Chapter 4 - Stormwater Hydrology

Stormwater hydrology defines the means and methods to calculating stormwater runoff from a designated area. This section documents the hydrologic practices used to establish design flows necessary to prepare the required stormwater peak flow and storage calculations.

4.1 References

Except where more stringent requirements are presented in this Design Manual, stormwater hydrology shall comply with state requirements. The primary design references are:

- VDOT Drainage Manual
- VA SWM Handbook
- BMP Clearinghouse

4.2 Design Frequencies

4.2.1 General

Design frequencies shall be selected consistent with good engineering practice and economics. The design frequency requirements given in this Design Manual are minimum, specific conditions may dictate that less frequent design frequency should be used.

4.2.2 Storm Drainage Systems

Storm drainage systems consist of manmade open channels, culverts, and storm drains. Designs shall be based on the following minimum design storm frequencies:

<u>Manmade Open Channels</u>:

Minor Channel Capacity	10-year
Minor Channel Protective Lining (Drainage Area 5 acres or less)	2-year
Minor Channel Protective Lining (Drainage Area over 5 acres)	10-year
Major Channel Capacity	100-year
Major Channel Protective Lining (100-year if potential for catastrophic failure)	10-year

Culverts:	
Principal Arterial Roads	25-year
Other Roads	10-year
Storm Drains	10-year

All storm drainage designs for open channels, culverts, and storm drains shall be checked for the 100-year flow condition where there is the possibility of flooding residences, commercial or industrial buildings, overtopping primary roads, experiencing significant economic loss, or catastrophic failure. Where justified by the consequences of failure, the minimum design frequency shall be increased.

4.2.3 Stormwater Management Facilities

Designs shall be in accordance with the VA SWM Handbook and BMP Clearinghouse.

4.3 Time of Concentration (t_c) and Travel Time (T_t)

4.3.1 General

Time of Concentration (t_c) is the length of time required for a drop of water to travel from the most hydraulically distant point in the watershed, or subwatershed to the point of analysis. Travel Time (T_t) is the length of time required for that same drop of water to travel from the study point at the bottom of the sub-watershed to the study point at the bottom of the whole watershed. The travel time is descriptive of the sub-watershed by providing its location relative to the study point of the entire watershed. Therefore Time of Concentration is the summation of Travel Time values for the various consecutive flow segments.

Travel Time and Time of Concentration generally consist of four flow types- overland flow, shallow concentrated flow, channelized flow, and pipe systems. Calculations shall be reviewed for reasonableness and the results shall be revised if needed to provide a reasonable velocity and flow time that will best represent the study area.

When designing a drainage system, the flow path is not necessarily the same before and after land disturbing activities have been completed. Therefore, the travel time path shall be reflective of the actual conditions both before and after the land disturbing activities.

In some cases, runoff from a portion of the drainage area that is highly impervious may result in a greater peak discharge than would occur if the entire area were considered. In this case, adjustments can be made to the drainage area by disregarding those areas where flow time is too slow to add to the peak discharge.

To prevent small drainage areas from skewing the time of concentration calculation results, when establishing sub drainage areas for analysis, the largest sub drainage area shall be no greater than 5 times the area of the smallest sub drainage area.

Time of concentration maps shall include segment lengths, elevations at beginning and end of segment, slopes, and flow types.

4.3.2 Overland Flow

Overland flow is flow that occurs at the upper end of a watershed, where flow is not concentrated and there are no channels. The length of overland flow shall be reflective of actual conditions and shall normally be <u>no greater than 150 feet</u>.

Where the overland flow does not contain any slopes exceeding 5% <u>AND</u> if the soils are not designated as highly erodible, a maximum length of overland flow of 200 feet may be used. Highly erodible soils are designated as United States Department of Agriculture Natural Resources Conservation Service land capability classification (LCC) classes IIIe, IVe, VI, VII, or VIII or having an erodibility index greater than or equal to 8. Overland flow shall be calculated using the Seelye chart contained in the Appendix 4A for the Rational Method or TR-55 for the SCS Method. Roughness coefficients (Manning's n) for sheet flow can be found in the TR-55 Manual.

4.3.3 Shallow Concentrated Flow

Shallow concentrated flow is the flow that occurs when minor rivulets form just downstream from the overland flow. The maximum allowable length for shallow concentrated flow shall be 1000 feet.

Shallow concentrated flow shall be calculated using the Overland Flow Velocity Chart from HEC-19 or by using the nomograph entitled "Time of Concentration of Small Drainage Basins," developed by P.Z. Kirpich. Copies of the Kirpich chart and nomograph are contained in Appendix 4A and shall be used for the Rational Method. TR-55 shall be used for the SCS Method. Results from the Kirpich nomograph shall be multiplied by 0.2 for paved channels.

4.3.4 Channelized Flow

Channelized flow occurs where stormwater flow converges in gullies, ditches, and natural or man-made water conveyances, including storm drain pipes and culverts.

Channelized flow shall be calculated by use of the nomograph entitled "Time of Concentration of Small Drainage Basins," developed by P.Z. Kirpich. A copy of the nomograph is contained in Appendix 4A and shall be used for the Rational Method. TR-55 shall be used for the SCS Method. Results from Kirpich nomographs shall be multiplied by 0.2 for paved channels.

4.3.5 Pipe Flow

Pipe flow is the flow that occurs through culverts and storm drains. Use full-flow pipe velocities, unless it may be demonstrated that the pipe will operate at partial full conditions. If it can be shown that the pipe will operate at partial full conditions, then the partial full pipe velocity may be used.

Design of flow through culverts is presented in Chapter 6.

Design of flow in storm drain systems is presented in Chapter 7.

4.4 Selection of Methodologies

4.4.1 General

There are a variety of widely used hydrologic methodologies. Each has its strengths and weaknesses. In the interest of standardizing hydrologic calculations, the following methodologies will be used for all projects, unless the County agrees that good engineering practice dictates the use of another method.

4.4.2 Peak Discharge Methods for Design of Storm Drainage Systems

The Rational Method may be used to design storm drainage conveyance systems for drainage areas up to 200 acres. Minimum time of concentration when using the Rational Method is 5 minutes.

The SCS method may be used for drainage areas up to 10 square miles.

For drainage areas greater than 10 square miles, calculations shall be performed using at least two separate methods as described in the VDOT Drainage Manual (SCS method, regression equations, and/or stream gage data). The design peak flow shall be selected based on a professional evaluation of the results of the various methods.

4.4.3 Hydrograph Methods for Design of Stormwater Management Facilities

The modified rational method may be used to design stormwater management facilities where drainage areas are less than 20 acres <u>and</u> times of concentration are less than 20 minutes. Minimum time of concentration when using the Rational Method is 5 minutes. Please be aware that DEQ's VRRM worksheet does not support the use of the Rational Method when designing BMPs; therefore, Roanoke County recommends using the SCS Method.

The SCS method may be used in all cases. The SCS method must be used where drainage areas are 20 acres or greater, or where times of concentration are 20 minutes or longer. Minimum time of concentration when using the SCS method is 6 minutes.

4.5 Methodologies

Following is an abbreviated discussion of each method. Refer to the VDOT Drainage Manual and the VA SWM Handbook for a more complete discussion.

