pre-construction condition of a site or portion thereof is a wooded land use with good hydrologic condition*

NRCS Methodology (TR-55)

Figure 2-1 Solution of runoff equation.



CN **= 98**

P **= 1.2 in.**

Q **= 1.0 in.**

NRCS Methodology (TR-55)

Average CN vs. Separate CN:

- N.J.A.C. 7:8-5.6(a)4: In computing stormwater runoff from all design storms, the design engineer shall consider the relative stormwater runoff rates and/or volumes of pervious and impervious surfaces separately to accurately compute the rates and volume of stormwater runoff from the site.

NRCS Methodology (TR-55)

Average CN vs. Separate CN (cont'd.):

- Due to the non-linear character of the equation and the presence of initial abstraction, averaging pervious and impervious CN can result in errors

- For the Water Quality Design Storm, 1 acre impervious with CN = 98 plus 2 acres grass lawn with CN = 65 generates runoff volumes as follows:

  = 1,089 cf, when averaged
  = 3,811 cf, when calculated separately & then added

Example Project

Developer wants to develop a 20 acre site:

Existing:

- Forested
- HSG ‘A’ soils
- 50 ft of sheet flow over an area with a 0.5% slope
- 1000 ft of shallow concentrated flow over an area with a 1% slope
- No channel flow occurs

Proposed:

- 100% impervious surfaces
- HSG ‘A’ soils
- 50 ft of sheet flow over an area with a 0.5% slope
- 1000 ft of shallow concentrated flow over an area with a 1% slope
- No channel flow occurs

Use the NRCS Method to calculate the volume generated by this site for the proposed condition during the Water Quality Design Storm.

NRCS Methodology (TR-55)

Proposed Total Runoff Amount:

$$Q \text{ (in)} = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Q = ?

P = 1.25 in (WQDS)

$S = \frac{1000}{CN} - 10$

NRCS Methodology (TR-55)

Curve Number (CN) = 98

Table 2-2a Runoff curve numbers for urban areas [1/]

Cover description: Cover type and hydrologic condition	Average percent impervious area [2/]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
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

NRCS Methodology (TR-55)

Proposed Total Runoff Amount:

$$Q\text{ (in)} = \frac{(1.25 - 0.2S)^2}{(P + 0.8S)}$$

P = 1.25 in (WQDS)

$$S = \frac{1000}{CN} - 10 = \frac{1000}{98} - 10 = 0.204\text{ in}$$

$$Q = \frac{(1.25 - 0.2(.204))^2}{(1.25 + 0.8(.204))} = 1.03\text{ in}$$

NRCS Methodology (TR-55)

Proposed Condition Runoff Volume:

$$V = QA$$

$$Q = 1.03 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}}$$

$$A = 20 \text{ ac} \times \frac{43{,}560 \text{ sf}}{1 \text{ ac}}$$

$$V = 74{,}778 \text{ cf}$$

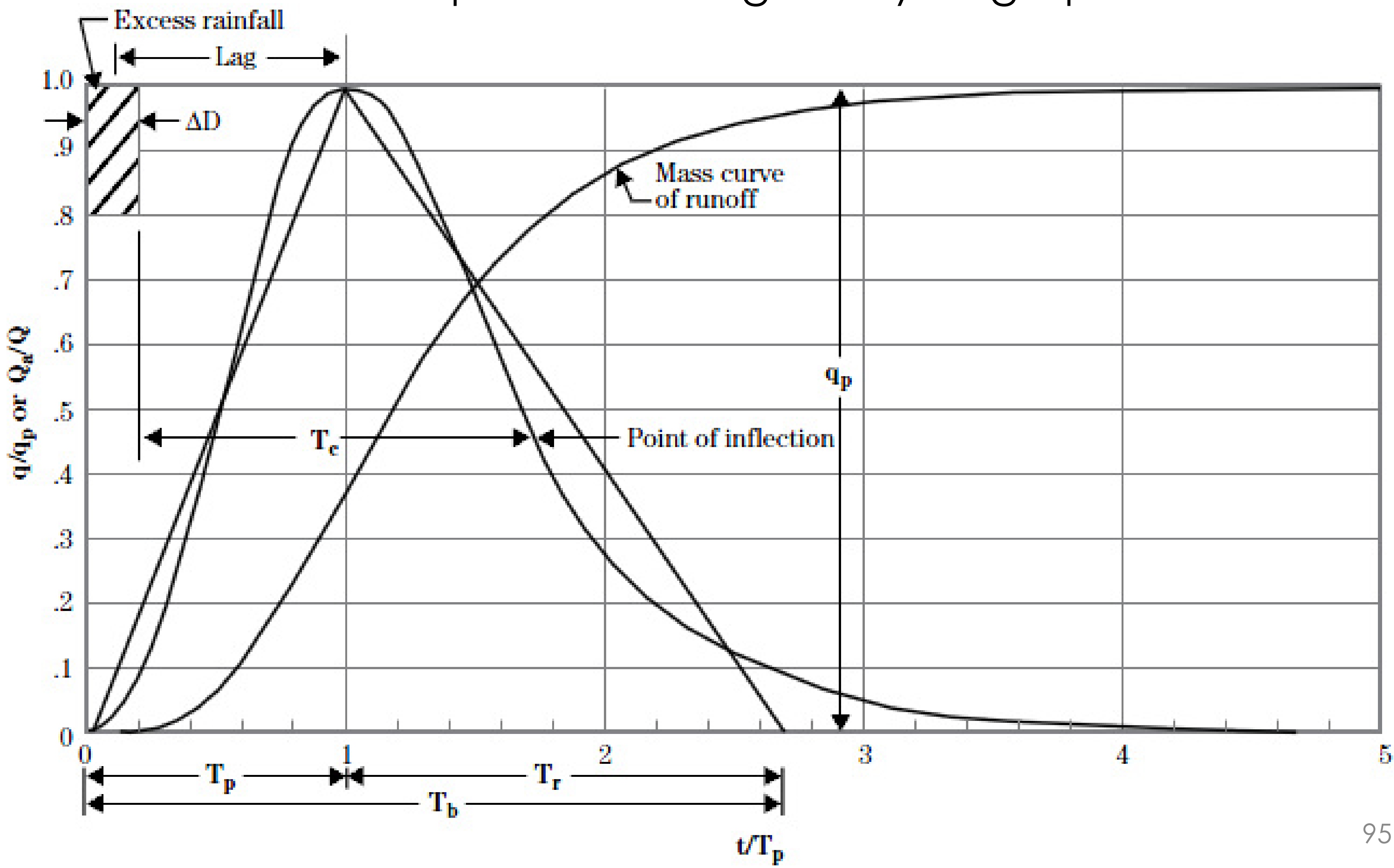
Dimensionless Unit Hydrograph

Synthetic Hydrographs:

- Developed for determining runoff hydrograph for ungauged watersheds
- Based on an average of natural watersheds with different sizes and geographic locations
- 2 are commonly used
  - SCS
  - DelMarVa

SCS Dimensionless Unit Hydrograph

Dimensionless curvilinear unit hydrograph and equivalent triangular hydrograph



DelMarVa Dimensionless Unit Hydrograph

- Particularly suited for the flat, coastal areas in Delaware, Maryland, Virginia and New Jersey
- Not used in all areas of the coastal plain (i.e. redevelopment in coastal plains)

