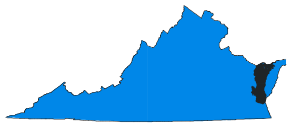
VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY



HYDROLOGY OVERVIEW and PRECIPITATION Unit IV

Stormwater Management

- **Works hand in hand with Erosion and Sediment Control**
- **Addresses Water Quantity and Water Quality**
  - **MS-19**
  - **Local Ordinances**
  - **State Programs**

Hydrology

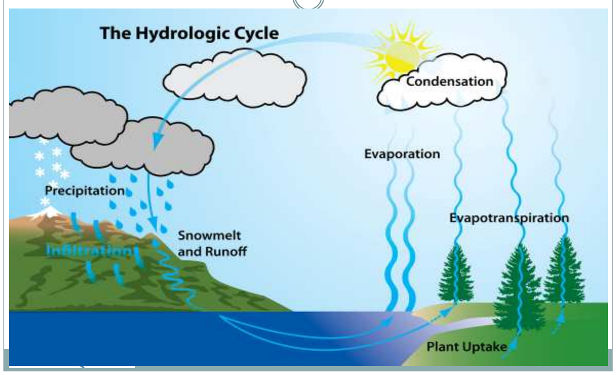
- While MS-19 and the VSMP regulations supplement and/or replaces each other, hydrology remains an important item for planning and things like ditch calculations
- This class focuses on methods for calculating flow velocity and discharge

Hydrology

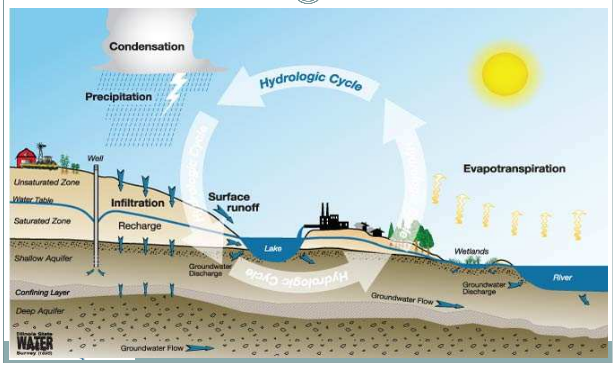
Look at:

- Hydrologic/Water Cycle
- Precipitation
- Runoff

Hydrologic Cycle



Hydrologic Cycle

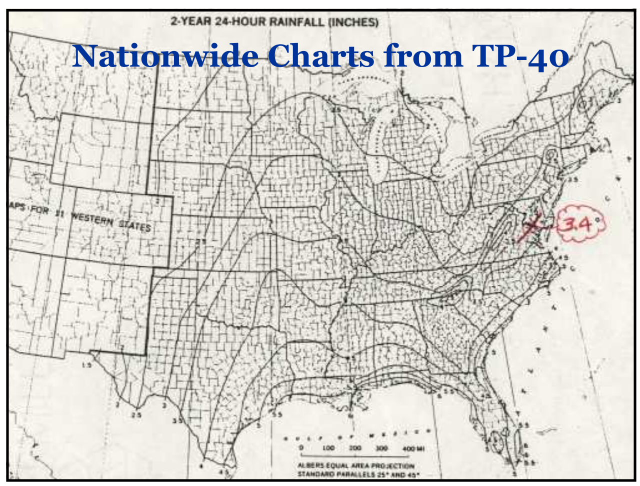


Precipitation

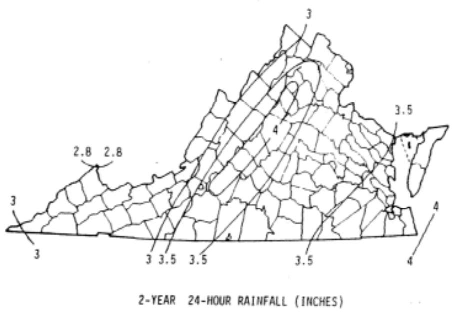
Return Period (T) = 1/Probability (P)

Example: 100 year event = 1/100 or .01 or 1% chance of occurring in any given year

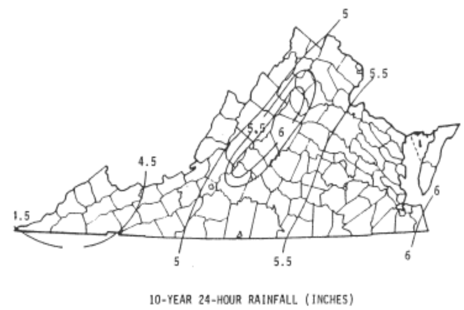
Nationwide Charts from TP-40



2-year 24 hour rainfall (inches)



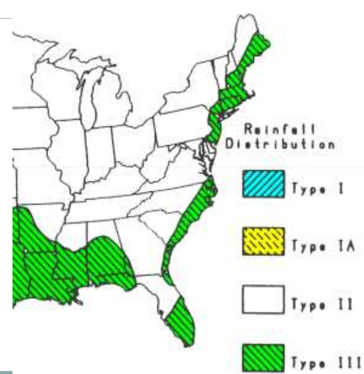
10-year 24 hour rainfall (inches)



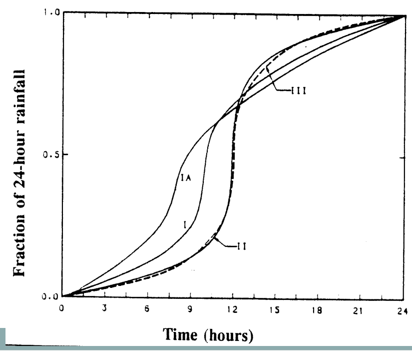
Precipitation

- **Storm duration (units of time)**
- **Storm depth (units of length)**
- **Storm intensity (I) = depth(d) / time(t)**
- **Distribution**

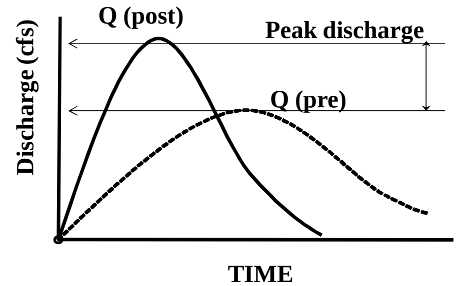
Rainfall Distribution



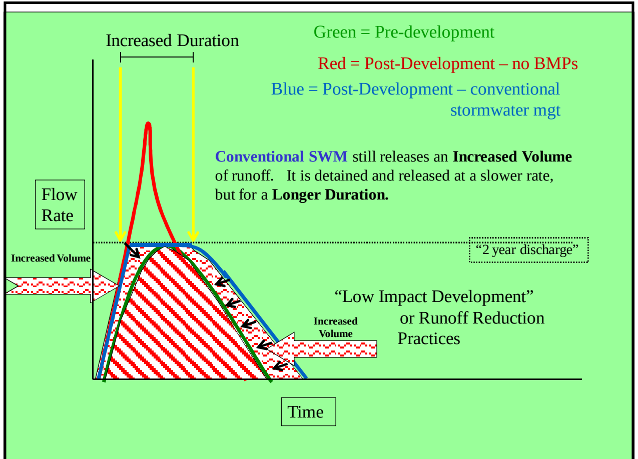
Rainfall Distribution



Hydrographs



Graphical representation of discharge over time



Synthetic Hydrograph

Modeled from watershed parameters and storm characteristics:

- **Rational Method**
- **Modified Rational**
- **NRCS - TR 55 Peak Discharge or Tabular**
- **Unit Hydrograph**

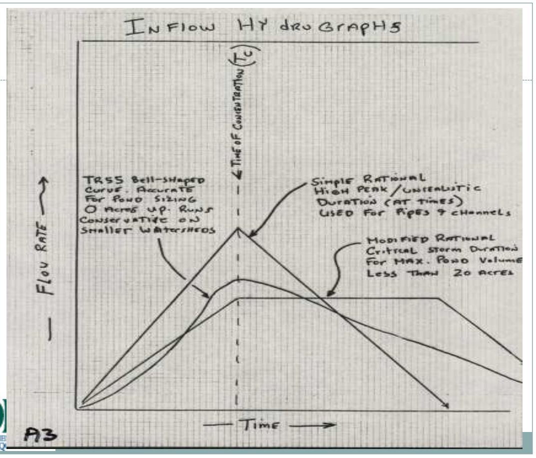


TABLE 5-1

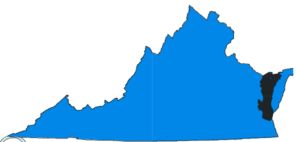
RUNOFF CALCULATION METHODS: SELECTION CRITERIA

Calculation Methods*

1. Rational Method
2. Peak Discharge Method
3. Tabular Method (TR-55)
4. Unit Hydrograph Method

Output Requirements	Drainage Area	Appropriate Calculation Methods
Peak Discharge only	up to 200 acres up to 2000 acres up to 20 sq. mi.	1, 2, 3, 4 2, 3, 4 3, 4
Peak Discharge and Total Runoff Volume	up to 2000 acres up to 20 sq. mi.	2, 3, 4 3, 4
Runoff Hydrograph	up to 20 sq. mi.	3, 4

* The Rational, Graphical Peak Discharge and Tabular methods of runoff determination are described in this chapter. The Unit Hydrograph method is described in the SCS National Engineering Handbook, Section 4, Hydrology.



UNIT IX – TIME OF CONCENTRATION

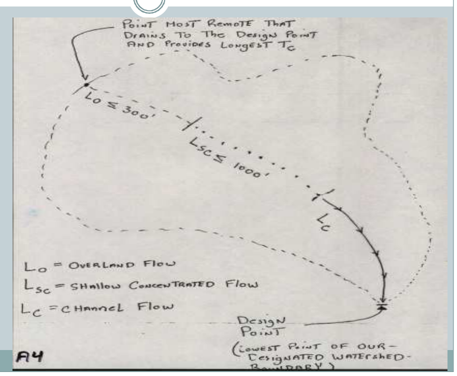
Time of Concentration (Tc)

- **Time of concentration (*Tc*) is the time it takes for runoff to flow along a path from the most *hydraulically* distant point in the watershed to the analysis point (slowest path)**
- **One of the principal inputs for calculating peak runoff from a watershed**

Time of Concentration

- **Flow path consists of three types of flow:**
  - **Overland Flow**
  - **Shallow Concentrated Flow**
  - **Channel Flow**
- **The travel time (*Tt*) for each type of flow is measured or calculated**
- **The time of concentration (*Tc*) is the sum of the travel times (*Tt*) for each type of flow**

Time of Concentration



Time of Concentration Overland Flow

- **Shallow sheet flow occurring in the upper reaches of a watershed**
- **Maximum length of flow up to 300 feet (some prefer 200 feet – will vary based on watershed characteristics)**
- **Calculating overland flow travel time is the most crucial for small watersheds-usually largest time component of calculation.**

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Time of Concentration Methods for Computing Overland Flow

- **Seelye Method**
- **Kinematic Wave Method**
- **NRCS Technical Release 55 (TR-55) Method**

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Overland Flow: Seelye Method

- **Seelye Chart, Plate 5-1, *VESCH* page V-11**
- **Simplest method - commonly used for small developments**
  - Step 1: Find flow LENGTH on the first axis
  - Step 2: Find CHARACTER OF GROUND on the second axis
  - Step 3: Draw a straight line between the points identified in Steps 1 and 2 and extend line to the PIVOT LINE
  - Step 4: Find PERCENT SLOPE on fourth axis
  - Step 5: Draw straight line connecting point where first line crosses PIVOT LINE through the PERCENT SLOPE and extend to the fifth axis
  - Step 6: Read INLET CONCENTRATION TIME where second line meets the fifth axis

Example:

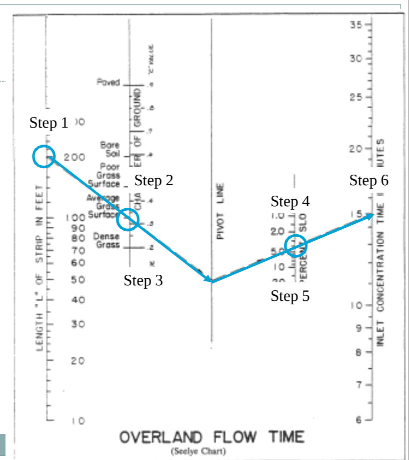
•200 ft flow path

•Average Grass Surface (“C” value 0.32)

•4% slope

Answer:

***Tt* = 15 minutes**



Overland Flow: Kinematic Wave Method

- **Allows for input of rainfall intensity values, providing overland flow travel time for a selected design storm**
- **Requires a "trial and error" approach, as the equation includes two unknown variables: rainfall intensity (*i*) and travel time (*Tt*)**

Overland Flow: Kinematic Wave Method

$$Tt = 0.93 \times \frac{L^{0.6} \times n^{0.6}}{i^{0.4} \times S^{0.3}}$$

L **= length of overland flow (feet)**
n **= Manning's roughness coefficient (Table 5-7)**
i **= rainfall intensity (inches/hour) (Plates 5-4 to 5-18)**
S **= slope (feet/feet)**

TABLE 5-7
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.