4.5.1 Rational Method

A. General

The Rational Method is expressed as:

$$Q = C_f CIA$$

Where:

- Q = Peak flow rate of runoff, cubic feet per second (cfs)
- C_f = Saturation factor
- C = Runoff coefficient representing a ratio of runoff to rainfall (dimensionless)
- I = Average rainfall intensity for a duration equal to the time of concentration for a selected return period, inches per hour (in/hr)
- A = Drainage area contributing to the design location, acres (ac)

B. Saturation Factor

The saturation factor (C_f) is an adjustment factor for modifying the runoff coefficient (C) for storms that are less frequent than a 10-year recurrence interval. The product of C_f and C should not be greater than 1.0.

Recurrence Interval (Years)	C_f
2, 5, and 10	1.0
25	1.1
50	1.2
100	1.25

Where the product of C_f and C is greater than 1.0, use 1.0.

C. Runoff Coefficient

The runoff coefficient (C) is a variable of the Rational Method that requires significant judgment and understanding for proper selection. A range of C-values for a given land use is given in Appendix 4A.

The coefficient must account for all the factors affecting the relation of peak flow to average rainfall intensity other than area adjustment. Some of these factors include land slope, condition of cover, and antecedent moisture condition.

As the slope of the drainage basin increases, the selected C-value should also increase. The lower range of C-values should be used where the majority of the slopes are less than 2-percent. The average range of C-values should be used where the majority of slopes are 2 to 5-percent. The higher range of C-values should be used where the majority of the slopes are greater than 5-percent.

The higher range of C-values should be used in clayey and other less pervious soil areas.

D. Average Rainfall Intensity

See the VA SWM Handbook. An IDF curve file is located on the Roanoke County webpage for use with HydroCAD and Hydraflow at http://www.roanokecountyva.gov/index.aspx?NID=317 C_f factors are not included for Q_{25} and Q_{100} in the IDF files and should be accounted for the calculations.

E. Drainage Area

Drainage area (DA) is measured in acres and is determined from evaluating a topographic map of the area.

4.5.2 Modified Rational Method

A. General

The Modified Rational Method is a means to generate hydrographs for small drainage areas. The parameters for the calculation are the same as the

Rational Method, except that a series of average rainfall intensities from different storms with the same frequency and different durations are computed. The hydrograph from the critical duration storm is used to design stormwater management facilities.

The Modified Rational Method recognizes that the duration of a storm is often longer than the time of concentration. This longer duration storm, even though it produces a lower peak Q, can produce a larger volume of runoff than the storm duration equal to the actual time of concentration of the drainage area. In order to ensure the proper design of stormwater management facilities, the runoff for the critical storm duration shall be used.

B. Hydrograph Assumptions

The hydrograph generated by the Modified Rational Method is based on the following assumptions:

- Time of Concentration (t_c) = Time to Peak (T_p) = Time to Recede (T_r)
- The length of the critical duration storm (D_e) is from 0 minutes until the time of selected duration.
- The rate of runoff is 0 at time 0 minutes. The rate of runoff increases linearly with time until the peak rate of runoff is reached at time T_p.
- The peak rate of runoff is maintained from time T_p until the duration of the storm (D_e). The rate of runoff then decreases to 0 at time D_e plus T_r.
- The peak rate of runoff is based on the average rainfall intensity (I) for the given storm duration.

C. Critical Duration Storm

The critical duration storm is the storm of a given frequency that has a duration that yields the greatest volume of storage in a stormwater management facility when the storm hydrograph is routed through the stormwater management facility. The critical duration storm may be estimated for preliminary purposes; however, the actual critical duration storm must be determined by routing the various duration storm hydrographs through the stormwater management facility and demonstrating which storm duration gives the greatest volume of storage.

4.5.3 SCS Method

A. General

The SCS Method may be used for computing peak flows and hydrographs for storms of selected return frequencies. This approach considers the time distribution of the rainfall, the initial rainfall losses to interception and depression storage and an infiltration rate that decreases during the course of a storm. The information required to use the SCS Method to determine the peak rate of runoff, or to develop a runoff hydrograph is:

- 24-hour total rainfall, and rainfall distribution type. The 24 hour precipitation rate is based upon NOAA values at the Roanoke Airport. These values can be found on Roanoke County's website or NOAA's website.

- Time of Concentration (t_c) in minutes, rounded up to the nearest whole minute;

- Curve Number (CN), which is determined by Cover Types and Hydrologic Soils Groups; and

- Drainage Area (A) in acres.

If the drainage basin is over 20 acres, or if it contains areas of different land uses, the drainage basin should be divided into sub-basins. Each sub-basin should have similar land uses. When sub-basins are used, the following information is required to use the SCS Method to determine the peak rate of runoff, or to develop a runoff hydrograph:

- 24-hour total rainfall, and rainfall distribution type. The 24 hour precipitation rate is based upon NOAA values at the Roanoke Airport.

- Time of Concentration (t_c) in minutes for each sub-basin, rounded up to the nearest whole minute;

- Curve Number (CN), which is determined by Cover Types and Hydrologic Soils Groups, for each sub-basin;

- Drainage Area (A) in acres, for each sub-basin; and

- Travel Time (T_t) of the flow from each sub-basin as it flows through downstream sub-basins.

If the SCS Method is being used to design a stormwater management facility, the following additional information is required to rout the runoff hydrograph through the facility and to generate an outflow hydrograph:

- Elevation – Storage Relationship
- Elevation – Discharge Relationship

B. 24-hour Rainfall and Distribution

The 24-hour rainfall is determined by NOAA precipitation amounts for Roanoke Airport.

C. Curve Number

The SCS method uses a combination of soil conditions and land use (ground cover) to assign a runoff factor to an area. These runoff factors, or runoff curve numbers (CN), indicate the runoff potential of an area. The CN requires significant judgment and understanding for proper selection. A table containing CNs for various cover types and soils conditions is contained in Appendix 4A.

When calculating existing rates of runoff (pre-construction), assume that all cover types are in good hydrologic condition.

Hydrologic Soils Groups (HSG) include types A, B, C, and D, with type A being the most permeable and type D the least permeable. Appendix 4B includes a listing of most soil names with their respective hydrologic soils types. Urban/udorthents soils shall be considered a Type D soil for design purposes. Soils maps for the Roanoke Valley may be obtained by referring to USDA web soil survey. Colored soil maps with support HSG documentation shall be included in the calculations packet

D. Drainage Area

Drainage areas for each sub-basin should be identified on an appropriate topographic map.

E. Elevation – Storage Relationship

When runoff hydrographs are being routed through a stormwater management facility, the relationship between the elevation (or depth) of stored water in the facility and storage volume needs to be known and input into the calculation. Often this information is obtained by determining the pond area bounded by contour lines on a grading plan. Enough data pairs (elevation – storage) must be provided to properly model conditions at transition points.

F. Elevation – Discharge Relationship

When runoff hydrographs are being routed through a stormwater management facility, the relationship between the elevation (or depth) of stored water in the facility and the discharge flow rate from the facility needs to be known and input into the calculation. The development of this relationship requires an understanding of the design conditions and underlying hydraulic principles. The hydraulic principals and equations governing the discharge rate will often change several times at varying elevations. These include weir flow, orifice flow, culvert inlet control, culvert outlet control, open channel flow, and possible effects from downstream backwater.

