APPENDIX D – STORMWATER METHODOLOGY

1.0 STORMWATER ANALYSIS AND BMP DESIGN METHODOLOGY

The Mountain Valley Pipeline Project in the Commonwealth of Virginia will consist of approximately 104 miles of 42 inch diameter pipeline to be constructed with four separate construction spreads. The Project's limits of disturbance (LOD) will consist of a 125-foot-wide construction corridor for the majority of the Project. Additional temporary workspace will be required in certain areas, such as for road, wetland, and waterbody crossings, and areas for staging and topsoil segregation. Additional construction components will include temporary contractor and pipe yards.

Stormwater analysis and Best Management Practices (BMP) designs will be performed for all Project site areas to ensure that the following Virginia state regulations have been satisfied:

- Water Quality (9VAC25-870-63)
- Water Quantity (9VAC25-870-66)
- Offsite Compliance Options (9VAC25-870-69)

For the majority of this Project, stormwater BMPs will be designed to reduce total phosphorous loading in order to meet stormwater quality requirements (see ***Section 1.1***) and/or reduce runoff peak flow rate and volume to meet water quantity requirements (see ***Section 1.2***). MVP will utilize specifications from the Draft 2013 or Published 2011 Virginia Stormwater BMP Clearinghouse for BMP design.

1.1 STORMWATER QUALITY CALCULATIONS

Stormwater quality will be evaluated using the Virginia Runoff Reduction Method (VRRM). The stormwater quality evaluation will demonstrate that the total phosphorous load does not exceed the threshold of 0.41 lbs./acre-year for new development. New impervious cover within the Project LOD will include access roads and pad sites. In instances where existing impervious areas, such as access roads, are to be used or improved for the Project, VRRM for re-development calculations will demonstrate either 10% or 20% reduction from predevelopment phosphorus loads based on land disturbance less than or greater than one acre, respectively.

To utilize the site specific annual rainfall values, noted in ***Section 1.1.1***, Version 2.8 of the VRRM spreadsheet will be used for design. At the Transco Interconnect site in Pittsylvania County, Version 3.0 of the VRRM spreadsheet will be used for design (per DEQ, Project Standards and Specifications Meeting, 09 March 2017, Virginia Department of Environmental Quality, Richmond, VA), because at this time the Version 3.0 Redevelopment VRRM spreadsheet accounts for lower total phosphorus loading rates for projects containing pre- and post-construction forested areas.

Only the site area, or the area within the LOD, will be considered when evaluating stormwater quality in each drainage area. Appropriate post-developed land covers will be used to calculate phosphorous loading per the VRRM spreadsheet. For pre-developed forested areas, under normal operating conditions, the post construction ROW will be considered Forest/Open Space land cover for water quality calculations. For pre-developed non-forested areas, under normal operating conditions, these areas will revert to pre-developed land use (e.g. agricultural uses including tilling, pasture, hayfield, etc.). Therefore, the post construction ROW in non-forested areas will be based on Table 1: Land Cover Guidance for VRRM Compliance Spreadsheets, Virginia Runoff Reduction Method Compliance Spreadsheet User's Guide & Documentation dated April 2016.

1.1.1 Annual Precipitation Data

Annual precipitation values range from 35 to 60 inches along the length of the Project. Therefore, local annual precipitation values will be used when performing water quality calculations (per DEQ, Stormwater Management Technical Meeting, 29 November 2016, Virginia Department of Environmental Quality, Richmond, VA). Refer to ***Figures 1 and 2*** below for local annual precipitation values obtained from PRISM weather stations.

