Ditch Treatment

1. Description

Roadside ditch management (RDM) treatments are best management practices (BMP) that are used to treat and infiltrate runoff by improving the shape of the ditch or by changing the existing ditch soil with more permeable material or adding amendments to enhance pollutant removal (e.g., wood chips). Some RDM treatments have a corresponding traditional stormwater treatment, which have more stringent requirements that may be difficult to implement in ditches. RDM versions are designed specifically for ditches with less requirements than traditional BMPs (e.g., bioretention), and in turn, have different methods of crediting (see Section 4.1: Credit Calculations). Some of these practices are fairly new with limited published research. This guide summarizes the current information and potential methodology to credit the practice. The following is a list of treatment practices, defined by the Chesapeake Bay Roadside Ditch Management Team [1].

TABLE 1: DESCRIPTION OF RDM TREATMENT

Treatment	Description
Ditch Widening	Grass channel with trapezoidal or two-stage cross-section
Soil Amendment	Tilling a soil media amendment into existing soil to decrease compaction
Soil Replacement	Removing and replacing existing soil with soil media to promote greater pollutant removal

Soil media includes options like compost, woodchips, sand, or bioretention mix. Performance enhancing devices (PEDs) can be used as a soil amendment or used with a soil replacement (i.e. bioretention media with biochar). PEDs include incorporating biochar, water treatment residuals, and other media enhancements into the normal media specificaiton.

2. Treatment Feasibility, Site Selection, and Practice Selection

2.1. Treatment Feasibility

Depending on site characteristics, treatment practices may be applied. Key constraints of ditch treatment include:

Existing Ditch Stability

- The velocity of water from the drainage area should not exceed the permissible velocity for channels lined with vegetation cover. It is recommended that the velocity of flow from a 1-inch rainfall not exceed 3 feet per second. This is to prevent the ditch from eroding, which can cause the treatment to fail. If the existing ditch vegetation can currently handle most rainfall events, the ditch is likely stable. The contributing drainage area should be stable without any actively eroding soils or bare patches (have 95% groundcover/forest cover). In cases such as agricultural areas where this may not be possible, erosion and sediment controls or pretreatment must be used to minimize the amount of sediment entering the practice. If the existing ditch is eroding and it is suspected that the velocity of the incoming water is too high, either install inlet protection such as riprap, or pick an alternative site. Instructions to calculate velocity can be found in the VA DEQ Stormwater Design Specification No 3. Grass Channel, page 11 (Manning's Equation) [2].

Available Space

- Soil amendments and replacements are best suited for ditches where the main bed can be excavated without destabilizing the side slopes. If not possible (e.g., side slopes already unstable, ditch too narrow), additonal space will be required to reshape a narrow ditch with a trapezoidal or parabolic bottom, side slopes 3:1 or flatter on the road side, and side slopes 2:1 or flatter on non-road side.

Longitudinal Slope

- Ditch treatments are limited to longitudinal slopes of less than 4%. Slopes steeper than 4% create rapid runoff velocities that can cause erosion and do not allow enough contact time for infiltration or filtering. If slopes are steeper than 4%, ditch retrofits would be better practices to implement. Channels designed with longitudinal slopes of less than 1% should be monitored carefully during construction to ensure a continuous grade, in order to avoid flat areas with pockets of standing water [2]. Also ensure that the inlet and outlet grade will allow for positive flow in and out of the practice.

Utilities

- For all roadside ditch projects, utilities can be a significant constraint. Designers should call the local utility location services to mark the lines and consult local utility design guidance for the required horizontal and vertical clearance between utilities and the bottom of the practice. Typically, utilities can cross grass channels if they are specially protected (e.g., double-casing) or are located below the channel invert.