4.7 Drainage Area Analysis

To prevent the undersizing of stormwater management components, upstream properties conditions shall be considered in the drainage area analysis. Stream channel and improvements to any conveyance system shall be analyzed.

When the drainage of a project leaves the site at multiple locations, the discharges at each location must be evaluated and addressed separately."

APPENDIX 4A

DESIGN AIDS

FROM CHAPTER 6, VDOT DRAINAGE MANUAL

Overland Flow Nomagraph – Seelye

Overland Flow Velocity

Time of Concentration for Small Drainage Basins – Kirpich

Average Velocities for Estimating Travel Time for Shallow Concentrated Flow

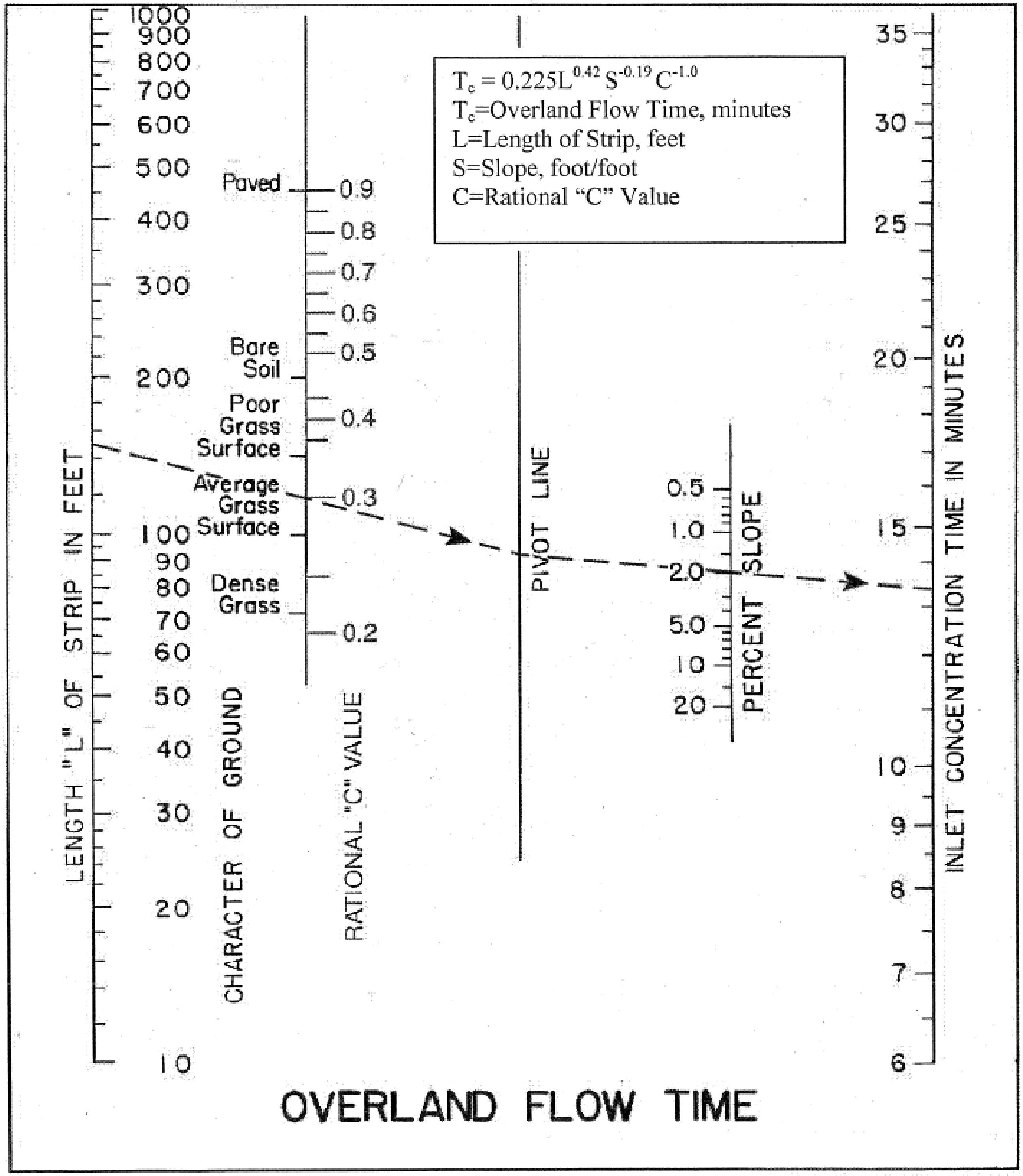
Rational Method Runoff Coefficients

Runoff Curve Numbers for Urban Areas

Runoff Curve Numbers for Cultivated Agricultural Areas

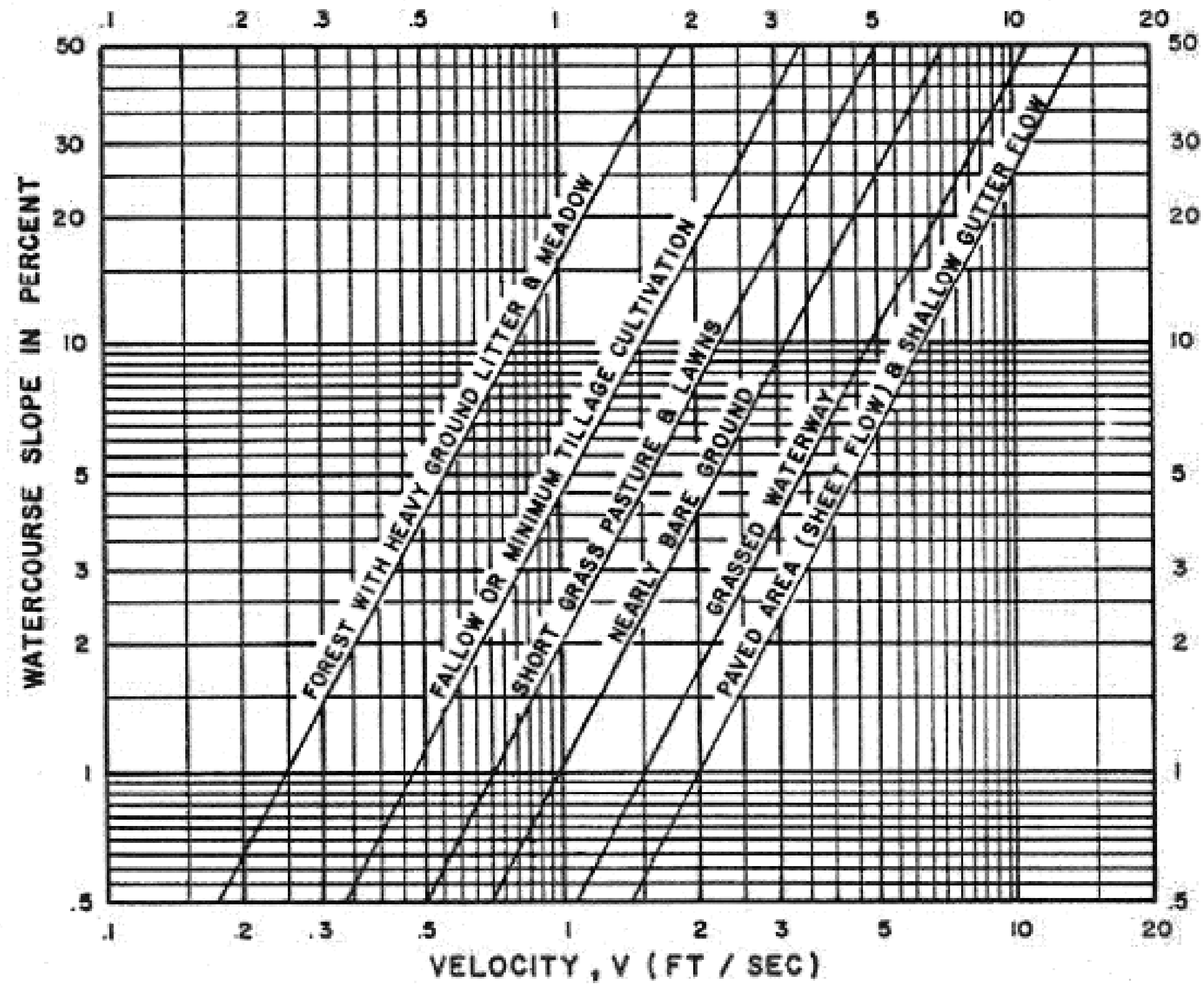
Runoff Curve Numbers for Other Agricultural Areas

