Roadside Ditch Management Manual

For Rural and Coastal Communities

FFY2017 Chesapeake Bay Regulatory and Accountability Program Grant

THE GREAT SEAL OF TALBOT COUNTY MARYLAND

CENTER FOR WATERSHED PROTECTION

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Contents

Introduction

The objective of this manual is to provide guidance on roadside ditch management practices that improve water quality and can be incorporated into existing management programs in rural eastern shore communities. Many of the management practices involve low or no-cost modifications to normal ditch maintenance; some have the potential to decrease maintenance costs.

Figure 1: Roadside Ditch in Talbot County

The selection of practices incorporated into this manual were based on improving water quality, while maintaining road safety, and minimizing additional costs associated with these changes. All the practices are within the Right-of-Way (ROW) to allow for easy implementation by government agencies. Although there are numerous practices that can improve water quality, the guide is a starting point for users who wish to improve water quality in their roadside ditches. The goal is for this manual to be a living document, intended to have practices added or modified as more information on successful implementations are gathered. As science and research progresses, additional management practices with water quality benefits can also be added.

How to Use this Manual

This manual provides a practical guide for users who maintain ditches to incorporate these beneficial practices into their existing programs. There are many existing resources available with this information about ditch management practices; this guide extracts applicable information from these resources to make it easily accessible. Additional resources are in the Appendix, as this document is only a portion of what can be done to ditches to improve water quality. The guide is available in editable form, allowing users to tailor the guide to their needs.

The manual is divided into two chapters. Chapter 1 includes well established practices that could be easily incorporated into existing roadside ditch management programs. While communities may only have the resources to accomplish a handful of these practices, the information is available to allow for long term planning for potential incorporation in the maintenance plan. Chapter 2 focuses on additional efforts that can improve water quality during ditch management, but additional resources external of existing programs may be needed. These include retrofitting a ditch into a dry swale, which may require engineering design. The manual encourages the idea of “dig once”, meaning that if heavy excavation is planned in a ditch (ex. culvert replacement), it is most cost effective and environmentally friendly to also incorporate a stormwater retrofit.

Chapter 1 includes improvements to existing roadside ditch management and is divided into six sections:

- Vegetation Establishment
- Mowing
- Herbicide Application
- Ditch Cleaning/Excavation/Stabilization
- Agricultural Leads
- Education and Outreach

Each section includes a summary, example practices that are not good for water quality, and examples of changes that are good for water quality and overall ditch management. The sections will provide a general overview of the topic, but the Appendices will include specifics that can be better tailored to your location or ditch.

Chapter 2 describes ditch reconstruction, which are changes to roadside ditches that require more design and engineering work. It is divided into two sections:

- Characteristics of ditches that would benefit from ditch reconstruction
- Ditch reconstruction opportunity

While the manual focuses on the Eastern Shore, many of the ideas can be incorporated in other roadside ditches. Although widening or expanding a ditch buffer may be beneficial, it requires coordination with land owners and is currently outside the scope of this project.

Manual Development

Talbot County is located on the Middle Eastern Shore of Maryland, where the rural landscape and proximity to the Chesapeake Bay have challenged local governments there to identify cost-effective solutions for meeting their Watershed Implementation Plan (WIP)'s urban nutrient and sediment reduction goals. With only 15% of the County's land area classified as "urban" (often, small towns), available space to install stormwater retrofits is limited, especially when considering that an even smaller portion of that land is publicly owned. The County, through engagement with numerous partners and stakeholders, has identified ditch management as one solution that would address these challenges while cost-effectively meeting requirements under Maryland's Phase II WIP. Roadside ditches are common landscape features on the Eastern Shore, paralleling both sides of much of the 370 miles of Talbot County roads, as well as 140 miles of private roads and 155 miles of state roads located in Talbot County. Cumulatively, these ditch networks intercept approximately 20% of the runoff and shallow interflow generated from adjacent land areas and transport this flow rapidly to nearby streams (Schneider and Boomer, 2016).

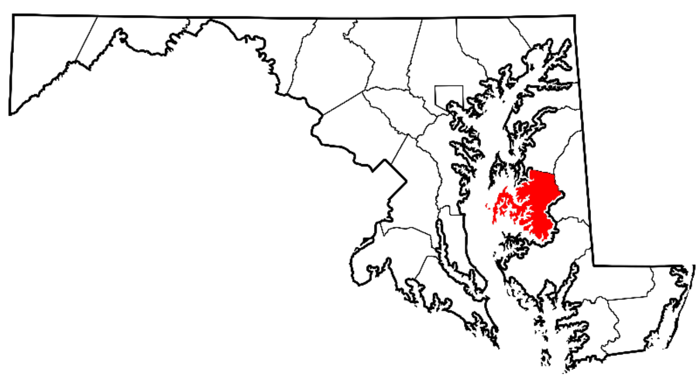


Figure 2: Talbot County Highlighted in Map of Maryland

As such, roadside ditches have a major influence on downstream water quality. They serve as rapid conduits of pollutants, such as sediment, nutrients, and bacteria, in runoff from farm fields and developed lands to surface waters. Ditches themselves can also be a major source of sediment when cleaned or scraped and left exposed to erosion during storms. Highway maintenance crews report that scraping without re-vegetation was a common practice throughout thousands of road miles (Schneider and Boomer, 2016). Ditches can transform contaminants, either acting as a filter or alternatively as a contaminant source. Because of the extent and location of roadside ditches on the Eastern Shore, there is great potential to significantly increase water quality improvements by progressively changing ditch management practices.

In recent years, several related efforts have been developed and successfully implemented in numerous areas throughout the Country. This manual, created by the Talbot County Department of Public Works and the Center for Watershed Protection, summarizes both routine maintenance changes, as well as large scale restoration projects that can be applied to roadside ditches. This project is also part of the ongoing efforts of the Healthy Waters Round Table organized by the Chesapeake Bay Foundation, which is working to improve coordination and collaboration of WIPs throughout the Eastern Shore. The Healthy Waters Round Table has identified best management practice (BMP) maintenance as one of its priorities, citing the need for better education of maintenance workers who, for example, may not understand the importance of “cleaning” a ditch without exposing raw soil and removing its vegetation. The 2015 Healthy Waters Round Table (2015) report states that, “Clear maintenance standards will be required to provide frontline workers and supervisors with an understanding and sensitivity for maintaining their organization’s healthy waters initiatives.” The proposed project seeks to accomplish this objective with regards to ditch management.

Although not a watershed plan, the proposed project also relates to the 2014 STAC Re-Plumbing the Chesapeake Watershed workshop report (Schneider and Boomer, 2016), which makes recommendations for improving roadside ditch management to meet TMDL water quality goals. The manual will address three of the STAC report’s concluding recommendations:

- Develop a broad-based education and outreach program to increase awareness and provide guidance to key stakeholder groups.
- As a core component of the education resources and outreach, develop BMP implementation guidelines that include a full inventory of BMPs categorized based on when and where a practice is appropriate. Guidance on where to target BMPs, based on performance-and cost-effectiveness, also is essential.
- Support funding for roadside ditch improvement and management practices.

After performing an extensive literature review to summarize best practices used by other jurisdictions as well as relevant research findings on ditch management, the Center worked with practitioners to develop roadside ditch practice recommendations that were simple and inexpensive to implement. Additionally, ditch reconstruction and education and outreach were included into the manual, as ditch reconstruction can achieve the highest amount of water quality improvements and education and outreach were consistently mentioned an issue by practitioners. The draft manual was reviewed by multiple organizations and changes have been incorporated into the final version of the manual.

Chapter 1: Management Improvements

Chapter 1 of this manual includes water quality benefiting management practices that can be easily incorporated into existing maintenance plans. These sections in this chapter include:

A. Vegetation Establishment
B. Mowing
C. Herbicide Application
D. Agricultural Leads/Side Inlets
E. Ditch Cleaning/Excavation/Stabilization
F. Education and Outreach

Each section starts with an explanation of the section, and then shows examples of problems that are commonly encountered in ditches and issues those problems may cause. At the bottom of a problem page is a reference to a solution page, which includes a practice that can decrease negative water quality impacts. The solutions provide a brief introduction to an improved management practice and resources for more information are available in the appendices.

Vegetation Establishment

Established ditch vegetation reduces long-term maintenance time and cost by stabilizing the soils, which prevents erosion and gullies. Vegetation can decrease erosive forces of water, which can damage road surfaces.

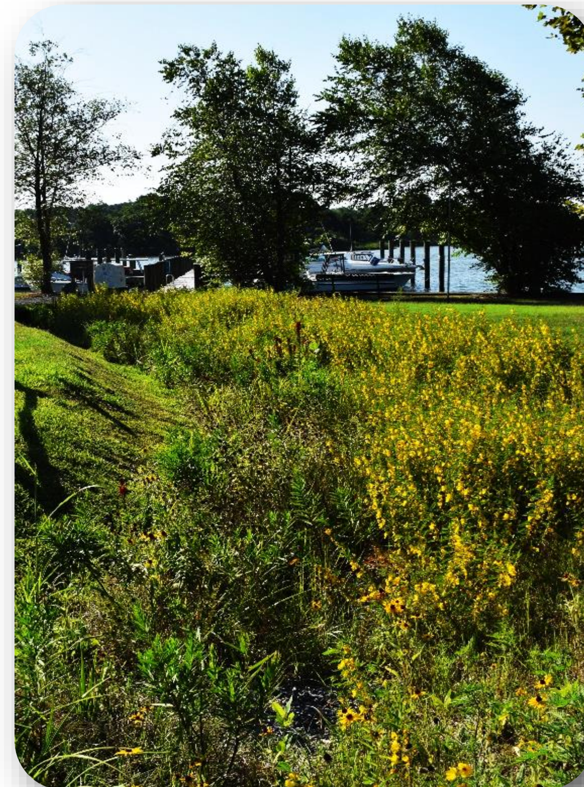


Figure 3: Well Established Vegetation in a Ditch

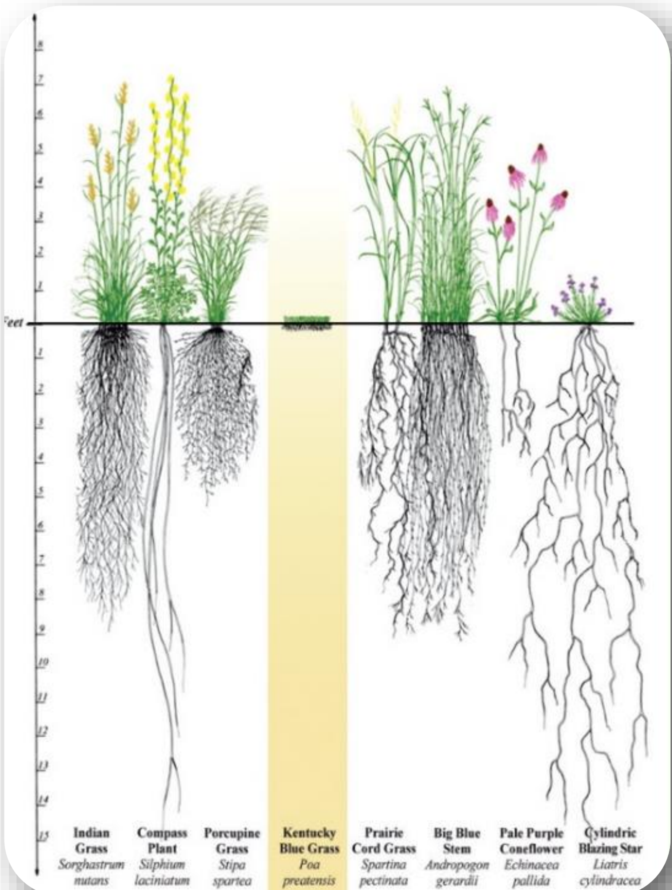


Figure 4: Example of Vegetation Root Systems (Conservation Research Institute modified by Tip of the Mitt Watershed Council)

Different types of vegetation planted in a ditch can improve water quality, stabilize soils, improve pollinator and wildlife habitat, and reduce maintenance activities. Deep-rooted vegetation can improve soil infiltration, which provides water quality treatment. The vegetation itself can also uptake pollutants from stormwater runoff. Native species and wildflowers can reduce mowing frequency, herbicide spraying, and presence of weeds.

Factors such as **slope**, **vegetation selection**, **timing**, **seeding rate**, and **maintenance during the first two growing seasons** after seeding play a critical role in vegetation establishment.

Since the vast network of existing ditches are typically already vegetated, this section primarily references the seeding and/or planting of newly constructed ditches, recently cleaned ditches, or places where targeted repair is necessary.

Problem: Low Diversity Grass Mix

When ditches are seeded with a low diversity grass mix, grass is more likely to die off during periods of stress. Visual signs of this include: bare unvegetated patches, brown grass or vegetation, erosion or sediment in the ditch, and little or no species diversity.

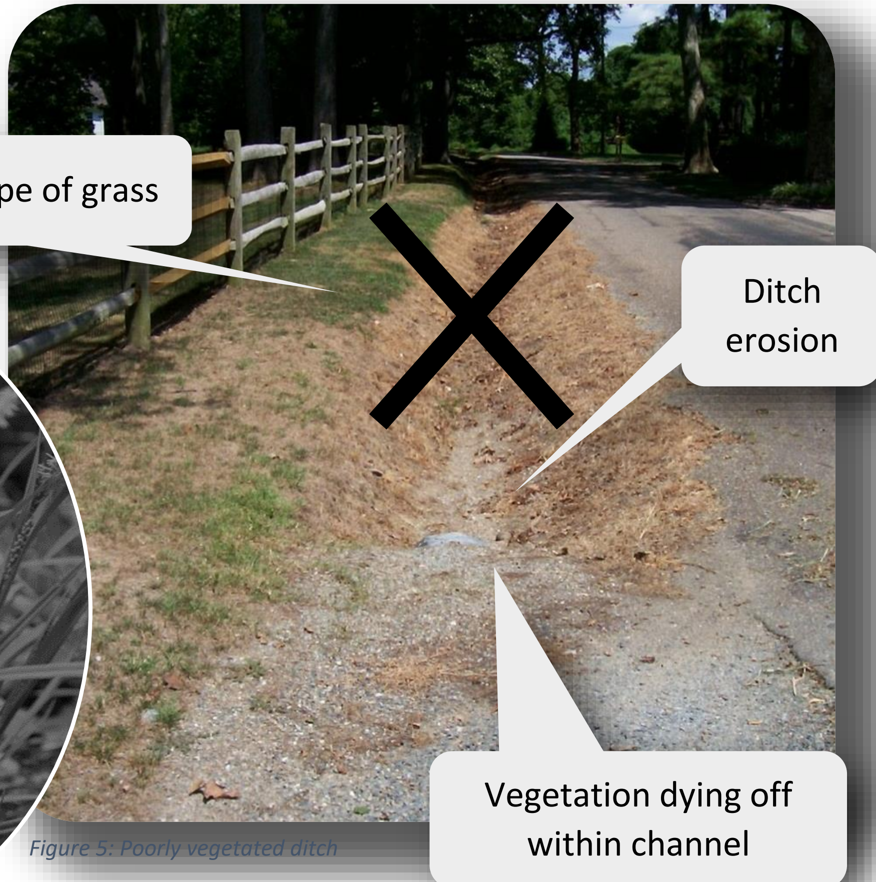
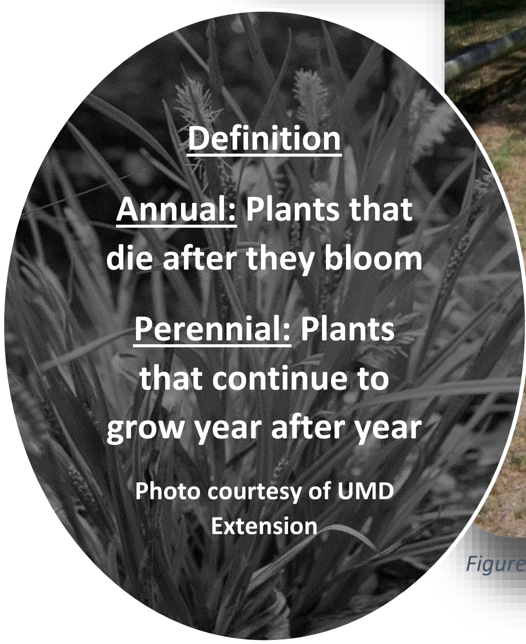


Figure 5: Poorly vegetated ditch



Negative Impact on Ditch

Annual grasses with shallower root systems are more prone to die off

↓

Ditch becomes unstable, allowing the surrounding soils to erode

↓

Ditch fills with sediment- holds less water

↓

Potential for flooding

Negative Impact on Environment

Pollutants (sediment, nitrogen and phosphorus) enters Chesapeake Bay, causing cloudy water and algae blooms, harming wildlife and potentially humans

Less diverse environment for insect and animal species

See Pages 13 for Solutions

Problem: Unvegetated Ditch

When a portion of the ditch is unvegetated with exposed bare soil, it can destabilize the ditch and cause erosion. Unvegetated sections can be due to the seed not germinating, new seedlings not establishing, grass dying off, or herbicide misuse.