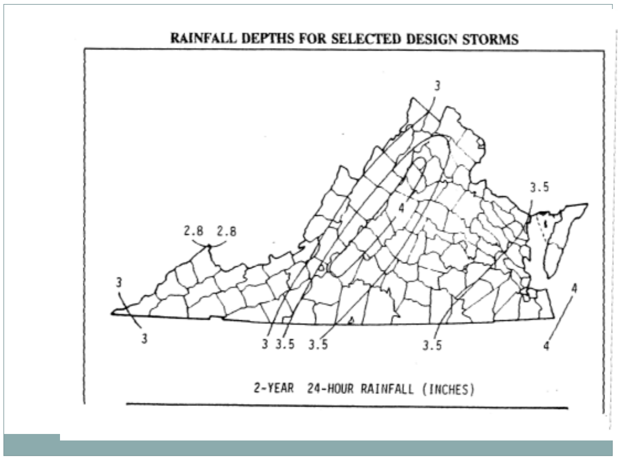
[3] When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Source: USDA-SCS

Overland Flow: NRCS TR-55 Method

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

L **= length of overland flow (feet)**
n **= Manning's roughness coefficient (Table 5-7)**
P_2 = 2 year, 24-hour rainfall in inches (Plate 5-19, page V-49)
s **= slope (feet/feet)**



Shallow Concentrated Flow: NRCS TR-55 Method

- Occurs where overland flow converges to form small rills, gullies, and swales
- Flow length 0 to 1000 feet maximum
- Refer to Plate 5-2 (page V-12) or Plate 5-23 (page V-53) to determine average velocity

Shallow Concentrated Flow: NRCS TR-55 Method

$$Tt = \left(\frac{L}{V \times t}\right)$$

- *L* = flow length (feet)
- *V* = average velocity (feet/second)
- *t* = conversion factor (60 to convert to minutes, 3600 to convert to hours)

Example:

•1% slope (0.01 ft/ft)

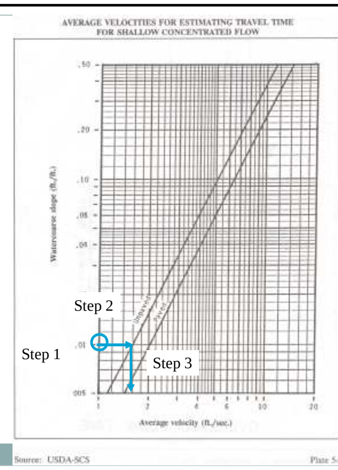
•Unpaved

•Length = 200 ft

Answer:

•*V* = 1.6 ft/second

•*Tt* = 200/(1.6 x 60) = 2.1 minutes



Channel Flow

- Occurs where concentrated flow occurs in channels with well-defined cross-section (streams, ditches, gutters, pipes, etc.)
- Use velocity from Manning's equation for open channel flow

Channel Flow
Manning's Equation

$$Tt = \left(\frac{L}{V \times t} \right)$$

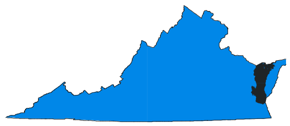
- L = channel flow length (feet)
- V = average velocity from Manning's equation (feet/second)
- t = conversion factor (use 60 to convert to minutes, 3600 to convert to hours)

Time of Concentration

- Sum overland flow travel time, shallow concentrated flow travel time, and channel flow travel time to the design point:

$$Tc = \sum Tt$$

DEQ
Virginia Department of Environmental Quality



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Look at:

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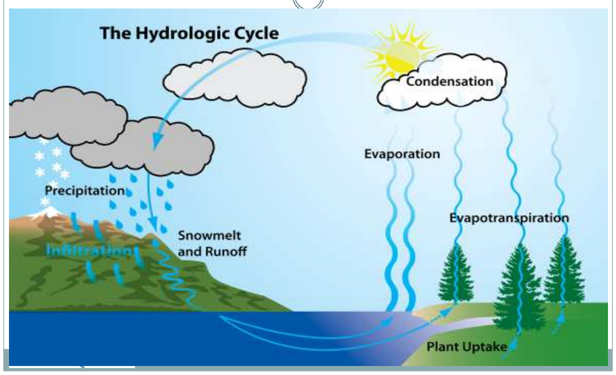
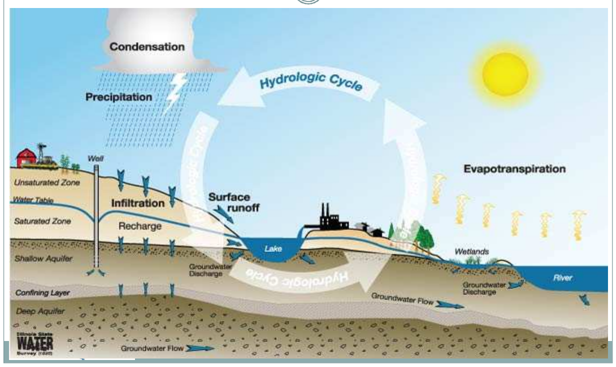
Hydrologic Cycle



Hydrologic Cycle



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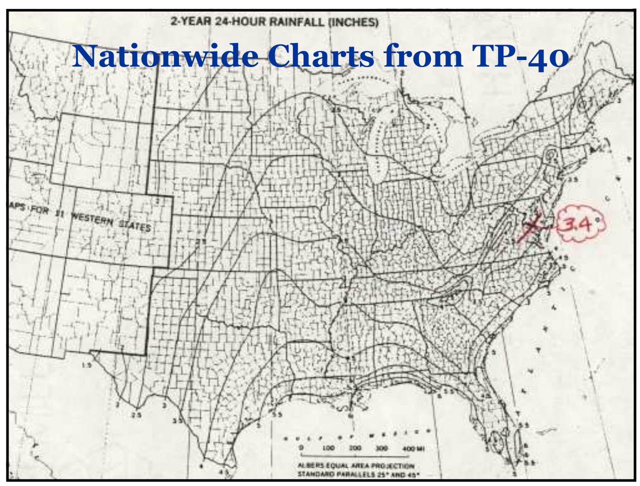
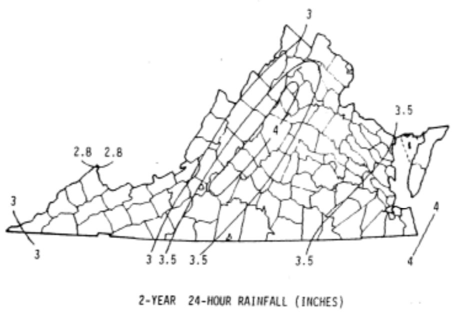
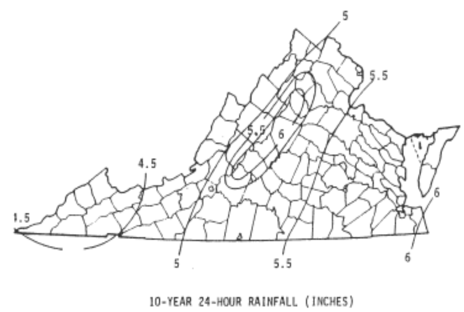


2-year 24 hour rainfall (inches)