2.2. Site Selection

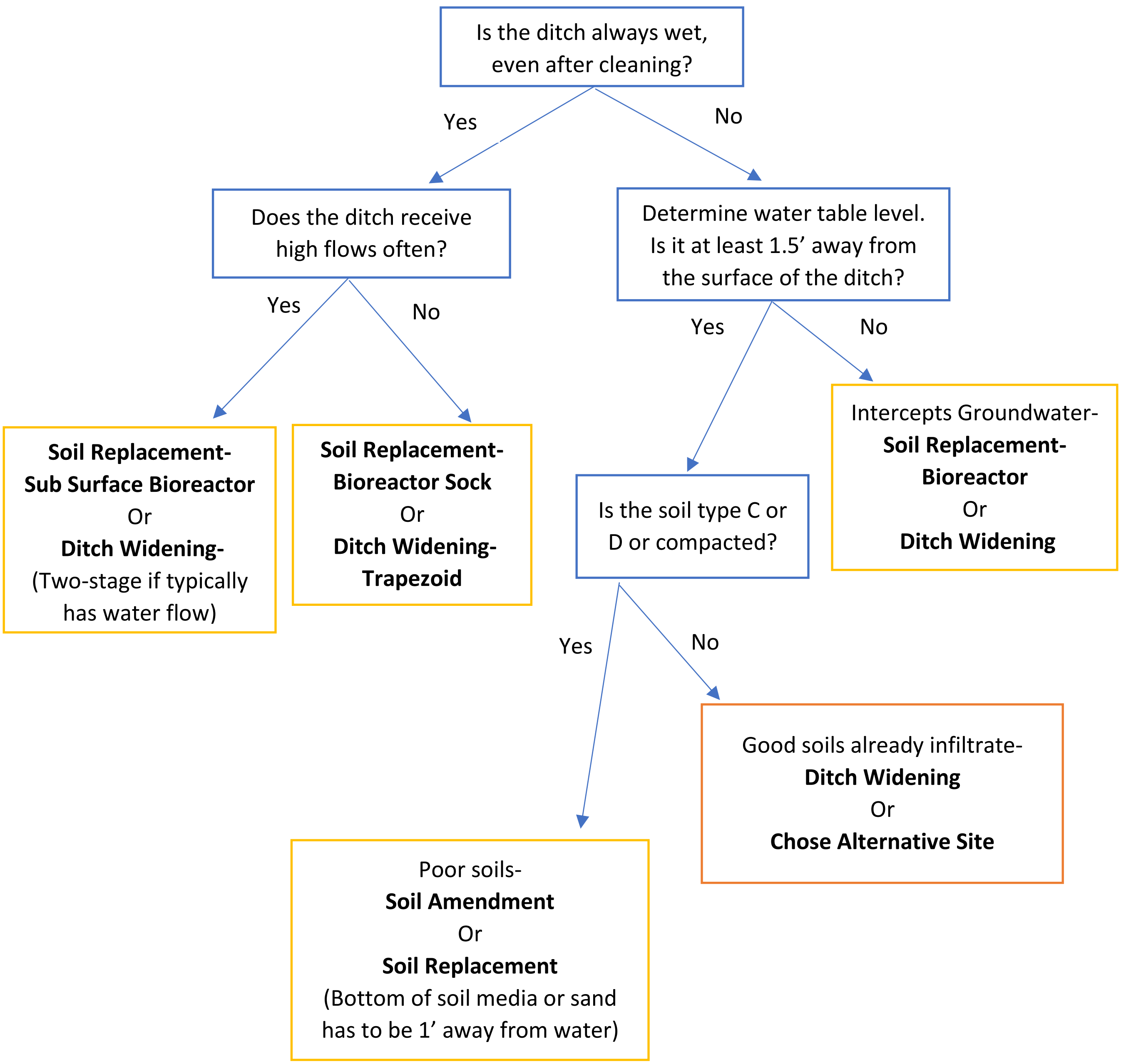
The follow are characteristics of an ideal potential treatment site:

- Limited/avoidable underground utilities
- Limited overhead utilities that can interfere with construction equipment and require utility pole setbacks
- Less than 2% longitudinal slope
- Wide right of way
- Ditch bottom and excavation depth accessible without entering ditch
- 3:1 side slopes or flatter
- The bottom of the ditch can be excavated without destabilizing the side slopes
- Stable upslope conditions
- Sites that currently require frequent maintenance may be a good candidate, if the issue can be resolved through one of these practices (if the cause of erosion is unknown or will not be remediated, it should not be chosen as a treatment site)
- Areas that receive low amounts of sediment

2.3.Treatment Practice Selection

Depending on site conditions and project goals, different treatment practices may be preferred. Figure 1 is a decision chart that may help in treatment selection.

FIGURE 1:DITCH TREATMENT DECISION CHART



Some other treatment practice parameters to consider are included in Table 2 below.