OVERLAND FLOW – SEELYE



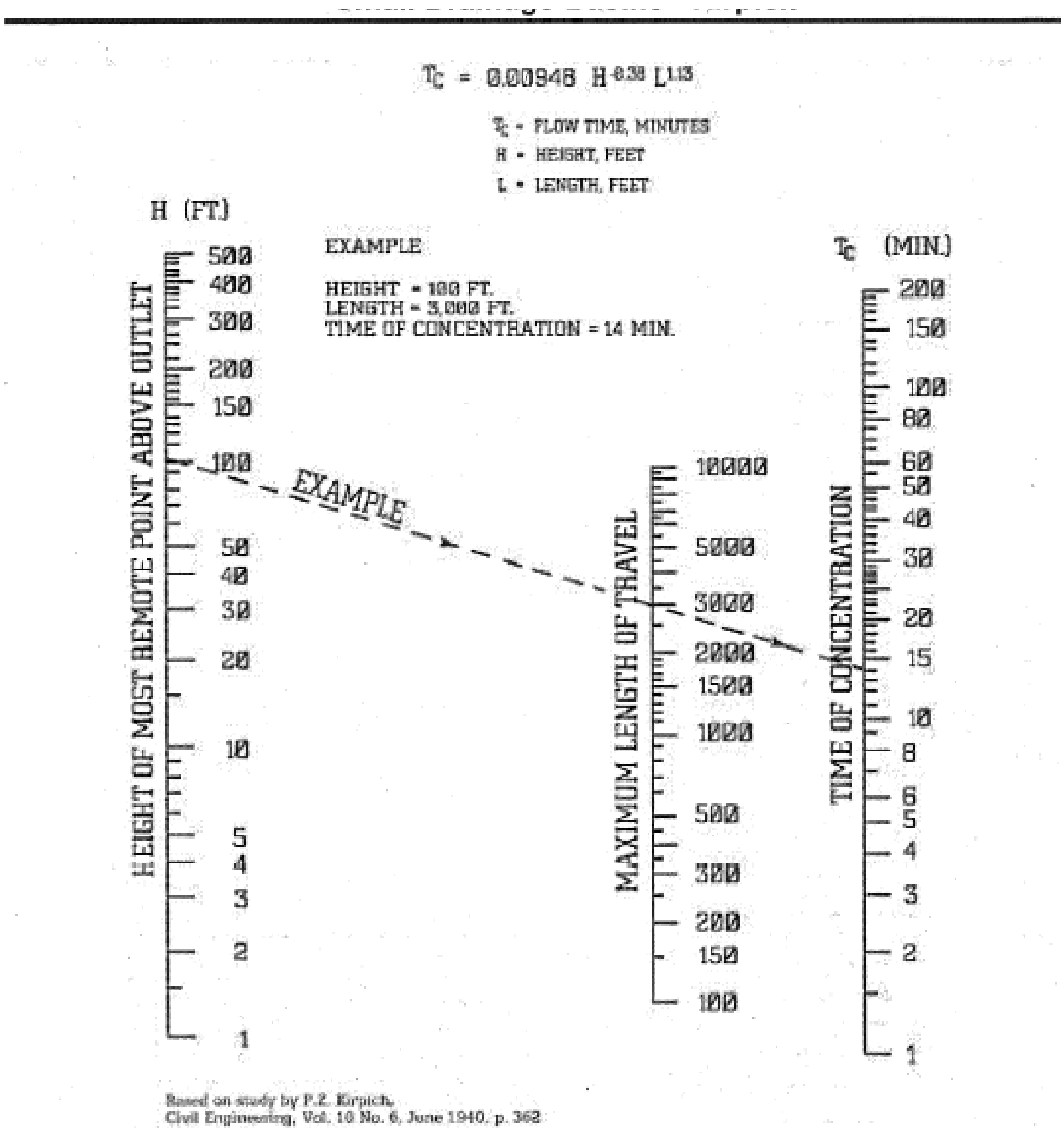
REPRINTED WITH PERMISSION FROM "DATA BOOK FOR CIVIL ENGINEERS" VOL. I - DESIGN 2ND EDITION (1951) BY E. E. SEELYE