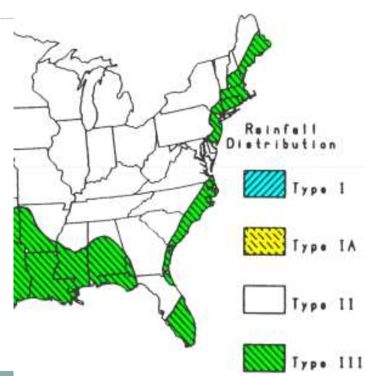
10-year 24 hour rainfall (inches)



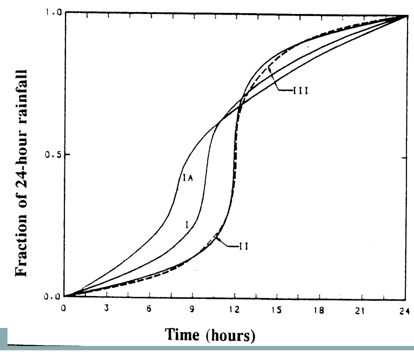
Precipitation

- Storm duration (units of time)
- Storm depth (units of length)
- Storm intensity (I) = depth(d) / time(t)
- Distribution

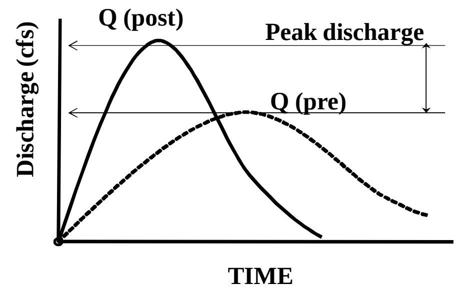
Rainfall Distribution



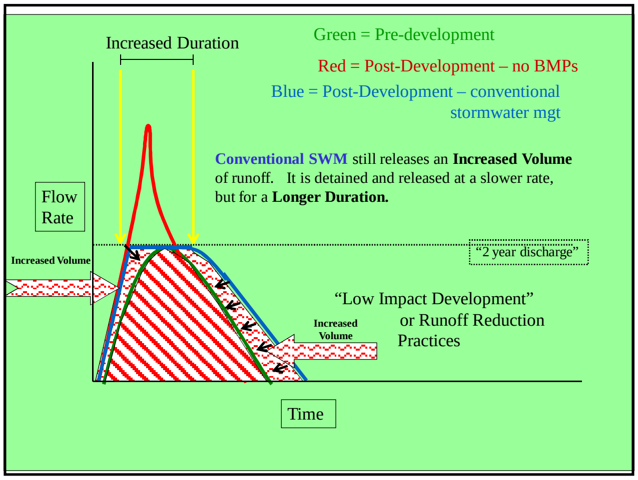
Rainfall Distribution



Hydrographs



Graphical representation of discharge over time



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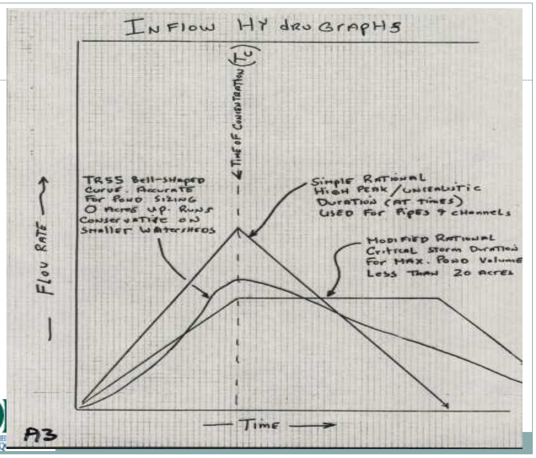

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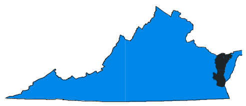

UNIT X – RATIONAL METHOD

Rational Method

- Method used to calculate peak discharge from a drainage area
- Most accurate when used on small, impervious, and homogenous watersheds (<200 acres)
- Assumes that a rainfall duration equal to the Time of Concentration (*Tc*) results in the greatest peak discharge

Rational Method

$$Q = CiA$$

Q = peak discharge/rate of runoff (cfs)
C = runoff coefficient
i = average rainfall intensity (inches/hour)
A = drainage area (acres)

Rational Method: Runoff Coefficient (C)

- Number relating the amount of runoff to the amount of rainfall (Table 5-2, page V-29)
- As the imperviousness of a drainage area increases, the value of C increases
- A C value of 1.0 would represent a complete runoff of all rainfall

TABLE 5-2
VALUES OF RUNOFF COEFFICIENT (C) FOR RATIONAL FORMULA

Land Use	C	Land Use	C
Business:		Lawns:	
Downtown areas	0.70-0.95	Sandy soil, flat, 2%	0.05-0.10
Neighborhood areas	0.50-0.70	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
Residential:		Agricultural land:	
Single-family areas	0.30-0.50	Bare packed soil	
Multi units, detached	0.40-0.60	* Smooth	0.30-0.60
Multi units, attached	0.60-0.75	* Rough	0.20-0.50
Suburban	0.25-0.40	Cultivated rows	
		* Heavy soil, no crop	0.30-0.60
		* Heavy soil, with crop	0.20-0.50
		* Sandy soil, no crop	0.20-0.40
		* Sandy soil, with crop	0.10-0.25
		Pasture	
		* Heavy soil	0.15-0.45
		* Sandy soil	0.05-0.25
		Woodlands	0.05-0.25
Industrial:		Streets:	
Light areas	0.50-0.80	Asphaltic	0.70-0.95
Heavy areas	0.60-0.90	Concrete	0.80-0.95
		Brick	0.70-0.85
Parks, cemeteries	0.10-0.25	Unimproved areas	0.10-0.30
Playgrounds	0.20-0.35	Drives and walks	0.75-0.85
Railroad yard areas	0.20-0.40	Roofs	0.75-0.95

Note: The designer must use judgement to select the appropriate "C" value within the range. Generally, larger areas with permeable soils, flat slopes and dense vegetation should have the lowest C values. Smaller areas with dense soils, moderate to steep slopes, and sparse vegetation should be assigned the highest C values.