TABLE 2: PRACTICE PARAMETERS

Parameters	Ditch Widening	Soil Amendment	Soil Media Replacement
Easement required	Potentially	No	No
Cost	Medium	Low	Low-Medium
Can be built on high water table	Yes	No	No, except bioreactor
Maintenance Requirement	Low- Vegetation Control/Mowing	Low- Vegetation Control/Mowing	Medium- Mowing, minor erosion repairs
Water Quality Benefits	Low	Low	Medium
Can be implemented during routine maintenance	Potentially, depends on existing cross section	Yes	Potentially, depends on depth of media

Soils

- Soil amendments and soil replacements work best if they are improving infiltration of compacted soils or soils with low infiltration. If soils already have high infiltration rates, it may not significantly improve water quality treatment. If the existing ditch currently holds water for and extended amount of time, even after cleaning, it is likely due to a less permeable soil (C or D). Soil information can be found on the NRCS Web Soil Survey or infiltration and soil testing can be performed to determine the soil type (Appendix 8-A of Stormwater Design Specification No. 8 Infiltration) [3].

Depth to Water Table

- The location of bioreactors should be in a ditch where the bottom of the bioreactor intersects the water table. The bottom of soil amendments and replacements should be at least 1 foot away from the water table.
- If the depth to water table is uncertain, a small well can be dug to estimate the water level (Figure 3). Using an auger, dig a 4-foot-deep hole in the ditch. If the hole fills in with soil, a PVC pipe can be inserted to maintain the structure of the hole (Figure 3). After 24 hours, determine if there is water in the well and if the bottom of the practice will be at least 1 foot from the water surface.

FIGURE 2: AUGERED MONITORING HOLE

FIGURE 3: PVC MONITORING WELL

3. Design Parameters and Construction Sequence

Ditch treatment requires a few design elements to properly construct. Design details for construction of this type of project include a map showing start and end points of ditch retrofit, cross section of the retrofit (include side slope, depth and percentage of media, type of media, and width of ditch), longitudinal slope, and flow direction. Simple designs (aerial photos with hand drawn designs, notes, GIS, etc.) may be allowed as long as they provide the required information.

Table 3 contains a summary of design parameters for ditch treatment.