OVERLAND FLOW VELOCITY



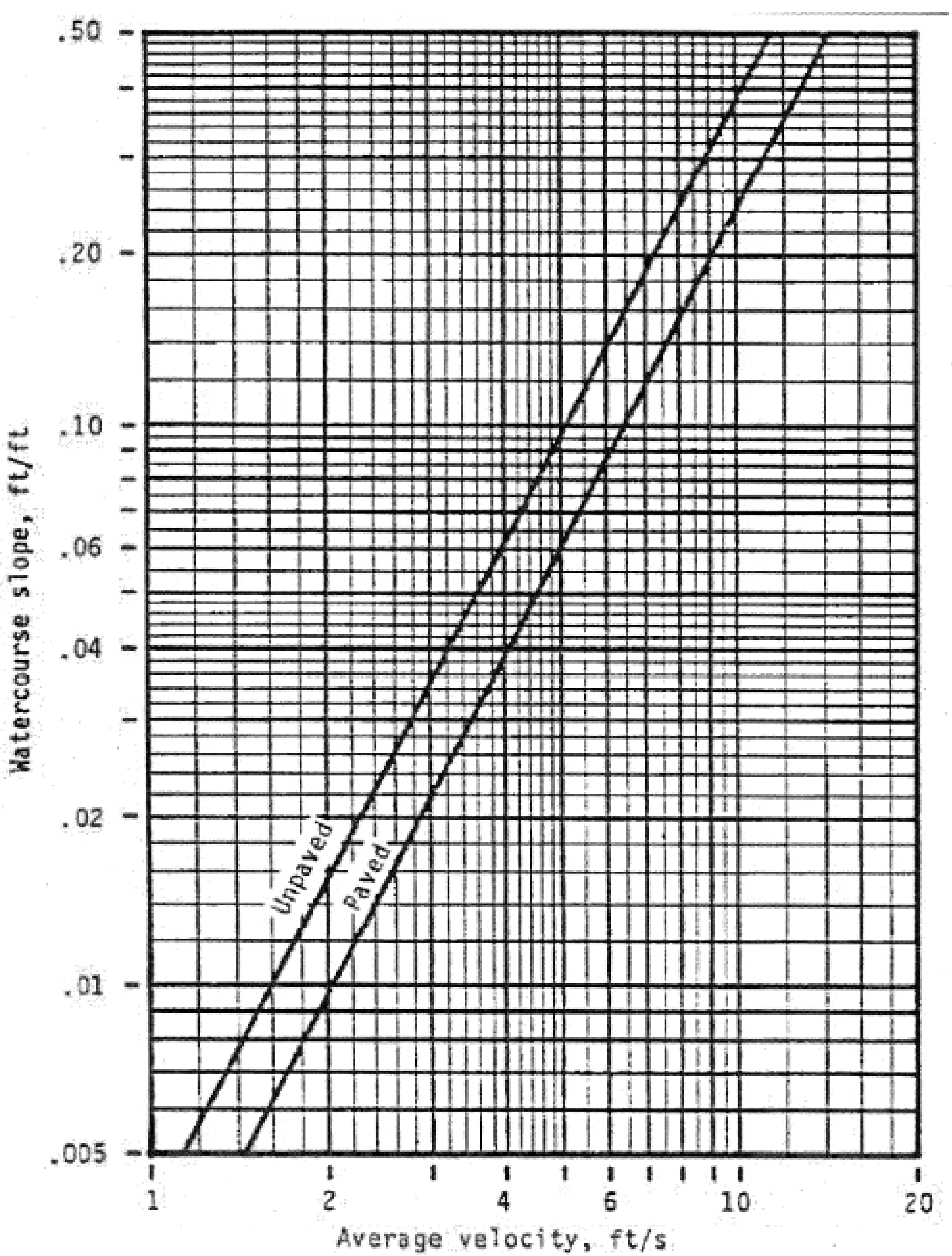
TIME OF CONCENTRATION - KIRPICH

(Note: Multiply Tc by 0.2 for Paved Channels)



TIME OF CONCENTRATION OF SMALL DRAINAGE BASINS

AVERAGE VELOCITIES FOR ESTIMATING TRAVEL TIME FOR SHALLOW CONCENTRATED FLOW



RATIONAL METHOD – RUNOFF COEFFICIENTS

Description of Area		Runoff Coefficients
Business: Industrial and Commercial		0.80-0.90
Apartments and Townhomes		0.65-0.75
Schools		0.50-0.60
Residential	- Lots 10,000 sf	0.40-0.50
	- Lots 12,000 sf	0.40-0.45
	- Lots 17,000 sf	0.35-0.45
	- Lots ≥ ½ acre	0.30-0.40
Parks, Cemeteries, and Unimproved Areas		0.20-0.35
Paved and Roof Areas		0.90
Gravel		0.90
Pervious Pavement		Varies**
Cultivated Areas		0.50-0.70
Pasture		0.35-0.45
Lawns		0.25-0.35
Forest		0.20-0.30
Steep Grass (2:1) *		0.40-0.70
Shoulder and Ditch Areas *		0.35-0.50

Comments:

1. The lowest range of runoff coefficients may be used for flat areas (areas where the majority of the grades and slopes are 2% and less).

2. The average range of runoff coefficients should be used for intermediate areas (areas where the majority of the grades and slopes are from 2% to 5%).

3. The highest range of runoff coefficients shall be used for steep areas (areas where the majority of the grades are greater than 5%), for cluster areas, and for development in clay soil areas.

4. The residential runoff coefficients include impervious and pervious amounts in the coefficient.

* Lower runoff coefficients should be used for permanent or established conditions (post-construction), i.e. sizing stormwater management basins.

* Higher runoff coefficients should be used to design roadside ditch linings (construction). The design considers the ditch lining as not yet established.

** Based upon Manufacturer's recommendation and BMP Clearinghouse specifications.

RUNOFF CURVE NUMBERS FOR URBAN AREAS

Cover type and hydrologic condition	Soil Group A	Soil Group B	Soil Group C	Soil Group D
Open space (lawns, parks, golf courses, cemeteries):				
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 (excluding right-of-way)	98	98	98	98
Streets and roads:				
Paved; curbs and storm drains (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
Urban districts:				
Commercial and business (85% average impervious area)	89	92	94	95
Industrial (72% average impervious area)	81	88	91	93
Residential districts by average lot size:				
0.10 or less, town houses (65% average impervious area)	77	85	90	92
¼ acre (38% average impervious area)	61	75	83	87
1/3 acre (30% average impervious area)	57	72	81	86
½ acre (25% average impervious area)	54	70	80	85
1 acre (20% average impervious area)	51	68	79	84
2 acre (12% average impervious area)	46	65	77	82
Developing urban areas:				
Newly graded areas (pervious areas only, no vegetation)	77	86	91	94

RUNOFF CURVE NUMBERS FOR CULTIVATED AGRICULTURAL AREAS

Cover type	Treatment	Hydrologic condition	Soil Group A	B	C	D
Fallow	Bare soil	---	77	86	91	94
	Crop residue Cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row Crops	Straight Row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR and CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C and CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & Terraced (C & T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T and CR	Poor	65	73	79	81
		Good	61	70	77	80
Small Grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR and CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C and CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T and CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast	SR	Poor	66	77	85	89
		Good	58	72	81	85
Legumes or rotation	C	Poor	64	75	83	85
		Good	55	69	78	83
Meadow	C&T	Poor	63	73	80	83
		Good	51	67	76	80

Comments:
Crop residue cover (CR) applies only if residue is on at least 5% of the surface throughout the year.
Poor = Factors impair infiltration and tend to increase runoff
Good = Factors encourage average and better than average infiltration and tend to decrease runoff.

RUNOFF CURVE NUMBERS FOR OTHER AGRICULTURAL AREAS

Cover type	Hydrologic condition	Soil Group			
		A	B	C	D
Pasture[1], grassland, or range-continuous forage for grazing	Poor Fair Good	68 49 39	79 69 61	86 79 74	89 84 80
Meadow – continuous grass, protected from grazing and generally mowed for hay		30	58	71	78
Brush[2] – brush-weed-grass mixture with brush as the major element	Poor Fair Good	48 35 30	67 56 48	77 70 65	83 77 73
Woods – grass combination (orchard or tree farm)	Poor Fair Good	57 43 32	73 65 58	82 76 72	86 82 79
Woods[3]	Poor Fair Good	45 36 30	66 60 55	77 73 70	83 79 77
Farmsteads – buildings, lanes, driveways, and surrounding lots		59	74	92	86

Comments:

Pasture Poor < 50% ground cover or heavily grazed with no mulch
Fair 50% to 75% ground cover and not heavily grazed
Good > 75% ground cover and lightly or only occasionally grazed

Brush Poor < 50% ground cover
Fair 50% to 75% ground cover
Good > 75% ground cover

Woods Poor – Forest litter, small trees and brush are destroyed by heavy grazing or regular burning
Fair – Woods grazed but not burned, and some forest litter covers the soil
Good – Woods protected from grazing, litter and brush adequately cover soil