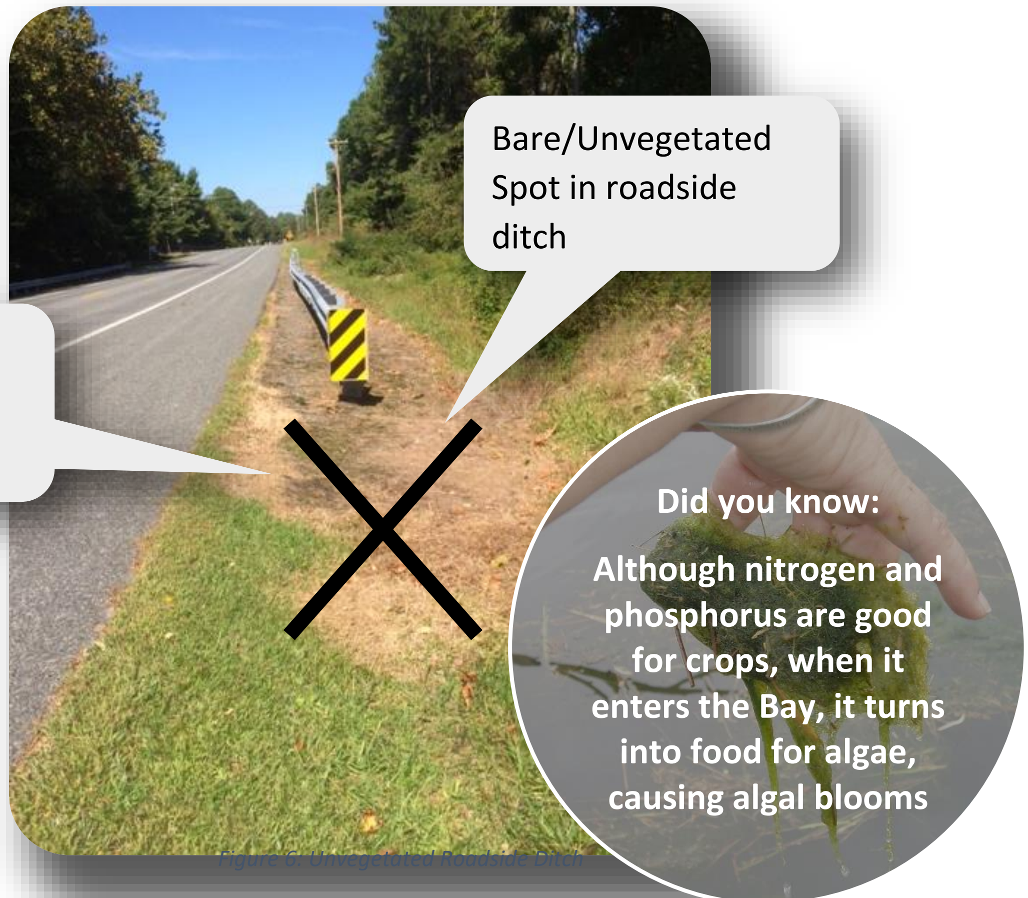


Figure 6: Unvegetated Roadside Ditch

Negative Impact on Ditch

No vegetation present to slow down runoff (fast moving water can cause more erosion)

Unvegetated areas are unstable, leading to erosion in the ditch

Could start to erode roadway

Negative Impact on Environment

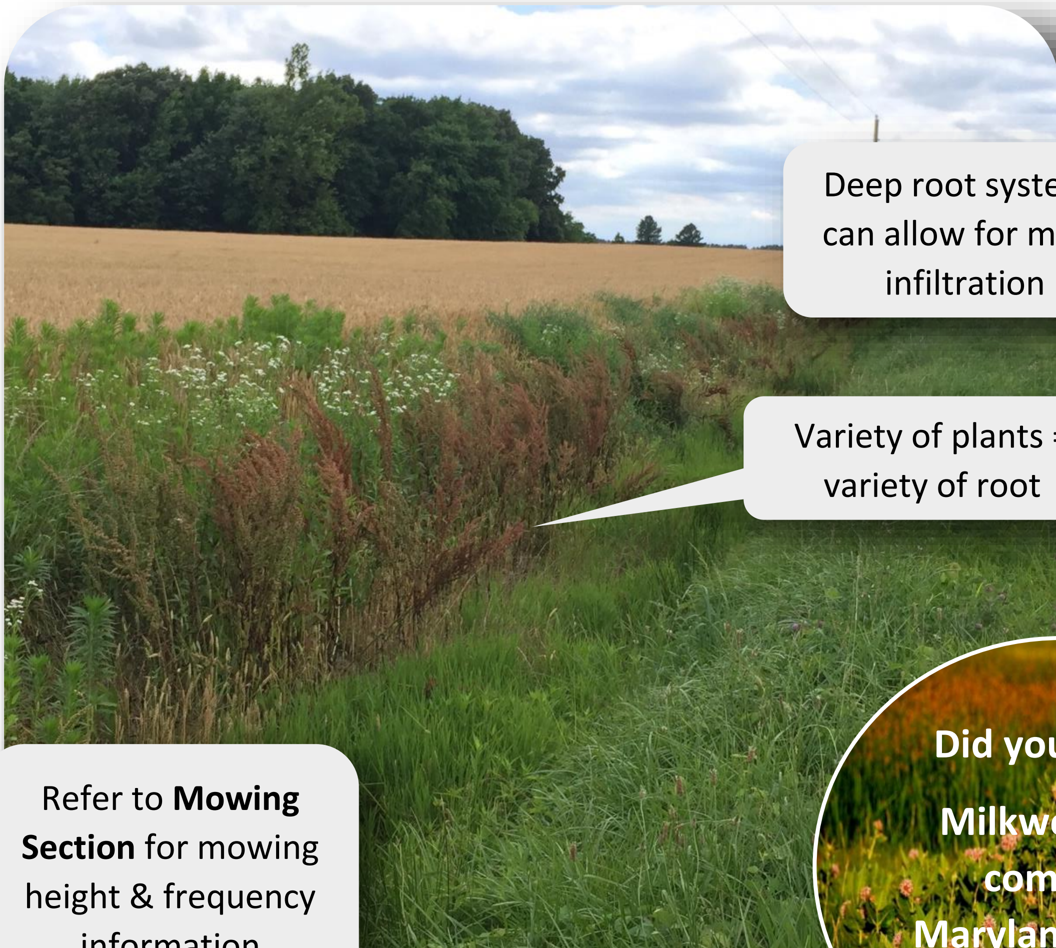
Pollutants (sediment, nitrogen and phosphorus) enter Chesapeake Bay, causing cloudy water and algae blooms, harming wildlife and potentially humans

Potential for invasive species to grow in bare spots

See Pages 14-17 for Solutions

Solution: Stabilize Ditch with Native Species Mix

Match seed mix to site conditions- see Eastern Shore Ditch Seed Selection Guide in **Appendix A-1**



Refer to **Mowing Section** for mowing height & frequency information

Figure 7: Well vegetated ditch

Impact on Ditch

Stabilizes ditches, less vegetation die off, less erosion

Impact on Environment

Native species have a variety of root structures and depths which increase:

- -Infiltration of water (can filter pollutes and reduce flooding)
- -Erosion control
- -Pollutant uptake

Native species are also resources for pollinator species. Pollinator species, in turn, are necessary to propagate vegetation.

Impact on Maintenance

Decreases maintenance as native species tend to require less upkeep

Solution: Sow Seed with Hydromulch

Sow seed with light layer of hydromulch (300 lb/acre). Cover with 2nd layer of hydromulch and tackifier (900 lb/acre).

Alternatively, sow seed by hand, then cover with hydromulch or erosion control blanket as site conditions dictate.

See also **Ditch Cleaning, Excavation, and Stabilization Section**

Figure 8: Ditch with Hydroseed
Image Credit: Cornell University
http://ei.cornell.edu/watersheds/Ditches/Ditch_7.html

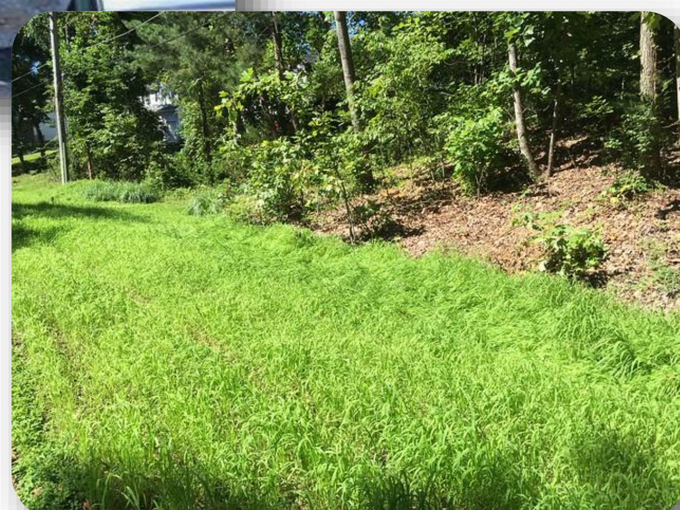


Figure 9: Vegetation after Hydromulch

Did you know: Hydromulch is hydroseed without seed

Impact on Ditch

Decreases seed wash off before rooting

⇓

Increases success of vegetation establishment

Impact on Environment

Vegetation reduces water velocity and settles out sediment before entering the Bay

⇓

Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Impact on Maintenance

Decreases maintenance by increasing vegetation survival

Solution: Sow Newly Constructed Areas Late Fall - Early Winter

Sow seed in late fall or early winter (Nov-Feb)- Although the seeds may not immediately sprout, some seeds require the cold moist period to trigger the seed's embryo. Seeds will germinate naturally when conditions are best for each species. This cold stratification process can occur naturally when seeded in late fall or early winter. If timing is not possible, cold-stratify seeds in refrigerator for 3 months prior if sowed in May-June. Sow any areas where soil has been re-exposed. See Appendix A-1 for seed selection resources and A-2 for more information on seeding techniques.

Figure 10: Newly graded ditch ready for seed application
Image courtesy of Leslie Cario

See **Appendix A-1** for seed selection resources and **A-2** for more information on seeding techniques.

Impact on Ditch

Better vegetation growth when seeds germinate

↓

Stabilizes ditches, less erosion

Impact on Environment

Vegetation reduces water velocity and settles out sediment before entering the Bay

↓

Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Impact on Maintenance

Reduces maintenance by reducing re-seeding

Solution: Control Weeds in 1st Growing Season	Impact on Ditch
When vegetation reaches 18”-24”, trim back to 6”-8” for first year (3-4 times as needed over the growing season)	Strategic height reduction **prevents weeds** from becoming dominant Mowing allows sunlight to reach native vegetation

Figure 11: Ditch with established pollinator species
Image courtesy of Leslie Cario

For additional management practices that benefit pollinators and wildflowers, see **Appendix A-3, A-4, A-5**

Impact on Environment

Timing of mowing protects Monarch butterflies during breeding (on Delmarva, aim to mow **before April 1, after Nov. 1, and in the latter third of June if necessary**)

Impact on Maintenance

Decreases need for weeding

Control Weeds in 2nd and 3rd Growing Seasons

Time weed control mowing with recommended mowing windows (see **Mowing Section**)

Early Spring (before April 1) trim back to 3.5”-4.5” and then maintain at 12”-15” by trimming approximately 2 times over growing season *for the second and third years.*

Avoid over-mowing, which can stunt plant growth, decrease blooms, and reduce amount and type of pollinators (3).

Swamp Milkweed

Figure 13: Swamp Milkweed
Image credit: https://www.fs.fed.us and Jennifer Anderson, USDA-NRCS PLANTS Database

Bee Balm with Pollinator (hummingbird moth)

Figure 12: Bee Balm with Pollinator
Image credit: http://ohioline.osu.edu

Impact on Ditch

Allows **native species** to grow and surpass many weed species

Impact on Environment

Timing of mowing protects Monarch butterflies during breeding– See **Mowing Section**

Grass buffers can also take up some of the nutrients from the field

Impact on Maintenance

Decreases need for weeding

Adds restrictions to mowing times

Works Cited

1. **USDA. *Conservation Fact Sheet: Native Herbaceous Plantings Establishment, Maintenance, and Management for Wildlife Habitat and Pollinators.***

2. USDA Maryland Conservation Planting Guide. Draft Nov. 2016, p. 39.

3. Barton, S et. al. *Enhancing Delaware Highway Roadside Vegetation Establishment and Management Manual.* Dover : Delaware Department of Transportation, 2009.

4. DOT, US. Roadside Best Management Practices that Benefit Pollinators.

5. 2016-2017, Ernst Conservation Seed Catalog.

Mowing

Mowing is one of the most common roadside maintenance practices. Mowing roadside ditches is necessary to maintain sight distance, enhance appearance, control undesirable vegetation, and provide proper drainage. Ditches should be shaped to fit mowers for ease of ditch maintenance.

Figure 14: Blades of Mowed Grass

Mowing to the proper height can encourage a healthy grass stand, provide habitat for pollinators and butterflies, and allow the ditch to perform stream-protection functions of runoff filtration and nutrient uptake.

If not performed carefully, mowing practices can weaken vegetation and increase maintenance needs. If vegetation in the ditch is unhealthy, or too short, the ditch will not be able to perform its stream-protection functions of trapping sediment and nutrients.

Mowing the front side of the ditch is a necessary activity for public safety and safe road sight distances. The bottom and back portions of the ditch may be mowed less frequently, only as specified, even as infrequently as once every year in Eastern Shore counties. The bottom and back portions of the ditch need only be mowed to keep trees and other woody vegetation from growing in the ditch.

Problem: Short Mowing Height

When grass is cut too short (also called scalping), it also shortens the grass roots and weakens the grass. The grass is less able to handle drought stress because there is less leaf tissue and root system. The vegetation is then more likely to die off and create bare or eroded spots, which need to be re-planted and maintained.

Figure 15: Scalped mowed section
Image Credit: http://lawnmastersllpc.com/blog/wp-content/uploads/2016/11/scalping-a-lawn.jpg

Negative Impact on Ditch

Short mowing height reduces root depth, weakens and kills grass

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Increases maintenance needs, re-seeding, and ditch erosion

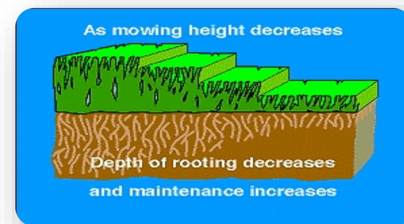


Figure 16: Mowing Height and Root Depth
Image Credit: http://www.whygoodnature.com/mowing-and-watering-tips

Negative Impact on Environment

Sediment enters Chesapeake Bay, causing cloudy water, harming wildlife

See Page 23, 26 for Solutions

Problem: Dull Blades

Mowing with a dull blade stresses the grass and weakens the vegetation cover. It can also lead to bare or eroded spots. Signs of dull blades include ragged or frayed ends of grass blades, brown or tan grass or ends of grass, and bare spots in the vegetation.

Figure 18: Channel with brown grass

Figure 17: Frayed grass due to dull blades
Image Credit: Missouri Botanical Gardens
http://wwww.missouribotanicalgarden.org

Negative Impact on Ditch

Damage to grass from dull blades can cause grass to die, exposing bare dirt

↓

Ditch erosion

Figure 19: Dull Blade
Image Credit:
https://www.mowersource.com

Negative Impact on Environment

Sediment enters Chesapeake Bay, causing cloudy water, harming wildlife

See Page 24, 26 Solutions

Problem: Mowing During Wet Conditions

Signs of mowing during wet conditions include rutting, torn up grass spots, and bare spots or exposed soil.

Mowing during wet conditions damages vegetation and makes vegetation recovery more difficult.

Figure 20: Damaged vegetation Image Credit: http://msue.anr.msu.edu/news/wet_spring_conditions_create_challenging_turfgrass_conditionsbehind-flail-mower-brush-mower-3.jpg

Negative Impact on Ditch

During wet conditions, the soils may not be suitable for equipment, causing mud tracks and **damaging vegetation**

↓

Limited recovery of damaged vegetation or during extreme weather conditions

↓

Weakened grass stand

↓

Ditch erosion

Negative Impact on Environment

Increases soil erosion, bring sediment into Chesapeake Bay

See Page 25-26 for Solutions

Solution: Set Mowing Height to Approximately ⅓ Grass Height

Set the mowing height to approximately 1/3 the existing grass height to avoid mowing too short and weakening grass. For many roadside ditches, only side closest to the road needs to be mowed regularly for safe road sight distance. Mowing at recommended height for grass (*3 ½" – 4 ½"*).

Figure 21: Mower Blades
Image Credit: https://www.orecamerica.com/wp-content/uploads/2015/01/walk-behind-flail-mower-brush-mower-3.jpg

Impact on Ditch

Deepens and strengthens roots

⇩

Improves vegetation density

Impact on Environment

Decreases dirt patches and sediment erosion

⇩

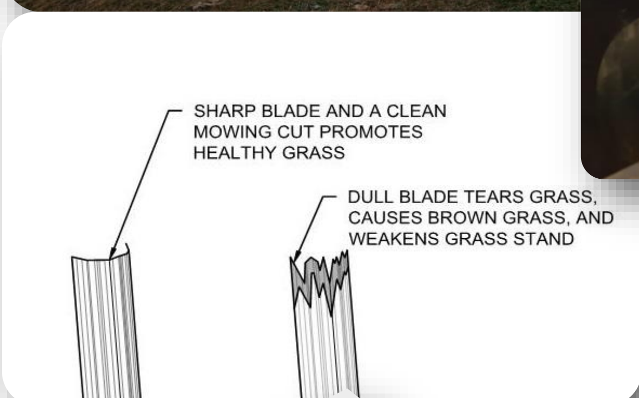
Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Impact on Maintenance

Reduces vegetation reestablishment costs

Solution: Sharpen Blades before each Mow

If blades are sharpened before each mow, it will help promote a healthy grass stand by decreasing damages to grass blades.



Sharp blade for mowing
No torn vegetation or browning

Figure 22: Sharpening Mower Blades

https://www.farmequipmentsalesinc.com/blade-sharpening
https://www.youtube.com/watch?v=U4ppmcUWAAM

Impact on Ditch

Improves vegetation health

Impact on Environment

Healthy vegetation reduces water velocity, uptakes nutrients, and settles out sediment before entering the Bay

⇩

Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Impact on Maintenance

Reduces vegetation reestablishment costs

Increases mower maintenance

Solution: Properly Time Mowing

Mow during **<u>dry weather,</u>** delay mowing until **<u>after the first frost, mow 2x/year</u>** before April 1, after October 15, (July 15-August 1 if necessary to maintain 12”-15”), leave perennial wildflower sites un-mowed over the winter to provide food and shelter for wildlife.

Figure 24: Monarch Butterfly - Example of a Pollinator

Figure 23: Ditch Vegetated with Native and Pollinator Species
Front side is mowed for driver safety, bottom and back side are mowed less frequently for pollinator species

Impact on Ditch

Decreases damages to grass and maintains long grasses and deep roots

Less erosion

Impact on Environment

Decreases sediment laden water in the Bay

Protects wild flowers and the pollinator habitats in ditches

Delaying mowing until plants bloom throughout the growing season improves survival of bees, butterflies, moths and pollinators

Impact on Maintenance

Reduces vegetation reestablishment costs

Reduces mowing frequency

Solution: Signage and Education

Homeowners may be concerned about tall vegetation. Reach out to homeowners to educate using resources in the ***Education and Outreach Section.*** Post **Do Not Mow** or **Do Not Spray** signs in or near ditches to alert landowners and mowing crews to pollinator and native species plantings.

Figure 27: Don't Mow Zone Sign
Image credit: https://www.jamescitycountyva.gov

Figure 27: Louisiana Do Not Mow Sign
Image credit: https://deq.louisiana.gov

Figure 27: Indiana Pollinator Habitat Sign
Image credit: https://www.in.gov

Impact on Ditch

Maintains health vegetation

↓

Stabilizes ditches, less erosion

Impact on Environment

Decreases sediment laden water in the Bay

Preserves native and pollinator species plantings in channels, such as milkweed

Figure 28: Milkweed. Image credit: https://extension.umd.edu/hgic/topics/butterfly-weed-milkweed

Impact on Maintenance

Reduces public maintenance complaints

Herbicide Application

Note: The use of herbicide is discouraged. Herbicides should not be used in general ditch maintenance. Herbicides should be used only when specified (and rarely) to remove invasive species and other weeds. Personnel who apply herbicide must be certified.

Over-application, inappropriate application, or broad application of herbicides can harm vegetation and degrade stormwater quality when excess herbicides are carried into stormwater runoff.

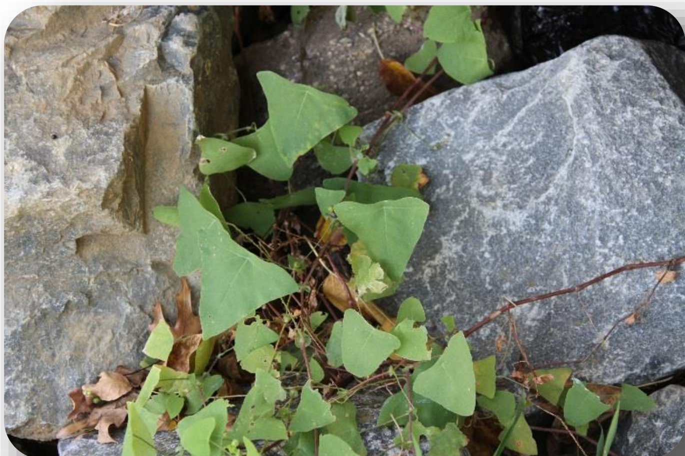


Figure 30: Mile a Minute- Invasive Species

In addition, overapplication of herbicides or application of the wrong type of herbicides is generally less cost-effective than focused application.

Proper herbicide application is important for maintaining beneficial vegetation in the channel and removing invasive species and weeds. Improper application can kill the beneficial vegetation along with the weeds, subjecting the channel to greater erosion potential. Therefore, practicing herbicide application techniques discussed in this section can improve the health of the ditch and reduce extraneous time and expense.

Figure 29: Ditch with Signs of Herbicide Application

Problem: Non-Specific Herbicide Application

If herbicides are broadly applied without targeting specific invasive species or weeds, it may damage or kill the beneficial vegetation. Visual signs of broadly applied herbicide include brown or dead vegetation along the entire ditch, dead beneficial vegetation, bare spots, and erosion.