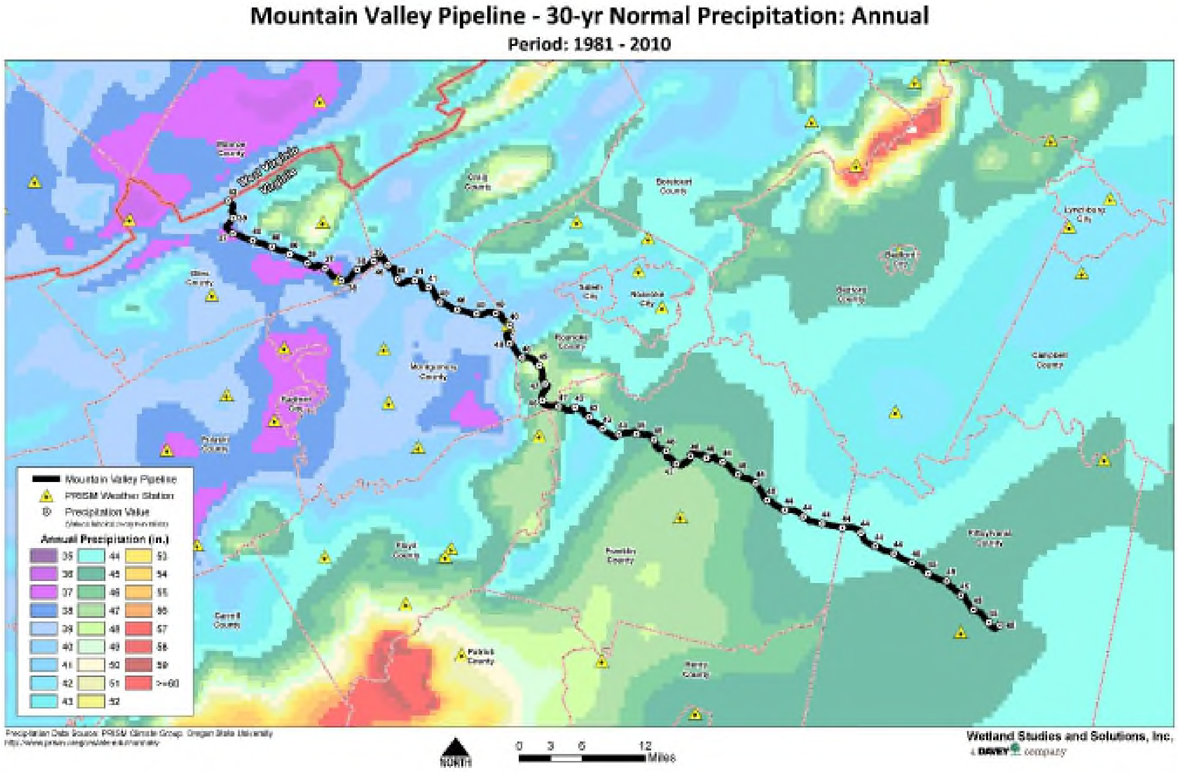


Figure 1. 30-Yr Annual Normal Precipitation – Raw Data

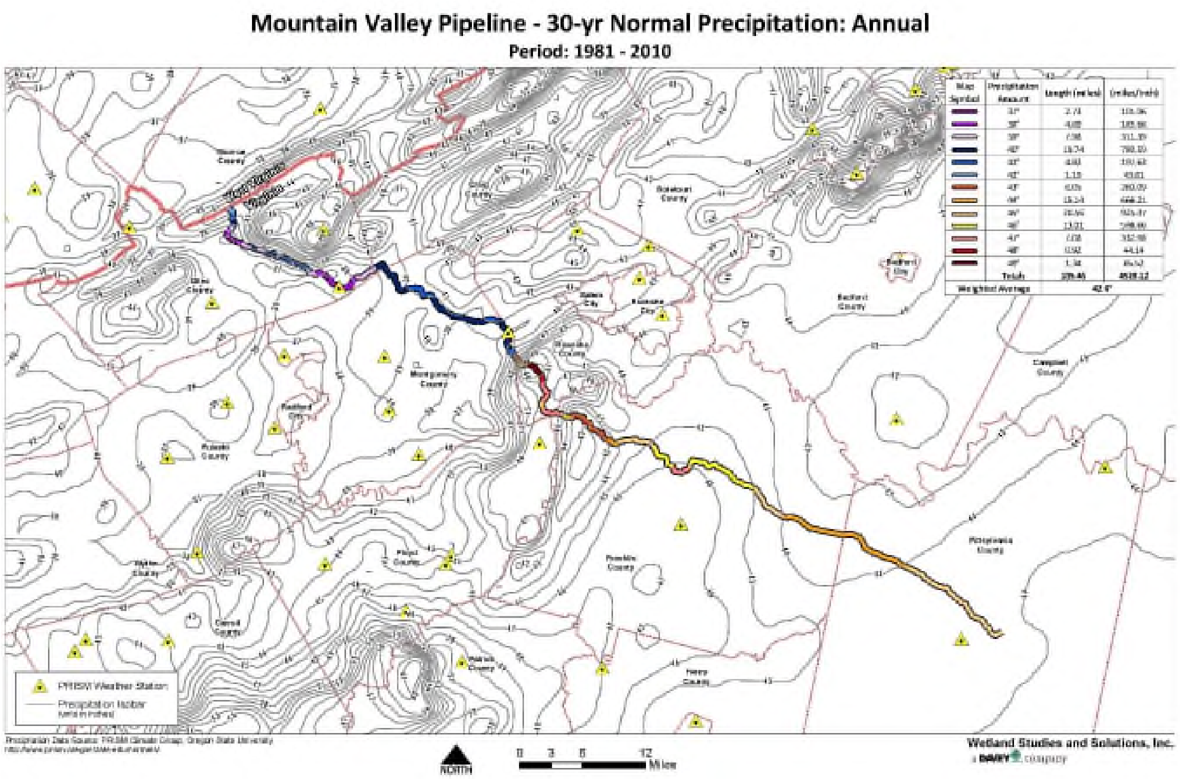


Figure 2. 30-Yr Annual Normal Precipitation – Pipeline Weighted Average Precipitation with Isobar

1.2 STORMWATER QUANTITY CALCULATIONS

The energy balance method will be applied to the 1-year storm event in order to meet the 9VAC-870-66 stormwater quantity requirements. The Hydraflow Hydrographs extension for AutoCAD Civil 3D will be used to calculate the peak flow rates and runoff volumes for the energy balance equations; Hydraflow Hydrographs will perform hydrologic calculations in accordance with the Natural Resource Conservation Service (NRCS; formerly Soil Conservation Service [SCS]) Technical Release 55 (TR-55) methods.

1.2.1 Energy Balance Method (9VAC-25-870-66 Part B)

The energy balance method equations, as detailed in 9VAC25-870-66.B.3.a, are as follows:

<u>Equation 1</u>

$$Q_{Developed} \leq I.F.* \left(Q_{Pre-developed} * RV_{Pre-developed}\right)/RV_{Developed}$$

<u>Equation 2</u>

$$Q_{Developed} \leq \; Q_{pre-developed}$$

where:	$Q_{Developed}$	=	The allowable peak flow rate of runoff from the developed site
	I.F.	=	Improvement Factor (0.8 for sites > 1 acre; 0.9 for sites ≤ 1 acre)
	$RV_{Developed}$	=	The volume of runoff from the site in the developed condition
	$Q_{Pre\text{-}Developed}$	=	The peak flow rate of runoff from the site in the pre-developed condition
	$RV_{Pre\text{-}Developed}$	=	The volume of runoff from the site in pre-developed condition

- The improvement factor used will be 0.8 in most cases.
- The majority of pre-developed conditions are forested.
- $Q_{Developed}$ need never be less than the following:

<u>Equation 3</u>

$$(Q_{Forest} * RV_{Forest})/RV_{Developed}$$

where:	Q_{Forest}	=	The peak flow rate of runoff from the site in a forested condition
	RV_{Forest}	=	The volume of runoff from the site in a forested condition
	$RV_{Developed}$	=	The volume of runoff from the site in the developed condition

- With the improvement factor, Equation 1 will result in a $Q_{Developed}$ lower than the value determined using Equation 3. Therefore, Equation 3 will be used for the majority of the Project to determine compliance with the Energy Balance Method and stormwater quantity requirements.

- Runoff volume (RV) and peak flow rate (Q) will be calculated in Hydraflow Hydrographs using TR-55 methodology as discussed in ***Section 1.2.3***, and the computed values corresponding to the 1-year 24-hour storm event for the pre-developed, developed, and forest conditions will be used to determine if the energy balance requirements (i.e., Equations 1 through 3 above) have been satisfied (see ***Section 1.2.4***).

1.2.2 Sheet Flow (9VAC-25-870-66 Part D)

If pre-development runoff conditions include sheet flow, and sheet flow can be maintained in the post-development condition, stormwater quantity regulations will be satisfied demonstrating no adverse effects on downstream properties per 9VAC-25-870-66 Part D. In this case, the Project site area would be exempt from the stormwater quantity requirements presented in ***Section 1.2.1***.

No adverse effects will be demonstrated by calculating the sheet flow velocity for the post-development 2-year 24-hour storm and comparing it to permissible velocities. Travel time will be calculated using Manning's kinematic solution:

Equation 4

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

where:	T_t	=	Travel time (hours)
	n	=	Manning's roughness coefficient
	L	=	Flow length (feet)
	P_2	=	2-year 24-hour rainfall (inches)
	s	=	Slope of hydraulic grade line (foot/foot)

The sheet flow travel time will then be converted to velocity via the following equation:

Equation 5

$$V = \frac{L}{3600T_t}$$

where:	V	=	Average velocity (foot/second)
	3600	=	Conversion from hours to seconds

Calculated post-development sheet flow velocities will be less than the permissible velocities.

- VESCH Table 5-14 Permissible Velocities for Grass Lined Channels
- VESCH Table 5-22 Permissible Velocities for Unlined Earthen Channels

If a level spreader is necessary to dissipate concentrated flow into sheet flow, the following specification will be used:

- Virginia Stormwater BMP Clearinghouse Specification No. 2 Sheet flow to a vegetated filter strip or conserved open space

Per 9VAC-25-870-66 Part D, no further water quantity controls are required "if all runoff from the site is sheet flow." Therefore, diversions will be used as necessary within the Project site area to route surface runoff through the level spreader. See ***Section 1.3.2*** for information pertaining to level spreader design.

1.2.3 Hydraflow Hydrographs – Q and RV Calculations

The Hydraflow Hydrographs extension for AutoCAD Civil 3D will perform peak flow rate and runoff volume calculations in accordance with the Natural Resource Conservation Service (NRCS; formerly Soil

Conservation Service [SCS]) Technical Release 55 (TR-55) methods for the 1-, 2-, and 10-year 24-hour storm events, and the results for the 1-year event will be used as inputs when completing the energy balance method calculations (see ***Section 1.2.1***). It should be noted that modelling up to the 10-year event is necessary because some stormwater BMPs, such as a grass channels and level spreaders, need to be shown to have enough capacity to convey up to the 10-year event.

Hydraflow Hydrographs requires the following input data in order to calculate peak flow rates and runoff volumes: drainage area, design storm precipitation data, curve number(s), time of concentration flow paths, and BMP storage and outlet data (if applicable; see ***Section 1.3.1***).