TABLE 3: DESIGN PARAMETER

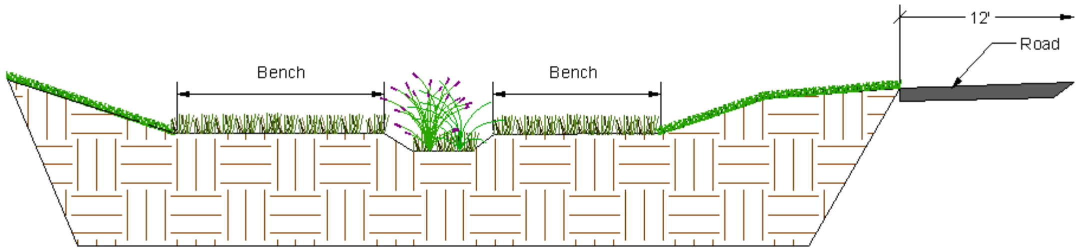
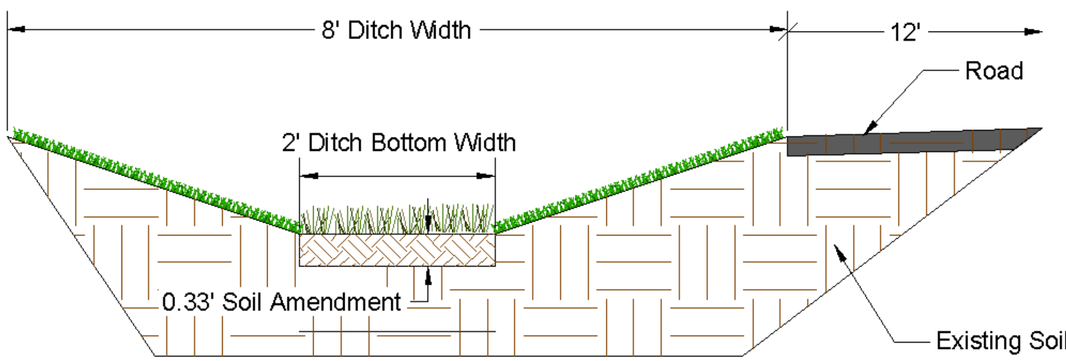
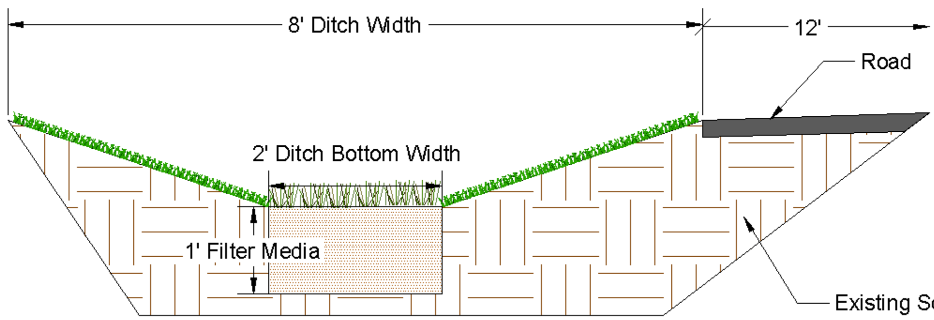
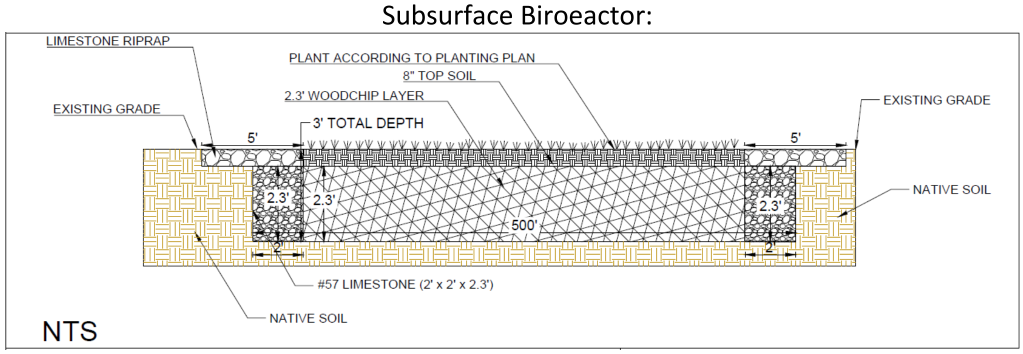
Parameter	Specification
All Treatment Practices	
Side Slopes (If reshaping ditch is necessary)	3:1 or flatter on road side, 2:1 or flatter on non-road side
Inlet and outlet protection	Provide riprap apron at all inlets and outlets
Longitudinal Slope	Less than 4%
Width of Bottom of Ditch	Minimum 2’ (except for two-stage ditch)
Erosion Control Matting	For higher velocity and steep slopes, erosion control matting may be necessary to protect the soils and seeds
Vegetation	Include vegetation that can withstand both wet and dry periods as well as relatively high velocity flows within the channel. Salt tolerant grass species and denser grasses are preferable. Grass species should have the following characteristics: A deep root system to resist scouring; a high stem density with well-branched top growth; water-tolerance; resistance to being flattened by runoff; and an ability to recover growth following inundation. Bermudagrass, Kentucky bluegrass, reed canarygrass, tall fescue, grass-legume mixture, red fescue See VA DCR Stormwater Design Specification No.3 Grass Channel [2] and No.10 Dry Swales [4] or local grass channel/dry swale design guidelines
Decompaction	After excavation, till the bottom of the ditch to a depth of 4-8 inches. Only till if soil is dry.

Performance Enhancing Devices	Incorporate 10% by volume of the PED. See the Performance Enhancing Devices Final Report for more information [5]
Bioreactor Only	
Woodchip Depth	Subsurface Bioreactor Only: Minimum of 2 feet and must intercept anaerobic conditions (low infiltration soils or high water table) Surface Bioreactor Only: Recommended 8”
Top Soil Depth	Subsurface Bioreactor Only: 8 inches
Woodchip Media	Woodchips free of fines, dirt, gravel, green material, ¼” to 1” [6]
Gravel Columns	Subsurface Bioreactor Only: #57 stone columns at beginning and end, and every 200’-250’ in between. #57 stone columns are 2’x2’x depth of bioreactor. Riprap on top of column, flush with ditch bottom.
Soil Amendment Only	
Amendment Material	Compost: 2:1 Soil to compost ratio, 100% material must pass through half inch screen, organic material 35%-65%, carbon/nitrogen ratio less than 25:1, dry bulk density 40-50 lbs/cubic foot PEDs: 10% by weight Bioretention Media: 2:1 Soil to media ratio, 85-88% sand, 8-12% soil fines, 3-5% organic matter in form of leaf compost; USDA soil types loamy sand, sandy loam, or loam Sand: 2:1 Soil to sand ratio, Clean AASHTO-M-6 or ASTM-C-33 concrete sand
Soil Replacement Only	
Replacement Media	Media has to have a porosity of .25 or higher. Existing soils can be used if soil test is done to ensure that the existing soil is USDA soil types loamy sand, sandy loam, or loam and have a Mehlich III, range of 18 to 40 mg/kg P. Bioretention Media: 2:1 Soil to media ratio, 85-88% sand, 8-12% soil fines, 3-5% organic matter in form of leaf compost; USDA soil types loamy sand, sandy loam, or loam Sand: 2:1 Soil to sand ratio, Clean AASHTO-M-6 or ASTM-C-33 concrete sand PEDs: 10% by weight added to media
Shape Change- Two Stage Ditch Only	
All	See NRCS Code 582 for more information
Bench Width (2-stage only)	Each bench should be at least 3x width of ditch bottom[1]. The benches are not required to be the same width.