Figure 31: Ditch with Herbicide Damage
Image Credit: Roger Bollman

Negative Impact on Ditch

Kills beneficial vegetation such as grasses and perennials

↓

Unvegetated areas are unstable, leading to erosion in the ditch

↓

Could start to erode roadway, compromising road integrity and function

Negative Impact on Environment

Herbicides can remain active for long periods of time, potentially causing soil and water contamination

See Page 31-35 for Solutions

Problem: Over Application of Herbicide

Different herbicides may have specific application rates, making it important to verify before applying. Using a higher than recommended rate can kill the top of the vegetation before the chemical is translocated to the roots to kill the whole plant **make herbicide ineffective, causing re-growth of weeds.** A ditch may have over-applied herbicide if the ditch has brown or dead vegetation along the entire ditch, bare spots, or erosion.

Landowners might apply herbicide to ditches incorrectly.
See Education and Outreach Section for resources

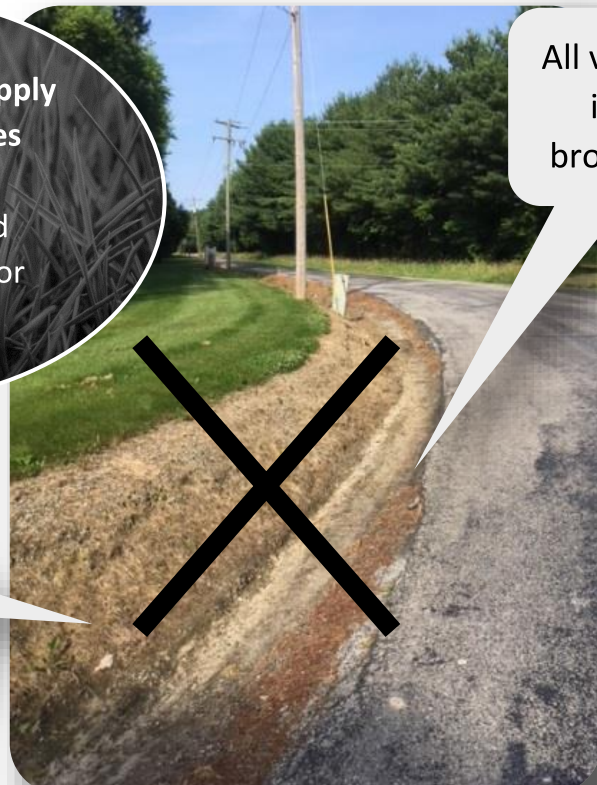


Figure 32: Ditch with Herbicide Damage, Image Credit: Roger Bollman

Negative Impact on Ditch

No vegetation present to stop sediment or slow runoff

↓

Unvegetated areas are unstable, leading to erosion in the ditch

Negative Impact on Environment

Sediment enters Chesapeake Bay, causing cloudy water and harming wildlife

↓

Herbicide can wash into groundwater or the Bay, polluting the water

See Pages 31-35 for Solutions

Problem: Applying Herbicide Incorrectly

If invasive species or weeds are still present after applying herbicides, it may have been applied during the wrong season or with the wrong herbicide. Herbicide is ineffective when applied in the incorrect season or to the incorrect part of the plant. Some herbicides are targeted to specific type of weeds, making them ineffective for others. See Appendix C for Herbicide Resources.

Image Credit: http://centralpaforest.blogspot.com/2017/10/woody-invasive-

Landowners might apply herbicide to ditches incorrectly. See Education and Outreach Section for resources

Negative Impact on Ditch

Invasive plants or weeds not killed with herbicide

Negative Impact on Environment

Herbicide can wash into groundwater or the Bay, polluting the water

Invasive species outcompete native species in the ditch and reduce habitat for pollinators

Incorrect application prompts application of more herbicide

See Pages 31-35 for Solutions

Solution: Ensure User Has Pesticide Applicator Certification

In the State of Maryland, the Maryland Department of Agriculture (MDA) issues various pesticide applicator certificates and licenses including:

- Private applicator certificates- for farmers who use a restricted pesticide on their own farm
- Commercial pest control licenses and applicator certificates- for pesticide businesses that offer pest controls services or apply general or restricted use pesticides for hire
- Pest control consultant licenses and certificates- for businesses that offer or supply technical advice or supervision, inspection for or identifying pests, or recommendations for the use of specific pesticide
- Public agency permits and applicator certificates- includes employees of federal, state, county, or local government that perform pest control using general or restricted use pesticides

Study material for the certification exam is available at the University of Maryland Extension Website http://pesticide.umd.edu/certified-applicator-training.html

For more information on MDA's pesticide applicator certification and licensing, see Appendix C-1

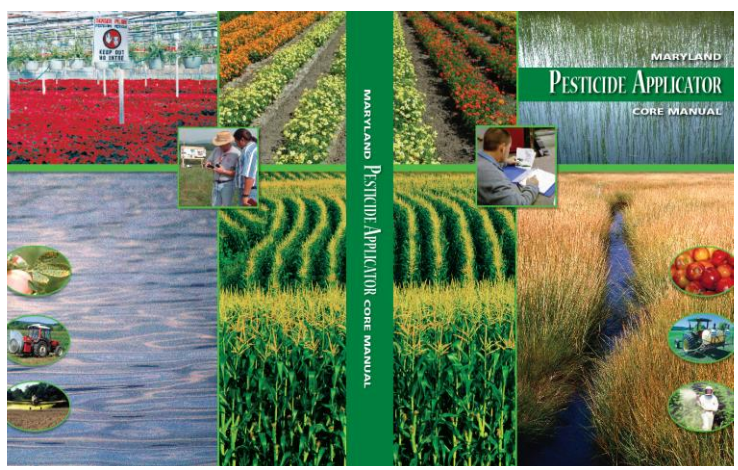


Figure 33: Maryland Pesticide Applicator Core Manual

Impact on Ditch

Herbicides used minimally, allowing beneficial vegetation to survive

⇩

Stabilizes ditches, less erosion

Impact on Environment

Reduces the amount of chemicals and pollutants in streams

Maintains water quality

Protects wild flowers and the pollinator habitats

Impact on Maintenance

Decreases unnecessary application of herbicide

Increases staff training

Solution: Spot-Treat Herbicide

Spot treat invasive species or weeds with focused-spray applicator. Spot treatment is just as effective and reduces the amount of pesticide applied.

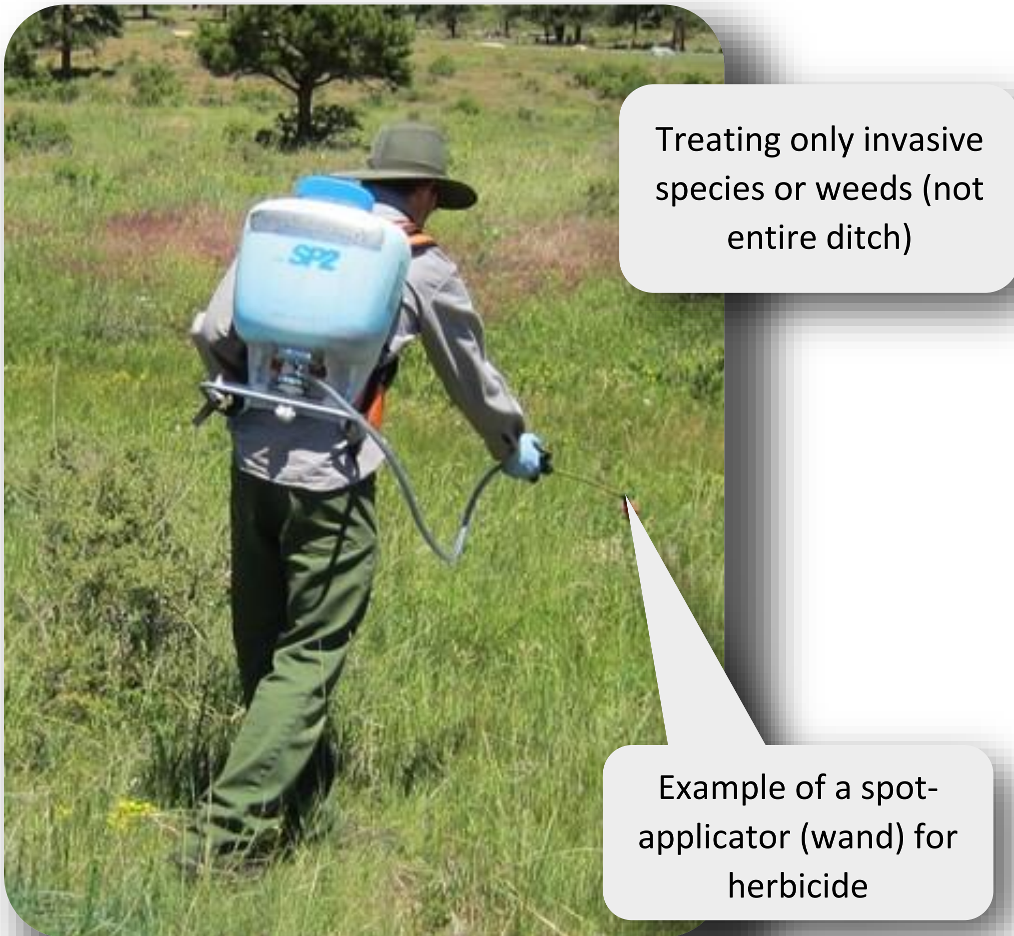


Figure 34 Spot-Treating with Herbicide
Image Credit: https://www.nps.gov/romo/learn/management/invasive_exotic_plant_mgmt_plan.htm

Impact on Ditch

Herbicides used minimally, allowing beneficial vegetation to survive

Stabilizes ditches, less erosion

Impact on Environment

Reduces the amount of chemicals and pollutants in streams

Maintains water quality

Protects wild flowers and the pollinator habitats

Impact on Maintenance

Decreases unnecessary application of herbicide

Increases staff training time

Solution: Use Selective Herbicides and Apply Correctly

Selective herbicides target specific plants, where as non-selective herbicides (aka broad spectrum) control all types of weeds. Selective herbicides are only toxic to certain types of plants and should only be applied to those plants.

SUMMER ANNUAL	WINTER ANNUAL	SUMMER/WINTER ANNUAL*	BIENNIAL	PERENNIAL
APPLE OF PERU (2)	CRESSLEAF GROUNDSEL (2, 5)	MARESTAIL (2, 4, 5)	GIANT HOGWEED (1)	AUTUMN OLIVE (2, 3)
KOCHIA (2, 4, 5)		WILD MUSTARD (2)	MUSK THISTLE (2)	CANADA THISTLE (2, 3)
MILE-A-MINUTE WEED (1, 5)			POISON HEMLOCK (2)	GRAPEVINE (1, 2)
PALMER AMARANTH (2, 5)			WILD CARROT (2)	BUSH HONEYSUCKLE (1, 2, 3)
RUSSIAN THISTLE (1, 4)			WILD PARSNIP (2)	JAPANESE KNOTWEED (1, 2)
SHATTER CANE (1)				JOHNSONGRASS (2, 3)
				KUDZU (1, 2, 3)
				NARROW LEAF CATTAIL AND HYBRID CATTAIL (1)
				OXEYE DAISY (2)
				PHRAGMITES (1)
				PURPLE LOOSESTRIFE (1, 2)
				TREE-OF-HEAVEN (2)

(1) Non-Selective, (2) Selective, (3) Residual, (4) Surfactant, (5) Pre-emergent
**Summer/Winter Annual: these plants may be found as either summer or winter annuals. If conditions are favorable, seeds may germinate twice in the same year adopting the seed germination timing of the other annual.*

Figure 35: Excerpt from Guide Roadside Integrated Vegetation Management of Prohibited Noxious Weeds in Ohio, See Appendix C-2.

Apply herbicides at the right time, on the right plant will help maximize the efficiency of herbicide treatment. Typically, annuals should be sprayed before they produce seed. Perennials should be sprayed in late summer/very early fall so chemicals are translocated more effectively to the roots as the plant prepares for dormancy.

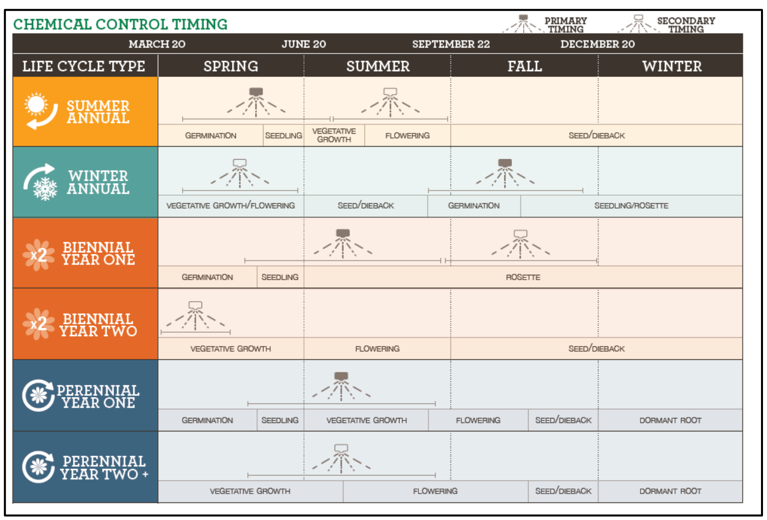


Figure 36: Excerpt from Guide Roadside Integrated Vegetation Management of Prohibited Noxious Weeds in Ohio, See Appendix C-2.

Various resources for herbicide selection are in **Appendix C.**

Impact on Ditch

Selective herbicides target specific weeds, maximizing efficiency of herbicide treatment

Retains beneficial vegetation

Stabilizes ditches, less erosion

Impact on Environment

Reduces the amount of chemicals and pollutants in streams

Impact on Maintenance

Decreases unnecessary application of herbicide

Increases staff training time

Solution: Educate Staff on Vegetation Identification and Herbicide Use

Most of the problems that arise from herbicide use are due to the lack of proper training on herbicide application methods and vegetation identification. Various educational guides have been created for these topics and can be found in Appendix C.

Identify and **eradicate** invasive species (Mile-a-Minute, Johnson grass, Kudzu, Phragmites, etc.)

Example of Mile-a - Minute

Impact on Ditch

Retains beneficial vegetation

↓

Stabilizes ditches, less erosion

Impact on Environment

Reduces unnecessary herbicide use

Reduces the amount of chemicals and pollutants in streams

Removes invasive species to support pollinator and native species

Impact on Maintenance

Minimizes need to re-apply if used correctly

Increases staff training time

Solution: Educate Landowners on Herbicide Use

Landowners and property managers might believe roadside ditches are part of their private property and apply herbicide on the ditches.

Landowners can face many of the same problems of over-application and improper application, which makes ditch maintenance and water quality management more challenging for ditch maintenance teams.

See the **Appendix C & F** and **Education and Outreach Section** for resources to reach out to landowners.

Figure 37 Over-Mowed Ditch Adjacent to Private Residence
Image Credit: Roger Bollman

Impact on Ditch

Discourage the use of herbicides by landowners

⇓

Reduces unnecessary herbicide use

⇓

Better overall vegetation health

Impact on Environment

Reduces unnecessary herbicide use

Reduces the amount of chemicals and pollutants in streams

Impact on Maintenance

Minimizes need to re-apply if used correctly

Reduces need to fix ditches

Ditch Cleaning, Excavation, and Stabilization

The goal of ditch cleaning, excavation, and stabilization is to remove sediment, leaf litter, and trash from the ditch, and to maintain ditch conveyance. Ditch cleaning is typically performed when ditches have impeded flow or during routine maintenance.

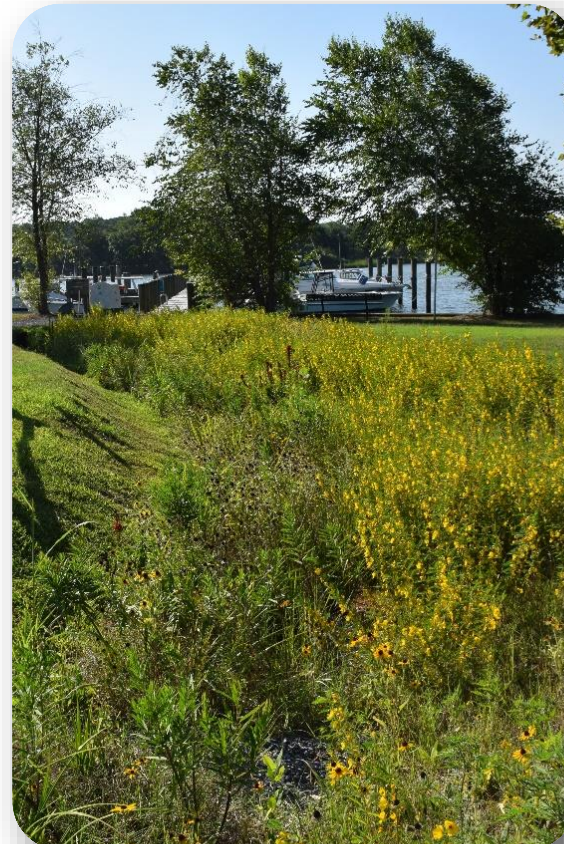


Figure 39 Ditch after Vegetation Establishment
Image provided by Leslie Cario

Figure 38 Ditch after Improper Cleaning
Image Credit: Roger Bollman

Ditch cleaning, excavation, and stabilization activities can involve restoring ditches to stable (non-eroding) shapes, regrading the ditch, removing excess sediment, applying slope stabilization matting, and seeding and establishing vegetation. However, ditch cleaning activities do not always require excavation or large equipment. Sometimes a "light touch" approach is all that is needed to clean the ditch and maintain and protect existing vegetation.

Unstable and unvegetated ditches allow the bare soils to erode into the waterways, increasing sediment, phosphorus, and nitrogen into the waterways, leading to poor water quality and harming aquatic life. These ditches tend to cause increased maintenance, since eroded soils can cause clogging downstream. Improvements in existing practices can help increase ditch stability while improving water quality and reduce overall maintenance costs.

Problem: Leaf Litter	Negative Impact on Ditch
Leaf litter is a common and seasonal ditch issue. Leaf litter in the ditch reduces ditch conveyance, but also leads to water quality degradation.  *Figure 40 Leaf Litter* *Image Credit: This Photo by Unknown Author is licensed under CC BY-SA*	Leaf litter kills vegetation underneath by blocking sunlight ⬇ Unvegetated areas are unstable, leading to erosion in the ditch
	Negative Impact on Environment
	As leaves break down they release nutrients (nitrogen and phosphorus) and organic matter ⬇ These pollutants degrade water quality and clouds water

See Page 42 for Solutions

Problem: Unstable Ditch Geometry

Signs of unstable ditch geometry include **steep vertical sides**, **incised ditch**, **bare spots**, **lack of vegetation**, and **sediment** in the ditch (including cloudy or brown water). The ideal ditch shape for stability is a gentle trapezoidal or parabolic shape. A steep ditch side slope can be caused by using an improperly sized bucket to clean the ditch ("over-ditching").

Figure 41: Unstable Ditch Geometry with Steep Side Slopes

Negative Impact on Ditch

Vegetation difficult to grow on steep side slopes

⬇

Ditch becomes unstable, allowing the surrounding soils to erode

⬇

Ditch fills with sediment- can't hold as much water

⬇

Potential for flooding

Negative Impact on Environment

Sediment enters Chesapeake Bay, causing cloudy water and harming wildlife

See Page 42 for Solutions

Problem: Poor Stabilization

Signs of poor stabilization include bare spots, sloughing (sides of ditch falling in), erosion, lack of vegetation, and signs of sediment in the ditch (including cloudy or brown water).

Lack of stabilization may be caused by improper installation of erosion control stabilization matting or by poor vegetation establishment and/or heavy rains.