1.2.3.1 Drainage Area Delineation

Drainage areas along the proposed pipeline route will be delineated based on rivers and tributaries that have been delineated by, and are therefore recognized by, the VADEQ (shapefile obtained from Virginia Environmental Geographic Information Systems [VEGIS] website: http://www.deq.virginia.gov/ConnectWithDEQ/VEGIS/VEGISDatasets.aspx, Dataset Name: 2014 Integrated WQ Report Rivers.zip). Only the portion of the corresponding VADEQ river/tributary drainage area that runs on to the project LOD will be considered; for pipeline sections that run across/through valleys (i.e., in the vicinity of stream crossings), the drainage area considered will be limited to the LOD. An example is provided in ***Figure 3***.

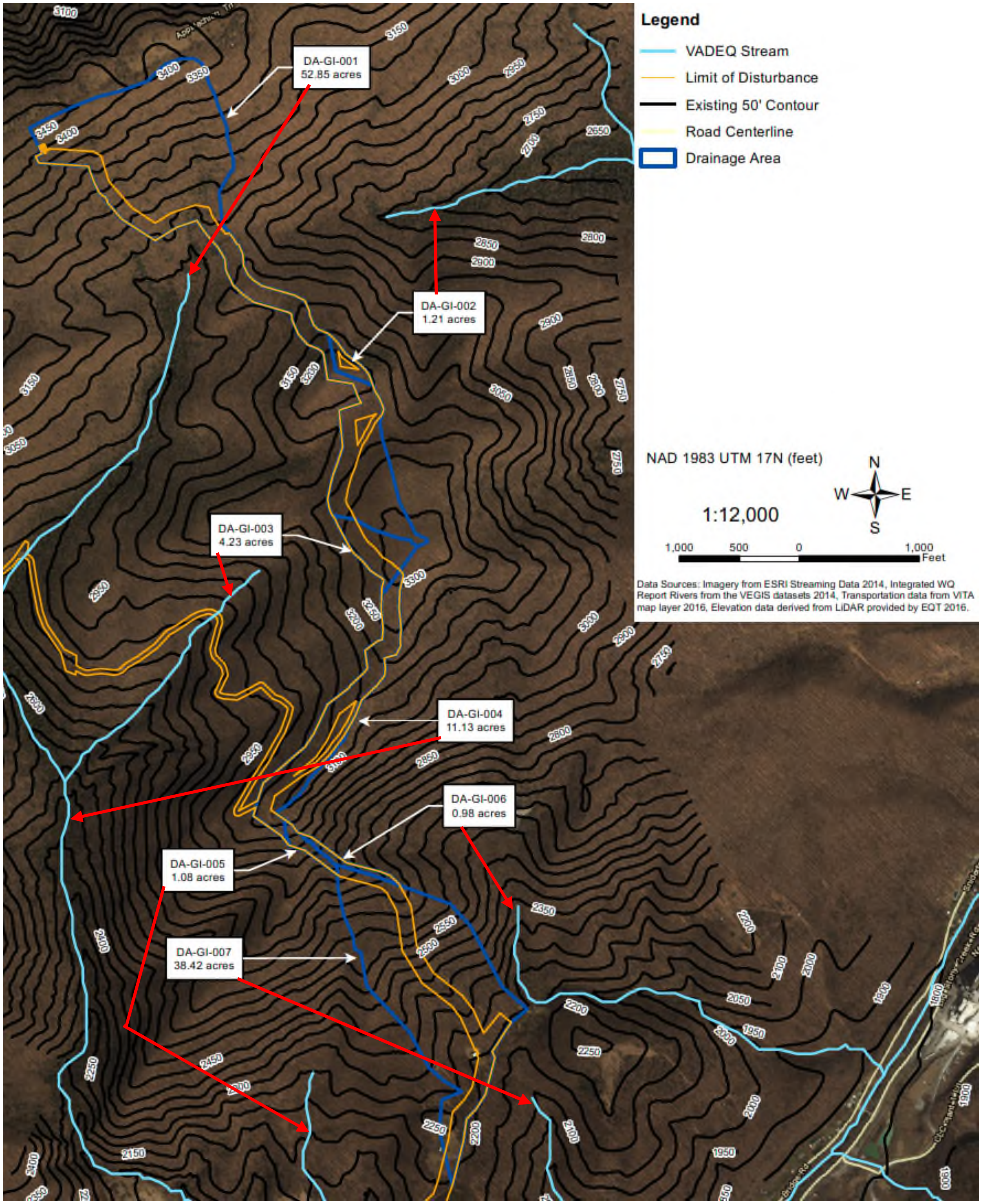


Figure 3. Giles County Drainage Area Delineation Example

1.2.3.2 Design Storm Precipitation Data

Design storm values for the 1-, 2-, and 10-year 24-hour storms were compiled from multiple sources including local code, the Virginia Stormwater Handbook 1999 Edition, the Virginia Stormwater Handbook DRAFT 2013 Edition, and the NOAA Atlas 14 data for the stations closest to the current pipeline alignment. To meet stormwater management requirements, projects are typically subject to the most stringent regulation. Therefore, the maximum rainfall intensity of the four sources will be used in stormwater calculations as presented on ***Figure 4***.

An NRCS Type II storm distribution will be used in Hydraflow Hydrographs, which is applicable to the Project location as shown on ***Figure 5***.

1.2.3.3 Curve Number (CN)

The NRCS Runoff Curve Number (CN) method is used to estimate runoff in Hydraflow Hydrographs. The NRCS runoff equation is:

<u>Equation 6</u>

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

where:	Q	=	Runoff (in)
	P	=	Rainfall (in)
	S	=	Potential maximum retention after runoff begins (in)

S is related to the soil and cover conditions of the drainage area through the CN. CN has a range of 0 to 100, and S is related to CN by:

<u>Equation 7</u>

$$S = \left(\frac{1000}{CN}\right) - 10$$

The major factors that determine CN are the hydrologic soil group (HSG) and land cover type. For pre-developed forested areas, under normal operating conditions, the pipeline right-of-way land cover type for the developed condition will be considered 50 feet of meadow and 75 feet of brush. For pre-developed non-forested areas, under normal operating conditions, the pipeline right-of-way land cover type for the developed condition will revert to the pre-developed land cover type. All land cover types are assumed to be in good condition. CN values will be obtained from Technical Release 55 (TR-55); an excerpt from the CN tables included in TR-55 is provided in ***Table 1***. The land cover and soil map data sources that will be used for this Project is as follows:

- *Land Use Data Source*: 2015 ESRI World Imagery Aerials and the Digitized Land Use.
- *Soil Map Data Source*: 2014 Gridded Soil Survey Geographic (SSURGO) soils dataset for the Commonwealth of Virginia, obtained from the USDA.

1.2.3.4 Time of Concentration Flow Paths

Stormwater moves through a given drainage area as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The time of concentration (TOC) is computed by summing all the travel times for consecutive components of the drainage conveyance system; TOC influences the shape and peak of the runoff hydrograph.

For the pre-developed condition, the time of concentration will be calculated in Hydraflow Hydrographs in accordance with TR-55 using the longest flow path from the most remote location within the drainage area to the outlet. For the developed condition, the time of concentration will be calculated in Hydraflow Hydrographs in accordance with TR-55 using a flow path that is representative of the hydrologic changes following construction (i.e., changes in surface water runoff due to permanent waterbars, stormwater BMPs, etc.).