Rational Method: Weighted Runoff Coefficient

- **If a drainage area has multiple land uses with different C values, then a weighted C value can be calculated**
- **Example: A 10.0 acre drainage area with 2 different land uses: 2 acres of parking lot (C = 0.95) and 8 acres of park (C = 0.25)**

DEQ
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Rational Method: Weighted Runoff Coefficient

- **Calculate a CA value for each land use:**

  C_1 x A_1 = 0.95 x 2 = 1.9

  C_2 x A_2 = 0.25 x 8 = 2.0
- **Add the CA values together and divide the sum by the total area:**

  (1.9 + 2.0)/10 = 3.9/10 = 0.39 = weighted C value

DEQ
VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

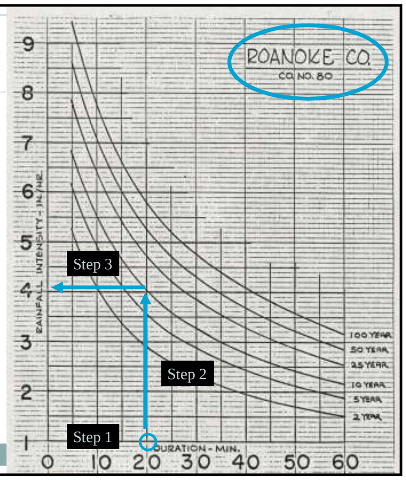
Rational Method: Average Rainfall Intensity (i)

- **In the Rational Method, the storm duration is assumed to be equal to the Time of Concentration (*Tc*)**
- **Select the proper Intensity-Duration-Frequency (IDF) curve from Plates 5-4 to 5-18, VESCH, pages V-14 to V-28**
  - **Step 1: Start with storm duration = *Tc* (minutes)**
  - **Step 2: Read up until you cross the storm frequency curve (2-year, 10-year, etc.)**
  - **Step 3: Read to the left and determine intensity (in/hr)**

DEQ
VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Example:

- **Roanoke County**
- ***Tc* = 20 minutes**
- **10-year storm frequency**



Answer:

- ***i* = 4.1 in/hr**

Rational Method

$$Q = CiA$$

$$Q = 0.39 \times 4.1 \times 10$$

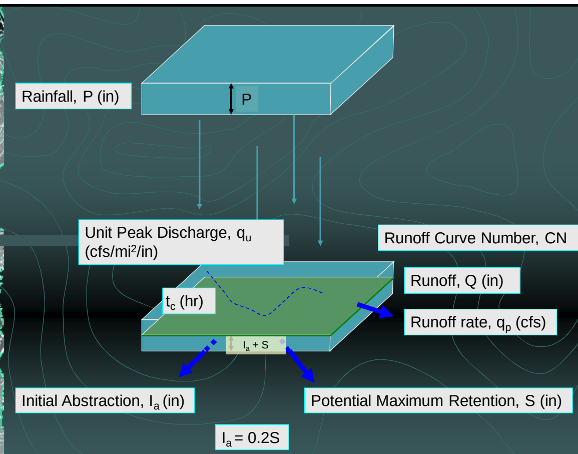
$$Q = 15.99 cfs$$

Rational Method: Assumptions and Limitations

- **Frequency of rainfall and runoff events similar**
- **Rainfall occurs at uniform intensity for a duration equal to *Tc* and over the entire area of a watershed.**
- **More accurate as imperviousness increases**
- **Less accurate as size of watershed increases**
- **Not suitable for basin design**

TR-55

GRAPHICAL PEAK DISCHARGE METHOD



Information you will need -

- Rainfall distribution (i.e., Type I, IA, II or III)
- Rainfall amount (P), in inches
- Weighted runoff curve number (CN)
- Initial abstraction (I_a)
- Ratio of I_a/P
- Total runoff (Q), in inches
- Time of concentration (t_c), in hours
- Drainage area, in square miles (A_m)

Peak Discharge Equation -

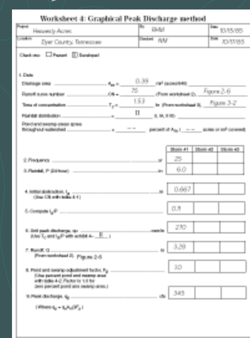
$$q_p = q_u A_m Q F_p$$

- Where:
  - q_p = peak discharge (cfs)
  - q_u = unit peak discharge (cfs/mi^2-in; csm/in)
  - A_m = drainage area (mi^2)
  - Q = runoff (in)
  - F_p = pond and swamp adjustment factor
- An example calculation is given starting on page V-31 of the DCR VESCH

Flowchart of computation activities -

Determine 24-hour rainfall (P) for desired design storm → Calculate weighted CN for site → Use CN with table to determine initial abstraction (I_a) → Compute I_a/P ratio → Determine time of concentration (t_c) → Use t_c and I_a/P to find q_u from chart → Calculate expected runoff (Q) → Determine pond and swamp adjustment factor (F_p) → Combine all the above factors and calculate peak discharge (q_p)

Typical worksheet -

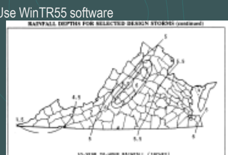


This, other worksheets and instructions can be found in the TR55 manual, which can be obtained on the Internet at http://www.wsi.nrcs.usda.gov/products/w2q/H&H/Tools_Models/other/TR55.html. It can also be found on page V-48 of the DCR VESCH.

A Windows computer program that performs TR55 calculations can be obtained at http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/WinTR55.html.

Step 1: Determine rainfall -

- Several ways
  - NOAA Atlas 14
  - Plates 5-19 through 5-21 on pages V-49 through V-51 of the VESCH
  - Tabular listing in Appendix 4B of the DCR Stormwater Manual
  - Figures B-3 through B-8 of the TR55 manual
  - Use WinTR55 software



Part of VESCH Plate 5-20

COUNTY	1	2	5	10	25	50	100	
Pittsylvania	2.8	3.5	4.5	5.2	6.2	6.7	7.5	
Powhatan	3.0	3.5	4.5	5.5	6.0	7.0	7.5	
Prince Edward	3.0	3.5	4.5	5.5	6.0	7.0	7.8	
Prince George		3.0	3.5	4.7	5.7	6.2	7.0	8.0
Prince William	3.0	3.5	4.5	5.3	6.0	7.0	7.8	
Pulaski	2.5	3.0	4.0	4.8	5.0	6.0	6.5	
Rappahannock	3.0	4.0	4.7	5.7	7.0	8.0	8.5	
Richmond	3.0	3.5	4.5	5.7	6.2	7.0	7.9	
Roanoke	3.0	3.5	4.5	5.0	6.0	6.7	7.5	

Part of Appendix 4B

Step 2: Calculate weighted CN -

- Need to know the Hydrologic Soil Group (HSG) for each of the soils at the site as well as the area of each soil type.
- Get soils information from:
  - Site drawings or E&S report
  - NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/)
  - Appendix 6C of the DCR VESCH
  - Appendix 4A of the DCR Stormwater Manual

Step 2: Continued …

- Look up CN numbers for the areas of the site in Table 5-5 (pages 5-56 through 5-59 of VESCH) or in TR55 Manual.