Negative Impact on Ditch

Vegetation may struggle to establish

↓

Bare patches or entire bare side slopes

↓

Sloughing ("falling-in") of ditch side slopes may occur because there is no vegetation keeping the soil in place

↓

Runoff flows at higher velocity since there is no vegetation to slow the water

↓

Ditch becomes unstable, allowing the surrounding soils to erode

Problem: Poor Stabilization (cont’d)	Negative Impact on Environment
Native vegetation not present to allow sediment to settle out or take up nutrients (phosphorus and nitrogen).  Ditch here is correct parabolic shape HOWEVER Vegetation is not established, and ditch could start eroding *Figure 42 Ditch without Vegetative Stabilization* *Image credit: Environmental Inquiry Cornell University*	Roadside ditch may transport sediment and nutrients (phosphorus and nitrogen) These pollutants enter the Chesapeake Bay, causing cloudy water and harming wildlife

See Page 42- 45 for Solutions

Problem: Incorrect Installation or Maintenance of Erosion and Sediment Controls

Erosion and sediment controls (ESC) are installed to prevent sediment pollution from entering the waterways. Typically only required during construction, installing these after disturbing soils is a good management practice. ESC, even if installed correctly, can shift or reach maximum capacity after rain events. ESC should be inspected following each rain event and fixed immediately. Signs of incorrect installation or maintenance of ESC include downstream sediment deposits, gaps in silt fence or compost filter socks, scour or erosion, or turbid water discharging.

Straw bales are typically not recommended for erosion control in ditches
Use an alternative such as compost filter sock

Figure 43 Straw Bale Sediment Control - NOT RECOMMENDED
Image credit: https://city.milwaukee.gov

Negative Impact on Ditch

Sediment able to move downstream of ditch

↓

Ditch becomes unstable, allowing the surrounding soils to erode

↓

Ditch fills with sediment- can't hold as much water

↓

Potential for flooding

Negative Impact on Environment

Roadside ditch may transport sediment and nutrients (phosphorus and nitrogen)

These pollutants enter the Chesapeake Bay, causing cloudy water and harming wildlife

See Page 45 for Solutions

Solution: Reshaping Ditch Geometry to Stable Shape

Maintain trapezoidal

or parabolic

ditch shape

Do not dig the ditch deeper than the original elevation

Avoid removing more material than necessary in the ditch. The ditch only needs to be cleaned if there is something blocking the flow. See Appendix D-1 for useful resources.

Figure 44 Ditch Reshaped to Stable Shape
Image provided by Talbot County

Impact on Ditch

Improves vegetation growth, reduces steep slopes and velocities

⇩

Stabilizes ditches, less erosion

Impact on Environment

Vegetation and gentle slopes reduce water velocity and settles out sediment before entering the Bay

⇩

Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Impact on Maintenance

Decreases need to re-seed ditch or clean out sediment buildup

Solution: Ditch Stabilization Lining

Immediately establishing vegetation after soil disturbance is the most cost-effective stabilization. Temporary slope stabilization lining, such as erosion control matting or jute netting, helps keep the soils stable while vegetation is growing. Lining can be temporary or permanent. The type of lining to use is based on the characteristics of the ditch (side slope, flow velocity, etc. See **Appendix D** for stabilization lining guide.

Fall 2017- Stabilization and seeding post grading

Summer 2018- Successful Vegetation Establishment

Impact on Ditch

Improves vegetation growth, decreases seed wash off before rooting

Increases success of vegetation establishment

Stabilizes ditch, less erosion

Impact on Environment

Vegetation and lining reduce water velocity and settles out sediment before entering the Bay

Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Ditch Stabilization Lining(cont'd)	Impact on Maintenance
Immediately establish vegetation and revisit to include native species during their appropriate planting season. See **Vegetation Establishment Section** for more information.  Permanent stabilization such as riprap at a culvert can improve overall ditch stabilization. A headwall or endwall may also be necessary if the area around the culvert has reoccurring erosion issues.  *Leave 1 ft. of riprap exposed on each end of culverts for easier maintenance when storm events occur.*	Decreases need to re-seed ditch, clean out sediment buildup, or fixing highly eroded ditches Increases cost for materials

Solution: Correct Installation and Maintenance of ESC

Train staff to correctly install and maintenance erosion and sediment controls. There are various ESC manuals produced by local, state, and federal resources. See Appendix E for a list of these resources. ESC that may be beneficial during ditch cleaning include compost filter sock and erosion control matting. Once these practices are installed, they need to be checked often to make sure they are working correctly, especially after a rain event. They also need to be removed when the site is stabilized.

Install erosion and sediment controls before ditch cleaning and reconstruction activities

Figure 45 Compost Filter Sock Installation
Image credit: Horsley Witten Group, CWP, NOAA

Figure 46 Compost Filter Sock Installation
Image credit: https://archive.epa.gov

Compost filter sock properly secured
Protects streams from sediment
Sediment is trapped behind compost filter sock

Impact on Ditch

Prevents sediment from leaving ditch

Increases ditch stability, leading to less erosion

Impact on Environment

Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Impact on Maintenance

Decreases need to re-seed ditch, clean out sediment buildup, or fix highly eroded ditches

Increases cost for materials

Increases staff training time

Agricultural Side Inlets (Agricultural Leads)

Agricultural side inlet (agricultural lead) maintenance is not part of the typical ditch maintenance schedule. However, the location where an agricultural side inlet meets the roadside ditch can be especially eroded and in need of stabilization. Sediment in these areas can lead to increased maintenance requirements.

In agricultural land use areas, roadside ditches not only drain runoff from the road, but may also drain water from the adjacent fields via agricultural leads. Agricultural side inlets can drain both surface water and shallow groundwater from fields. The runoff and shallow groundwater often contain nutrients, herbicides, pesticides, and sediment from the fields. While modification of the countless private agricultural side inlets would be impractical, practices can be implemented where roadside ditches intersect agricultural side inlets to stabilize the ditch and provide opportunities for nutrients, herbicides, pesticides, and sediment to be removed from the water.

Figure 47 Agricultural Side Inlets in Talbot County, MD

Figure 48 Agricultural Side Inlet Emptying into Roadside Ditch

Problem: Lack of Stabilization of Agricultural Side Inlets

Signs of instability of agricultural side inlets include bare spots, scour, erosion, lack of vegetation, and signs of sediment in the roadside ditch (including cloudy or brown water).

The runoff and shallow groundwater carried by agricultural side inlets often contains nitrogen, phosphorus, herbicides, pesticides, and sediment from fields. These substances are harmful to water quality and can pollute roadside ditches and, ultimately, stream

Figure 49: Scour at Agricultural Side Inlet

Negative Impact on Ditch

High-velocity flows from side inlets erodes and scours ditch

Sediment deposits can cover grasses and impede vegetation growth. This can also cause vegetation "matting", where the vegetation prevents any water from infiltrating into soils

Negative Impact on Environment

Pollutants (sediment, nitrogen and phosphorus) enters Chesapeake Bay, causing cloudy water and algae blooms, harming wildlife and potentially humans

Herbicides from fields kill ditch- stabilizing vegetation and can wash into groundwater or the Bay, polluting the water

See Pages 48-50 for Solutions

Solution: Vegetation Establishment

Side inlet channel stabilization provides opportunity for water energy dissipation and sediment settling. If the water flowing from the agricultural field is a ditch, vegetation is the most efficient way to stabilize a ditch. If establishing new vegetation in high velocity ditches, erosion control matting such as Curlex® may be useful to ensure the seeds are established without washing away. High velocities flows may kill vegetation, which will destabilize the ditch. Other solutions below may be better options for high flow ditches.

See the **Appendix D** for more ditch lining information

Impact on Ditch

Traps sediment leaving side inlet

Increases ditch stability, leading to less erosion

Slows down flow coming from the field, leading to less erosion

Impact on Environment

Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Impact on Maintenance

Decreases need to fix highly eroded or clogged ditches

Decreases potential to erode roadways

Increases material cost

Solution: Grass Buffer

If flow coming from a field can become sheet flow through a grass buffer, that is good solution for unstable agricultural side inlets. Grass buffers, also called vegetated filter strips, are low slope areas between the field and the ditch. These will only work if there is a wide right of way. If not, landowner easements may be necessary.

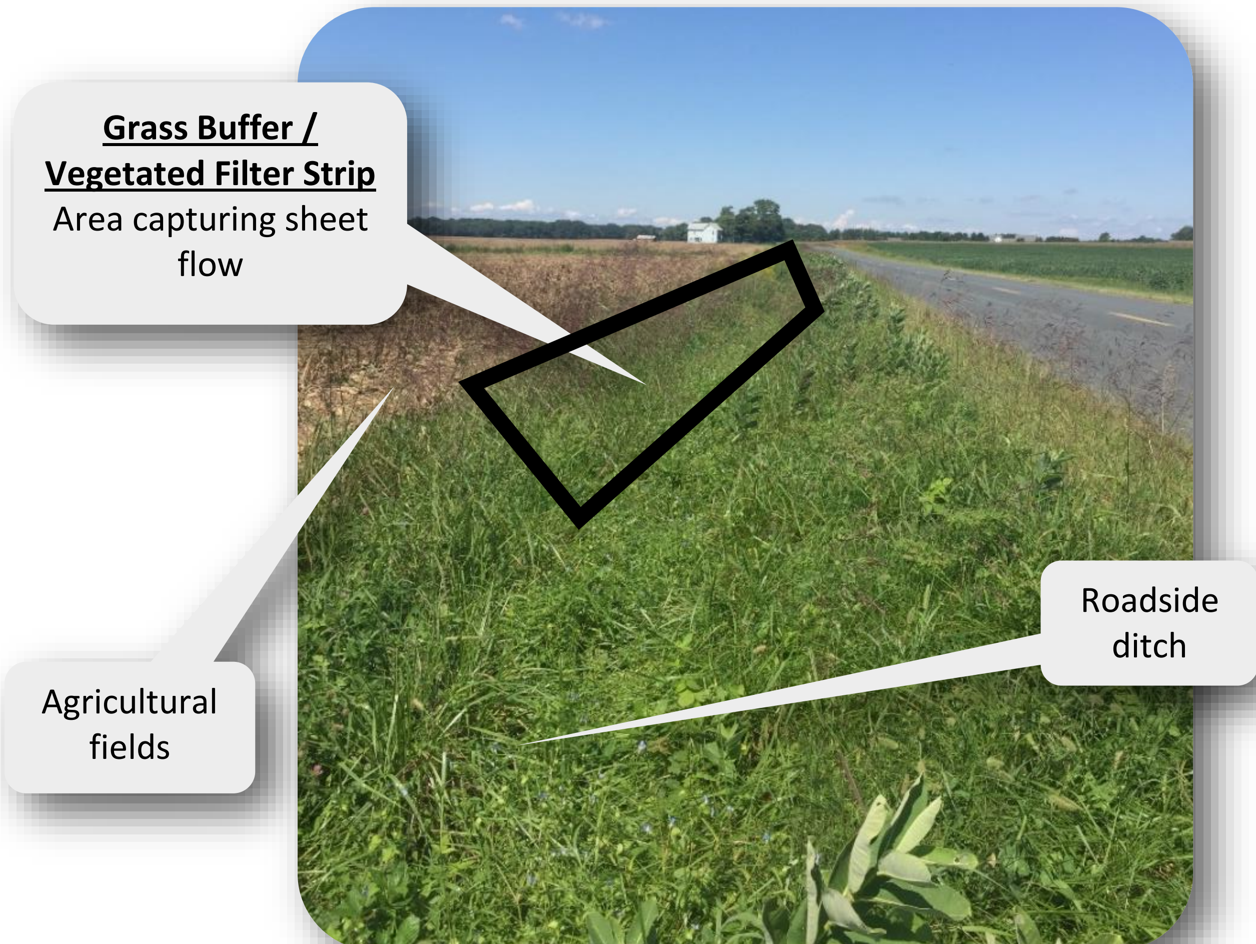


Figure 50: Grass Buffer Provided between Agricultural Field and Roadside Ditch

Impact on Ditch

Increases ditch stability, leading to less erosion

Slows down flow coming from the field, leading to less erosion

Impact on Environment

Increases time for water to infiltrate into soils

Increases nutrient uptake from field runoff

Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Impact on Maintenance

Decreases need to fix highly eroded or clogged ditches

Decreases potential for road erosion

Increases material cost

Solution: Riprap Apron

Place **<u>riprap apron</u>** at the discharge point of agricultural side inlet up to the roadside slope. This minimally impacts the field, yet provides stable slopes for fast flowing water to enter the ditch. See Appendix E and G-1 for more design information.

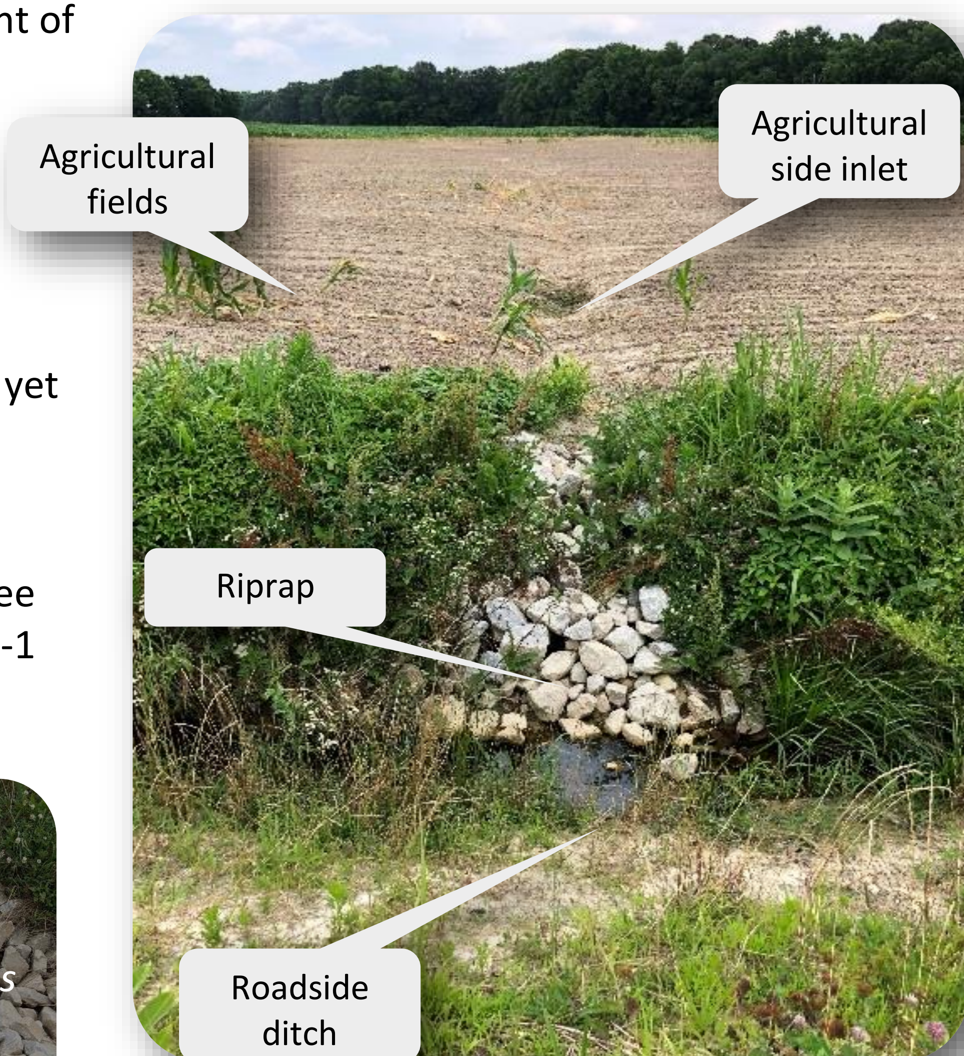


Figure 51 Stabilized Agricultural Side Inlet

Impact on Ditch

Traps sediment leaving agricultural side inlet

Dissipates energy from the water

Decreases erosion and stabilizes intersection of agricultural side inlet and roadside ditch

Impact on Environment

Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Impact on Maintenance

Decreases need to fix highly eroded or clogged ditches

Decreases potential for road erosion

Increases material cost

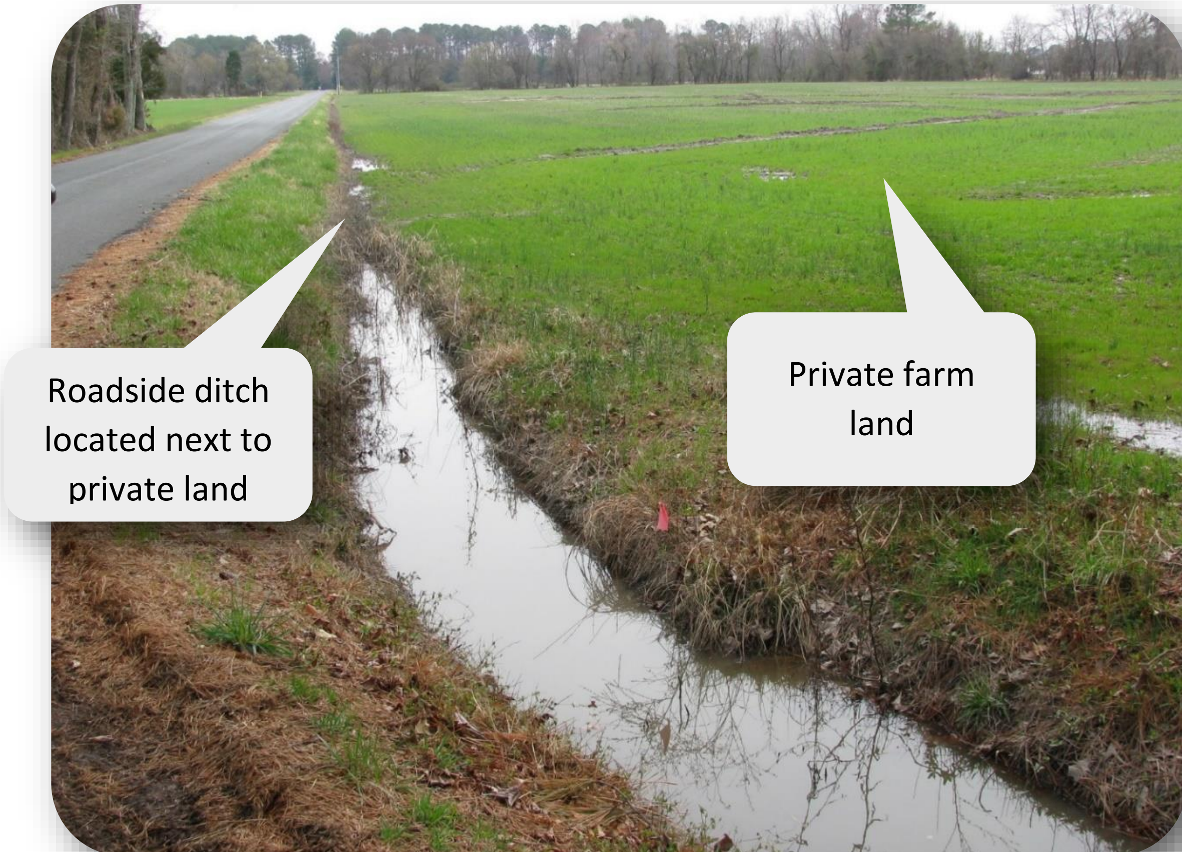
Education and Outreach

Education and outreach to staff and the public are both important elements of ditch management activities. One obstacle to improving water quality through roadside ditch maintenance is adoption of the practices; the connection between these practices and environmental improvements may not necessarily be clear.

Resistance to improving ditches may come from government officials, citizens, and even designers and maintenance personnel. Education and outreach can affirm the environmental and fiscal benefits of roadside ditch maintenance. Also, since most ditches are next to farms, landowner agreements will have to be made for any practices that may affect their land. Maintenance crews will have to receive additional training on ditch maintenance practices.