Table 4 illustrates cross section examples of the different types of treatment practices.

[1] https://agbmps.osu.edu/bmp/open-channeltwo-stage-ditch-nrcs-582 : This source says 3, but a bit wide for a roadside one https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17770.wba

Table 4: Design Examples

Treatment	Design
Shape Change- Two stage ditch	
Soil Amendment	
Soil Replacement	
Soil Replacement - Bioreactors	Subsurface Biroeactor: 

	Surface Bioreactor (bioreactor sock) [7] 

3.1.Construction Sequence and Inspection

Provide erosion and sediment controls according to the local requirements. Some examples include straw wattles or filter sock around the outlet of the treatment practice.

FIGURE 4: FILTER SOCK AT THE END OF A TREATMENT PRACTICE

The following is a typical construction sequence to install a treatment practice, although the steps may be modified to adapt to different site conditions.

1. Installation should only begin after there is no active erosion upstream. Additional E&S controls may be needed during construction, particularly to divert stormwater from construction until the filter bed and side slopes are fully stabilized.
2. (Optional) If the side slopes and width of the ditch do not meet the parameters described in this guidance, it is best to reshape the ditch first and allow it to stabilize before excavating for media replacement. Flatter side slopes and a wider bottom are more stable and less prone to disturbance from equipment during excavation. Unstable side slopes can lead to clogging of the soil media, decreasing the lifespan of the retrofit.
3. Excavators or backhoes should work from the sides to excavate the treatment area to the appropriate design depth and dimensions. Excavating equipment should have buckets with adequate reach so they do not have to sit inside the footprint of the treatment area. If the full length of the treatment cannot be finished within one day, work in sections (e.g., 50-feet in length) that can be completed with seeding and/or stabilization matting at the end of the day.
4. (Soil amendment, soil replacement) The bottom of the treatment should be ripped, roto-tilled or otherwise scarified to depth of at least 6 inches to promote greater infiltration.

5. (Soil replacement only) Obtain soil media that meets the specifications and apply in 12-inch lifts until the desired top elevation is achieved.
6. (Optional) To incorporate PEDs: Incorporate amendments according to the PED Section in the soil layer.
7. (Optional) Add 8 inches of top soil on top amended or replaced meida to reach the desired top elevation. This top soil layer is to allow for plants to grow in the ditch.
8. Prepare planting bed for specified vegetation, install erosion control matting, and spread seed (Figure 5)
9. Inspect the ditch after a significant rain event to ensure that the practice is stable. Also inspect the ditch to make sure the vegetation is established and survives during the first growing season following construction.

FIGURE 5: INLET PROTECTION AND EROSION CONTROL MATTING (CURLEX®)

Subsurface Bioreactor

Before installing the woodchips, excavate the existing ditch to install the gravel columns every 250 feet, with at least one at the beginning and one at the end. Fill in trench with #57 stone and a layer of riprap on top. Cover column with filter fabric until ditch is stabilized.

Surface Bioreactor (Bioreactor Sock)

The benefit of surface bioreactors is the simplicity in design and installation. To install, scrape down two inches into the ditch bottom to clear vegetation, level substrate, and create a small depression that captures water. Lay the bioreactor sock in the depression (polypropylene mesh filled with woodchips, closed off by zip ties) and insert rebar through the sock into the ground to secure.

