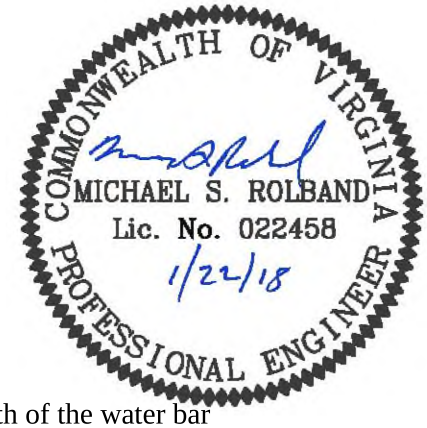


MVP 17.3

WATER BAR END TREATMENT SIZING AND DETAILS

1/22/18

The purpose of this detail is to document the methodology developed to size the length of the water bar end treatments to ensure flow leaving the permanent right-of-way is in the form of non-erosive sheet flow. Rather than perform a detailed, specific design for each and every water bar, this proposed methodology would provide conservatively sized end treatment lengths based primarily on the contributing drainage area. The intent is to provide several, incremental lengths that can be easily selected for each water bar that ensures the proposed length is not only adequate to produce sheet flow, but also facilitates constructability. This approach was performed for a test area within Spread 8, to demonstrate the methodology to be used as a template over the entire length of the pipeline project. The remainder of this detail outlines the approach and suggested end treatment lengths to be used for the project.

Flow Rate Computation

To calculate the required length of the end treatments, the flow rate to each water bar resulting from the 10-yr storm was necessary. Given the small size of the sub-sheds, use of the Rational Method to compute the flow rates was deemed to be an appropriate methodology. Each parameter and how they were computed is described below:

$$Q = C\,i\,A$$

Where:

Q = *10-yr flow rate, cfs*

C = *Runoff Coefficient:*

This parameter was determined using Table 4-5b in the *Virginia Stormwater Management Handbook* that provides C factors in relation to hydrologic soil groups, land uses, and land slopes. This provides a direct link to the NRCS methodologies employed for other aspects of this project and also accounts for the increase in runoff that results solely as a result of the steep slopes. For this exercise, Meadow, > 6% slope was used:

TABLE 4 - 5b

Rational Equation Coefficients for SCS Hydrologic Soil Groups (A, B, C, D)

Rural 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		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

Source: Maryland State Highway Administration

As noted in Table 4-5b, the maximum slope represented is ">6%", although project slopes exceed this level in certain areas. However, the applicability of using the Rational Method for this analysis and, as a result, the need to provide a link between CN and C factor warrants the use of this table.

i = *Intensity, in/hr:*

The Intensity-Duration-Frequency (I-D-F) curve for Pittsylvania County was used for this analysis as it was determined to be the most conservative County data for the pipeline project. It was derived using the VDOT Drainage Manual, *Appendix 6C-1, B, D and E Factors – Application* as it has been determined by VDOT/DCR that use of the BDE factors is appropriate for Rational Method calculations in smaller watersheds. The time of concentrations were computed using Seelye method (VDOT's preferred method, described in *Appendix 6D-1* of the VDOT Drainage Manual):

$$T_C = 0.225L^{0.42}S^{-0.19}C^{-1.0}$$

Where,

T_c = *Overland flow time, minutes*

L = *Length of strip, feet*

S = *Slope, feet/feet*

C = *Rational "C" value for ground character*

A = *Contributing Drainage Area, ac:*

Drainage areas to each water bar were delineated using available 2-ft C.I. topography.

Weir Flow Computation

With the flow to the water bars determined in the manner described above, the next step was to model the flow over the end treatments in order to compute the required length, as well as the sheet flow velocity below the level section to ensure it will not be erosive. To determine these parameters, flow over the level sections was modeled as a broad crested (rectangular) weir:

$$Q = C_w L H^{3/2}$$

Where:

Q = *10-yr flow rate, cfs*

C_w = *Rectangular Weir Coefficient, 3.33*

L = *Weir Length, ft*

H = *Head Over Weir, ft:*

This term is set to be 0.1 ft to ensure flow downslope of the end treatment is in the form of sheet flow.

Velocity Computation

To assess the velocity of the sheet flow downslope of the end treatment, Manning's equation was used:

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

Where:

V = *Overland Velocity, ft/s*

n = *Manning's Coefficient:*

This parameter was assumed to be 0.24 for sheet flow in "dense grasses" (TR-55, Table 3-1. Areas below the end treatments will be seeded with a native grasses and woody species, so the "dense grasses" n value was deemed to be the most appropriate vs the "short prairie grass" (n = 0.15) or "Bermuda grass" (n = 0.41) alternatives).