Staff Training on Plant Identification	Impact
Maintenance staff can target specific species to be removed during ditch maintenance activities. See Appendix C-3, 4, 5 and F for resources. Recommend training be held during cold months for fewer ticks, snakes, etc.  *Figure 52 Invasive Species Identified for Removal by Staff*	Targeting specific plants for removal improves longevity of other plants ⇩ Decreases ditch erosion by maintaining beneficial plants

Staff Training on Reconstructed Ditch Maintenance and Erosion and Sediment Controls	Impact
Since reconstructed ditches (See Ditch Reconstruction Chapter), such as bioreactors and bioswales, do not have the same maintenance practices as a regular ditch, training will be needed to ensure proper maintenance. Proper erosion and sediment control installation and maintenance will help protection the ditches. See Appendix D-9, 10, 11 and F for resources.  *Figure 53: In-the-field BMP training*	Ditches are protected from sedimentation with proper installation of Erosion and Sediment Controls ⇩ Increased stream quality Maintenance for each ditch is suited to the ditch type ⇩ Improves longevity of ditch

Outreach and Education to Farmers and Landowners	Impact
Many roadside ditches are located on or near private land and cooperation  *Figure 54: Private Property Adjacent to Roadside Ditch* with farmers and landowners may be needed for implementation and maintenance of ditch improvements. See Appendix F for resources for farmers and landowners.	Landowners and farmer may also maintain the ditch themselves ⇩ Education on ditch maintenance may be needed for landowners to perform maintenance Education also needed to ensure citizens can recognize water quality enhancement practices in ditches adjacent to their properties

Chapter 2: Ditch Reconstruction

Chapter 2 contains reconstruction practices that typically require more resources than normal ditch maintenance. These practices may require engineering and permitting to be constructed. Chapter 2 is in two sections:

- Characteristics of ditches that would benefit from ditch reconstruction
- Ditch reconstruction opportunities including:
  - Bioreactors
  - Performance Enhancing Devices
  - Dry Wells
  - Bioswale
  - Two-stage ditch

Figure 55: Reconstructed Roadside Ditch

Like Chapter 1, at the bottom of each ditch characteristic page is reference to a corresponding ditch reconstruction opportunity page. Various ditch reconstruction opportunities have been studied for water quality improvements, such as two-stage ditches, water control structures, bioreactors, bioswales, and phosphorus-sorbing materials. These changes can improve infiltration, water treatment, and groundwater recharge.

Site constraints can prohibit some reconstruction practices. Utility lines (underground and overhead), trees, equipment access ability, high groundwater table, traffic safety, or landowner agreements are a few things that could affect the site selection.

Figure 56 Roadside Ditch Undergoing Reconstruction

Ditch Reconstruction practices are not typical ditch maintenance activities and are often costly.

These practices must be planned and designed to provide intended road safety, they are not an in-the-field ditch maintenance approach.

However, cost of implementation can be reduced where ditch maintenance activities are already planned and equipment is already mobilized, i.e. “dig once”.

Ditch Characteristics

Narrow Right-of-Way

Signs of a ditch reconstruction opportunity in a narrow right-of-way are vertical, incised (“cut-out”), or unvegetated side slopes, as well as the presence of sediment in the roadside ditch. It is difficult for vegetation to grow on these side slopes.

Figure 57: Ditch Reconstruction Opportunity in Narrow Right-of-Way

Negative Impact on Ditch

Maintenance vehicle buckets are too wide for these ditches, causing too much of the soil to be removed, creating steep side slopes

↓

Vegetation not well-established on ditches with steep side slopes

↓

Runoff flows more quickly in unvegetated channels and can erode downstream ditch

↓

Reduced opportunity in ditch for sediment to settle out of water

Negative Impact on Environment

Sediment enters receiving streams and reduces stream water quality

See Pages 59-61 for Reconstruction Opportunities

Wide Right-of-Way

Wide right-of-ways can provide space for various types of reconstruction practices that can improve water quality. If the ditch already has some issues, such as bare spots, erosion, or incised or steep slopes, it can also be a good location.

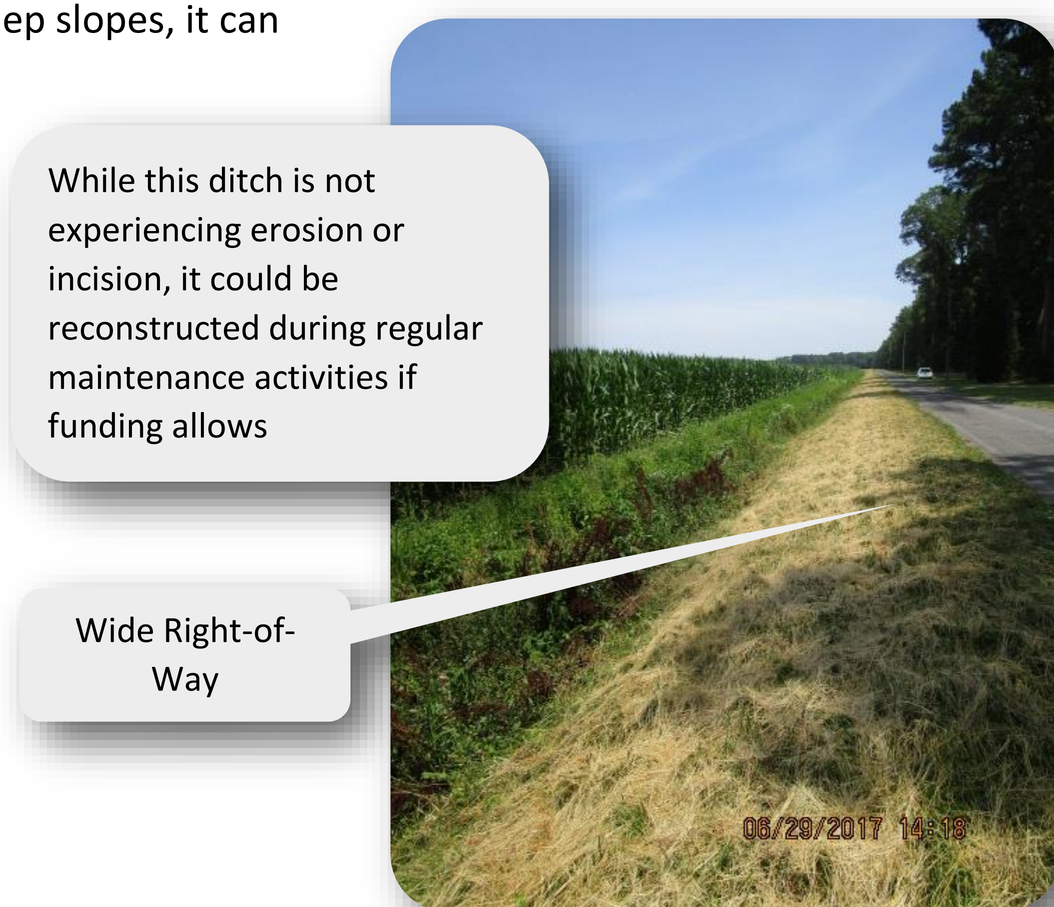


Figure 58: Ditch Reconstruction Opportunity in Wide Right-of-Way

Negative Impact on Ditch

There are generally no negative impacts on the ditch from a wide right-of-way.

Negative Impact on Environment

There are generally no negative impacts on the environment from a wide right-of-way.

See Pages 59-64**Error! Bookmark not defined.** for Reconstruction Opportunities

Ditch Undergoing Other Maintenance Activities

A ditch undergoing other maintenance activities can be a great opportunity for ditch reconstruction. The ditch might be scheduled to be re-seeded or re-stabilized, or equipment such as excavators may be on-site. Since the ditch is likely already going to be destabilized for the maintenance activity, adding a reconstruction project would reduce the impact of the reconstruction. Ditch reconstruction should occur prior to ditch re-seeding or re-stabilization.

Figure 59: Ditch Undergoing Other Maintenance Activities

Negative Impact on Ditch

Ditches undergoing maintenance are destabilized

⬇

Can cause soil erosion in ditch

Negative Impact on Environment

Sediment enters Chesapeake Bay, causing cloudy water and harming wildlife

See Pages 59-64 for Reconstruction Opportunities

Ditch Reconstruction Opportunities

Bioreactor

A bioreactor replaces existing ditch soil with woodchips and a layer of topsoil. The ditch is replanted with native vegetation. Gravel columns are dispersed throughout the ditch to allow for water to enter woodchip layer. See appendix G for higher quality images of design.

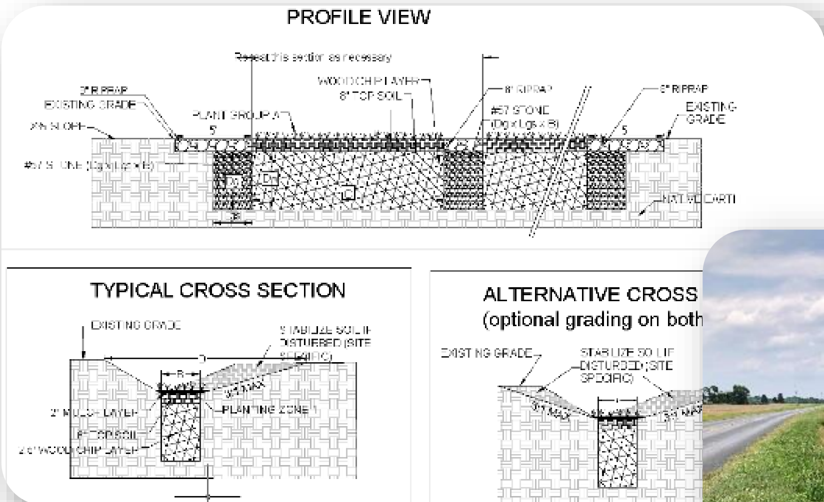


Figure 60: Bioreactor Example Detail

From the surface, a bioreactor is not always identifiable. Restoration signs can help inform the public and maintenance staff

Figure 61: Completed Bioreactor in Talbot County, MD

Impact on Ditch

The ditch will be destabilized during construction, but with correct ESC, it should not cause extended damage.

The ditch should retain less water, as the water is able to infiltrate into the soils

Impact on Environment

Reducing runoff into Bay

Specific **bacteria** turn nitrate into nitrogen gas, thereby removing it from the water

Decreases sediment laden water in the Bay, which impacts various marine life (vegetation growth, fish habitat, algal blooms)

Impact on Maintenance

After construction, similar maintenance as a normal ditch

Decreases potential for flooding

Performance Enhancing Devices

Performance Enhancing Devices (PED) are soil amendments that can be mixed into the top layer of soil to improve infiltration and pollution reduction. These include biochar, waste water treatment plant residuals, and alum flocs. See Appendix G for more information.

Additives typically mixed with existing soil to at least 6” depth

Often used in conjunction with other ditch reconstruction practices *(bioswales, bioreactors, etc.)*

Figure 62: Biochar being spread into a ditch prior to mixing

Impact on Ditch

The ditch will be destabilized during construction, but with correct ESC, it should not cause extended damage.

The ditch should retain less water, as the water is able to infiltrate into the soils

Impact on Environment

Reduces presence of phosphorus and nitrogen in the stormwater runoff

Impact on Maintenance

After construction, similar maintenance as a normal ditch

Decreases potential for flooding

Dry Well

Dry wells are holes or trenches that are filled with gravel to retain water to allow for the water to infiltrate into the surrounding soil. See Appendix G for more information.

Figure 63 Completed Dry Well
Image credit: Fairfax County Government

Dry wells can be used with limited right-of-way available

Dry wells are installed in the footprint of the bottom of ditch
Gravel provided for pretreatment

Figure 64 Dry Well Installation Example Image credit: Roc Community Summit https://roccommunitysummit.org

Impact on Ditch

The ditch will be destabilized during construction, but with correct ESC, it should not cause extended damage.

The ditch should retain less water, as the water is able to infiltrate into the soils

Impact on Environment

Provides infiltration of runoff

Reduces presence of sediment, phosphorus, and nitrogen entering the Bay

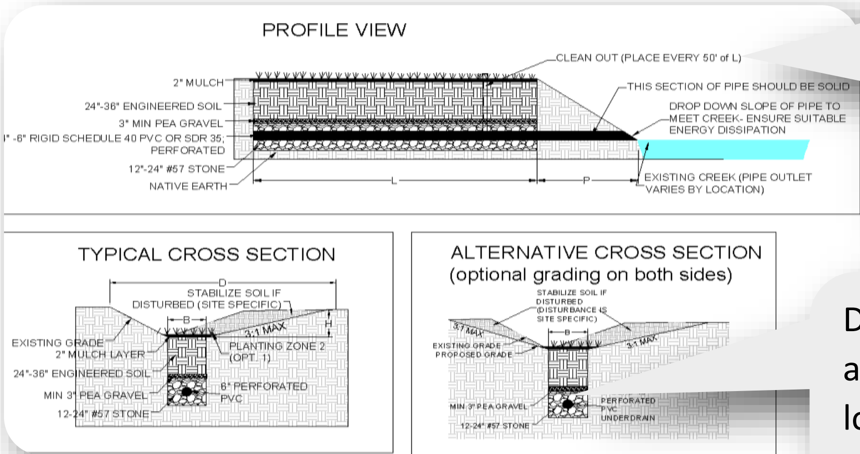
Impact on Maintenance

After construction, similar maintenance as a normal ditch

Decreases potential for flooding

Bioswale

Bioswales (or linear bioretention) are layers of engineered soil media and gravel that help remove pollutants (sediment, nitrogen, and phosphorus) from water entering the ditch. See Appendix G for more information.



Bioswale replaces existing ditch soil with a layer of gravel and engineered soil media

Figure 65 Bioswale Example Detail

Depending on soil type, an underdrain may be located at bottom of practice and outlet into existing storm system

Figure 66 Completed Bioswale
Image credit: Talbot County, MD

Impact on Ditch

The ditch will be destabilized during construction, but with correct ESC, it should not cause extended damage.

The ditch should retain less water, as the water is able to infiltrate into the soils

Impact on Environment

Bioswale provides infiltration of runoff

Reduces presence of sediment, phosphorus, and nitrogen entering the Bay

Impact on Maintenance

After construction, similar maintenance as a normal ditch

Decreases potential for flooding

If an underdrain is used, they will need to be inspected periodically

Two Stage Ditch

A two-stage ditch requires more space than all the other reconstruction practices. It includes a low flow ditch and a wider floodplain ditch to allow for water to spread out and slow down during storms. See Appendix G for more information.

Two-stage ditch with benches that allow water to flood during bigger storms

Figure 67: Two-Stage Ditch

Wide ditch right-of-way needed

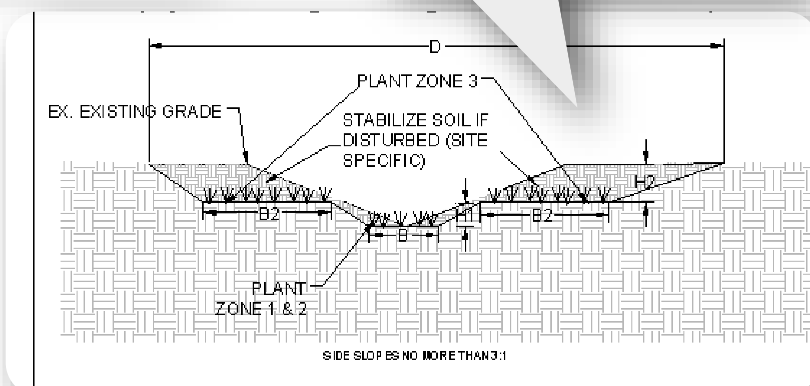


Figure 68 Two-Stage Ditch Example Detail

Impact on Ditch

Increases ditch stability, decreases erosion

Impact on Environment

Mimics natural stream flow

Opportunity in ditch for sediment to settle out of water and uptake of phosphorus and nitrogen

Less sediment enters receiving streams, improved stream water quality

Impact on Maintenance

More self-sustaining than conventional ditches – fewer maintenance requirements

Reshaping a Ditch

Reshape the ditch to 3:1 side slopes or flatter with a trapezoidal or parabolic cross section. Depending on the extent of the excavation, additional engineering may be needed to ensure the new shape provides adequate drainage.

Figure 69 Equipment Mobilized for Ditch Maintenance Used for Ditch Reconstruction

Impact on Ditch

Increases stability of ditch and decreases erosion potential

Impact on Environment

Improves water quality by decreasing sediment, phosphorus, and nitrogen in ditch

Impact on Maintenance

Decreases need to fix highly eroded or clogged ditches

Decreases potential to erode roadways

Conclusion

Improving the maintenance of roadside ditches has the potential to significantly improve water quality in the Chesapeake Bay. This impact is even greater around the Eastern Shore, as many ditches flow directly into the Bay. The manual provides starting point for ditch maintenance programs to incorporate simple changes to enhance water quality. Many of these changes will not only improve water quality, but also reduce erosion of the ditches, which reduces maintenance efforts.

The manual also provides information on how to identify potential sites for stormwater retrofit projects, which can provide an even larger improvement in water quality. As noted previously, a restoration project may require engineering design and funding outside of the typical maintenance budget.

As research and technology progress, this manual can be further developed to include other maintenance practices that can improve water quality. Additional resources can be added to the Appendix for guidance. Efforts in the Chesapeake Bay Program have been made to provide guidelines on crediting pollutant reduction from roadside ditch management practices. As these guidelines are developed, it will help justify these practices and provide more guidance on creditable ways to enhance roadside ditches.

Appendix

The Appendix list below is the information provided in each Appendix folder. The link is provided if the folder is unavailable. Resources that do not have links are included in this document. Excerpts from some of the resources also provided in the document.