Factors that affect TOC include surface roughness, slope, and flow path length. TOC flow paths and associated slopes will be determined using existing contour data. Each flow type (i.e., sheet flow, shallow concentrated flow and open channel flow) is described below in more detail.

Sheet Flow

Sheet flow is flow over plane surfaces. With sheet flow, the friction value (Manning's n) is an effective roughness coefficient that includes the effect of raindrop impact, drag over the plane surface, obstacles such as litter, crop ridges, and rocks, and erosion and transportation of sediment. ***Table 2*** provides Manning's n values for sheet flow for various surface conditions.

Generally, beyond 100 feet the flow becomes concentrated flow. Therefore, a maximum sheet flow length of 100 feet will be used for this Project.

Shallow Concentrated Flow

The following counties place restrictions on the length of shallow concentrated flow:

- Franklin County
    - Maximum shallow concentrated flow lengths are 1,000-feet
- Roanoke County
    - Maximum Shallow concentrated flow lengths are 1,000-feet

These restrictions on shallow concentrated flow will only be used when completing stormwater calculations in these counties. In other counties, surface flow along the flow path following 100 feet of sheet flow will be considered shallow concentrated flow until the flow becomes channelized.

Open Channel Flow

Open channel flow is assumed when flow becomes channelized, and a determination can be made as to when flow becomes channelized along the flow path based on existing contour data or aerial imagery. Bank full flow for a representative cross section along the channel is assumed in Hydraflow Hydrographs for the purpose of calculating time of concentration. ***Table 3*** provides Manning's n values for open channel flow.

1.2.4 Hydraflow Hydrographs Output and Energy Balance Calculations

Hydraflow Hydrographs performs calculations in accordance with TR-55 and provides a runoff hydrograph output for each modeled condition (i.e., pre-developed, developed, and forest). The calculated peak flow rate (Q) and hydrograph volume, or runoff volume (RV), for the 1-year 24-hour storm event will be obtained from the corresponding "Hydrograph Summary Report" page of the Hydraflow Hydrographs output report as shown on ***Figure 6***. Those results will be used as inputs when completing the energy balance method calculations (see ***Section 1.2.1***).

If the energy balance requirements are not satisfied, stormwater BMP design is required (see ***Section 1.3***).

1.3 STORMWATER BMP DESIGN

For this project, stormwater Best Management Practices (BMPs) will be designed as needed to meet stormwater quality (see ***Section 1.1***) and quantity (see ***Section 1.2***) requirements. MVP will utilize specifications from the Virginia Stormwater BMP Clearinghouse for BMP design. Although all BMPs will be considered for use to satisfy quality requirements, the specifications listed below are those most likely to be implemented with this Project:

- Specification No. 2 Sheet flow to a vegetated filter strip or conserved open space
- Specification No. 3 Grass channels
- Specification No. 4 Soil compost amendment

Stormwater BMP details are included in Appendix B – MVP Typical Construction Details. It should be noted, Specification No. 2 may be exempt from stormwater quantity requirements presented in ***Section 1.2.1***, per 9VAC25-870-66 Part D, if it can be demonstrated that sheet flow results in no adverse effects on downstream properties. Refer to ***Section 1.2.2*** for further discussion on sheet flow.

In instances where there is no feasible stormwater BMP design option that can be implemented to satisfy stormwater quality requirements , MVP will purchase off-site nutrient credits from registered mitigation banks in accordance with 9VAC25-870-69; the registered mitigation bank must be located within the same or an adjacent HUC watershed and demonstrate the required number of credits are available for purchase.

1.3.1 BMP Sizing Calculations

Stormwater BMPs will be designed to reduce total phosphorous loading in order to meet stormwater quality requirements (see ***Section 1.1***) and/or reduce runoff peak flow rate and volume to meet water quantity requirements (see ***Section 1.2***). The effect of routing runoff through stormwater BMPs is achieved in Hydraflow Hydrographs by routing the drainage area hydrograph for the developed condition to a “Pond” element; “Pond” elements are defined in Hydraflow Hydrographs by entering stage-storage and outlet data. It should be noted that level spreaders (Specification No. 2) are not defined using “Pond” elements in Hydraflow Hydrographs because they are designed to provide outlet protection and, as detailed in Specification No. 2, serve a water quality function; level spreaders are not sized to reduce runoff peak flow rate and volume. See ***Section 1.3.2*** for information pertaining to level spreader design.

For grass channel BMPs (Specification No. 3), the subsurface storage within the soil amendment area and surface storage up to a 1-ft ponding depth above the soil amendment area (assuming 1-ft check dam height within channels) will be considered when calculating BMP stage-storage data. A rectangular weir with a crest elevation corresponding to 1-ft above ground surface (i.e., assumed check dam height within channel) will be assumed when defining the BMP outlet. The Excel spreadsheet that will be used to calculate stage-storage data for grass channels is shown on ***Figure 7***.

For waterbars with soil amendment BMPs (Specification No. 4), the subsurface storage within the soil amendment area and surface storage up to a 0.5-ft ponding depth area above the soil amendment area (assuming 0.5-ft height of compost filter sock at the ends of permanent waterbars) will be considered when calculating BMP stage-storage data. If there are multiple waterbars with soil amendment BMPs within a drainage area, the storage associated with each individual BMP will be summed across the drainage area and used as input for Hydraflow Hydrographs. A rectangular weir with a crest elevation corresponding to 0.5-ft above ground surface (i.e., assumed height of compost filter sock at the ends of permanent waterbars) will be assumed when defining the BMP outlet. The Excel spreadsheet that will be used to calculate stage-storage data for waterbars with soil amendments is shown on ***Figure 8***.

In instances where stormwater BMPs are needed in order to meet water quantity requirements, the stormwater BMP design will be an iterative process during which BMPs will be re-sized across the drainage area as necessary until the energy balance requirements are satisfied (see ***Section 1.2.1***). ***Figure 9*** shows where the calculated peak flow rate (Q) and hydrograph volume, or runoff volume (RV), for the developed condition with BMPs appear on the Hydraflow Hydrographs output report; these will be the values that will be used as inputs when completing the energy balance method calculations.

1.3.2 Additional BMP Design Calculations

Additional calculations will be completed for the following stormwater BMPs in order to show that the design meets the corresponding specifications: Sheet Flow to a Vegetated Filter Strip or Conserved Open Space (Specification No. 2) and Grass Channels (Specification No. 3).

Level Spreaders (Specification No. 2)

Level spreaders will be designed in accordance with the following specification:

- Virginia Stormwater BMP Clearinghouse Specification No. 2 Sheet flow to a vegetated filter strip or conserved open space

Per the specification listed above, level spreaders should be designed to accommodate the peak flow rate corresponding to the 10-year 24-hour design storm. The goal when designing a level spreader is to ensure an appropriate length of the discharge feature – a length that does not allow for erosive velocities down slope.

Specification No. 2 requires a level spreader length of 13 feet per 1 cubic feet per second (cfs) of flow when discharging to native grasses or thick ground cover, and a length of 40 feet per 1 cfs of flow when discharging to a forested or reforested buffer.

Grass Channels (Specification No. 3)

Grass channel design must meet the criteria set forth in Virginia BMP Clearinghouse Specification No. 3. Criteria include 10-year 24-hour design storm capacity as well as shear and velocity values within prescribed limits for the grass lining specified in VESCH Table 5-14 Permissible Velocities for Grass Lined Channels. Grass channel calculations within Specification No. 3 are based on open channel equations. The Excel spreadsheet that will be used for grass channel design calculations is shown on ***Figure 10***.