R = *Hydraulic Radius, ft:*

This term is defined as the cross-sectional flow area divided by the wetted perimeter. However, for shallow, wide flow this can be assumed to be equal to the flow depth. In this case this is set to the specified flow depth of 0.10 ft, per the following example (for an assumed 10 ft end treatment):

$$\begin{aligned} R &= A / WP \\ &= (0.1\ ft * 10\ ft) / (0.1\ ft + 10\ ft + 0.1\ ft) \\ &= 1.0\ ft^2 / 10.2\ ft \\ &= 0.098\ ft \end{aligned}$$

Use depth = 0.10 ft

S = *Overland Slope, ft/ft:*

This parameter was measured for each water bar. A sheet flow path was delineated from the water bar end treatment perpendicular to contours until reaching either another downstream water bar or 100 feet, whichever occurred first. Slope was calculated by dividing the difference between the start and ending elevation and the total sheet flow path length.

Methodology

To compute the required length of the water bar end treatment, the weir equation was solved for length (L) using the flow rate determined by the Rational Equation, along with the other parameters defined above. To facilitate this process, a spreadsheet based calculator was developed:

Example

End Treatment Length Calculator

Enter Site Specific Data	T_c =	15	time of concentration to water bar, min
	A =	1.79	water bar drainge area, ac
	S =	0.35	weir discharge overland slope, ft/ft
Computed	i =	4.5	computed from IDF, in/hr
Enter Flow Parameters	C =	0.19	assumes >6% slope, meadow
	C_w =	3.33	weir coefficient (rectangular)
	n =	0.24	sheetflow, dense grasses
	H =	0.1	sheetflow depth over weir, ft

Computed Weir Length ------> **14 ft**

Velocity Check ------> **0.79 fps**

Site data is entered, including the time of concentration (T_c), drainage area (A), and overland slope below the end treatment (S). Using the entered T_c, the intensity (i) is calculated from the Pittsylvania I-D-F curve. The flow rate is computed using the Rational Equation and entered into the weir equation to solve for the end treatment length (via lookup tables). A check of the velocity is also performed using Manning's equation with the overland slope term entered into the calculator. This process was repeated for each of the 47 separate water bars analyzed in this example watershed.

Results for Spread 8 Test Area

To test out the proposed end treatment sizing methodology to be used as a project standard, it was applied to size the end treatments for the test area within Spread 8. The following plot (Figure 1) summarizes the computed end treatment lengths vs the size of the contributing watershed for each of the 47 water bars (detailed data is presented in Table 1). Note that four water bars (6, 18, 45, and 46) required site specific analyses.