Appendix A: Vegetation Resources

1. Eastern Shore Ditch Seed Selection- Chesapeake Horticultural Services

Appendix A-1
Ditch Seeding - Species Composition
Last Updated June 2019

Zone 1 – Swale Bottom	Common Name	Max Height (ft.)	Root Depth (in.)	Form	Pollinator Value	Stratification/ Pre-treatment (highlighted species that can be sown in the near term without stratification)	Seeds/lb	Seeds/lb of mix	Typical Seeding Rate (% of mix)	% of Mix (only includes species that can be sown without cold stratification)
Acorus americanus	sweet flag	6	10	rhizomatous		3 month	70,000	-	1-5%	0%
Asclepias incarnata	swamp milkweed	5	18	rhizomatous	very high	3 month	70,000	-	1-5%	0%
Bidens cernua	nodding bur marigold	3	8	single crown re-seeding annual	medium	0/GA	130,000	130	1-2%	10%
Carex crinita	fringed sedge	4	18	bunch- type sedge		2-3 month	650,000	-	1-10%	0%
Carex vulpinoidea	fox sedge	3	16	bunch- type sedge		0	1,297,000	5,188	1-40%	40%
Iris versicolor	blue flag iris	2		rhizomatous	low	3 month	18,000	-	1-5%	0%
Juncus effusus	soft rush	4	24	bunch-type rush		0	45,359,000	90,718	1-5%	20%
Leersia oryzoides	rice cutgrass	3	14	rhizomatous warm season		1-2 month	610,000	-	1-20%	0%
Liatris spicata	blazing star	1-5	14	rhizomatous corms	high	2-3 month	100,000	-	1-5%	0%
Ludwigia alternifolia	seedbox	1-2				0/GA	20,800,000	20,800	0.5-2%	10%
Mimulus ringens	monkey flower	2-4		rhizomatous, re-seeds	medium	0	22,900,000	11,450	0.3-1%	5%
Rhexia mariana	MD meadow beauty	2.5			medium	1-2 month		-	0.5-1%	0%
Scirpus atrovirens	green bulrush							-		0%
Scirpus pungens	common three-square	4	14	rhizomatous		1-2 month	260,000	-	1-10%	0%
Verbena hastata	blue vervain	2-5		single stem	high	0	1,488,000	2,232	1-4%	15%
Zizia aurea	golden Alexander	3			medium	3 month	172,000	-	1-3%	0%

Zone 2 – Ditch Slope						Stratification/ Pre-treatment (highlighted species that can be sown in the near term without stratification)	Seeds/lb	Seeds/lb of mix	Typical Seeding Rate (% of mix)	% of Mix (only includes species that can be sown without cold stratification)
Agrostis stolonifera	creeping bentgrass	1-2	12	stoloniferous		0	6,129,000	12,258	5-25%	20%
Asclepias syriaca	common milkweed	5		spreading roots	very high	3 month	70,000	-	1-3%	0%
Asclepias tuberosa	butterfly milkweed	1-3	16	multi-stem tubers	very high	0-3 month	70,000	35	1-3%	5%
Aster laevis	smooth aster	1-4	10	branched stem	very high	3 month	1,014,000	-	1-3%	0%
Aster novae-angliae	New England aster	2-6		branched stem	very high	3 month	1,100,000	-	1-3%	0%
Baptisia australis	false indigo	5		legume	medium	scarify, innoculate	22,000	7	0.5-2%	3%
Chamaecrista fasciculata	partridge pea	3	14	bunch-type legume, re-seeding annual	high	scarify, innoculate	65,000	65	1-10%	10%
Chasmanthium latifolium	sea oats	4	10	rhizomatous bunchgrass		0	90,000	135	1-40%	15%
Echinacea purpurea	purple coneflower	5	24		high	3 month	116,000	-	1-5%	0%
Elymus virginicus	VA wild rye	3-6	12	cool season bunchgrass		0	73,000	73	1-25%	10%
Eragrostis spectabilis	purple lovegrass	1-3	4	short-rhizomed bunchgrass		0	1,000,000	500	1-5%	5%
Eupatorium coelestinum	mistflower	1-3	14	rhizomatous	very high	2-3 month	1,500,000	-	0.5-2%	0%
Helianthus angustifolius	swamp sunflower	1.5-5	6	rhizomatous multi-stemmed	high	2-3 month	504,000	-	1-5%	0%
Monarda fistulosa	wild bergamot	5	4	rhizomatous	high	0/GA	1,272,500	636	0.3-2%	5%

Chesapeake Horticultural Services

Appendix A-1
Ditch Seeding - Species Composition
Last Updated June 2019

Panicum rigidulum	redtop panicgrass	4	6	bunchgrass		3 month	797,000	-	1-50%	0%
Penstemon digitalis	foxglove beardtongue	4	8	rhizomatous	high	3 month	400,000	-	1-5%	0%
Pycnanthemum tenuifolium	narrowleaf mountain mint	2.5		spreading roots	very high	0/GA	6,048,000	1,210	0.1-0.5%	2%
Rudbeckia hirta	black eyed Susan	1-3	10	re-seeds	medium	0/GA	1,576,000	1,576	1-5%	10%
Schizachyrium scoparium	little bluestem	2-3	10-96	bunchgrass		0	200,000	200	10-67%	10%
Solidago rugosa	rough goldenrod	1-3.5	12	rhizomatous	very high	0/GA	1,000,000	500	0.5-1%	5%
Tradescantia virginiana	VA spiderwort	3	4		high	3 month	175,000	-	1-3%	0%

Supplemental Aquatic Seeding						Stratification/ Pre-treatment (highlighted species that can be sown in the near term without stratification)	Seeds/lb	Seeds/lb of mix	Typical Seeding Rate (% of mix)	% of Mix (only includes species that can be sown without cold stratification)
**Alisma subcordatum*	water plantain	2	20	single crown	low	3 month	825,000	-	0.5-1%	0%
Peltandra virginica	arrow arum					0	600	3		50%
**Pontederia cordata*	pickerelweed	3	10	bunch-type aquatic		0	5,000	25		50%
**Sagittaria latifolia*	duck potato	3	18	tuber		3 month	67,000	-	1-10%	0%
Saururus cernuus	lizard tail							-		0%

Brackish Water						Stratification/ Pre-treatment (highlighted species that can be sown in the near term without stratification)	Seeds/lb	Seeds/lb of mix	Typical Seeding Rate (% of mix)	% of Mix (only includes species that can be sown without cold stratification)
Hibiscus moscheutos	marsh hibiscus							-		
Kosteletzkya virginica	seashore mallow							-		
Scirpus pungens	common three-square	4	14	rhizomatous		1-2 month	260,000	-	1-10%	0
Solidago sempervirens	seaside goldenrod							-		

Chesapeake Horticultural Services

2. Enhancing Delaware Highway Roadside Vegetation Establishment and Management Manual. Dover: Delaware Department of Transportation, 2009.
    - https://deldot.gov/Publications/manuals/edh/pdfs/edh_establishment_management.pdf
3. Native Herbaceous Plantings- Establishment, Maintenance and Management for Wildlife Habitat and Pollinators, January 2017
    a. http://www.xerces.org/wp-content/uploads/2014/12/JobSheet-and-Addendum_MD_CnsrvCvr.pdf
4. Roadside Best Management Practices that Benefit Pollinators: Handbook for Supporting Pollinators through Roadside Maintenance and Landscape Design, 2015
    - http://www.xerces.org/wp-content/uploads/2016/08/BMPs_pollinators_landscapes.pdf
5. Integrated Vegetation Management Manual for Maryland Highways SHA, Wildflower Program page 5.1-5.5, October 2003
    - http://www.oedtoolkits.net/epd.qatoolkit/ViewStdDocs.aspx?id=181

6. Pollinators and roadside BMPs for managers and decision makers. US DOT FHA. 2015
    - http://www.xerces.org/wp-content/uploads/2016/07/BMPs_pollinators_roadsides.pdf

Appendix B: Mowing Resources

1. Integrated Vegetation Management Manual for Maryland Highways SHA page 3.1-3.8, October 2003
    - http://www.oedtoolkits.net/epd.qatoolkit/ViewStdDocs.aspx?id=181

2. Pollinators and roadside BMPs for managers and decision makers. US DOT FHA. 2015. Page 4-6, 6-1
    - http://www.xerces.org/wp-content/uploads/2016/07/BMPs_pollinators_roadsides.pdf
3. Progressive Management Practices for Drainage Systems on the Eastern Shore of MD. Jason Keppler, John Roderick, and Maryland Department of Agriculture.
    - Weed wiper technology, excerpt page 6 and 16

Weed Wiper Technology

Public Drainage Associations on the Lower Eastern Shore traditionally contract to have the drainage ditches cleared out of all vegetation in order to maximize the conveyance capacity of the system. This can be handled in two ways; mowing and chemical spraying. Spraying of the ditches with a broad-spectrum herbicide totally eradicates all vegetation and habitat which has a potential negative environmental impact. Mowing is usually done to a cut height of 2" to 6" on the maintenance access and bank slopes. While this efficiently keeps the ditches open and moves the stormwater through the system away from the fields, it provides very little "roughness" or trapping efficiency for sediments, nutrients and flow alternation.

Based upon some previous 319 grant funding a promising new alternative maintenance option is currently being utilized in some drainage systems in the Upper Choptank watershed. Utilizing specialized applicator equipment to selectively apply herbicides to just the tall growing woody vegetation in drainage ditches, the "weed wiper" technology is gaining support. The benefit of this practice is that it leaves the low growing vegetation in the ditch to continue to maintain stability on horizontal and slope areas of the ditch. The "weed wiper technology," instead of broadcast spraying for total vegetation eradication, can work to increase the roughness on the banks and to provide a continued wildlife habitat.

6

Based upon cost comparisons the weed wiper application cost about $350 per mile and is good for three years. These compare to annual mowing costs for drainage ditch maintenance which average $250 per mile but must be done on an annual basis. The weed wiper cost advantage is ½ of the traditional cost of ditch maintenance.

Appendix C: Herbicide Application Resources

1. Maryland Department of Agriculture Pesticide Applicator Certification and Licensing Website
    - https://mda.maryland.gov/plants-pests/Pages/licensing_and_certification.aspx
2. Guide for Roadside Integrated Vegetation Management of Prohibited Noxious Weeds in Ohio, Davey Resources Group

- Contains noxious weed identification guide, including seasonal differences and control methods; applicator worksheets, including calibration for spray gun or backpack sprayer, herbicide per acre rate and herbicide percent solution
- Staff training resource
- http://daveytree.uberflip.com/i/795219-odot-guide-for-rivm/5

3. Integrated Vegetation Management Manual for Maryland Highways SHA page 2.1-2.78, October 2003
    - Includes type of weed, type of materials used, method of application, and recommended timing
    - http://www.oedtoolkits.net/epd.qatoolkit/ViewStdDocs.aspx?id=181

4. Plant Invaders of Mid-Atlantic Natural Areas National Park Service / US Fish and Wildlife Service, 2014
    - Includes of 80 species with photos, description, and prevention and control
    - Staff training resource
    - https://www.invasive.org/alien/pubs/midatlantic/midatlantic.pdf
5. Pollinators and roadside BMPs for managers and decision makers. US DOT FHA. 2015. Page 6-2
    - http://www.xerces.org/wp-content/uploads/2016/07/BMPs_pollinators_roadsides.pdf

Appendix D: Ditch Cleaning/Excavation/Stabilization Resources

1. Field Guide for Maintaining Rural Roadside Ditches: Protecting Lakes and Streams through Proper Ditch Maintenance. Fortin Consulting, Inc., University of Minnesota Sea Grant Program, the National Resources Research Institute, University of Minnesota Duluth. 2014
    - https://conservancy.umn.edu/bitstream/handle/11299/187059/Ditch%20Guide%20FINAL.pdf?sequence=1&isAllowed=y

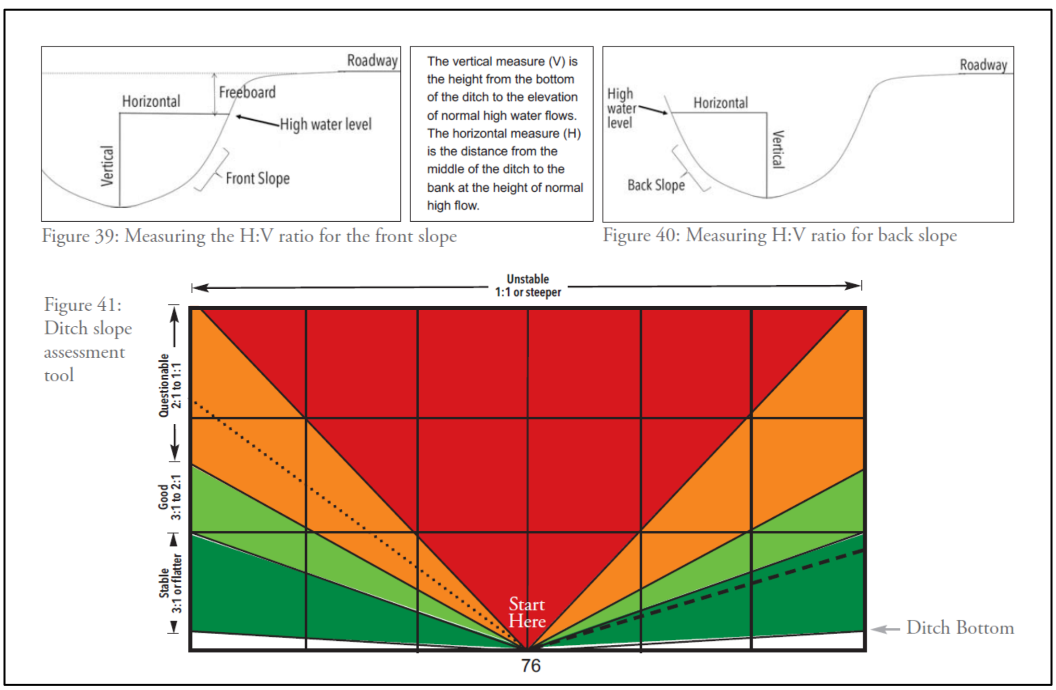


Figure 70: Excerpt from page 76 on Ditch Side Slope

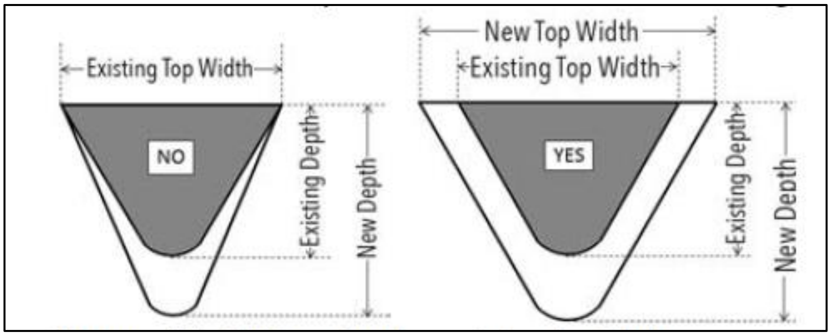


Figure 71: Excerpt from page 51: Maintain the original width to depth ratio when excavating

Table 3. Seed Protection Recommendations for Ditches[12]

Protection Type	Side Slope Horizontal:Vertical	Notes
Mulch	3:1 or flatter	Must be anchored in place; hydromulch with a tackifier is best.
Straw erosion control blanket, netting on 1 or 2 sides	3:1 to 2:1	Most common temporary stabilization method for ditch bottoms. For blanketed areas next to DNR protected waters and certain other streams, use a natural netting and stitching. 2-sided netting recommended for slopes longer than 50 ft.
Wood fiber blanket, netting on 1 or 2 sides	3:1 or steeper	2-sided netting recommended for moderate slopes (between 3:1 and 2:1) longer than 50 ft or slopes steeper than 2:1
Turf reinforcement mats	2:1 to 1:1	Permanent surface stabilization. Synthetic (polypropylene) fibers. For higher velocity flows or areas prone to erosion.

Figure 72: Excerpt from page 37- Types of seed protection

2. Manual of Temporary Erosion Control Products for Roadside Ditches. Hazem Elzarka, Ce Gao, John Matos, Debaditya Chakraborty. 2017
    - Includes flowchart on how to choose types of erosion control products
    - https://rosap.ntl.bts.gov/view/dot/34810/dot_34810_DS1.pdf?

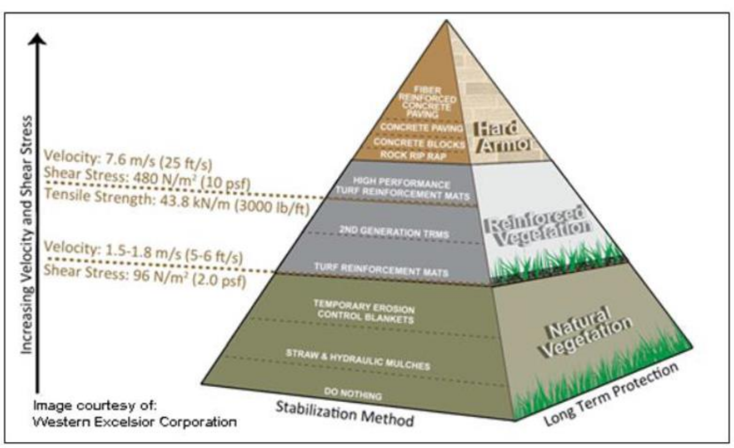


Figure 73: Excerpt from page 14- Selection of erosion control products based on shear stress (Western Excelsior Corporation)

3. Effective and Efficient Roadside Ditch Cleaning using BMPS for Erosion and Sediment Control, 2017
    - Includes review of various ditch cleaning machines
    - https://rosap.ntl.bts.gov/view/dot/34833/dot_34833_DS1.pdf?
    - Excerpts from page 108-110

Chapter 7 – Conclusions, Recommendations and Future Research

7.1. Conclusions

ODOT maintains approximately 43,000 lane miles of roadside ditches creating significant constraints on budgets and labor. The goal of this research is to improve ODOT's current process of maintaining ditches. To achieve this goal, the research team first evaluated the conventional methods that ODOT currently utilizes for roadside ditch cleaning. Such conventional methods which utilize a mini-excavator or a Gradall were found to have the following difficulties:

1. High cost: The cost analysis estimated the average cost/mile of cleaning a ditch with conventional methods currently used by ODOT to be $15,285 per mile.
2. V-shaped ditches: V-shaped ditches created by conventional methods cause more erosion and sedimentation as they concentrate surface flow.
3. Deep ditches: Over time, conventional methods lead to over-ditching and create deep ditches. Deep ditches are hazardous to pedestrian and cars and capture greater amounts of groundwater which destabilize the ditch's slopes.
4. Stripping of the vegetative cover: Ditches that are stripped of the vegetative cover during ditch cleaning are prone to significant erosion. These ditches should be immediately seeded to control erosion and sedimentation and promote treatment of the storm runoff prior to discharge into the receiving waterbody. The problem with current ODOT procedures is that in some cases, ditches that are cleaned are not seeded and in other cases, seeded ditches fail to establish vegetation.

To reduce the difficulties associated with current ODOT ditch maintenance procedures discussed above, the research team developed a matrix of alternatives that compared and contrasted solutions that are available today and provided the following recommendations for field testing:

108

1. Testing the Ditchmaster Model 800 effectiveness in cleaning ditches: The DM800 uses a horizontal rotating auger to remove spoil material from ditch bottoms. Solid materials then travel through a three stage conveyor mechanism and is dropped into an attached dump truck that is pulled by the DM. The DM produces a shallow and relatively smooth round ditch bottom. This facilitates establishment of grasses which filter out contaminants and can be maintained by routine mowing. The preliminary cost analysis estimated that the DM800 will cut the cost/mile of cleaning a ditch to $5,954/mile.
2. Testing temporary erosion control products that are currently available in the market and evaluate their effectiveness in protecting seeded ditches and in establishing vegetation. These products include different types of hydraulic mulch, erosion control blankets and straw mulch.

Field tests of the DM have revealed its inability of cleaning ditches that have wet and sticky soil. This is considered a major limitation as it limits its use for "emergency" ditching to relieve flooding during seasonal rain storms or spring thaw runoff. Although the revised cost/mile for cleaning a ditch using a DM ($7,836) is significantly more than the preliminary estimate/mile ($5,954), it is still almost 50% of the cost of cleaning the ditch using conventional ditch cleaning methods. In spite of the DM significant limitation discussed above, the benefits of the DM resulting from a better production rate, cheaper cost/mile and a more environmentally friendly ditch configuration can potentially make it a useful component of an integrated ditch maintenance system (IDMS) as described in more detail in the next section. For the DM to be a useful component of an IDMS, it should only be used when the ditch is dry. In Ohio, the chances of ditches being dry are typically higher from May 15th to October 15th. During these 5 months, even if it rains, the ditches will dry faster because of the relatively warm weather. Another advantage of conducting the ditch cleaning during those months, is that seeding and establishment of permanent vegetation will likely be more successful.

Field tests of temporary erosion control products (TECPs) have revealed the potential benefits of using such products in controlling erosion of the slopes and bottoms of the ditches after

109

cleaning. Such benefits can occur with the careful selection of the right TECP product and its correct installation. A "Temporary Erosion Control Products for Roadside Ditches" manual was developed to familiarize highway maintenance personnel with best practices for installation, recommended application rates and selection methods of TECPs.