TABLES

Table 1 – Excerpt CN Table from TR-55

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

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	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

Table 2 – Manning's n Values for Sheet Flow

Land Surface Type	Manning n
Urban:	
Concrete, Asphalt, or Gravel	0.005 – 0.015
Average Grass Cover	0.40
Rural Residential (1 - 10 acre lots, maintenance or grazing assumed)	0.40
Urban Residential (maintained lawns assumed, with effects of landscaping, driveways, roofs included in combined value):	
1 - 3 building units/acre	0.30
3 - 10 building units/acre	0.20
> 10 building units/acre	0.15
Commercial/Industrial (effects of landscaping, driveways, roofs included in combined value)	0.11
Grass:	
Average Grass Cover	0.40
Poor Grass Cover, Moderately Rough Surface	0.30 – 0.40
Light Turf	0.20
Dense Turf	0.17 – 0.80
Dense Grass	0.17 – 0.30
Bermuda Grass	0.30 – 0.48
Dense Shrubbery and Forest Litter	0.40
Natural:	
Short Grass Prairie	0.10 – 0.20
Poor Grass Cover, Moderately Rough Surface	0.30 – 0.40
Sparse Vegetation	0.05 – 0.13
Oak Grasslands, Open Grasslands	0.60
Dense Cover of Trees and Bushes	0.80
Rangeland:	
Typical	0.13
No Debris Cover	0.09 – 0.34
20% Debris Cover	0.05 – 0.25
Woods:	
Light Underbrush	0.40
Dense Underbrush	0.80
Rural Residential (1 – 10 acre lots, Maintenance or grazing assumed)	0.40
Cultivated Areas:	
Bare Packed Soil (free of stone)	0.10
Fallow (no residue)	0.05
Conventional Tillage:	
No Residue	0.06 – 0.12
With Residue	0.16 – 0.22

Table 2 – Manning's n Values for Sheet Flow

Land Surface Type	**Manning n**
Chisel Plow:	
No Residue	0.06 – 0.12
With Residue	0.10 – 0.16
Fall Disking (with residue)	0.30 – 0.50
No Till:	
No Residue Cover	0.04 – 0.10
20 – 40% Residue Cover	0.07 – 0.17
60 – 100% Residue Cover	0.17 – 0.47
Rural Residential (1 – 10 acre lots, maintenance or grazing assumed)	0.40
Sources: *-USACE, 1998, HEC-1 Flood Hydrograph Package User's Manual, Hydrologic Engineering Center, Davis, CA* *-Soil Conservation Service, 1986, Urban Hydrology for Small Watersheds, Technical Release 55, U.S. Department of Agriculture, Washington, DC*	

Table 3 – Manning's n Values for Open Channel Flow

Channel Type		**Manning n**		
		Min.	Normal	Max.
1.	**Lined or Constructed Channels**			
a.	***Cement:***			
	Neat, surface	0.010	0.011	0.013
	Mortar	0.011	0.013	0.015
b.	***Concrete:***			
	Trowel finish	0.011	0.013	0.015
	Float finish	0.013	0.015	0.016
	Finished, with gravel on bottom	0.015	0.017	0.020
	Unfinished	0.014	0.017	0.020
	Gunite, good section	0.016	0.019	0.023
	Gunite, wavy section	0.018	0.022	0.025
	On good excavated rock	0.017	0.02	-
	On irregular excavated rock	0.022	0.027	-
c.	***Concrete Bottom Float Finish with sides of:***			
	Dressed stone in mortar	0.015	0.017	0.020
	Random stone in mortar	0.017	0.020	0.024
	Cement rubble masonry, plastered	0.016	0.020	0.024
	Cement rubble masonry	0.020	0.025	0.030
	Dry rubble or riprap	0.020	0.030	0.035
d.	***Gravel Bottom with sides of:***			
	Formed concrete	0.017	0.020	0.025
	Random stone mortar	0.020	0.023	0.026
	Dry rubble or riprap	0.023	0.033	0.036
e.	***Brick:***			
	Glazed	0.011	0.013	0.015
	In cement mortar	0.012	0.015	0.018
f.	***Masonry:***			
	Cemented rubble	0.017	0.025	0.030
	Dry rubble	0.023	0.032	0.035
g.	***Dressed Ashlar / Stone Paving***	0.013	0.015	0.017
h.	***Asphalt:***			
	Smooth	0.013	0.013	0.017
	Rough	0.016	0.016	0.017
i.	***VegetalLining***	0.030	-	0.500
j.	***Wood:***			
	Planed, untreated	0.010	0.012	0.014

Table 3 – Manning's n Values for Open Channel Flow

Channel Type	**Manning n**		
	Min.	Normal	Max.
Planed, creosoted	0.011	0.012	0.015
Unplaned	0.011	0.013	0.015
Plank with battens	0.012	0.015	0.018
Lined with roofing paper	0.010	0.014	0.017
2. Excavated or Dredged Channels			
a. Earth, Straight, and Uniform:			
Clean, recently completed	0.016	0.018	0.020
Clean, after weathering	0.018	0.022	0.025
Gravel, uniform section, clean	0.022	0.025	0.030
With short grass, few weeds	0.022	0.027	0.033
b. Earth Winding and Sluggish:			
No vegetation	0.023	0.025	0.030
Grass, some weeds	0.025	0.030	0.033
Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
Earth bottom and rubble sides	0.028	0.030	0.035
Stony bottom and weedy banks	0.025	0.035	0.040
Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-Excavated or Dredged:			
No vegetation	0.025	0.028	0.033
Light brush on banks	0.035	0.050	0.060
d. Rock Cuts:			
Smooth and uniform	0.025	0.035	0.040
Jagged and irregular	0.035	0.040	0.050
e. Channels not Maintained, Weeds and Brush Uncut:			
Dense weeds, high as flow depth	0.050	0.080	0.120
Clean bottom, brush on sides	0.040	0.050	0.080
Same as above, highest stage of flow	0.045	0.070	0.110
Dense brush, high stage	0.080	0.100	0.140
3. Main Channels			
a. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective	0.040	0.048	0.055
f. Same as (d) with more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080