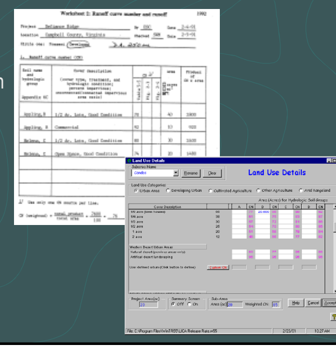
TABLE 5-5*

RUNOFF CURVE NUMBERS FOR GRAPHICAL PEAK DISCHARGE METHOD

COVER DESCRIPTION			HYDROLOGIC SOIL GROUP A	B	C	D
Fully Developed Urban Areas (Vegetation Established)						
Open Space (lawns, parks, etc.)	Poor Condition; Grass		68	79	86	89
	Fair Condition; Grass 50 - 75% cover		49	69	79	84
	Good Condition; Grass > 75% cover		39	61	74	80
Impervious Areas	Paved parking lots, roofs, driveways		98	98	98	98
Streets and Roads	Paved; curbs and storm sewers		98	98	98	98
	Paved; open ditches (w/right-of-way)		83	89	92	93
	Gravel (with right-of-way)		76	85	89	91
	Dirt (with right-of-way)		72	82	87	89
Urban Districts		Average % Impervious				
	Commercial and Business	85	89	92	94	95
	Industrial	72	81	88	91	93

Step 2: Concluded

- Calculate weighted average CN for site
- Example worksheet given on page V-46 of the VESCH



Step 3: Determine Initial Abstraction -

- Look up I_a values in Table 5-9 on page V-64 of the DCR VESCH

TABLE 5-9

I_a VALUES FOR RUNOFF CURVE NUMBERS

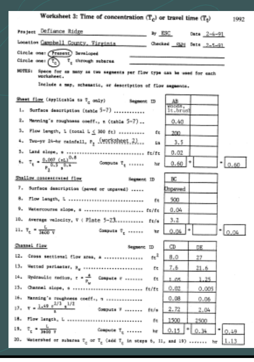
Curve Number	I_a (inches)	Curve Number	I_a (inches)	Curve Number	I_a (inches)
40	3.000	60	1.333	80	0.500
41	2.878	61	1.279	81	0.469
42	2.762	62	1.226	82	0.439
43	2.651	63	1.175	83	0.410
44	2.545	64	1.125	84	0.381
45	2.444	65	1.077	85	0.353
46	2.348	66	1.030	86	0.326
47	2.255	67	0.985	87	0.299
48	2.167	68	0.941	88	0.273
49	2.082	69	0.899	89	0.247
50	2.000	70	0.857	90	0.222
51	1.922	71	0.817	91	0.198
52	1.846	72	0.778	92	0.174
53	1.774	73	0.740	93	0.151
54	1.704	74	0.703	94	0.128
55	1.636	75	0.667	95	0.105
56	1.571	76	0.632	96	0.083
57	1.509	77	0.597	97	0.062
58	1.448	78	0.564	98	0.041
59	1.390	79	0.532		

Step 4: Compute I_a/P ratio -

- Relatively straightforward step
- Simply divide the I_a value obtained from Table 5-9 in Step 3 by the P value obtained in Step 1.

Step 5: Determine Time of Concentration (tc) -

- Example worksheet on page V-42 of VESCH



Worksheet 3: Time of concentration (T_c) or travel time (T_t) 1992

Project Defiance Ridge By ESC Date 2-4-91

Location Campbell County, Virginia Checked Date 2-5-91

Circle one: (Present) Developed

Circle one: (T_c) T_t through subarea

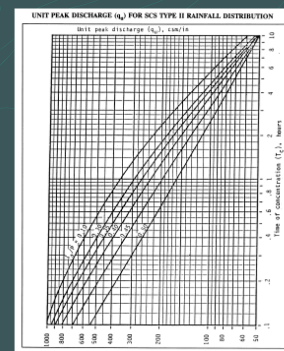
NOTES: Space for as many as two segments per flow type can be used for each worksheet.

Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to T_c only)		Segment ID	AB		
1. Surface description (table 5-7)			woods, lt. brush		
2. Manning's roughness coeff., n (table 5-7)			0.40		
3. Flow length, L (total L ≤ 300 ft)	ft		200		
4. Two-yr 24-hr rainfall, P_2 (worksheet 2)	in		3.5		
5. Land slope, s	ft/ft		0.02		
6. $T_t = \frac{0.007 (nL)^{0.8}}{P_2^{0.5}\, s^{0.4}}$ Compute T_t	hr		0.60	+	= 0.60
Shallow concentrated flow		Segment ID	BC		
7. Surface description (paved or unpaved)			Unpaved		
8. Flow length, L	ft		500		
9. Watercourse slope, s	ft/ft		0.04		
10. Average velocity, V (Plate 5-23)	ft/s		3.2		
11. $T_t = \frac{L}{3600\,V}$ Compute T_t	hr		0.04	+	= 0.04
Channel flow		Segment ID	CD	DE	
12. Cross sectional flow area, a	ft^2		8.0	27	
13. Wetted perimeter, p_w	ft		7.6	21.6	
14. Hydraulic radius, $r = \frac{a}{p_w}$ Compute r	ft		1.05	1.25	
15. Channel slope, s	ft/ft		0.02	0.005	
16. Manning's roughness coeff., n			0.08	0.06	
17. $V = \frac{1.49\, r^{2/3}\, s^{1/2}}{n}$ Compute V	ft/s		2.72	2.04	
18. Flow length, L	ft		1500	2500	
19. $T_t = \frac{L}{3600\,V}$ Compute T_t	hr		0.15	+ 0.34	= 0.49
20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19)	hr				1.13

Step 6: Find q_u on chart -

- Use I_a/P ratio calculated in Step 4 and t_c value found in Step 5 to find q_u on chart provided as Plate 5-25 on page V-55 of DCR VESCH



Step 7: Determine expected runoff -

- Two methods:
  - Use CN value to find expected runoff from Table 5-6 on page V-60 of VESCH
  - Calculate runoff using NRCS TR55 equation:

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

where

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

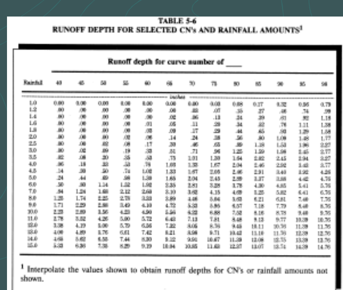


TABLE 5-6
RUNOFF DEPTH FOR SELECTED CN's AND RAINFALL AMOUNTS[1]

Rainfall	Runoff depth for curve number of ___ 40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1] Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

Step 8: Pond & Swamp Adjustment -

- Factor not always needed
- Needed if ponds and/or swamps are scattered throughout the watershed, but not on the path used to determine t_c
- Determine percentage of the drainage area represented by swamps and/or ponds
- Look up F_p in Table 5-10 on page V-65 of VESCH

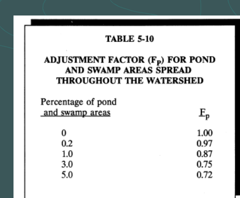


TABLE 5-10

ADJUSTMENT FACTOR (F_p) FOR POND AND SWAMP AREAS SPREAD THROUGHOUT THE WATERSHED

Percentage of pond and swamp areas	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