Figure 1

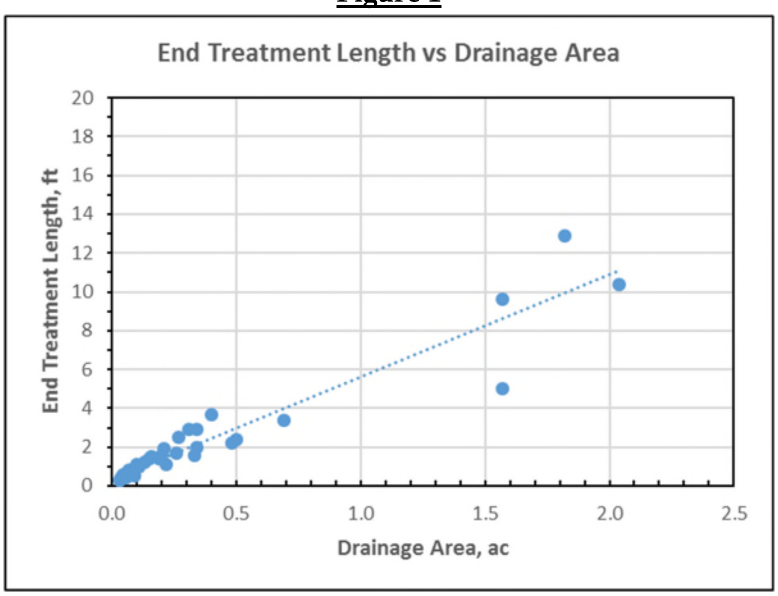


Table 1 – Test Watershed

Waterbar	Drainage Area (ac)	T_c (min)	Slope (ft/ft)	Velocity (fps) 10-yr	Velocity (fps) 100-yr	C	End Treatment Length (ft)
1	0.69	10	0.47	0.92	1.05	0.10	3.4
2	0.22	10	0.49	0.94	1.05	0.10	1.1
3	0.33	11	0.41	0.86	0.96	0.10	1.6
4	0.48	12	0.47	0.92	1.05	0.10	2.2
5	0.50	11	0.51	0.96	1.08	0.10	2.4
6	1.57	28	0.44	0.89	1.02	0.10	5.0
7	0.09	9	0.37	0.81	0.94	0.11	0.5
8	0.04	7	0.40	0.85	1.00	0.19	0.4
9	0.04	6	0.30	0.73	0.80	0.19	0.5
10	0.05	6	0.31	0.74	0.82	0.19	0.6
11	0.10	6	0.30	0.73	0.84	0.19	1.1
12	0.05	7	0.32	0.76	0.89	0.19	0.5
13	0.05	7	0.32	0.76	0.89	0.19	0.5
14	0.05	7	0.30	0.73	0.86	0.19	0.5
15	0.05	7	0.32	0.76	0.89	0.19	0.5
16	0.05	7	0.30	0.73	0.86	0.19	0.5
17	0.20	14	0.36	0.80	0.91	0.19	1.6
18	2.04	41	0.33	0.77	0.89	0.17	10.4
19	0.34	12	0.30	0.73	0.84	0.19	2.9
20	0.40	10	0.24	0.66	0.75	0.19	3.7
21	0.16	10	0.23	0.64	0.74	0.19	1.5
22	0.27	10	0.20	0.60	0.68	0.19	2.5
23	0.15	10	0.22	0.63	0.72	0.19	1.4
24	0.06	12	0.21	0.61	0.73	0.19	0.4
25	0.07	7	0.22	0.63	0.70	0.19	0.8
26	0.13	10	0.18	0.57	0.66	0.19	1.2
27	0.04	10	0.21	0.61	0.68	0.19	0.4
28	0.03	12	0.08	0.38	0.41	0.19	0.3
29	0.07	10	0.27	0.69	0.78	0.19	0.7
30	0.05	9	0.21	0.61	0.70	0.19	0.5
31	0.08	10	0.22	0.63	0.70	0.19	0.8
32	0.08	9	0.22	0.63	0.71	0.19	0.8
33	0.34	28	0.27	0.69	0.80	0.19	2.0
34	0.26	21	0.38	0.82	0.96	0.19	1.7
35	0.19	16	0.34	0.78	0.90	0.19	1.4
36	0.08	9	0.29	0.72	0.82	0.19	0.8
37	0.04	9	0.56	1.00	1.14	0.19	0.4
38	0.04	7	0.53	0.97	1.15	0.19	0.4
39	0.04	9	0.22	0.63	0.71	0.19	0.4
40	0.03	9	0.36	0.80	0.91	0.19	0.3
41	0.06	8	0.31	0.74	0.86	0.19	0.5
42	0.11	11	0.17	0.55	0.63	0.19	1.0
43	0.21	10	0.17	0.55	0.63	0.19	1.9
44	0.10	9	0.14	0.50	0.57	0.19	1.0
45	1.57	27	0.42	0.87	1.00	0.19	9.6
46	1.82	20	0.22	0.63	0.72	0.19	12.9
47	0.31	10	0.13	0.48	0.55	0.19	2.9

Overland Velocities

As depicted in Table 1, overland velocities below the end treatments will remain well below erosive levels, which was assumed to be equal to 2.25 fps for a sandy loam, earthen lining under critical conditions (VESCH, Table 5-22 – lowest velocity). Note that the downslope areas will be vegetated and thus will be able to withstand an even higher velocity. To reiterate, even assuming an earthen lining expected velocities are well below erosive levels. To provide additional assurance that the areas below the water bar will remain stable, a check of the velocities for the 100-yr storm was also performed. Even under this extreme storm event, overland velocities also remain below erosive levels (Table 1).

Proposed End Treatment Lengths

Based on this analysis, end treatment lengths from 5 to 13 ft would ensure sheet flow from all of the water bars in this watershed is achieved (note many are much shorter than 5 ft, but that would present constructability issues). The goal now is to apply these results to the remainder of the project where less pervious soil types exist (i.e. C and D soils). There is also a desire to provide a method whereby the end treatment lengths can be selected based on CN and contributing drainage area alone, without performing detailed calculations. There is recognition that use of this simplified process requires built-in factors of safety to ensure sheet flow is always produced, and this has been achieved.