3.2. Construction Inspection

Inspections during and immediately after construction are needed to ensure that the treatment practice is built in accordance with the standard designs and parameters. Use a detailed inspection checklist that requires sign-offs by qualified individuals at critical stages of construction to ensure that the contractor's or roadcrew's interpretation of the plan is consistent with standard practice requirements. A construction inspection checklist should include:

- Check the soil media to confirm that it meets specifications and is installed to the correct depth.
- Check elevations such as inverts for the inflow and outflow points, elevation of the various layers.
- Verify the proper coverage and depth vegetation or soil matting has been achieved following construction, both on the filter bed and the side-slopes.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The project should be inspected after the first major rain event. The post-storm inspection should focus on whether the desired flow is occurring and the project objectives are still being met. Also, inspectors should check that the treatment drains completely within a 72-hour drawdown period. Minor adjustments are normally needed as a result of this post-storm inspection (e.g. spot reseeding, gully repair, added armoring at inlets or outfalls, and check dam realignment).

Procedures for Acceptance

Project acceptance is a visual inspection that takes place after the first major rain event after the construction phase is over to make sure it is working and meeting its project objectives. If so, the practice is accepted by the local stormwater management authority. Post construction acceptance should also include an as-built drawing or sketch showing:

- Start and end of the ditch treatment project
- Type of treatment
- Depth and type of replaced media
- Dimensions of new ditch

A written inspection report is part of every inspection and should include:

- The date of inspection;
- Name of inspector;
- The condition of:
  - Side slopes
  - Main bed
  - Inlet and outlets
  - Soil permeability
  - Vegetation
  - Any other item that could affect the proper function of the stormwater management system
- Description of needed maintenance

4. Sediment and Nutrient Crediting Protocol and Design Example

4.1. Credit Calculations

The Chesapeake Bay Program has sediment and nutrient credit protocols for various best management practices. None of the ditch treatment practices have a protocol specifically for it; therefore, crediting methods from similar practices are used. It is assume all the treatment practices are stormwater treatment (ST).

To determine the runoff volume treated by a retrofit practice, the amount of water held in the practice and the impervious area treated is needed. The standard equation used to determine the amount of runoff volume in inches treated at the site is:

$$\text{Runoff Depth Captured per Impervious Acre (inches)} = \frac{RS(12)}{IA}$$

Where:

RS = Runoff Storage Volume (cubic feet)
IA = Impervious Area (square feet)

For soil amendments and replacements, the runoff storage volume is the water stored in the soil media layer.

RS = Depth of filter media x length of ditch x width of ditch x 0.25 (porosity of filter media)

$RS_{shape\ change}$ *= 2"/12 x length of ditch x width of ditch*

For shape change treatment, the runoff storage volume is the thin layer of water being trapped between the vegetation. For crediting, it is estimated to be 2 inches of ponding.

Table 5 summarizes how to calculate the runoff storage volume for the different treatment practices. Soil amendment has a maximum credit depth of 8 inches, as this is typically the maximum depth to easily amend. If deeper treatment is needed, soil replacement should be considered.

Table 5: Treatment and Crediting Reference

Treatment	Runoff Storage Volume
Shape Change	Ponding= 2" Maximum
Soil Amendment	Soil Amendment Depth = 8" Maximum
Soil Replacement	Soil Replacement Depth

To use the retrofit curves, take the ***runoff depth captured per impervious acre*** value and find where it intersects either the ST curve. The y-axis value will be the removal rate. Nitrogen, phosphorus and sediment each have their own graphs. Retrofit curve equations are provided in Table 6 for ease of use. Enter the ***runoff depth captured per impervious acre*** as the x value and the output, y, is the removal rate for the corresponding pollutant.

Table 6: Retrofit Curve Equations

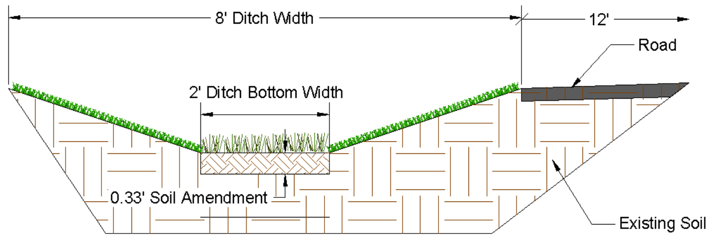
TN	$y = 0.0152x^5 - 0.131x^4 + 0.4581x^3 - 0.8418x^2 + 0.8536x - 0.0046$
TP	$y = 0.0239x^5 - 0.2058x^4 + 0.7198x^3 - 1.3229x^2 + 1.3414x - 0.0072$
TSS	$y = 0.0304x^5 - 0.2619x^4 + 0.9161x^3 - 1.6837x^2 + 1.7072x - 0.0091$