Step 9: Complete calculation

- Now that all the background variable values have been determined, use the peak discharge equation to calculate the peak discharge

$$q_p = q_u A_m Q F_p$$

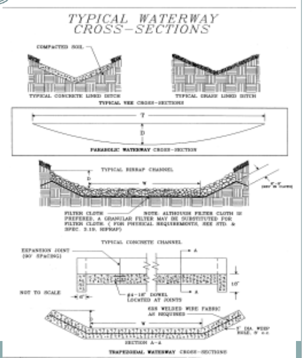
  - q_u from Step 6
  - A_m from site information provided with plans
  - Q from Step 7
  - F_p from Step 8

Limitations

- Peak discharge method – no hydrograph generated, cannot be used for routing (basin design)
- Only one main stream in watershed. Can be applied to multiple stream branches with nearly equal t_c
- Watershed must be hydrologically homogeneous (uniform distribution of land use, soils, and cover) – represented by one CN

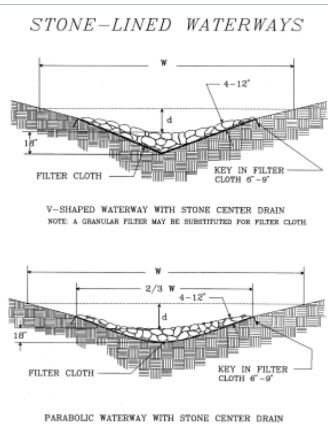

Plan review involves verification of channel adequacy

Stormwater Conveyance Channel-3.17



Reviewing Channel Design

- **Top width of parabolic and v-shaped channels not to exceed 30'**
- **Bottom width of trapezoid and grass lined not to exceed 15'**
- **Outlet protection**
- **Grass lined channels stabilized by the permanent seeding and/or sodding specification**
- **Bermudagrass sprigging irrigate for 4 weeks**
- **Erosion netting**
- **Riprap use Std & Specs**



Concrete lined channels

- ***Must have moist subgrade***
- ***Transverse joints at 20' intervals***
- ***Expansion joints every 100'***

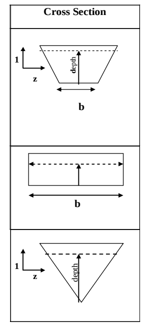
Open Channel Flow: MS - 19 - Adequate Channel

- **One-percent rule**
- **Man-made**
  - **Capacity - 10-year discharge**
  - **Stability - 2-year discharge**
- **Natural**
  - **Capacity - 2-year discharge**
  - **Stability - 2-year discharge**
- **Storm Sewer Systems - Capacity for 10-year storm**
- **Natural Channel Design … Man-Made→Natural**

Channel Analysis: MS - 19

Channel capacity

- **Based on channel geometry and lining (roughness)**
- **Compare to drainage area and design storm**



Channel Analysis: MS - 19

Channel lining

- **Permissible velocity of lining compared to velocity of design storm**
- **Permissible velocities in Table 5-14 (V – 120) or in manufacturer's specifications**

Channel Slope	Lining	Velocity* (ft./sec.)
0 - 5%	Bermudagrass	6
	Reed canarygrass Tall fescue Kentucky bluegrass	5
	Grass-legume mixture	4
	Red fescue Redtop Sericea lespedeza Annual lespedeza Small grains Temporary vegetation	2.5
5 - 10%	Bermudagrass	5
	Reed canarygrass Tall fescue Kentucky bluegrass	4
	Grass-legume mixture	3
Greater than 10%	Bermudagrass	4
	Reed canarygrass Tall fescue Kentucky bluegrass	3

* For highly erodible soils, decrease permissible velocities by 25%.

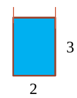
Manning's Equation

$$V = \frac{1.49}{n} \times R^{(2/3)} \times \sqrt{s}$$

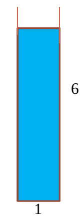
V = velocity (fps)
n = Manning's roughness coefficient (dimensionless)
R = hydraulic radius (A/P)
- **A= wetted cross sectional area**
- **P=wetted perimeter(ft)**

s = slope (in ft/ft - NOT percent slope)

Hydraulic radius



A= 2x3 = 6
P= 3+2+3= 8
R= A/P = 6/8 = 0.75



A= 1x6 = 6
P= 6+1+6= 13
R= A/P = 6/13 = 0.46

Open Channel Flow: Roughness Coefficients - Manning's (n)

Concrete Pipe	.012 to .016
Earthen Ditch	.017 to .025
Canal w/ stone bed & weeds on bank	.025 to .04
Earth bottom & rubble sides	.028 to .035

Table 5-8 (p. V-62)

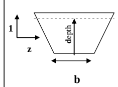
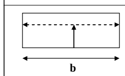
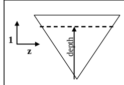
TABLE 5-8

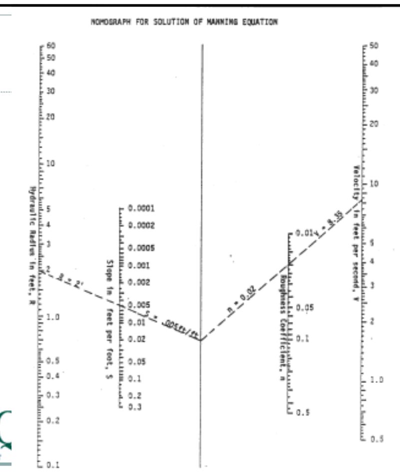
MANNING'S "n" VALUES

Surface	Best	Good	Fair	Bad
Uncoated cast-iron pipe	0.012	0.013	0.014	0.015
Coated cast-iron pipe	0.011	0.012*	0.013*	
Commercial wrought-iron pipe, black	0.012	0.013	0.014	0.015
Commercial wrought-iron pipe, galvanized	0.013	0.014	0.015	0.017
Riveted and spiral steel pipe	0.013	0.015*	0.017*	
Common clay drainage tile	0.011	0.012*	0.014*	0.017
Neat cement surfaces	0.010	0.011	0.012	0.013
Cement mortar surfaces	0.011	0.012	0.013*	0.015
Concrete pipe	0.012	0.013	0.015*	0.016
Concrete-lined channels	0.012	0.014*	0.016*	0.018
Cement-rubble surface	0.017	0.020	0.025	0.030
Dry-rubble surface	0.025	0.030	0.033	0.035
Canals and ditches:				
Earth, straight and uniform	0.017	0.020	0.0225*	0.025
Rock cuts, smooth and uniform	0.025	0.030	0.033	0.035
Rock cuts, jagged and irregular	0.035	0.040	0.045	
Winding sluggish canals	0.0225	0.025*	0.0275	0.030
Dredged earth channels	0.025	0.0275*	0.030	0.033
Canals with rough stony beds, weeds on earth banks	0.025	0.030	0.035*	0.040
Earth bottom, rubble sides	0.028	0.030*	0.033*	0.035

* Values commonly used in designing.