To establish the link between the Rational coefficient (C) and the computed CN's for typical land use within the permanent ROW, consider the following comparison (Table 2):

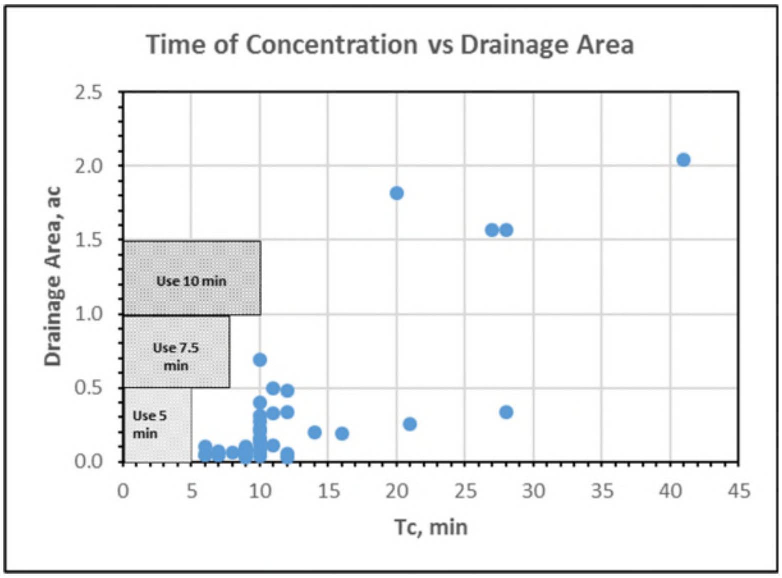
Table 2

		Hydrologic Soil Group			
		A	***B***	***C***	***D***
Woods	**C**	0.08	0.15	0.17	0.21
	CN	30	55	70	77
Meadow	**C**	0.10	0.19	0.22	0.25
	CN	30	**58**	**71**	**78**
Pasture	**C**	0.10	0.22	0.31	0.35
	CN	39	61	74	80

The analysis for this test watershed utilized the actual HSG's, which were B soils in all areas except for Drainage Area A that has A soils. The other parameters used in this analysis include a "meadow" land use with slopes greater than 6% (note all C values in Table 2 represent slopes > 6%). This represents a C factor of 0.19 and a corresponding CN of 58, as shown in Table 3. A CN of 58 is the highest value for this example, so the use of the 0.19 C factor is justified (note a C factor of 0.10 was used in for the first 6 water bars, as shown in Table 1). However, other areas of the project do have higher curve numbers, due primarily to less pervious soil types. This suggests use of C factors of 0.22 and 0.25, as depicted in Table 3, would be more appropriate in those areas and thus these higher values were also considered in this analysis.

In addition to soil type (i.e. CN), another consideration that will impact the lengths of the water bars is the time of concentration. A review of the T_c's in the test watershed suggests a conservative approach would be to assume tiered durations based on the size of the contributing watershed, whereby the selected T_c is less than the computed T_c. The actual values measured for each watershed are presented graphically in Figure 2, along with the assumed T_c value for each drainage area category:

Figure 2



Applying the above CN's and values for the T_c results in the following end treatment lengths:

Table 3

		End Treatment Lengths (ft)		
D.A. (ac)	**T_c (min)**	**CN ≤ 58**	**CN ≤ 71**	**CN ≤ 78**
≤ 0.5	5	6	7	8
0.5 ≤ 1.0	7.5	11	12	14
1.0 ≤ 1.5	10	14	17	19

To add a factor of safety and to simplify constructability, end treatment sizes depicted in Table 3 were rounded up to lengths of 10, 15, and 20 ft (Table 4). Recognizing this resulted in lengths of 10, 15, or 20 ft for all CN's except for those <58 (B soils), a further conservative simplification was made to use the three specified lengths for all land uses. The end result that is **proposed for use throughout the entire project is presented in the "Preferred" column in Table 4**:

Table 4

	End Treatment Lengths (ft)				
D.A. (ac)	**CN ≤ 58**	**CN ≤ 71**	**CN ≤ 78**	**CN > 78**	***Preferred***
≤ 0.5	10	10	10	**Site Specific**	***10***
0.5 ≤ 1.0	15	15	15		***15***
1.0 ≤ 1.5	15	20	20		***20***
> 1.5	20	n/a	n/a		***Site Specific***

For drainage areas of larger than 1.5 ac, or for areas with a CN greater than 71 (selected because a CN of 71 corresponds with a Rational "C" coefficient that results in sizing of end treatments within Table 5 drainage area tiers), a site-specific analysis will be performed to ensure a maximum end treatment maximum length of 20 ft will be sufficient. This may require the placement of additional water bars, or a longer water bar when the cross-slope angle allows a longer length.