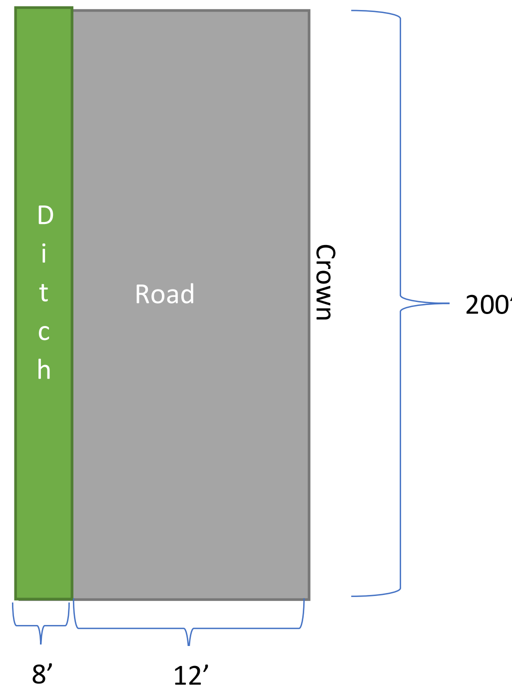
Once the removal rate is found, the total load reduced can be calculated:

Removal rate (%) * Loading Rate (lb/acre/yr) * drainage area (acres) = Load Reduction

If there is more than one type of loading rate land use, a composite number should be used.

4.2.Credit Calculation Example





A ditch receives a soil amendment with compost treatment and is mixed to a depth of 4 inches (0.33'). The ditch is 8' wide (total) and 200' long. The contributing drainage area is the road, which is 12' by 200'. The DA is from the middle of the road (the crown) to the edge of the ditch.

Runoff Storage Volume (RS)= (0.33*2*200*0.25)

= 33 cubic feet

Impervious Drainage Area = 200' x 12' = 2400 square feet

Runoff Depth Captured per Impervious Acre (inches) = 33 cubic feet * 12/ 2400 square feet = 0.17"

Using the equations in Table , the removal rate is:

Total Nitrogen Removal: 11.5%
Total Phosphorus Removal: 18.1%
Total TSS Removal: 23.1%

The loading rates can be found using the Chesapeake Assessment Scenario Tool (CAST) Model. For this example, the loading rates from Table 7 were used:

TABLE 7: LOADING RATE FROM "FINAL MODEL DOCUMENTATION FOR THE MIDPOINT ASSESSMENT-5/11/2018" DOCUMENT

Land Use	N (lbs/acre/year)	P (lbs/acre/year)	TSS (tons/acre/year)
Developed Non-regulated Road	22.45	0.83	1.49

With the drainage area of 2400 sf (0.055 acres), the load reduction can be calculated as shown in Table 8.

TABLE 8: LOAD REDUCTION CALCULATIONS

Pollutant	Removal Rate from ST Curves	Loading Rate from Table 6 (lbs/acre/year)	Load Reduction (lbs/year)
Nitrogen	11.5%	22.45	11.5%*22.45*0.055=0.14
Phosphorus	18.1%	0.83	18.1%*.83*0.055= 0.008
TSS	23.1%	2980	23.1%*2980*0.055= 37.9

4.3. Performance Enhancing Devices

Performance enhancing devices (PEDs) can be used as a soil amendment or used with a soil replacement (i.e. bioretention media with biochar). For treatments that include PEDs, 10% is added to the retrofit curve removal rates for phosphorus.

Using the previous soil amendment example, if the soil was amended with 10% biochar, the removal rates would be calculated as shown in Table 9.

TABLE 9: LOAD REDUCTION CALCULATIONS WITH PEDS

Nutrient	Compost Only, No Biochar	With Biochar	Load Reduction (lbs/year)
Nitrogen	11.5%	11.5%	0.14
Phosphorus	18.1%	18.1%+(10%*18.1%)=19.9%	0.009
TSS	23.1%	23.1%	37.9

5. Maintenance and Visual Indicators

Routine maintenance checkups occur annually as part of regular maintenance visits and are used to immediately correct minor maintenance problems. The checkups are also used to provide quality control on maintenance activities, determine whether the road crew needs to schedule a follow up visit to repair moderate maintenance problems.