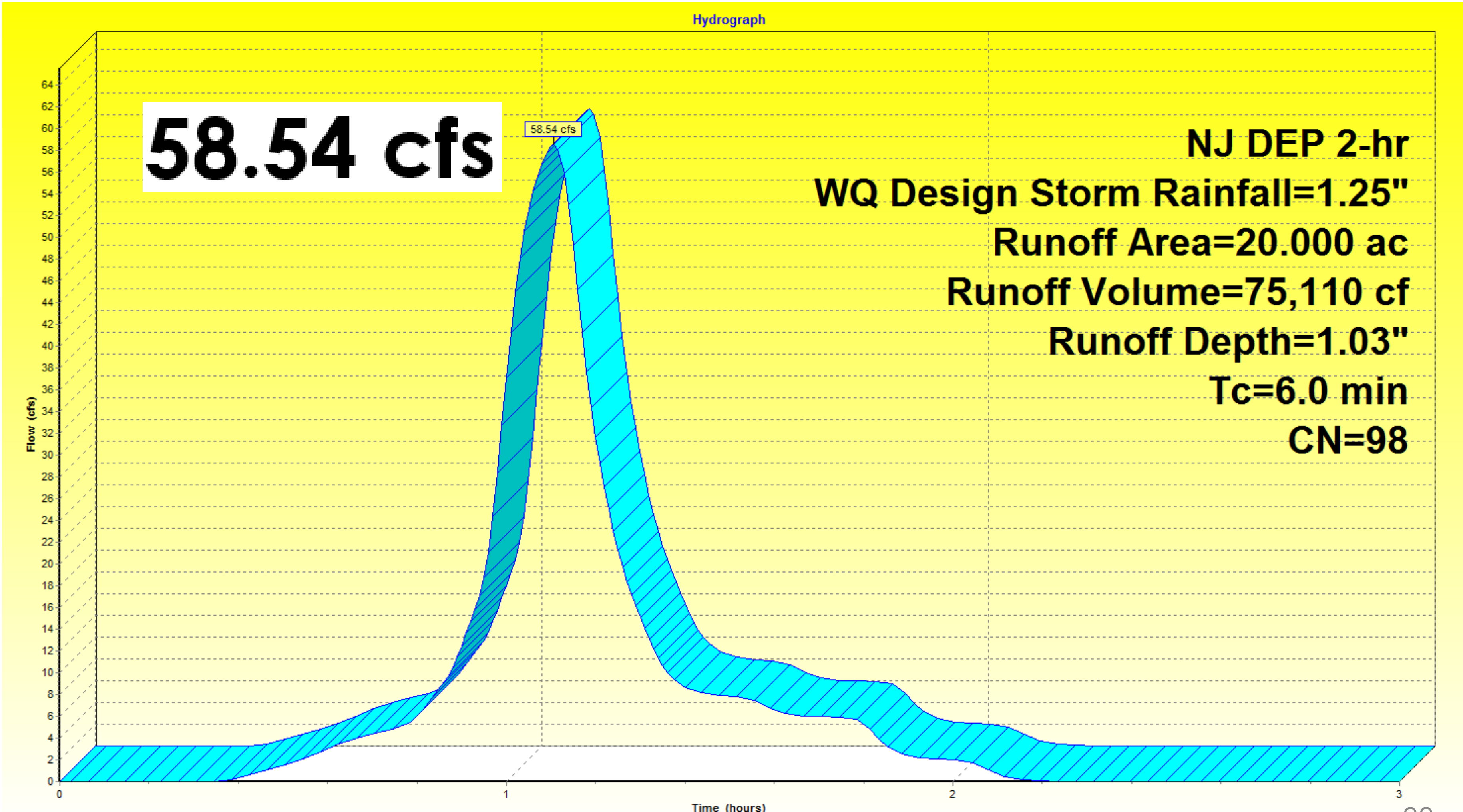
Dimensionless Unit Hydrograph

Unit Hydrograph Info:

- SCS
  - 484 peaking factor
  - 37.5% of runoff in rising limb
- DelMarVa
  - 284 peaking factor
  - 22% runoff in rising limb