APPENDIX 4B
DESIGN AIDS

FROM CHAPTER 4, VA SWM HANDBOOK

Rational Equation Coefficients for SCS Hydrological Soil Groups, Urban Land Uses

Rational Equation Coefficients for SCS Hydrological Soil Groups, Rural and Agricultural Uses

Roughness Coefficient "n" for Manning Equation – Sheet Flow

Roughness Coefficient "n" for Manning Equation – Pipe Flow

Roughness Coefficient "n" for Manning Equation – Constructed Channels

Roughness Coefficient "n" for Manning Equation – Natural Stream Channels

Hydrologic Soils Names in Virginia (7 sheets)

RATIONAL EQUATION COEFFICIENTS
FOR SCS HYDROLOGIC SOIL GROUPS (A, B, C, D)
URBAN LAND USES

STORM FREQUENCIES OF LESS THAN 25 YEARS													
Land Use	**Hydrologic condition**	**Hydrologic Soil Group/Slope**											
		A			**B**			**C**			**D**		
		0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+
Paved Areas and Impervious Surfaces		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Open Space, Lawns, etc	Good	0.08	0.12	0.15	0.11	0.16	0.21	0.14	0.19	0.24	0.20	0.24	0.28
Industrial		0.67	0.68	0.68	0.68	0.68	0.69	0.68	0.69	0.69	0.69	0.69	0.70
Commercial		0.71	0.71	0.72	0.71	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Residential Lot size 1/8 acre		0.25	0.28	0.31	0.27	0.30	0.35	0.30	0.33	0.38	0.33	0.36	0.42
Lot size ¼ acre		0.22	0.26	0.29	0.24	0.29	0.33	0.27	0.31	0.36	0.30	0.34	0.40
Lot size 1/3 acre		0.19	0.23	0.26	0.22	0.26	0.30	0.25	0.29	0.34	0.28	0.32	0.39
Lot size ½ acre		0.16	0.20	0.24	0.19	0.23	0.28	0.22	0.27	0.32	0.26	0.30	0.37
Lot size 1 acre		0.14	0.19	0.22	0.17	0.21	0.26	0.20	0.25	0.31	0.24	0.29	0.35

RATIONAL EQUATION COEFFICIENTS
FOR SCS HYDROLOGIC SOIL GROUPS (A, B, C, D)
RURAL AND AGRICULTURAL LAND USES

STORM FREQUENCIES OF LESS THAN 25 YEARS														
Land Use	**Treatment/ Practice**	**Hydrologic condition**	**Hydrologic Soil Group/Slope**											
			A			**B**			**C**			**D**		
			0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+
Pasture or Range	Non-contoured	Good	0.07	0.09	0.10	0.18	0.20	0.22	0.27	0.29	0.31	0.32	0.34	0.35
	Contoured	Good	0.03	0.04	0.06	0.11	0.12	0.14	0.24	0.26	0.28	0.31	0.33	0.34
Meadow			0.06	0.08	0.10	0.10	0.14	0.19	0.12	0.17	0.22	0.15	0.20	0.25
Wooded		Good	0.05	0.07	0.08	0.08	0.11	0.15	0.10	0.13	0.17	0.12	0.15	0.21
Fallow	Straight Row		0.41	0.48	0.53	0.60	0.66	0.71	0.72	0.78	0.82	0.84	0.88	0.91
Row Crops	Straight Row	Good	0.24	0.30	0.35	0.43	0.48	0.52	0.61	0.65	0.68	0.73	0.76	0.78
	Contoured	Good	0.21	0.26	0.30	0.41	0.45	0.49	0.55	0.59	0.63	0.63	0.66	0.68
	Contoured and Terraced	Good	0.20	0.24	0.27	0.31	0.35	0.39	0.45	0.48	0.51	0.55	0.58	0.60
Small Grain	Straight Row	Good	0.23	0.26	0.29	0.42	0.45	0.48	0.57	0.60	0.62	0.71	0.73	0.75
	Contoured	Good	0.17	0.22	0.27	0.33	0.38	0.42	0.54	0.58	0.61	0.62	0.65	0.67
	Contoured and Terraced	Good	0.16	0.20	0.24	0.31	0.35	0.38	0.45	0.48	0.50	0.55	0.58	0.60
Closed-seeded Legumes Or Rotation Meadow	Straight Row	Good	0.15	0.19	0.23	0.31	0.35	0.38	0.55	0.58	0.60	0.63	0.65	0.66
	Contoured	Good	0.14	0.18	0.21	0.30	0.34	0.37	0.45	0.48	0.51	0.58	0.60	0.61
	Contoured and Terraced	Good	0.07	0.10	0.13	0.28	0.32	0.35	0.44	0.47	0.49	0.52	0.54	0.56

ROUGHNESS COEFFICIENT "n" FOR MANNING EQUATION – SHEET FLOW

Surface Description	n
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	0.24
Bermuda Grass	0.41
Range (Natural)	0.13
Woods:	
Light Underbrush	0.40
Dense Underbrush	0.80

ROUGHNESS COEFFICIENT "n" FOR MANNING EQUATION – PIPE FLOW

Material	"n" Range From	To
Coated Cast Iron	0.010	0.014
Uncoated Cast Iron	0.011	0.015
Vitrified Sewer Pipe	0.010	0.017
Concrete Pipe	0.013	
Common Clay Drainage Tile	0.011	0.017
Corrugated Metal (2 2/3 x ½)	0.023	0.026
Corrugated Metal (3x1 and 6x1)	0.026	0.029
Corrugated Metal (6x2 structural plate)	0.030	0.033
HDPE	0.012	

ROUGHNESS COEFFICIENT "n"
FOR MANNING EQUATION – CONSTRUCTED CHANNEL

Lining Material	"n" Range From	To
Concrete Lined	0.012	0.016
Cement Rubble	0.017	0.025
Earth, Straight and Uniform	0.017	0.022
Rock Cuts, Smooth and Uniform	0.025	0.033
Rock Cuts, Jagged and Irregular	0.035	0.045
Winding, Sluggish Canals	0.022	0.027
Dredged Earth Channels	0.025	0.030
Canals with Rough Stony Beds, Weeds on Earth Banks	0.025	0.035
Earth Bottom, Rubble Sides	0.028	0.033
Small Grass Channels:		
Long Grass – 13"	0.042	
Short Grass – 3"	0.034	

ROUGHNESS COEFFICIENT "n"
FOR MANNING EQUATION – NATURAL STREAM CHANNEL

Channel Lining	"n" Range From	To
1. Clean, Straight Bank, Full Stage No Rifts or Deep Pools	0.025	0.030
2. Same as #1, Some Weeds and Stones	0.030	0.035
3. Winding, Some Pools and Shoals, Clean	0.033	0.040
4. Same as #3, Lower Stages, More Ineffective Slope and Sections	0.040	0.050
5. Same as #3, Some Weeds and Stones	0.035	0.045
6. Same as #4, Stony Sections	0.045	0.055
7. Sluggish River Reaches, Rather Weedy with Very Deep Pools	0.050	0.070
8. Very Reedy Reaches	0.075	0.125