Table 3 – Manning's n Values for Open Channel Flow

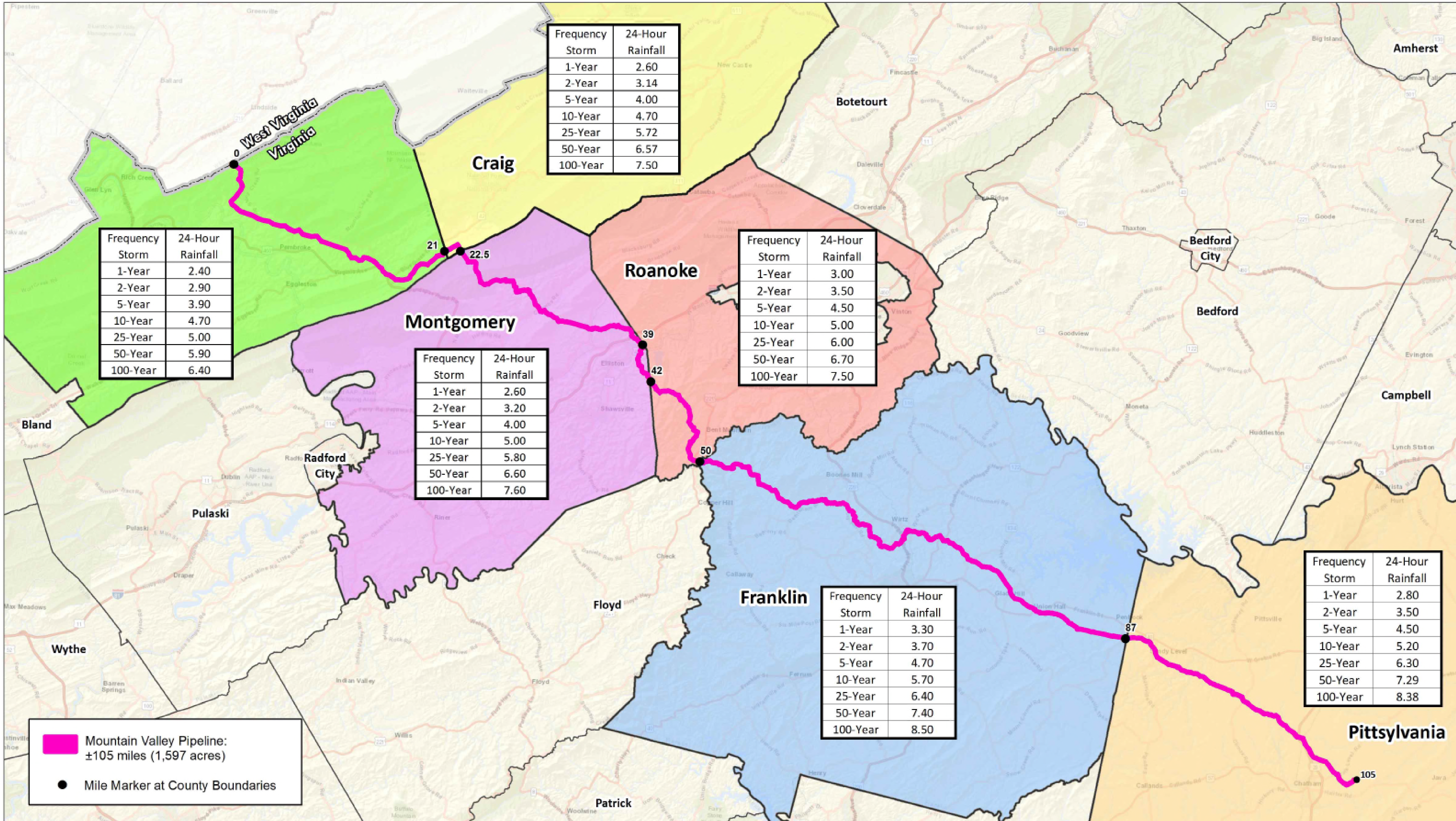
Channel Type	**Manning n**		
	Min.	Normal	Max.
h. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
4. Mountain Streams, No Vegetation in Channel, Banks usually Steep, Trees and Brush along Banks Submerged at High Stages			
a. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. Bottom: cobbles with large boulders	0.040	0.050	0.070
Sources:			
-ASCE, (1982), Gravity Sanitary Sewer Design and Construction, ASCE Manual of Practice No. 60, New York, NY			
-Chow, V.T., (1959), Open Channel Hydraulics, McGraw-Hill, New York, NY			

FIGURES

FIGURE 4

Local Storm Events

Recommended Design Storms Data



Craig

Frequency Storm	24-Hour Rainfall
1-Year	2.60
2-Year	3.14
5-Year	4.00
10-Year	4.70
25-Year	5.72
50-Year	6.57
100-Year	7.50

Giles

Frequency Storm	24-Hour Rainfall
1-Year	2.40
2-Year	2.90
5-Year	3.90
10-Year	4.70
25-Year	5.00
50-Year	5.90
100-Year	6.40

Montgomery

Frequency Storm	24-Hour Rainfall
1-Year	2.60
2-Year	3.20
5-Year	4.00
10-Year	5.00
25-Year	5.80
50-Year	6.60
100-Year	7.60

Roanoke

Frequency Storm	24-Hour Rainfall
1-Year	3.00
2-Year	3.50
5-Year	4.50
10-Year	5.00
25-Year	6.00
50-Year	6.70
100-Year	7.50

Franklin

Frequency Storm	24-Hour Rainfall
1-Year	3.30
2-Year	3.70
5-Year	4.70
10-Year	5.70
25-Year	6.40
50-Year	7.40
100-Year	8.50

Pittsylvania

Frequency Storm	24-Hour Rainfall
1-Year	2.80
2-Year	3.50
5-Year	4.50
10-Year	5.20
25-Year	6.30
50-Year	7.29
100-Year	8.38

NORTH

Sources:
1. Virginia Stormwater Management Handbook, 1999 edition, Appendix 4-B.
2. Erosion and Sediment Control and Stormwater Management Manual for Franklin County, Virginia, July 2016.
3. Roanoke County Stormwater Management Design Manual, March 22, 2016; NOAA Precipitation Rates, retrieved from http://www.roanokecountyva.gov/index.aspx?NID=317.
4. NOAA Atlas 14 Point Precipitation Frequencey Estimates, retrieved from http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=va.
5. Virginia Stormwater Management Handbook, 2013 Draft edition, Appendix 11-B.