4. Improving Roadside Ditch Maintenance Practices in Ohio. Matos, J. A., 2016
    - https://etd.ohiolink.edu/!etd.send_file?accession=ucin1470753590&disposition=inline
5. Roadside Ditches Best Management Practices to Reduce Floods, Droughts, and Water Pollution, Rebecca Schneider. 2010
    - https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/0/5949/files/2016/08/RoadsideDitches-fact-sheet-pdf-2j1nacx.pdf
6. Cost Effective and Sustainable road slope stabilization and erosion control. NCHRP. 2012
    - https://www.researchgate.net/profile/Xianming_Shi/publication/262301284_Cost-Effective_and_Sustainable_Road_Slope_Stabilization_and_Erosion_Control/links/0a85e53745763d32bf000000.pdf

TABLE 6
SUMMARY OF EROSION CONTROL TECHNIQUES

Treatment Component		Stabilization Method or Depth	Pros	Cons
Grass	Hand seeding	Shallow	No equipment required	
	Hydroseeding	Shallow	High success rate	Lack of available of equipment, limited application distance
	Sod	Shallow	High success rate	
	Slips	Shallow	Can be used to create drainage channels	Hand planting takes time
Mulching	Wood, leaf litter, straw, bark, stone	Surface	Keeps soil moist and cool, protects surface from erosion	If mulching with wood chips, nutrients may be removed from soil
Blankets and Mats	Jute, geosynthetics, rock	Surface	Keep soil moist and cool, protect surface from erosion. Aid in revegetation of steep slopes and where revegetation may be difficult	Nonbiodegradable products should be cleaned from the site
Check Dams	Inert (stone, wood, concrete)	Concentrate and control surface water flow	Reduce suspended solids in runoff	Maintenance may be required to clean out deposited sediment
	Live (vegetated)	Concentrate and control surface water flow	Reduce suspended solids in runoff; roots increase slope stabilization; modify shallow slope hydrology	Maintenance may be required to clean out deposited sediment
Wattles and Rolls	Inert (geosynthetic, straw, coir, pine needle)	Protect against sheet flow, reduce surface water velocity by breaking up the slope	Reduce suspended solids in runoff	Maintenance may be required to clean out deposited sediment, restake and replacement may be necessary; nonbiodegradable products need to be cleaned from the site
	Live (vegetated)	Protect against sheet flow, reduce surface water velocity by breaking up the slope	Reduce suspended solids in runoff; modify shallow slope hydrology	Maintenance may be required to clean out deposited sediment, restaking and replacement may be necessary
Straw Bale Barriers		Slow surface flow	Reduce suspended solids in runoff; can be used at base of slopes and around drains	Wet bales can be heavy and difficult to move; baling material may need to be removed from site if nonbiodegradable
Silt Fences		Reduce surface flow	Reduce suspended solids in runoff; can be used at base of slopes and around drains	Difficult to construct and maintain; need to be removed from the site

Figure 74: Excerpt from page 54- Summary of Erosion Control Techniques

7. Design and Estimating Principles for Category 700- Landscaping. MD SHA.
    - Describes types of soil stabilization matting and how to select based on ditch characteristics
    - https://www.roads.maryland.gov/OED/SHALandscapeEstimatingManual.pdf
    - Excerpts from page N-41- N-42. See document for explanation of Soil Stabilization Matting (SSM) types

Table 709-B
Calculation of Shear Stress

Shear Stress (τ) is a measure of the force of moving water against the substrate and is calculated as:

$\tau = \gamma \cdot R \cdot Sw$ where:
τ = Shear Stress (lb/ft^2) γ = Weight Density of Water (lb/ft)
R = Average water depth (Hydraulic Radius) (ft)
Sw = Water Surface slope (ft/ft)

Table 709-C
Calculation of Flow Velocity

Flow Velocity (V) is a measure of water flow through a defined area, usually a channel and is calculated as:

$V = 1.486/n \cdot R^{2/3} \cdot S^{1/2}$ where:
V = Flow Velocity (ft/sec) n = Manning's Roughness Coefficient
R = Hydraulic Radius (ft) S = Channel Slope (ft/ft)

Table 709-D
SSM Use in Channels

Flow Velocity (ft/sec)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9+
Shear Stress (lb/ft^2)	0.0		0.5		1.0		1.5		2.0			2.5	3.0	3.5	4.0	4.5		5.0	5+
Type A	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Type B	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Not Applicable	Not Applicable	Not Applicable
Type C	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Effective	Effective	Effective	Effective	Not Applicable
Type D	Applicable	Applicable	Applicable	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Type E	Effective	Effective	Effective	Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Rip Rap or SP	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Effective	Effective

(green)	Effective Range
(olive)	Applicable, but maybe not preferable or cost effective
(pink)	Not Applicable

SSM on Slopes. Some SSM may be required for slopes where straw and wood cellulose fiber cannot be applied, or the slopes/soils have high erosion potentials. Use Table 709-D as a guide. The Engineering Geology Division (OMT-EGD) may be contacted for assistance on geotechnical analyses.

Table 709-E
SSM Use on Slopes

Slope	6:1 or Flatter			4:1			3:1			2.5:1			2:1			Steeper than 2:1[a]
Length of Slope (ft)	0-30	30-60	60-120	0-30	30-60	60-120	0-30	30-60	60-120	0-30	30-60	60-120	0-30	30-60	60-120	
Type A	Applicable	Applicable	Applicable	Applicable	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Not Applicable	Effective	Not Applicable	Not Applicable	Not Applicable
Type B	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Effective	Applicable	Effective	Effective	Not Applicable
Type C	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable	Effective	Effective	Effective	Not Applicable
Type D	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Not Applicable
Type E	Effective	Effective	Effective	Effective	Effective	Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Note: [a] Slopes steeper than 2:1 must be engineered., and Reinforced Soil Slope may be appropriate.

Contact Engineering Geology Division (OMT-EGD) for assistance for all slopes steeper than 2:1.

(green)	Effective Range
(olive)	Applicable, but maybe not preferable or cost effective
(pink)	Not Applicable

8. Minnesota Manual, Minnesota Board of Water and Soil Resources. N.d. Mn Public Drainage Manual
    - https://drainage.pca.state.mn.us/index.php?title=Main_Page

Erosion and Sediment Control

9. 2011 Maryland Standards and Specifications for Soil Erosion and Sediment Control
    - https://mde.state.md.us/programs/Water/StormwaterManagementProgram/Documents/2011%20MD%20Standard%20and%20Specifications%20for%20Soil%20Erosion%20and%20Sediment%20Control.pdf
    - Excerpts from B.36-37: How to choose soil stabilization matting

B-4-6 STANDARDS AND SPECIFICATIONS

FOR

SOIL STABILIZATION MATTING

Definition

Material used to temporarily or permanently stabilize channels or steep slopes until groundcover is established.

Purpose

To protect the soils until vegetation is established.

Conditions Where Practice Applies

On newly seeded surfaces to prevent the applied seed from washing out; in channels and on steep slopes where the flow has erosive velocities or conveys clear water; on temporary swales, earth dikes, and perimeter dike swales as required by the respective design standard; and, on stream banks where moving water is likely to wash out new vegetative plantings.

Design Criteria

1. The soil stabilization matting that is used must withstand the flow velocities and shear stresses determined for the area, based on the 2-year, 24-hour frequency storm for temporary applications and the 10-year, 24-hour frequency storm for permanent applications. Designate on the plan the type of soil stabilization matting using the standard symbol and include the calculated shear stress for the respective treatment area.
2. Matting is required on permanent channels where the runoff velocity exceeds two and half feet per second (2.5 fps) or the shear stress exceeds two pounds per square foot (2 lbs/ft^2). On temporary channels discharging to a sediment trapping practice, provide matting where the runoff velocity exceeds four feet per second (4 fps).
3. Temporary soil stabilization matting is made with degradable (lasts 6 months minimum), natural, or manmade fibers of uniform thickness and distribution of fibers throughout and is smolder resistant. The maximum permissible velocity for temporary matting is 6 feet per second.
4. Permanent soil stabilization matting is an open weave, synthetic material consisting of non-degradable fibers or elements of uniform thickness and distribution of weave throughout. The maximum permissible velocity for permanent matting is 8.5 feet per second.
5. Calculate channel velocity and shear stress using the following procedure:

    Shear Stress (τ) is a measure of the force of moving water against the substrate and is calculated as:

    $$\tau = \gamma \cdot R \cdot S_w$$

    where:

    τ = shear stress (lb/ft^2)
    γ = weight density of water (62.4 lb/ft^3)
    R = average water depth (hydraulic radius) (ft)
    S_W = water surface slope (ft/ft)

B.36

Velocity (v) measures the rate of flow through a defined area and is calculated as:

$$v = \frac{1.486 R^{2/3} s^{1/2}}{n}$$

where:

v = velocity (ft/sec)
n = Manning's roughness coefficient
R = hydraulic radius (ft)
s = channel slope (ft/ft)

6. Use Table B.7 to assist in selecting the appropriate soil stabilization matting for slope applications based on the slope, the slope length, and the soil-erodibility K factor.

Table B.7: Soil Stabilization on Slopes

Slope	**20:1 or Flatter** (≤5%)			**<20:1 to 4:1** (>5 - 25%)			**<4:1 to 3:1** (>25 - 33%)			**<3:1 to 2.5:1** (>33 - 40%)			**<2.5:1 to 2:1**** (>40 - 50%)		
Slope Length (feet)*	0-30	30-60	60-120	0-30	30-60	60-120	0-30	30-60	60-120	0-30	30-60	60-120	0-30	30-60	60-120
Straw Mulch/Wood Cellulose Fiber				**for K ≤ 0.35*****											
Temporary Matting with Design Shear Stress ≥ 1.5 lb/sf															
Temporary Matting with Design Shear Stress ≥ 1.75 lb/sf															
Temporary Matting with Design Shear Stress ≥ 2.0 lb/sf															
Temporary Matting with Design Shear Stress ≥ 2.25 lb/sf															

Effective range for all K values unless otherwise specified

* Slope length includes contributing flow length.
** Slopes steeper than 2:1 must be engineered.
*** Soil having a K value less than or equal to 0.35 can be stabilized effectively with straw mulch or wood cellulose fiber when located on slopes steeper than 5%. Soil stabilization matting is required on all slopes steeper than 5% that have soil with a K factor greater than 0.35. K factor ratings are published in the NRCS Soil Survey http:// websoilsurvey.nrcs.usda.gov/app. During construction or reclamation, the soil-erodibility K value should represent the upper 6 inches of the final fill material re-spread as the last lift. Only the effects of rock fragments within the soil profile are considered in the estimation of the K value. Do not adjust K values to account for rocks on the soil surface or increases in soil organic matter related to management activities.

Maintenance

Vegetation must be established and maintained so that the requirements for Adequate Vegetative Establishment are continuously met in accordance with Section B-4 Vegetative Stabilization.

B.37

- Excerpts from D.9-D.10: Riprap inflow protection, useful at the end of pipes or agricultural leads

D-3 STANDARDS AND SPECIFICATIONS

FOR

INFLOW PROTECTION

D-3-1 RIPRAP INFLOW PROTECTION

Definition

A flow channel lined with rock or recycled concrete equivalent.

Purpose

To provide stable conveyance of concentrated runoff into sediment trapping practices or down steep slopes.

Conditions Where Practice Applies

Where the slope of the inflow channel is steeper than 10:1 but flatter than 4:1. Runoff may be directed to the inflow channel by means of dikes or swales.

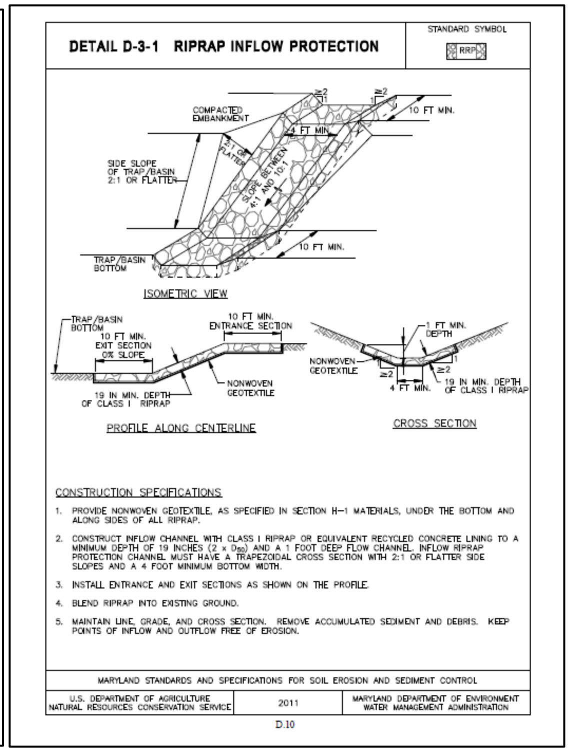
Design Criteria

1. Drainage area is limited to 10 acres. For larger drainage areas an engineered design must be provided based on adequate and non-erosive flow of runoff from the 2-year storm.
2. This practice may be used for permanent riprap inflow protection when design computations are provided demonstrating adequate and non-erosive conveyance of the 10-year storm. Recycled concrete equivalent must not be used in permanent applications.
3. Slopes flatter than 10:1 may be stabilized in accordance with temporary swale or earth dike criteria, as applicable. For slopes steeper than 4:1, use gabion inflow protection.

Maintenance

The line, grade, and cross section must be maintained. Accumulated sediment and debris must be removed. The points of inflow and outflow must be kept free of erosion.

D.9



- Excerpt from page E.2-E.3: Silt fence specification- silt fence is a common installed incorrectly

E-1 STANDARDS AND SPECIFICATIONS

FOR

SILT FENCE

Definition

A temporary barrier of woven geotextile used to intercept, retain, and filter surface runoff from disturbed areas.

Purpose

To intercept sediment-laden sheet flow runoff allowing the deposition of sediment transported from upslope. Silt fence is not to be used as a velocity check in swales or placed where it will intercept concentrated flow.

Conditions Where Practice Applies

Silt fence is limited to intercepting sheet flow runoff from small disturbed areas. The use of silt fence is based on slope length and steepness of the contributing drainage area.

Design Criteria

Table E.1: Silt Fence Design Constraints

Average Slope Steepness	Maximum Slope Length	Maximum Silt Fence Length
Flatter than 50:1 (<2%)	300 feet*	Unlimited
50:1 to 10:1 (2-10 %)	125 feet	1,000 feet
<10:1 to 5:1 (>10-20%)	100 feet	750 feet
<5:1 (>20%)	40 feet	250 feet

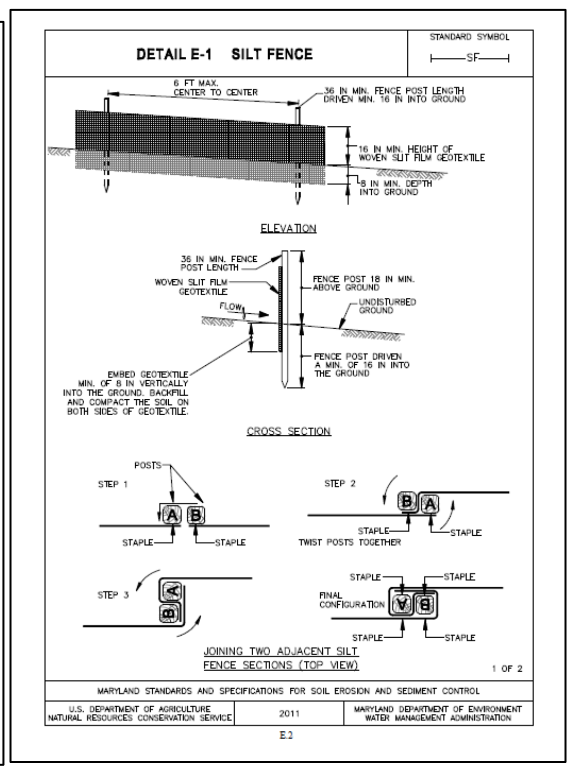
* Maximum slope length is unlimited on Hydrologic Soil Group (HSG) "A" soils.

1. The use of silt fence must conform to the design constraints listed in Table E.1 above.
2. The area downgrade of the silt fence must be undisturbed ground.
3. Silt fence is to be placed on the contour.
4. Silt fence should be used with caution in areas where rocky soils may prevent trenching.
5. Extend both ends of the silt fence a minimum five (5) feet horizontally upslope at 45 degrees to the main fence alignment to prevent runoff from going around the ends of the silt fence.

Maintenance

Accumulated sediment and debris must be removed when bulges develop in the silt fence or when sediment reaches 25 percent of the fence height. The geotextile must be replaced if torn. If undermining occurs, reinstall fence.

E.1



10. Stormwater BMP Maintenance, Chesapeake Stormwater Network
    - https://chesapeakestormwater.net/training-library/stormwater-bmp-maintenance/
11. Environmentally Sensitive Maintenance for Dirt and Gravel Roads page 5.1-5.17
    - https://www.epa.gov/sites/production/files/2015-10/documents/environmentallysensitivemaintenance_dirtgravelroads.pdf

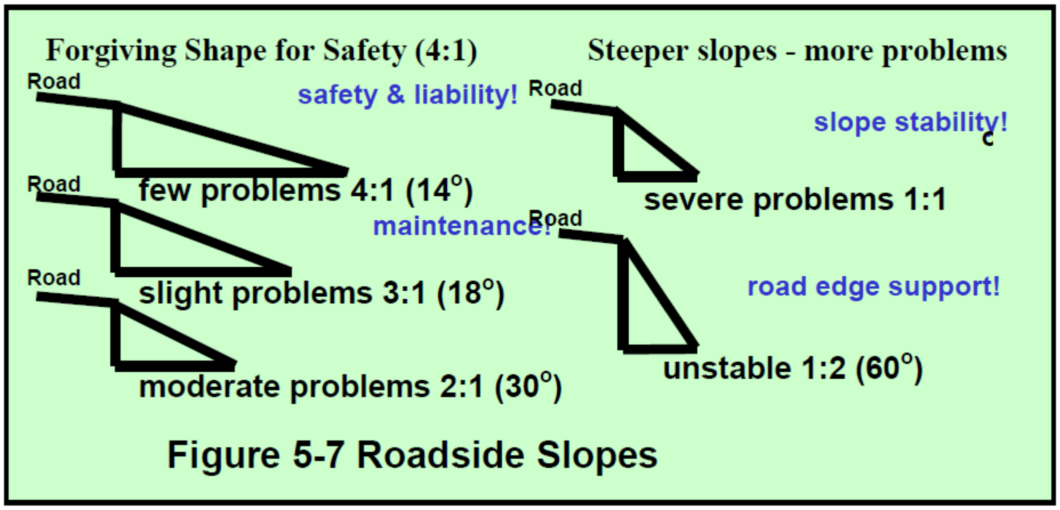


Figure 5-7 Roadside Slopes

Figure 75: Excerpt from page 5-11- Various side slopes of ditches

Appendix E: Agricultural Leads/Side Inlets Resources

See Appendix D

1. 2011 Maryland Standards and Specifications for Soil Erosion and Sediment Control
    - https://mde.state.md.us/programs/Water/StormwaterManagementProgram/Documents/2011%20MD%20Standard%20and%20Specifications%20for%20Soil%20Erosion%20and%20Sediment%20Control.pdf
    - Excerpts from D.9-D.10: Riprap inflow protection, useful at the end of pipes or agricultural leads

D-3 STANDARDS AND SPECIFICATIONS

FOR

INFLOW PROTECTION

D-3-1 RIPRAP INFLOW PROTECTION

Definition

A flow channel lined with rock or recycled concrete equivalent.

Purpose

To provide stable conveyance of concentrated runoff into sediment trapping practices or down steep slopes.

Conditions Where Practice Applies

Where the slope of the inflow channel is steeper than 10:1 but flatter than 4:1. Runoff may be directed to the inflow channel by means of dikes or swales.

Design Criteria

1. Drainage area is limited to 10 acres. For larger drainage areas an engineered design must be provided based on adequate and non-erosive flow of runoff from the 2-year storm.
2. This practice may be used for permanent riprap inflow protection when design computations are provided demonstrating adequate and non-erosive conveyance of the 10-year storm. Recycled concrete equivalent must not be used in permanent applications.
3. Slopes flatter than 10:1 may be stabilized in accordance with temporary swale or earth dike criteria, as applicable. For slopes steeper than 4:1, use gabion inflow protection.

Maintenance

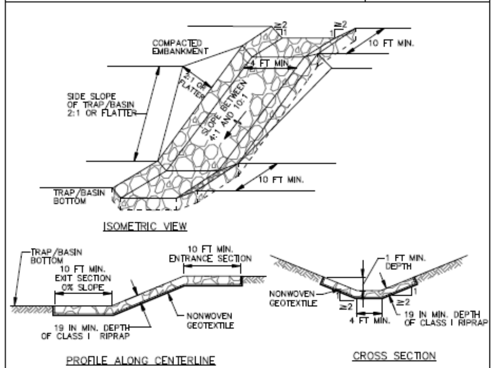
The line, grade, and cross section must be maintained. Accumulated sediment and debris must be removed. The points of inflow and outflow must be kept free of erosion.