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
APPOMATTOX	B	AQUENTS	D	AQUULTS	D
ARAPAHOE	B/D	ARCOLA	C	ARGENT	D
ASBURN*	C	ASHE	B	ASHLAR	B
ASSATEAGUE	A	ATKINS	D	ATLEE	C
AUGUSTA	C	AURA	B	AUSTINVILLE	B
AXIS	D	AYCOCK	B	BACKBAY	D
BADIN	B	BAILE	D	BAILEGAP	B
BAMA	B	BAYBORO	D	BEACHES	D
BECKHAM	B	BELHAVEN	D	BELTSVILLE	C
BELVOIR	C	BERKS	C	BERMUDIAN	B
BERTIE	B	BIBB	D	BILTMORE	A
BIRDSBORO	B	BLADEN	D	BLAIRTON	C
BLAND	C	BLEAKHILL	C	BLUEMONT*	B
BOHICKET	D	BOJAC	B	BOLLING	C
BOLTON	B	BONNEAU	A	BOOKWOOD	B
BOTETOURT	C	BOURNE	C	BOWMANSVILLE	B/D
BRADDOCK	B	BRADLEY	C	BRANDYWINE	C
BRECKNOCK	B	BREMO	C	BRENTSVILLE	C
BROADWAY	B	BROCKROAD	C	BRUSHY	B
BUCHANAN	C	BUCKHALL	B	BUCKS	B
BUCKTON	B	BUFFSTAT	B	BUGLEY	C/D
BUNCOMBE	A	BURKETOWN	C	BURROWSVILLE	C
CALVERTON	C	CALVIN	C	CAMOCCA	A/D
CANEYVILLE	C	CARBO	C	CARDIFF	B
CAROLINE	C	CARRVALE	D	CARTECAY	C
CATASKA	D	CATHARPIN	C	CATLETT	C/D
CATOCTIN	C	CATPOINT	A	CAVERNS	B
CECIL	B	CHAGRIN	B	CHAPANOKE	C

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
CHASTAIN	D	CHATUGE	D	CHAVIES	B
CHENNEBY	C	CHESTER	B	CHEWACLA	C
CHICKAHOMINY	D	CHILHOWIE	C	CHINCOTEAGUE	D
CHIPLEY	C	CHISWELL	D	CHRISTIAN	C
CID	C	CLAPHAM*	C	CLEARBROOK	D
CLIFTON	C	CLUBCAF	D	CLYMER	D
COASTAL BEACH	D	CODORUS	C	COLFAX	C
COLLEEN	C	COLVARD	B	COMBS	B
COMUS	B	CONETOE	A	CONGAREE	B
COOSAW	B	COROLLA	D	CORYDON	D
COTACO	C	COURSEY	C	COWEE	B
COXVILLE	D	CRAIGSVILLE	B	CRAVEN	C
CREEDMOOR	C	CROTON	D	CULLEN	C
CULPEPER	C	DALEVILLE	D	DANDRIDGE	D
DAVIDSON	B	DAWHOO VARIANT	B/D	DECATUR	B
DEKALB	C	DELANCO	C	DELOSS	B/D
DERROC	B	DILLARD	C	DOGUE	C
DOROVAN	D	DOTHAN	B	DRAGSTON	C
DRALL	B	DRYPOND	D	DUCKSTON	A/D
DUFFIELD	B	DULLES	D	DUMFRIES	B
DUNBAR	D	DUNNING	D	DUPLIN	C
DURHAM	B	DYKE	B	EBBING	C
EDGEHILL	C	EDNEDYTOWN	B	EDNEYVILLE	B
EDOM	C	ELBERT	D	ELIOAK	C
ELIOK	C	ELKTON	C/D	ELLIBER	A
ELSINBORO	B	EMPORIA	C	ENDCAV	C

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
ENON	C	ENOTT	C	ERNEST	C
EUBANKS	B	EULONIA	C	EUNOLA	C
EVANSHAM	D	EVARD	B	EVERGREEN	B
EXUM	C	FACEVILLE	B	FAIRFAX	B
FALLSINGTON	B/D	FAUGUIER	C	FAYWOOD	C
FEATHERSTONE	D	FISHERMAN	D	FLATWOODS	C
FLETCHER	B	FLUVANNA	C	FLUVAQUENTS	D
FORESTDALE	D	FORK	C	FRANKSTOWN	B
FREDERICK	B	FRENCH	C	FRIPP	A
GAILA	B	GAINESBORO	C	GALESTOWN	A
GEORGEVILLE	B	GILPIN	C	GLADEHILL	B
GLENELG	B	GLENVILLE	C	GLENWOOD	B
GOLDSBORO	B	GOLDSTON	C	GOLDVEIN	C
GORESVILLE*	B	GREENLEE	B	GRIMSLEY	B
GRITNEY	C	GROSECLOSE	C	GROVER	B
GUERNSEY	C	GULLION	C	GUNSTOCK	C
GUYAN	C	GWINNETT VARIENT	B	HAGERSTOWN	C
HALEWOOD	B	HARTLETON	B	HATBORO	D
HAWKSBILL	B	HAYESVILLE	B	HAYMARKET	D
HAYTER	B	HAYWOOD	B	HAZEL	C
HAZEL CHANNERY	C	HAZELTON	B	HELENA	C
HERNDON	B	HIWASSEE	B	HOADLY	C
HOBUCKEN	D	HOGELAND*	C	HOLLYWOOD	D
HUNTINGTON	B	HYATTSVILLE	B	HYDE	B/D
HYDRAQUENTS	B	INGLEDOVE	B	IREDELL	C/D

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
IRONGATE	B	IUKA	C	IZAGORA	C
JACKLAND	D	JEDBURG	C	JEFFERSON	B
JOHNS	C	JOHNSTON	D	JUNALUSKA	B
KALMIA	B	KELLY	D	KEMPSVILLE	B
KENANSVILLE	A	KENANSVILLE VARIANT	C	KEYPORT	C
KINKORA	D	KINSTON	B/D	KLEJ	B
KLINESVILLE	C/D	KONNAROCK	C	LAIDIG	C
LAKEHURST VARIANT	A	LAKELAND	A	LANEXA	D
LANSDALE	B	LAROQUE	B	LAWNES	D
LEAF	D	LEAKSVILLE	D	LECK KILL	B
LEEDSVILLE*	B	LEETONIA	C	LEGORE	B
LEHEW	C	LENOIR	D	LEON	B/D
LEVY	D	LEW	B	LEWISBERRY	B
LIBRARY	D	LIGNUM	C	LILY	B
LINDSIDE	C	LITTLEJOE	B	LITZ	C
LLOYD	C	LOBDELL	B	LODI	B
LOUISA	B	LOUISBURG	B	LOWELL	C
LUCKETTS	B	LUCY	A	LUGNUM	C
LUMBEE	B/D	LUNT	C	LYNCHBURG	C
MACOVE	B	MADISON	B	MAGOTHA	D
MANASSAS	B	MANOR	B	MANTACHIE	C
MANTEO	C/D	MARBIE	C	MARGO	B
MARLBORO	B	MARR	B	MARUMSCO	C
MASADA	C	MASSANETTA	B	MASSANUTTEN	B
MATAPEAKE	B	MATNELFLAT	B	MATTAN	D