<table>
<tr><th colspan="2">INDICATOR</th><th>Pass</th><th>Minor</th><th>Moderate</th><th>Severe</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Inlet and outlet erosion</td><td>None</td><td>Some rill erosion</td><td>Erosion of 6" or less</td><td>Erosion of more than 6"</td></tr>
<tr><td colspan="4">
Severe Erosion at Inlet</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Side Slope and bed erosion</td><td>None</td><td>Some rill erosion</td><td>Erosion of 6" or less (or side slope 25% steeper than design)</td><td>Erosion of more than 6"(or side slope 50% steeper or more)</td></tr>
<tr><td colspan="4">
Severe side slope erosion</td></tr>
</table>

<table>
<tr><th colspan="2">INDICATOR</th><th>Pass</th><th>Minor</th><th>Moderate</th><th>Severe</th></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Vegetation Cover</td><td>>90% cover</td><td>75-90% cover</td><td>50-75% cover</td><td>Less than 50% cover</td></tr>
<tr><td colspan="4">
Severe vegetation cover condition on side slopes</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Vegetative Maintenance</td><td>Well maintained, few weeds</td><td>Isolated areas need re-seeding or weeding</td><td>Needs major mowing and weed eradication</td><td>Needs major mowing or shrub/tree removal or replanting</td></tr>
<tr><td colspan="4">
Major vegetation maintenance- shrub removal</td></tr>
</table>

INDICATOR		Pass	Minor	Moderate	Severe
5	*Sediment Deposition*	*None*	*A few isolated caking areas*	*Deposits up to 3" deep*	*Deposits more than 3" deep*
		 Minor sediment deposition	 Major sediment deposition- Deposits up to 3”		

6. Verification Procedures

Inspection of this practice is needed to verify that the ditch treatment has been implemented and runoff water is being treated and therefore can continue to earn its pollutant reduction credits, in the context of either a local or Bay-wide TMDL. The inspection should occur a minimum of once every 3 years and include comparing the as-builts and field assessments. Verification uses a subset of the list of visual indicators that assess the hydrologic function and pollutant removal capability of the RDM practice, by answering three simple questions:

1. Does it still physically exist. i.e. can you find it and are the conditions and cover in the contributing drainage area still the same?
2. Is it still operating to treat and reduce runoff as it was originally designed?
3. Is the maintenance condition sufficient to still support its pollutant reduction functions?

Table 10 provides specific visual indicators that should be used to answer the questions above. A “severe” maintenance problem detected for one or more of these indicators, means that the facility fails and will lose pollutant removal credits unless it is brought back into compliance.

TABLE 10: PERFORMANCE VERIFICATION INDICATORS

Condition Type	Visual Indicators	Description
Hydrologic Condition	Severe inlet obstruction	Runoff is not able to get into ditch
	Severe erosion at outlet	Runoff is bypassing treatment
	Standing water for an extended period of time	Runoff is not fully being treated
Maintenance Condition	Inadequate vegetative cover	Runoff is not fully being treated
	Severe inlet or side slope erosion	Sediment delivery to filter bed

References

[1] Chesapeake Bay Roadside Ditch Management Team, "Draft Technical Memo," 2017.

[2] Viriginia DEQ, "Virginia DEQ Stormwater Design Specification No. 3 Grass Channels," 1 3 2011. [Online]. Available: https://www.swbmp.vwrrc.vt.edu/wp-content/uploads/2017/11/BMP-Spec-No-3_GRASS-CHANNELS_v1-9_03012011.pdf.

[3] VA DEQ, "VA DEQ Stormwater Design Specification NO. 8 Infiltration," 1 1 2013. [Online]. Available: http://chesapeakestormwater.net/wp-content/uploads/downloads/2014/04/VA_BMP_Spec_No_8_INFILTRATION_FINAL_Draft_v2-0_01012013.pdf.

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[5] D. Hirschman, B. Seipp and T. Schueler, "Final Report- Performance Enhancing Devices for Stormwater Best Management Practices," 24 4 2017. [Online]. Available: http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2017/05/APRIL-26-FINAL-PED-DOCUMENT.pdf.

[6] L. Christianson, "Woodchip Bioreactors for Nitrate in Agricultural Drainage," *Agriculture and Environment Extension Publications ,* 2011.

[7] R.L. Schneider E. Chase S. Dunn W. Pluer N. Baker and S. Bloser, "Using Scaled-down Woodchip Bioreactors in Roadside Ditches to Filter out Dissolved Nitrate (Draft)," This work was funded through the U.S.D.A.'s Conservation Innovation Program, support from Bradford County Soil and Water Conservation District, USDA Hatch Grant to Cornell. Cornell University, Ithaca, NY; PA Center for Dirt and Gravel Roads, PA State Univ, 2018.

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