To summarize, the following water bar end treatment lengths (Table 5) will be used for this project:

Table 5

Water Bar End Treatment Level Weir Section Lengths	
D.A. (ac)	**Length (ft)**
≤ 0.5	10
0.5 ≤ 1.0	15
1.0 ≤ 1.5	20
> 1.5*	Site Specific

*or Curve Numbers > 71

Design Basis

As described in this analysis, this proposed methodology provides for end treatment lengths that are extremely conservative. A summary of how this is achieved is provided below:

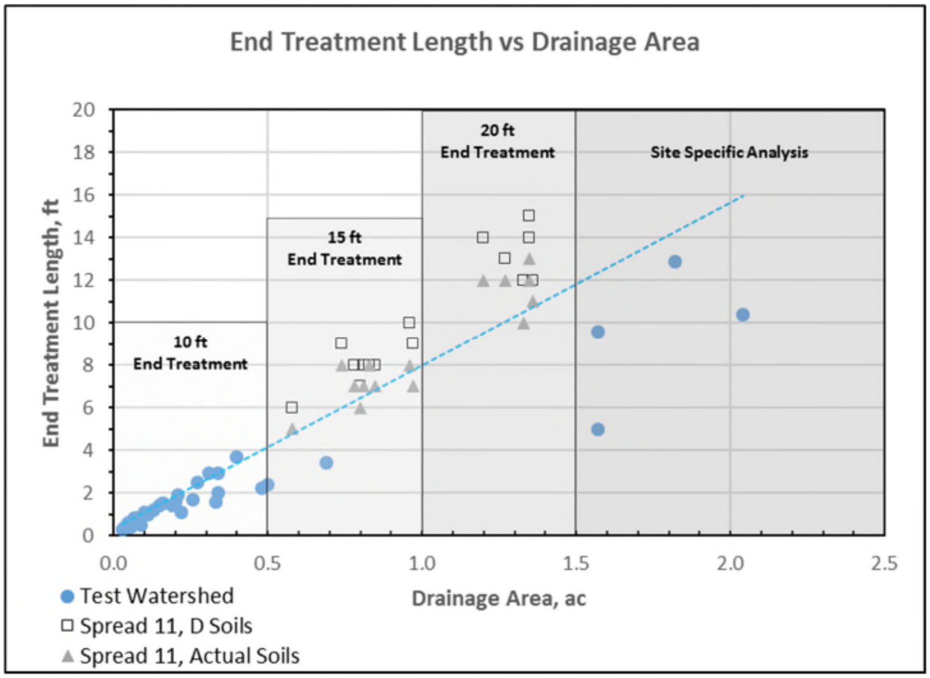
1) In this test watershed, 49% of the end treatment lengths were ≤ 1 ft in length (Table 1), yet the minimum specified end treatment length is 10 ft. In fact, for each drainage area category in this test watershed, the specified end treatment length is significantly longer than necessary to achieve non-erosive sheetflow. However, this test watershed included only one drainage area between 0.5 and 1.5 ac. Therefore, to test the methodology on larger drainage areas, another section of the project (Spread 11) was analyzed. The intent was to provide areas that were not only larger, but that also had "D" soils (most conservative assumption). The review of the project for this analysis did not result in areas that met these criteria. Thus, the sizing methodology was tested on these larger watersheds under 2 scenarios – using actual soil types (mostly "B" soils), as well as assuming all "D" soils. The results are tabulated in Table 6.