Open Channel Flow

Section	Area a	Wetted Perimeter P	Hydraulic Radius R = a/P	Top Width T
	$bd + zd^2$	$b + 2d(z^2+1)^{1/2}$	$\frac{bd + zd^2}{b + 2d(z^2+1)^{1/2}}$	$b + 2zd$
	bd	b + 2d	$\frac{bd}{b + 2d}$	b
	zd^2	$2d(z^2+1)^{1/2}$	$\frac{zd^2}{2d(z^2+1)^{1/2}}$	2zd



Continuity Equation

$Q = V * A$

- Q = discharge (cfs)
- V = velocity (from Manning's, fps)
- A = Cross sectional area (ft^2)

cfs = fps * ft^2

Open Channel Flow

Manning Equation

$V = (1.49/n) * (R^{2/3}) * (S^{1/2})$

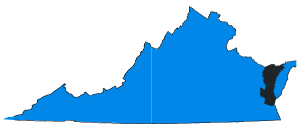
Continuity Equation

$Q = V * A$

by substitution,

Discharge Equation:

$Q = (1.49/n) * S^{1/2} * R^{2/3} * A$



Unit XIII

Minimum Standard 19 (a Summary)

Erosion and Sediment Control For Plan Reviewers

Consisted of:

- **A review of the structures (Day 1)**
- **Plan review for stormwater (Day 2)**

But in essence they all related to MS-19

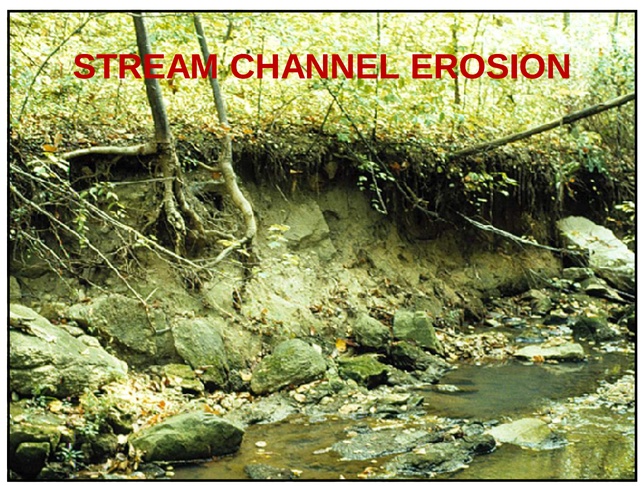
MS-19

"Properties and receiving waterways downstream of any land development project shall be protected from sediment deposition, erosion, and damage due to increases in volume, velocity, and peak flow rate of stormwater runoff . . . "

STORMWATER MANAGEMENT

Streams are in equilibrium with their watershed

- **Greater imperviousness = greater runoff**
- **Issue: How will the change in the drainage area affect a given channel?**



4VAC50-30-40.19.a :

Concentrated stormwater runoff leaving a development site shall be discharged directly into an adequate natural or man-made receiving channel, pipe or storm sewer system.

4VAC50-30-40.19.

a. For those sites where runoff is discharged into a pipe or pipe system (or any man-made conveyance), downstream stability analyses at the outfall of the pipe or pipe system shall be performed.

4VAC50-30-40.19.

b. Adequacy of all channels and pipes shall be verified in the following manner:

(1) 1% Rule; or

(2) (a) Natural channels: 2-year storm will not overtop channel banks nor cause erosion of channel bed or banks; and

4VAC50-30-40.19. (cont.) :

(b) Man-made channels: 10-year storm will not overtop banks and 2-year storm will not cause erosion of channel bed or banks; and

(c) Pipes and storm sewer systems: 10-year will be contained within the pipe or system.

Stream Restoration and Relocation Projects (11/21/2012)

! Those that use natural channel design are not man-made channels and are exempt from any flow rate capacity and velocity requirements for natural or man-made channels:

Channel Analysis:

- **Channel geometry - three cross sections 50’ apart from discharge point.**
- **Channel lining**
- **Channel slope**
- **Energy slope - hydraulic grade line calculation of the existing or proposed pipe system**

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Channel Analysis (cont.):

Applicant should investigate the channel to verify that the cross sections provided are an accurate depiction of the channel and that there are no significant restrictions downstream.

Adequate channel?

- Velocity (rational Method)
- Volume (graphical Peak Discharge)
- Duration (Time of Concentration)
- Frequency

Note: this needs to be checked for onsite channels as well

Urban Stream Problems

- Subjective analysis of natural channels
- Impervious surfaces result in increased volume, velocity, frequency, and peak rates of flow.
- Detention practices address velocity and peak rates of flow, but do not address volume, frequency, and duration.

Inadequate channels

4VAC50-30-40.19.c. :

"If existing natural receiving channels or previously constructed man-made channels or pipes are not adequate, the applicant shall:

4VAC50-30-40.19.c. (cont.) :

(1) Improve the channel to a condition where a 10-year storm will not overtop the banks and a 2-year storm will not cause erosion to the channel bed or banks;

4VAC50-30-40.19.c. (cont.) :

(2) Improve the pipe or pipe system to a condition where the 10-year storm is contained within the appurtenances;

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4VAC50-30-40.19.c. (cont.) :

(3) *Develop a site design* that will not cause the pre-development peak runoff rate from a two-year storm (natural receiving channel) or a ten-year storm (manmade) to increase.

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Working with the Landscape…
“Better Site Design”
“Limited Impact Design”


Design Principles:
• Utilize existing vegetation & topography
• Limit and disconnect impervious surfaces
• Encourage infiltration where appropriate
TOYOTA


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4VAC50-30-40.19.c. (cont.) :

(4) Provide a combination of channel improvement, stormwater detention or other measures which is *satisfactory to the plan-approving authority* to prevent downstream erosion.

SWM Regulations 4VAC3-20-81:

"Downstream properties shall be protected . . ."

- **Compliance with MS-19**
- **1-year extended detention**
- **Localities may adopt more stringent criteria**

2011 Stormwater Regulations

$$Q_{post} \text{ x } RV_{post} \leq I.F. \text{ x } (Q_{pre} \text{ x } RV_{pre})$$

Where

- Q_{pre} =Pre-development peak flow rate (cfs)
- RV_{pre} = Pre-development runoff volume (in.)
- Q_{post} = Post-development peak flow rate (cfs)
- RV_{post} = Post development runoff volume (in.)
- I.F. = Improvement factor (0.8 for sites>1 acre, 0.9 for sites < 1 acre

MS-19 *(11/21/2012)*

(l.) For projects approved before July 1, 2014, if you can meet the energy balance equation in the stormwater regulations you satisfy MS-19

(m.) Projects approved after July 1, 2014, must comply with the Virginia Stormwater Management Act including the Grandfathering provisions

(n.) Meeting the requirements of the Virginia Stormwater Management Act satisfies MS-19.

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