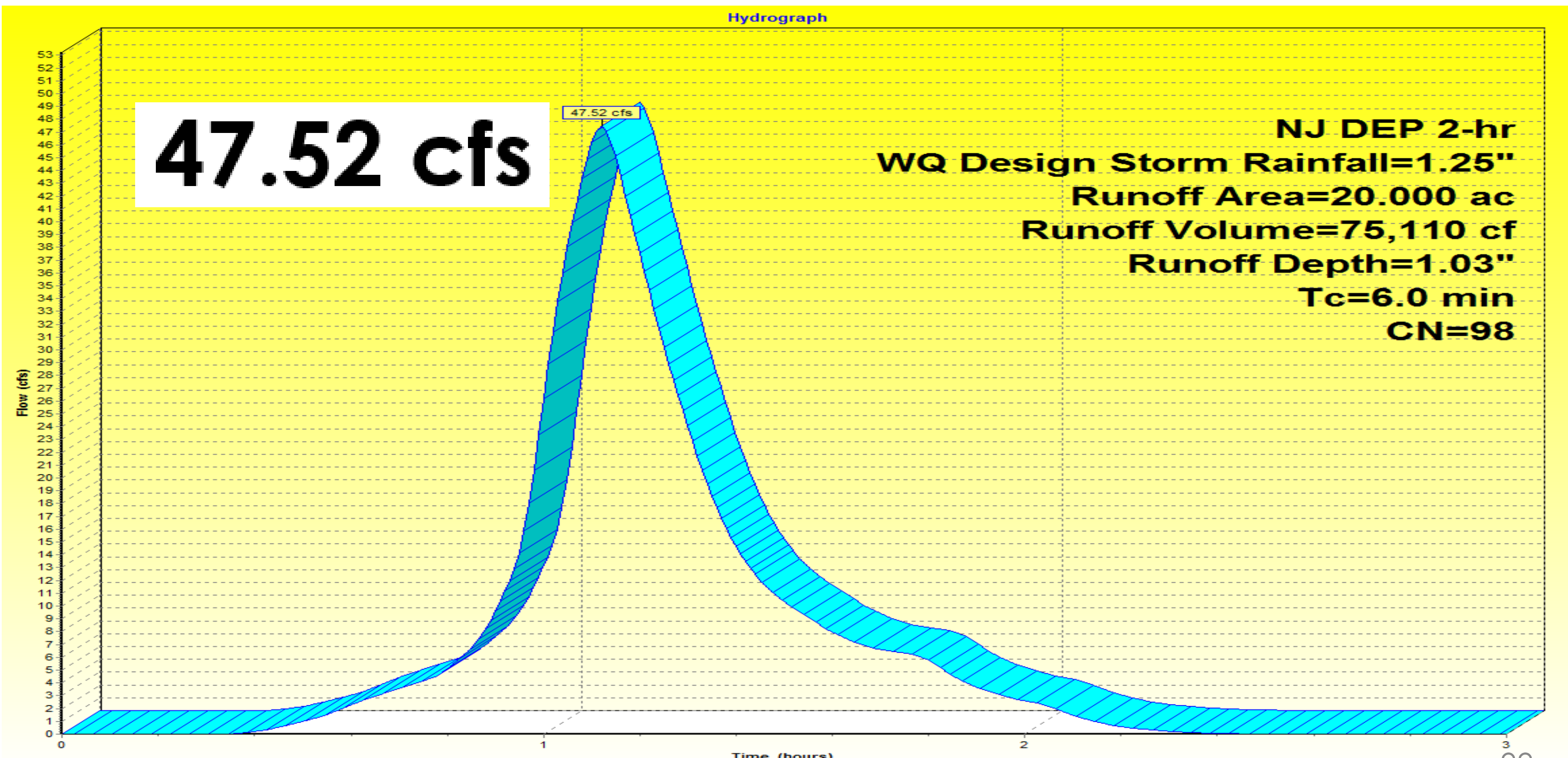
Dimensionless Unit Hydrograph

SCS:



Dimensionless Unit Hydrograph

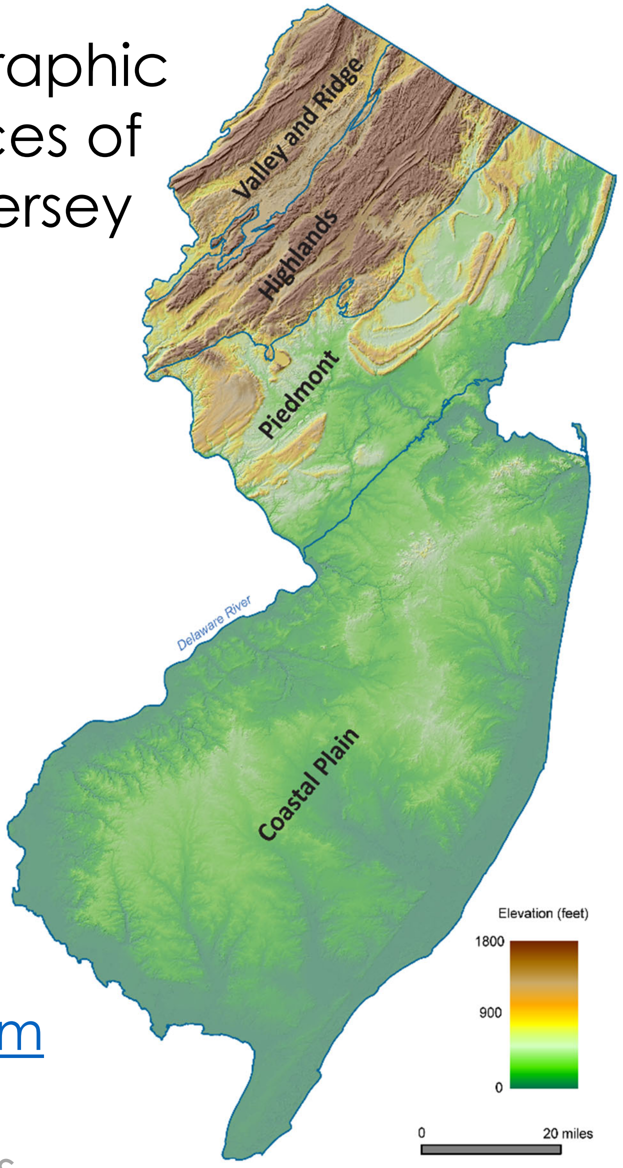
DelMarVa:



DelMarVa Dimensionless Unit Hydrograph

- Conditions for use
  - Watershed slope ≤ 5%
  - Coastal Plain physiography
  - Land use is rural or agricultural
    - Significant storage in swales and depressions
    - Not heavily urbanized
    - No significant impervious cover

Physiographic Provinces of New Jersey

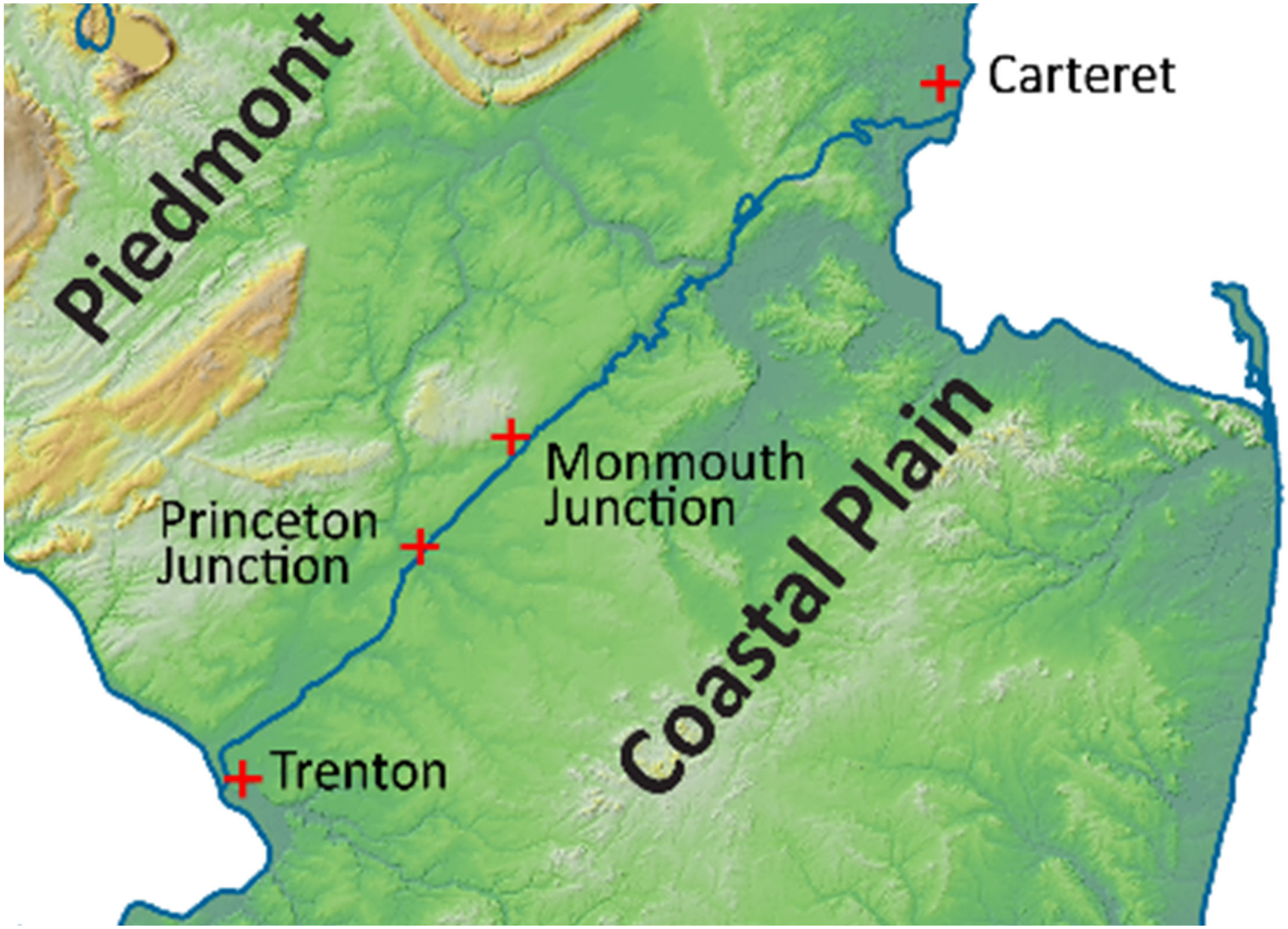


https://www.nj.gov/dep/stormwater/rainfalldata.htm

Imagery modified from New Jersey Geological Survey Information Circular, Physiographic Provinces of New Jersey, 2006

DelMarVa Dimensionless Unit Hydrograph

Physiographic Provinces of New Jersey



Imagery modified from New Jersey Geological Survey Information Circular, Physiographic Provinces of New Jersey, 2006

More Information

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