Table 6 – Portions of Spread 11

	Waterbar	Drainage Area (ac)	T_c (min)	Slope (ft/ft)	Velocity (fps) 10-yr	Velocity (fps) 100-yr	C	End Treatment Length (ft)
Spread 11 - Assumes D soils	1	0.80	20	0.13	0.48	0.57	0.25	7
	2	1.33	22	0.29	0.72	0.82	0.25	12
	3	0.58	14	0.13	0.48	0.56	0.25	6
	4	0.81	17	0.70	1.12	1.29	0.25	8
	5	0.78	14	0.10	0.42	0.50	0.25	8
	6	0.96	17	0.15	0.52	0.58	0.25	10
	7	0.85	19	0.30	0.73	0.84	0.25	8
	8	0.97	22	0.03	0.23	0.26	0.25	9
	10	0.83	21	0.14	0.50	0.56	0.25	8
	11	1.35	16	0.17	0.55	0.63	0.25	14
	12	1.27	15	0.11	0.44	0.51	0.25	13
	13	1.35	14	0.19	0.58	0.66	0.25	15
	14	1.20	13	0.20	0.60	0.67	0.25	14
	15	0.74	11	0.39	0.84	0.94	0.25	9
	17	1.36	21	0.05	0.30	0.35	0.25	12
Spread 11 - Uses actual soils type	1	0.80	27	0.13	0.48	0.57	0.19	6
	2	1.33	28	0.29	0.72	0.85	0.19	10
	3	0.58	20	0.13	0.48	0.57	0.19	5
	4	0.81	24	0.70	1.12	1.28	0.19	7
	5	0.78	19	0.10	0.42	0.50	0.19	7
	6	0.96	23	0.15	0.52	0.61	0.19	8
	7	0.85	26	0.30	0.73	0.84	0.19	7
	8	0.97	30	0.03	0.23	0.27	0.19	7
	10	0.83	21	0.14	0.50	0.56	0.19	8
	11	1.35	22	0.17	0.55	0.63	0.19	12
	12	1.27	21	0.11	0.44	0.50	0.19	12
	13	1.35	19	0.19	0.58	0.67	0.19	13
	14	1.20	18	0.20	0.60	0.68	0.19	12
	15	0.74	13	0.39	0.84	0.97	0.22	8
	17	1.36	28	0.05	0.30	0.34	0.19	11

The end treatment lengths computed by the sizing methodology, considering both the test watershed and larger drainage areas contained in Spread 11, provides for end treatment lengths that are significantly longer than necessary to provide for non-erosive sheetflow. The results are presented graphically in Figure 3. The trend line depicts all data except the assumed “D” soil types for Spread 11 (i.e. it utilizes actual soils for all depicted Spread 11 data).

Figure 3



For what is likely to be the most commonly encountered drainage area of less than 0.5 ac (based upon this detailed analysis for Spread 8), the installed end treatment length will be a minimum of 2.5 times longer than necessary.

2) The methodology will only be applied for drainage areas of less than 1.5 ac and for soils with a CN below 71. Larger watersheds and drainage areas with a CN > 71 will require site specific analyses to determine the end treatment length. As a result, watersheds that have an increased potential of problematic erosion will be more carefully reviewed on an individual basis.

3) The sheetflow velocities below the end treatments were assessed in this test watershed (10-yr storm) and compared to allowable velocities for bare earth - an extremely conservative approach. Even with this assumption, velocities will remain well below erosive levels. An analysis of the overland velocities for even a 100-yr event was also performed (Table 1) and even under this extreme storm event, velocities remain below erosive levels.

4) While the results provided by the proposed design methodology have been shown to be extremely conservative, the simplicity of the process itself will also facilitate accurate and conservative designs. The methodology allows for the implementation of a rapid, repeatable design process that also facilitates construction without risking damage to the environment. By reducing the need for site specific analyses for each and every end treatment, the chance for errors is significantly reduced.

Adaptive Management

Inherent with any hydrologic calculations is a level of uncertainty. The proposed end treatment length sizing methodology is extremely conservative and therefore mitigates much of this uncertainty. In addition to the conservative sizing methodology, however, there are also post-construction protocols in place that will provide additional assurances that the water bar end treatments will remain stable. In accordance with the guidelines contained in the approved plans for the project, post-construction monitoring and maintenance will be performed until such time as the disturbed pipeline area has been deemed to be permanently stabilized. As outlined in *Section 2.0 General Requirements* of the Project Standards & Specifications, inspections will be performed by DEQ-certified MVP inspectors to ensure any areas of erosion are quickly identified and promptly corrected. If field conditions warrant, the field inspectors can lengthen the water bar end treatment or recommend installation of additional water bar(s) to reduce the contributing drainage area and resulting velocities.

Based on the above (conservative design methodology and the adaptive monitoring and maintenance plan), MVP is confident the water bar end treatments will effectively control stormwater runoff in a manner that meets all state stormwater management requirements.

L:\22000s\22800\22865.01\Admin\04-ENGR\Spread 8 DA delineation\Level Spreader Sizing\012218 Final\2018-01-22_End Treatment Sizing MVP 17.3 FINAL RL.docx