0 2.5 5 10 Miles

Wetland Studies and Solutions, Inc.
a DAVEY company

Figure 5 – Approximate Geographic Boundaries for NRCS Rainfall Distributions

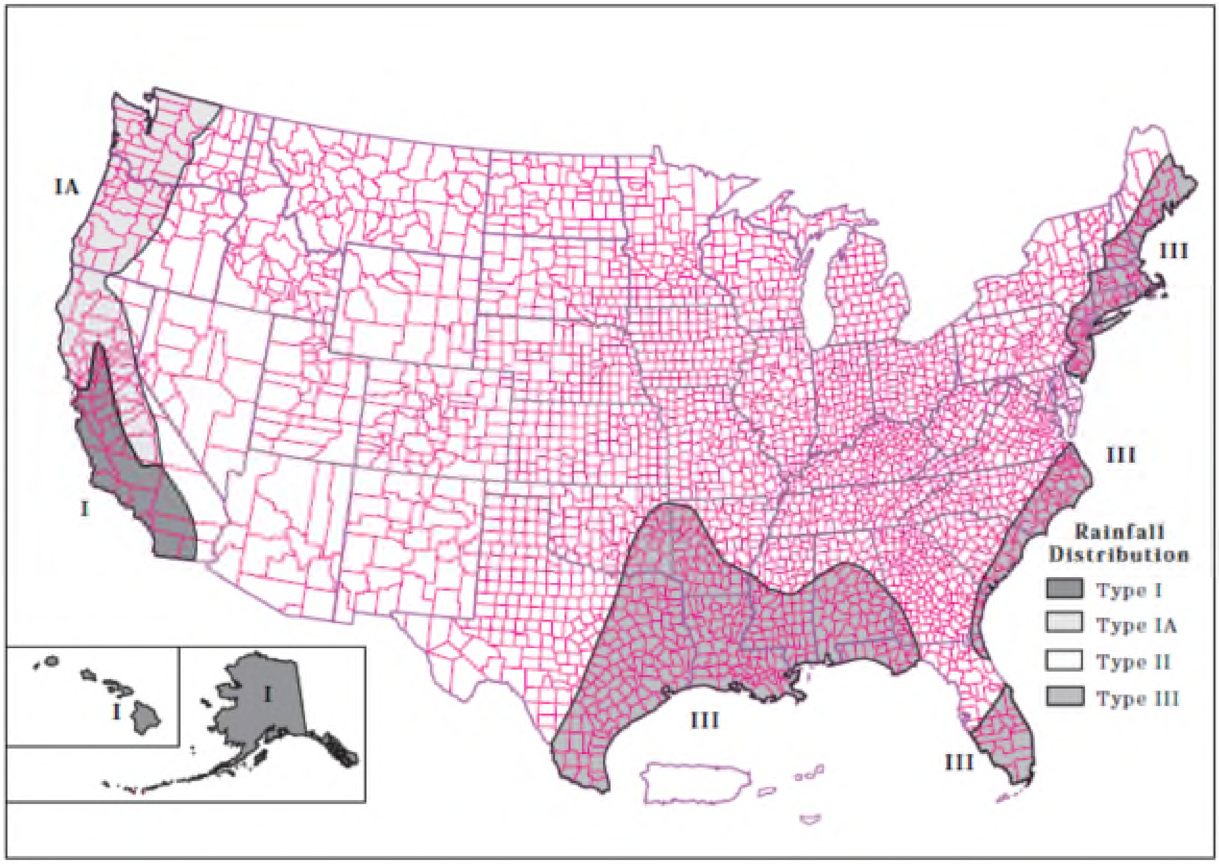


Figure 6 – Q and RV Output from Hydraflow Hydrographs

3

Hydrograph Summary Report

Hydraflow Hydrographs Extension for AutoCAD® Civil 3D® 2015 by Autodesk, Inc. v10.4

Hyd. No.	Hydrograph type (origin)	Peak flow (cfs)	Time interval (min)	Time to Peak (min)	Hyd. volume (cuft)	Inflow hyd(s)	Maximum elevation (ft)	Total strge used (cuft)	Hydrograph Description
1	SCS Runoff	0.083	1	1440	1,835	——	——	——	DA-GI-001 PRE
2	SCS Runoff	0.059	1	1440	956	——	——	——	DA-GI-001 POST
3	SCS Runoff	0.059	1	1440	956	——	——	——	DA-GI-001 Pre-Forest

Figure 7 – Grass Channel BMP Storage Volume Calculations Spreadsheet

Equations Used:

[1] $V_{gravel\ storage\ behind\ each\ check\ dam} = L*W_{bottom\ of\ channel}*D_{gravel}*(40/100)$

[2] $V_{soil\ storage\ behind\ each\ check\ dam} = L*W_{bottom\ of\ channel}*D_{soil}*(20/100)$

[3] $V_{surface\ storage\ behind\ each\ check\ dam} = 0.5*L*D*(W_{top\ of\ check\ dam} + W_{bottom\ of\ channel})/2$

[1] Equation #2b under "Volume Reduction Calculations" in Section 6.4.5 of PA BMP Manual, assuming that gravel is made up of 40% voids.

[2] Equation #2b under "Volume Reduction Calculations" in Section 6.4.5 of PA BMP Manual, assuming that soil compost amendment is made up of 20% voids.

[3] Equation under "Volume Reduction Calculations" in Section 6.4.8 of PA BMP Manual.

Inputs:

Depth of Gravel Layer, D_{gravel} (ft) =	0	
Depth of Soil Amendment Area, D_{soil} (ft) =	1	Refer to Table 4.3 in VA DEQ Stormwater Design Specification No. 4; Note that compost amendment may not be necessary for HSG A/B soils
Total Length of Channel in Drainage Area, L_{total} (ft) =	645.01	
Average Length of Channel Behind Each Check Dam, L (ft) =	49.61615385	
Bottom Width of Channel, $W_{bottom\ of\ channel}$ (ft) =	2	Channel bottom width should be 4-8' per VA DEQ Stormwater Design Specification No. 3. Separate channel design calculations show that for the proposed channel dimensions, the 10-year design flow is contained within the channel (minimum of 6 inches of freeboard) and the flow velocity within the channel is non-erosive up to the 10-year design storm event per VA DEQ Stormwater Design Specification No. 3.
Channel Side Slopes (H:V) =	3	Channel side slopes should be 3H:1V or flatter per VA DEQ Stormwater Design Specification No. 3. Separate channel design calculations show that for the proposed channel dimensions, the 10-year design flow is contained within the channel (minimum of 6 inches of freeboard) and the flow velocity within the channel is non-erosive up to the 10-year design storm event per VA DEQ Stormwater Design Specification No. 3.
Number of Check Dams in Drainage Area, n =	13	
Design Infiltration Rate, IR (in/hr) =	0.2	Min. rate of 0.30 in/hr for HSG A soils and 0.15-0.30 in/hr for HSG B soils (see Chap. 4, p. 4-30 in VA Stormwater Management Handbook Volume II (First Edition, 1999)
Top Width of Check Dam, $W_{top\ of\ check\ dam}$ (ft) =	8	
Surface Ponding Depth, D (ft) =	1	Assume 1' check dam height within channels
Check Dam Side Slopes (H:V) =	2	Rock check dam side slopes should be 2H:1V per VADEQ 1992 Manual detail

Calculations:

Total Storage Depth per BMP (ft) =	2
Surface Storage Volume Behind Each Check Dam (cf) =	124.0403846
Subsurface Storage Behind Each Check Dam (cf) =	19.84646154
Total Storage Volume Behind Each Check Dam (cf) =	143.8868462
Total BMP Storage Volume in Drainage Area (cf) =	1870.529
Calculated Infiltration Period per BMP (hr) =	87

Depth-Storage Data

Depth (ft)	Width (ft)	Length (ft)	Storage Volume in Channel Behind Check Dam (cf)	Storage Volume in Drainage Area (cf)
0	2	49.61615385	0	0
0.5	2	49.61615385	9.923230769	129.002
1	2	49.61615385	19.84646154	258.004
1.5	5	51.61615385	81.86665385	1064.2665
2	8	53.61615385	143.8868462	1870.529
2.5	11	55.61615385	205.9070385	2676.7915

Figure 8 – Waterbar with Soil Amendment BMP Storage Volume Calculations Spreadsheet

Equations Used:

[1]Vgravel storage = $L*W*D_{gravel}*(40/100)$

[2]Vsoil storage = $L*W*D_{soil}*(20/100)$

[3]Vsurface storage = $[W*S*D^2]+[L*S*D^2]+[W*L*D]+[((2*S*D)^2*D)/3]$

[1]Equation #2b under "Volume Reduction Calculations" in Section 6.4.5 of PA BMP Manual, assuming that gravel is made up of 40% voids.

[2]Equation #2b under "Volume Reduction Calculations" in Section 6.4.5 of PA BMP Manual, assuming that soil compost amendment is made up of 20% voids.

[3]Equation #1 under "Volume Reduction Calculations" in Section 6.4.5 of PA BMP Manual, but calculation also takes into account surface side slopes.