D.9

DETAIL D-3-1 RIPRAP INFLOW PROTECTION

STANDARD SYMBOL

RRP



CONSTRUCTION SPECIFICATIONS

1. PROVIDE NONWOVEN GEOTEXTILE, AS SPECIFIED IN SECTION H–1 MATERIALS, UNDER THE BOTTOM AND ALONG SIDES OF ALL RIPRAP.
2. CONSTRUCT INFLOW CHANNEL WITH CLASS I RIPRAP OR EQUIVALENT RECYCLED CONCRETE LINING TO A MINIMUM DEPTH OF 19 INCHES (2 x D_{50}) AND A 1 FOOT DEEP FLOW CHANNEL. INFLOW RIPRAP PROTECTION CHANNEL MUST HAVE A TRAPEZOIDAL CROSS SECTION WITH 2:1 OR FLATTER SIDE SLOPES AND A 4 FOOT MINIMUM BOTTOM WIDTH.
3. INSTALL ENTRANCE AND EXIT SECTIONS AS SHOWN ON THE PROFILE.
4. BLEND RIPRAP INTO EXISTING GROUND.
5. MAINTAIN LINE, GRADE, AND CROSS SECTION. REMOVE ACCUMULATED SEDIMENT AND DEBRIS. KEEP POINTS OF INFLOW AND OUTFLOW FREE OF EROSION.

MARYLAND STANDARDS AND SPECIFICATIONS FOR SOIL EROSION AND SEDIMENT CONTROL		
U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE	2011	MARYLAND DEPARTMENT OF ENVIRONMENT WATER MANAGEMENT ADMINISTRATION

D.10

2. Field Guide for Maintaining Rural Roadside Ditches: Protecting Lakes and Streams through Proper Ditch Maintenance. Fortin Consulting, Inc., University of Minnesota Sea Grant Program, the National Resources Research Institute, University of Minnesota Duluth. 2014
   - https://conservancy.umn.edu/bitstream/handle/11299/187059/Ditch%20Guide%20FINAL.pdf?sequence=1&isAllowed=y

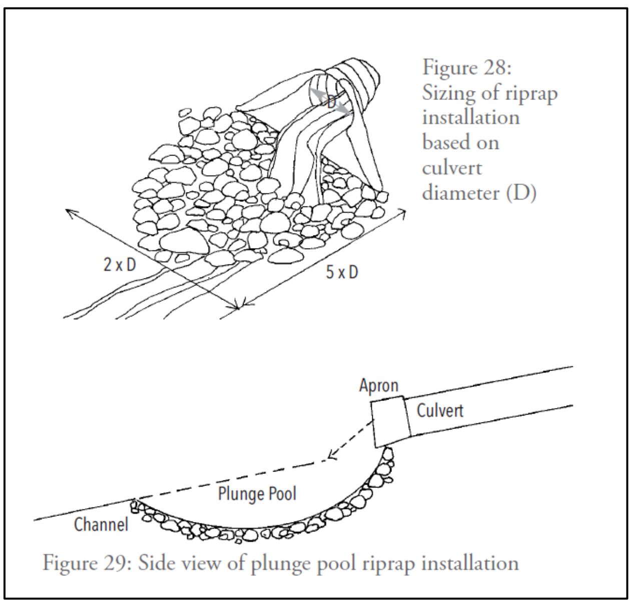


Figure 28: Sizing of riprap installation based on culvert diameter (D)

Figure 29: Side view of plunge pool riprap installation

Figure 76: Excerpt from page 54. Example of plunge pool at the outlet of an agricultural lead

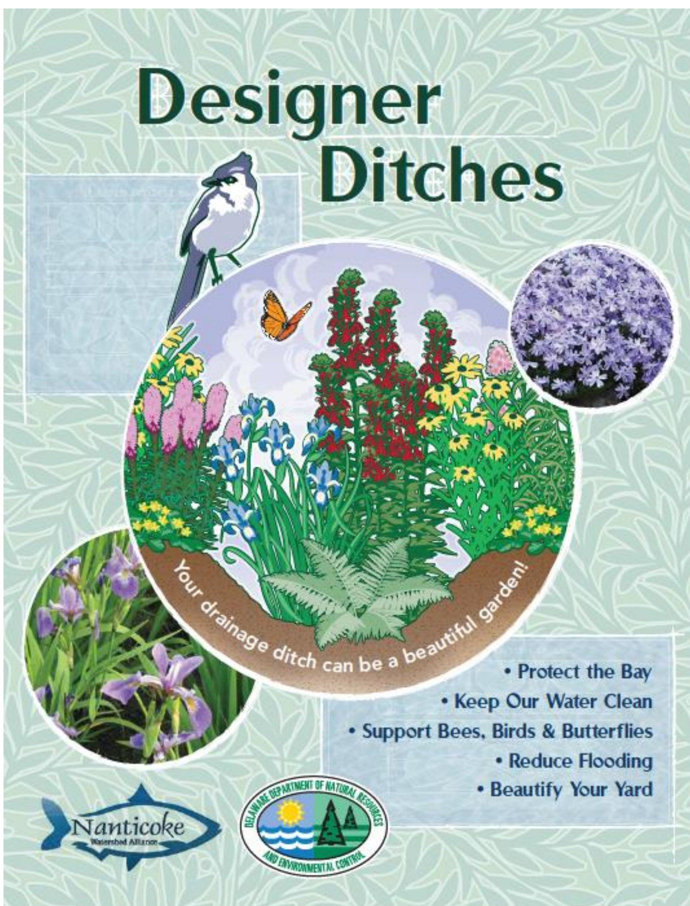
Appendix F: Education and Outreach Resources

Homeowner Guides for Vegetation Resources

1. Landscaping with Native Plants Maryland Native Plant Society
   a. https://mdflora.org/resources/Publications/GardenersGuidelines/Landscaping-Natives.pdf
2. Recommended Native Plants for Maryland
   a. https://extension.umd.edu/hgic/topics/recommended-native-plants-maryland
3. Native Plants for Wildlife Habitat and Conservation Landscaping US Fish and Wildlife
   a. https://www.fws.gov/Chesapeakebay/pdf/NativePlantsforWildlifeHabitatandConservationLandscaping.pdf
4. Attracting Pollinators to Your Garden Using Native Plants
   a. https://www.fs.fed.us/wildflowers/pollinators/documents/AttractingPollinatorsV5.pdf

Homeowner Guides for Ditch Maintenance

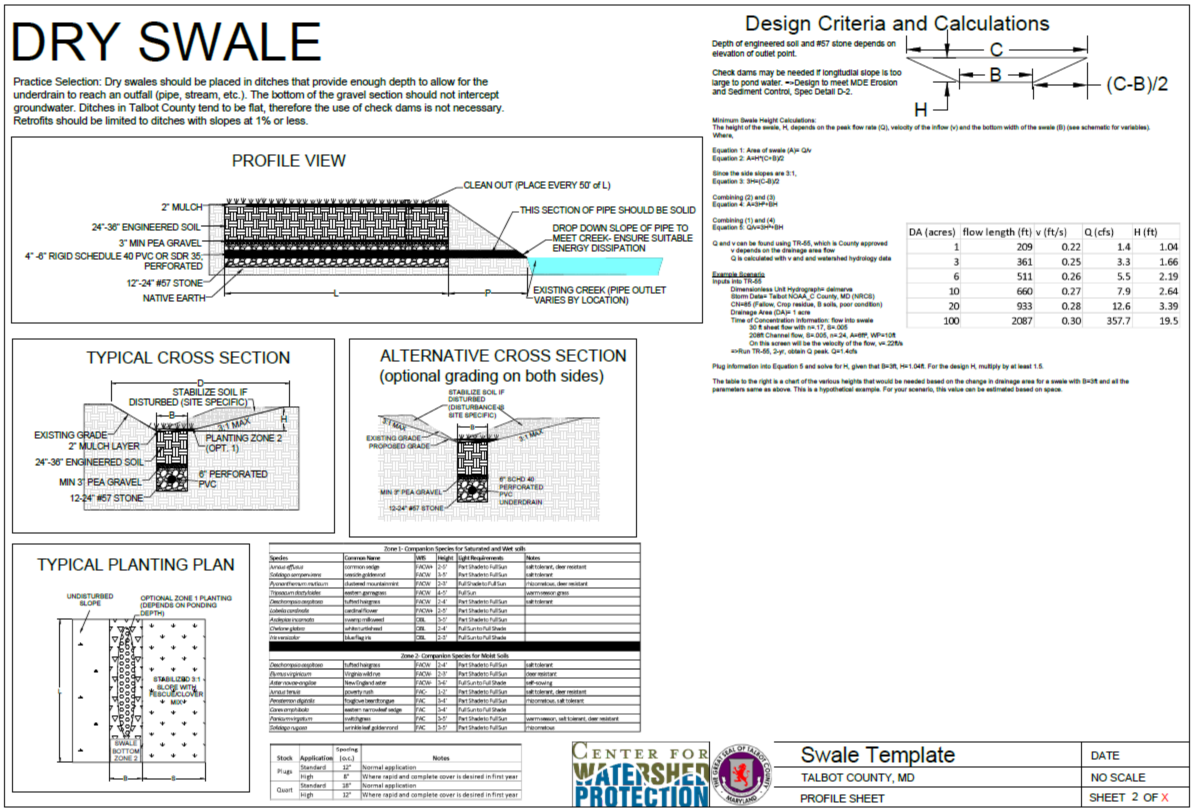
5. Roadside Ditch Maintenance, Chesapeake, VA.
   a. http://www.cityofchesapeake.net/Assets/documents/departments/public_works/Brochures/Stormwater-Roadside-Maintenance-Brochure.PDF
6. Designer Ditches, Nanticoke Watershed Alliance
   a. Includes printable handbooks
   b. https://nanticokeriver.org/restoration/designer-ditches/
   c. Excerpt from page 1 of 6a



7. Pollinators and roadside BMPs for managers and decision makers. US DOT FHA. 2015
    a. Includes methods to educate public and staff
    b. http://www.xerces.org/wp-content/uploads/2016/07/BMPs_pollinators_roadsides.pdf

Appendix G: Ditch Reconstruction Resources

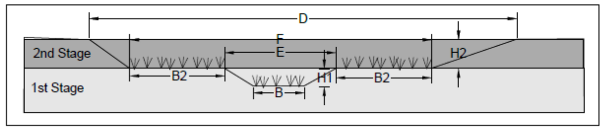
1. Talbot County Ditch Retrofit Project Designs



TWO-STAGE DITCH

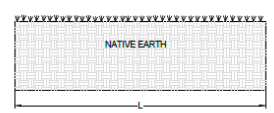
Practice Selection: A two-stage ditch should be used of there is enough width perpendicular to the road. Ditches in Talbot County tend to be flat, therefore the use of check dams is not necessary. Retrofits should be limited to ditches with slopes at 1% or less.

Design Criteria and Calculations

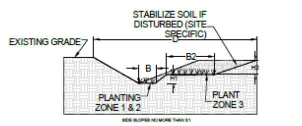


- bench stability important
- look for ditches that show signs of natural bench
- in cohesive soils, slope from first stage to second stage are typically steeper than 1.5:1
- side slope on 2nd stage should be 2:1 or flatter
- best suited for da 1-10 sq. mi., bed slope less than 0.5%p- if developing a 2 stage ditch without constraints, benches should be used on both sides

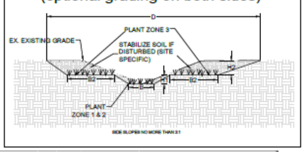
PROFILE VIEW



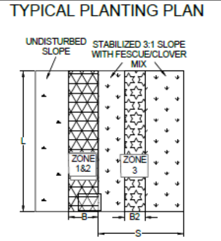
TYPICAL CROSS SECTION



ALTERNATIVE CROSS SECTION
(optional grading on both sides)



TYPICAL PLANTING PLAN



Species	Common Name	WIS	Height	Light Requirements	Notes
Zone 1- Companion Species for Saturated and Wet soils					
Juncus effusus	common sedge	FACW+	2-5'	Part Shade to Full Sun	salt tolerant, deer resistant
Solidago sempervirens	seaside goldenrod	FACW	3-5'	Part Shade to Full Sun	salt tolerant
Pycnanthemum muticum	clustered mountainmint	FACW	2-3'	Full Shade to Full Sun	rhizomatous, deer resistant
Tripsacum dactyloides	eastern gamagrass	FACW	4-5'	Full Sun	warm season grass
Deschampsia cespitosa	tufted hairgrass	FACW	2-4'	Part Shade to Full Sun	salt tolerant
Lobelia cardinalis	cardinal flower	FACW+	2-5'	Part Shade to Full Sun	
Asclepias incarnata	swamp milkweed	OBL	3-5'	Part Shade to Full Sun	
Chelone glabra	white turtlehead	OBL	2-4'	Full Sun to Full Shade	
Iris versicolor	blue flag iris	OBL	2-3'	Full Sun to Full Shade	
Zone 2- Companion Species for Moist Soils					
Deschampsia cespitosa	tufted hairgrass	FACW	2-4'	Part Shade to Full Sun	salt tolerant
Elymus virginicus	Virginia wild rye	FACW-	2-3'	Part Shade to Full Sun	deer resistant
Aster novae-angliae	New England aster	FACW-	3-6'	Full Sun to Full Shade	self-sowing
Juncus tenuis	poverty rush	FAC-	1-2'	Part Shade to Full Sun	salt tolerant, deer resistant
Penstemon digitalis	foxglove beardtongue	FAC	3-4'	Part Shade to Full Sun	rhizomatous, salt tolerant
Carex amphibola	eastern narrowleaf sedge	FAC	3-4'	Full Sun to Full Shade	
Panicum virgatum	switchgrass	FAC	3-5'	Part Shade to Full Sun	warm-season, salt tolerant, deer resistant
Solidago rugosa	wrinkle leaf goldenrod	FAC	3-5'	Part Shade to Full Sun	rhizomatous
Zone 3- Companion Species for Dry Soils					
Chasmanthium latifolium	Indian woodoats	FACU	3-5'	Full Sun to Full Shade	warm season
Dennstaedtia punctilobula	eastern hayscented fern	FACU-	15-24"	Part Shade to Full Shade	rhizomatous, deer resistant
Andropogon virginicus	broomsedge bluestem	FACU	2-3'	Part Shade to Full Sun	warm-season, salt tolerant, deer resistant
Schizachyrium scoparium	little bluestem	FACU	3-4'	Part Shade to Full Sun	warm-season, deer resistant
Panicum amarum	bitter panicgrass	FACU-	3-4'	Part Shade to Full Sun	warm season, salt tolerant, deer resistant
Bouteloua curtipendula	sideoats grama		18-30"	Full Sun	rhizomatous, warm season, salt tolerant, deer resistant

Stock	Application	Spacing (o.c.)	Notes
Plugs	Standard	12"	Normal application
	High	8"	Where rapid and complete cover is desired in first year
Quart	Standard	18"	Normal application
	High	12"	Where rapid and complete cover is desired in first year

CENTER FOR WATERSHED PROTECTION

Swale Template	DATE
TALBOT COUNTY, MD	NO SCALE
PROFILE SHEET	SHEET 3 OF X

DITCH BIOREACTOR

Practice Selection: Dinitrifcation ditches should be placed in areas where the bottom of the woodchips will intercept groundwater.

Design Criteria and Calculations

Width of swale (B) and length of swale (Ls) is dependent on site constraints
Depth of bioreactor (Dw) is dependent on water table - woodchips should intercept groundwater to encourage anaerobic conditions. Dw shall be between 3'-5'.
There should be 1 gravel column for every 100 feet of woodchip section.

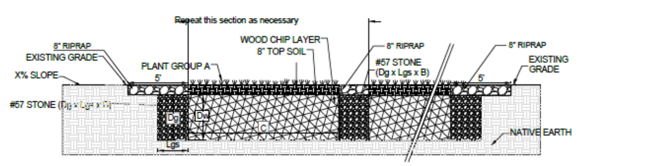
How to calculate woodchip length (lw) and gravel length (Lg)
(time it takes to fill up gravel volume cannot be more than the time it takes the water to exit into the bioreactor)

Volume of water in woodchip section (V1)= pore space (E) * Volume of woodchip section (Vw)
V1 / 24 hours = volume of water per hour to fillup bioreactor in 24 hours
V1 / 24 hours = cross sectional area of gravel where water enters reactor (Area of gravel, Ag) x hydraulic conductivity of gravel (ks) / safety factor (SF)

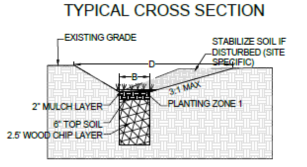
Relationship derivation:
E=.4
ks = 70 in/hr
SF=10
(eq. 1) Volume of bioreactor (Vw)=420Area of gravel (Ag)
(eq. 2) Area of Gravel (Ag)= Length of Gravel (Lg) xWidth of Gravel (Wg)
(eq. 3) Volume of bioreactor (Vw)= Length (Lw) x Width (Ww) x Depth (Dw)
(eq. 4) Width of bioreactor (Ww)=Width of gravel (Wg)=Base of Swale (B)
Therefore with (1) and (3):
Vw=420Ag=Lw*Ww*Dw, substituting (2)
420 (Lg/Wg)=Lw*Ww*Dw
420(Lg/Wg)/(Lw*Ww)=Dw, subsituting (4) and canceling out Wg
420Lg/Lw=Dw
Lg=Dw*Lw/420, where 3'≤Dw≤5'

Example:
Depth of practice = 3ft (constrained by site)
Allowable length of practice=Lw=300 ft (constrained by site)
Lg=3ft * 300ft /420ft = 2.14ft
This is the total length of gravel and bioreactor (not broken into repeated sections)

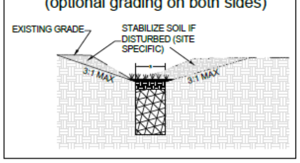
PROFILE VIEW



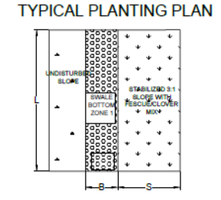
TYPICAL CROSS SECTION



ALTERNATIVE CROSS SECTION
(optional grading on both sides)



TYPICAL PLANTING PLAN



Species	Common Name	WIS	Height	Light Requirements	Notes
Zone 1- Companion Species for Saturated and Wet soils					
Juncus effusus	common sedge	FACW+	2-5'	Part Shade to Full Sun	salt tolerant, deer resistant
Solidago sempervirens	seaside goldenrod	FACW	3-5'	Part Shade to Full Sun	salt tolerant
Pycnanthemum muticum	clustered mountainmint	FACW	2-3'	Full Shade to Full Sun	rhizomatous, deer resistant
Tripsacum dactyloides	eastern gamagrass	FACW	4-5'	Full Sun	warm season grass
Deschampsia cespitosa	tufted hairgrass	FACW	2-4'	Part Shade to Full Sun	salt tolerant
Lobelia cardinalis	cardinal flower	FACW+	2-5'	Part Shade to Full Sun	
Asclepias incarnata	swamp milkweed	OBL	3-5'	Part Shade to Full Sun	
Chelone glabra	white turtlehead	OBL	2-4'	Full Sun to Full Shade	
Iris versicolor	blue flag iris	OBL	2-3'	Full Sun to Full Shade	

Stock	Application	Spacing (o.c.)	Notes
Plugs	Standard	12"	Normal application
	High	8"	Where rapid and complete cover is desired in first year
Quart	Standard	18"	Normal application
	High	12"	Where rapid and complete cover is desired in first year

CENTER FOR WATERSHED PROTECTION

Swale Template	DATE
TALBOT COUNTY, MD	NO SCALE
PROFILE SHEET	SHEET 4 OF X

2. Maryland Stormwater Design Manual
    a. https://mde.maryland.gov/programs/water/stormwatermanagementprogram/pages/stormwater_design.aspx

3. Performance Enhancing Devices for Stormwater Best Management Practices
    a. http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2017/05/APRIL-26-FINAL-PED-DOCUMENT.pdf
4. Enhanced Roadside Ditch Management
    a. https://chesapeakestormwater.net/events/webcast-enhanced-roadside-ditch-management/