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
MATTAPEX	C	MATTAPONI	C	MAURERTOWN	D
MAYODAN	B	MCGARY	C	MCQUEEN	C
MEADOWS	D	MEADOWVILLE	B	MECKLENBURG	C
MEGGETT	D	MELFA	D	MELVIN	D
MILLROCK	A	MINNIEVILLE	C	MIXED ALLUVIUM	D
MOLENA	A	MONACAN	C	MONGLE	C
MONONGAHELA	C	MONTALTO	C	MONTRESSOR*	B
MONTROSS	C	MOOMAW	C	MORRISONVILLE*	B
MORVEN	B	MOUNT LUCAS	C	MT WEATHER*	B
MUCKALEE	D	MUNDEN	B	MURRILL	B
MYATT	D	MYATT VARIANT	D	MYERSVILLE	B
NAHUNTA	C	NANSEMOND	C	NASON	B
NAWNEY	D	NEABSCO	C	NESTORIA	C/D
NEVARC	C	NEWARK	C	NEWBERN	C
NEWFLAT	D	NEWHAN	A	NEWMARC	C
NICHOLOSON	C	NIMMO	D	NIXA	C
NOLICHUCKY	B	NOLIN	B	NOMERVILLE	B
NORFOLK	B	OAKHILL	B	OAKLET	C
OATLANDS	B	OCCOQUAN	B	OCHLOCKONEE	B
OKEETEE	D	OPEQUON	C	ORANGE	D
ORANGEBURG	B	ORENDA	B	ORISKANY	B
OSIER	A/D	OTHELLO	C/D	PACOLET	B
PACTOLUS	A	PAGEBROOK	D	PAMLICO	D
PAMUNKEY	B	PAMUNKEY VARIANT	A	PANORAMA	B
PARKER	B	PARTLOW	D	PASQUOTANK	B/D
PEAKS	C	PEAWICK	D	PENN	C/D

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
PHILO	B	PHILOMOMT*	B	PINEYWOODS	D
PINKSTON	B	PISGAH	C	POCATY	D
POCOMOKE	B/D	POINDEXTER	B	POLAWANA	A/D
POOLER VARIANT	D	POPE	B	POPLIMENTO	C
PORTERS	B	PORTSMOUTH	B/D	POUNCEY	D
PUNGO	D	PURCELLVILLE	B	PURDY	D
RABUM	B	RAINS	B/D	RAMSEY	D
RAPIDAN	B	RAPPHANNOCK	D	RARITAN	C
RAYNE	B	READINGTON	C	REAVILLE	C
REMLIK	A	RIGLEY	B	RION	B
RIVERVIEW	B	ROANOKE	D	ROHRERSVILLE	D
ROSS	B	ROWLAND	C	RUMFORD	B
RUSHTOWN	A	RUSTON	B	SAFELL	B
SASSAFRAS	B	SASSAFRAS	B	SAUNOOK	B
SAVANNAH	C	SCATTERSVILLE*	C	SCHAFFENAKER	A
SEABROOK	C	SEDGEFIELD	C	SEKIL	B
SENECA	B	SEQUOIA	C	SHELOCTA	B
SHENVAL	B	SHERANDO	B	SHEVA	C
SHOTTOWER	B	SINDION	B	SKETERVILLE	C
SLABTOWN	B	SLAGLE	C	SLICKENS	B
SNICKERSVILLE	B	SPEEDWELL	B	SPESSARD	A
SPIVEY	B	SPOSTSYLVANIA	C	SPRIGGS	C
SPRINGWOOD	B	STANTON	D	STARR	C
STATE	B	STEINSBURG	C	STONEVILLE	B
STUART	C	STUMPTOWN	B	SUCHES	B
SUDLEY	B	SUEQUEHANNA	D	SUFFOLK	B
SUSDLEY	B	SUSQUEHANNA	D	SWAMP	D

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
SWEETAPPLE	B	SWIMLEY	C	SYCOLINE	D
SYLCO	C	SYLVATUS	D	TALLADEGA	C
TALLAPOOSA	C	TARBORO	A	TATE	B
TATUM	B	TETOTUM	C	THUNDER	B
THURMONT	B	TIDAL MARSH	D	TIMBERVILLE	B
TIOGA	B	TOCCOA	B	TODDSTAV	D
TOMOTLEY	B/D	TOMS	C	TORHUNTA	C
TOTIER	C	TOXAWAY	B/D	TRAPPIST	C
TREGO	B	TRENHOLM	D	TUCKAHOE	B
TUMBLING	B	TURBEVILLE	C	TUSQUITEE	B
TYGART	C	UCHEE	A	UDIFLUVENTS	B
UNISON	B	VANCE	C	VARINA	C
VAUCLUSE	C	VERTREES	B	WADESBORO	B
WAHEE	D	WAKULLA	A	WALLEN	B
WARMINSTER	C	WATAUGA	B	WATEREE	B
WATT	D	WAXPOOL	D	WEAVER	C
WEAVERTON*	C	WEBBTOWN	C	WEDOWEE	B
WEEKSVILLE	B/D	WEHADKEE	D	WEIKERT	C/D
WESTMORELAND	B	WESTON	D	WESTPHALIA	B
WEVERTON	B	WHEELING	B	WHITE STONE	D
WHITEFORD	B	WICKHAM	B	WILKES	C
WOLFGAP	B	WOODINGTON	B/D	WORSHAM	D
WRIGHTSBORO	C	WRYICK	B	WURNO	C
WYRICK	B	YADKIN	C/D	YEMASSEE	C
YEOPIM	B	YORK	C	ZEPP	B
ZION	C	ZOAR	C		

APPENDIX 4C

INFORMATION FROM VDOT
HYDRAULIC DESIGN ADVISORIES

Rainfall Intensities (inches/hour) for the Roanoke Valley (Based on VDOT HDA 05-03)

Note: For use with the Rational Method only. Use NOAA precipitation chart for SCS Method.

RAINFALL INTENSITY (IN/HR) FOR THE ROANOKE VALLEY

		Storm Duration (min)													
		5	10	15	20	25	30	35	40	45	60	75	90	105	120
Storm Recurrance Interval	2	4.39	3.51	2.94	2.54	2.24	2.01	1.82	1.67	1.54	1.26	1.07	0.94	0.83	0.75
	5	5.33	4.29	3.62	3.14	2.79	2.52	2.30	2.12	1.96	1.63	1.40	1.23	1.10	1.00
	10	6.04	4.91	4.18	3.66	3.26	2.96	2.71	2.51	2.34	1.96	1.69	1.50	1.35	1.23
	25	6.78	5.49	4.68	4.11	3.69	3.36	3.10	2.88	2.70	2.28	2.00	1.79	1.63	1.50
	50	7.37	5.96	5.09	4.49	4.04	3.70	3.42	3.19	3.00	2.56	2.26	2.04	1.87	1.73
	100	8.08	6.49	5.56	4.92	4.46	4.10	3.81	3.57	3.37	2.92	2.61	2.37	2.19	2.04

Table based on VDOT Hydraulic Design Advisory HAD 05-03

$I_f = B / (t_c + D)^E$ where:

I_f = Rainfall intensity for a given recurrence interval, f, in inches per hour

t_c = Watershed time of concentration (assumed to equal the storm duration), in minutes
B,D,E = As taken from HDA 05-03 table for [Roanoke] [Roanoke (city)] based on the designated storm frequency.