Inputs:

Depth of Gravel Layer, D_{gravel} (ft) =	0	
Depth of Soil Amendment Area, D_{soil} (ft) =	1	Refer to Table 4.3 in VA DEQ Stormwater Design Specification No. 4; Note that compost amendment may not be necessary for HSG A/B soils
Length of Waterbar Soil Amendment Area, L (ft) =	5	Assume max. length of 50' for waterbar soil amendment areas (i.e., limited to permanent ROW)
Width of Waterbar Soil Amendment Area, W (ft) =	2	
Inside Embankment Side Slopes, S (H:V) =	2	Assume 2H:1V surface side slopes for waterbars
Number of Perm. Waterbars in Drainage Area, n =	10	
Design Infiltration Rate, IR (in/hr) =	0.2	Min. rate of 0.30 in/hr for HSG A soils and 0.15-0.30 in/hr for HSG B soils (see Chap. 4, p. 4-30 in VA Stormwater Management Handbook Volume II (First Edition, 1999)
Surface Ponding Depth, D (ft) =	0.5	Assume 0.5' CFS height at the end of waterbars

Calculations:

Total Storage Depth per BMP (ft) =	1.5
Surface Storage Volume per BMP (cf) =	9.166666667
Subsurface Storage Volume per BMP (cf) =	2
Total Storage Volume per BMP (cf) =	11.16666667
Total BMP Storage Volume in Drainage Area (cf) =	111.6666667
Calculated Infiltration Period per BMP (hr) =	67

Depth-Storage Data

Depth (ft)	Width (ft)	Length (ft)	Storage Volume per BMP (cf)	Storage Volume in Drainage Area (cf)
0	2	5	0	0
0.5	2	5	1	10
1	2	5	2	20
1.5	4	7	11.16666667	111.6666667
2	6	9	31.33333333	313.3333333

Figure 9 - Q and RV Output from Hydraflow Hydrographs for Developed Condition with BMPs

Hydrograph Summary Report

Hydraflow Hydrographs Extension for AutoCAD® Civil 3D® 2015 by Autodesk, Inc. v10.4

Hyd. No.	Hydrograph type (origin)	Peak flow (cfs)	Time interval (min)	Time to Peak (min)	Hyd. volume (cuft)	Inflow hyd(s)	Maximum elevation (ft)	Total strge used (cuft)	Hydrograph Description
1	SCS Runoff	0.007	1	804	232	------	------	------	DA-GI-006 PRE
2	SCS Runoff	0.008	1	800	232	------	------	------	DA-GI-006 POST
3	SCS Runoff	0.007	1	804	232	------	------	------	DA-GI-006 Pre-Forested
4	Reservoir	0.006	1	1023	120	2	2856.50	112	WB Soil Amend Storage

Figure 10 – Grass Channel Design Calculations Spreadsheet

CHANNEL DESIGN DATA

PROJECT NAME:	**MVP Project - Transco Interconnect Site**		
LOCATION:	**Pittsylvania County, VA**		
PREPARED BY:	**DJW**	**DATE:**	May 31, 2017
CHECKED BY:	**0**	**DATE:**	January 0, 1900

CHANNEL OR CHANNEL SECTION	CH-A (MIN)	CH-A (MAX)	CH-B (MIN)	CH-B (MAX)	CH-C	CH-D	CH-E	CH-F	
TEMPORARY OR PERMANENT? (T OR P)	P	P	P	P	P	P	P	P	
SPECIAL PROTECTION WATERSHED? (YES OR NO)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
DESIGN STORM (2, 5, OR 10 YR)	10	10	10	10	10	10	10	10	
ACRES (AC)	8.12	8.12	1.61	1.61	0.48	0.80	2.09	0.80	
MULTIPLIER (1.6, 2.25, OR 2.75)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Qr (REQUIRED CAPACITY) (CFS)[1]	11.68	11.68	2.59	2.59	0.77	1.44	3.36	1.44	
Q (CALCULATED AT FLOW DEPTH d) (CFS)	11.68	11.68	2.59	2.59	0.77	1.44	3.36	1.44	
VEGETATIVE LINING RETARDANCE	--	--	--	--	--	--	--	--	
PROTECTIVE LINING[2]	Bermudagrass	Bermudagrass	Bermudagrass	Bermudagrass	Bermudagrass	Bermudagrass	Bermudagrass	Bermudagrass	
n (MANNING'S COEFFICIENT)[2]	0.064	0.042	0.067	0.057	0.076	0.068	0.114	0.101	
Va (ALLOWABLE VELOCITY) (FPS)	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	
V (CALCULATED AT FLOW DEPTH d) (FPS)	1.86	4.42	1.50	2.09	1.05	1.42	0.49	0.63	
τ_a (MAX ALLOWABLE SHEAR STRESS) (LB/FT^2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
τ_d (CALC'D SHEAR STRESS AT FLOW DEPTH d) (LB/FT^2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
CHANNEL BOTTOM WIDTH (FT)	2.00	2.00	2.00	2.00	2.00	2.00	10.00	0.00	
CHANNEL SIDE SLOPES LEFT, Z_1 (H:V)	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	
CHANNEL SIDE SLOPES RIGHT, Z_2 (H:V)	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	
D (TOTAL DEPTH) (FT)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	
CHANNEL TOP WIDTH @ D (FT)	14.00	14.00	14.00	14.00	14.00	10.00	18.00	8.00	
d (CALCULATED FLOW DEPTH) (FT)	1.15	0.66	0.49	0.39	0.26	0.37	0.61	1.07	
CHANNEL TOP WIDTH @ FLOW DEPTH d (FT)	8.91	5.97	4.97	4.35	3.58	3.48	12.43	4.26	
BOTTOM WIDTH:DEPTH RATIO (12:1 MAX)	1.74	3.02	4.05	5.11	7.60	5.40	16.48	N/A	
d_{50} STONE SIZE (IN)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
A (CROSS-SECTIONAL AREA) (SQ. FT.)	6.28	2.64	1.72	1.24	0.73	1.02	6.81	2.27	
R (HYDRAULIC RADIUS)	0.677	0.427	0.336	0.277	0.200	0.278	0.535	0.476	
S (BED SLOPE)[3] (%)	1.08	4.87	1.97	3.54	2.45	2.32	0.33	0.50	
S_c (CRITICAL SLOPE) (%)	7.08	3.53	9.71	7.46	14.71	10.84	23.84	21.26	
$.7S_c$ (%)	4.95	2.47	6.79	5.23	10.30	7.59	16.69	14.88	
$1.3S_c$ (%)	9.20	4.59	12.62	9.70	19.13	14.09	30.99	27.64	
STABLE FLOW? (Y/N)	Y	Y	Y	Y	Y	Y	Y	Y	
FREEBOARD BASED ON UNSTABLE FLOW (FT)	0.16	0.22	0.06	0.06	0.02	0.04	0.02	0.05	
FREEBOARD BASED ON STABLE FLOW (FT)	0.29	0.17	0.12	0.10	0.07	0.09	0.15	0.27	
MINIMUM REQUIRED FREEBOARD[4] (FT)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
DESIGN METHOD FOR PROTECTIVE LINING[5] PERMISSIBLE VELOCITY (V) OR SHEAR STRESS (S)	V	V	V	V	V	V	V	V	

1. Use 10-Year 24-Hour peak flow for channel drainage area as calculated in Hydraflow Hydrographs using TR-55 methodology.

2. Adjust "n" value for changes in channel liner and flow depth. For vegetated channels, provide data for manufactured linings without vegetation and with vegetation in separate columns.

3. Slopes may not be averaged.

4. For grass/vegetated channels, the minimum freeboard is 0.5 ft per VA DEQ Stormwater Design Specification No. 3.

5. Permissible velocity lining design method is not acceptable for channels with a bed slope of 10% or greater. Shear stress lining design method is required for channels with a bed slope of 10% or greater. Shear stress lining design method may be used for any channel bed slope.