RURAL PROPERTY SURFACE WATER MANAGEMENT

SURFACE DISPERSION, INFILTRATION TRENCHES, & BIOINFILTRATION SWALES

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Document typeset by Ani Jayakaran and is dedicated to those who appreciate LaTeX and the work of Edward R. Tufte and Donald E. Knuth.

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Introduction

The management of stormwater and methods to limit its devastating impacts on receiving water bodies has been the focus of much research, legislation, and action in the United States. While most of the work has focused on urban watersheds, rural watersheds are not immune from the challenges posed by polluted stormwater entering rural waterways. Stormwater runoff is the water that flows off a surface after a rainfall event. The surface generating that flow is typically anthropogenic and has been modified for human habitation. For example, rainfall flowing off a rooftop, a lawn, a lot that has been cleared of its native vegetation, a gravel road, a parking lot, all produce what is called stormwater runoff. Stormwater runoff, when left unmanaged, can cause flooding downstream and can transport pollutants from landscape to waterway, adversely impacting aquatic ecosystems.

Washington State University (WSU) Extension and the Washington Stormwater Center (WSC) have partnered to develop peer-reviewed guidance tools and training programs to empower agency, municipal, tribal staff, and landowners to effectively manage and reduce polluted runoff in rural areas. Water quality improvement efforts in Washington state have been centered on urban runoff. The focus of this project is to address rural stormwater impacts. Working with an advisory committee comprised of stakeholders from Clallam, Jefferson, Kitsap, and Mason counties and others, the project team will:

- Seek solutions for rural stormwater issues.
- Identify training and guidance material needs
- Develop educational materials such as factsheets, short videos, and a comprehensive webpage.
- Provide training opportunities to key stakeholders.
- Highlight sites that demonstrate best practices.
- Inform stakeholders across the state about the resources developed.

The following sections of this document outline the role of sustainable stormwater management practices in mitigating the harmful impacts of unchecked and unmanaged rural stormwater.

This document is written as a broad introduction to three possible strategies that might be used for managing stormwater on a rural property. This document is NOT a how-to-build-a-stormwater management system; instead, it provides information on the advantages and disadvantages of three systems, essential conditions for their feasibility, and an overview of maintenance considerations. We envision the audience for this document to be county stormwater planners, conservation district staff, contractors, landscape professionals, and rural residents who want to know more about the options at hand to manage stormwater on their rural lots.

A survey of stakeholders was conducted in April 2021 to obtain input and guidance for the project. The survey was designed to help project staff understand the audience's needs early in the project to learn what educational materials they need to assist rural property owners in managing stormwater runoff. The survey also sought potential members to serve on an Advisory Committee for the project. Respondents were provided a list of nine rural stormwater management methods identified by the project team to fit the grant's needs and goals. In addition, participants were asked to select the top three that they would like to have more information about. Based on this survey, the installation and maintenance of three types of stormwater management methods are detailed in further sections.

What are the top rural stormwater management methods you want information about, for you or to share with you clients? Choose only 3.

Answer	%	Count
Surface Dispersion Systems	20%	42
Bioswales	17%	36
Gravel Trenches	14%	30
Rain Gardens Bioretention	14%	28
Piped Infiltration Systems	10%	20
Permeable Interlocking Pavers	7%	14
Perforated Stub-out Downspout Connection	6%	12
Pervious Concrete	5%	10
Porous Asphalt	4%	8
Other	3%	7

Table 1: Responses to survey question: 'What are the top rural stormwater management methods you want information on?'

THE NEED FOR THIS DOCUMENT stems from the fact that most stormwater management efforts have focused on urban watersheds given the high densities of people and impervious areas. However, there is a growing recognition that polluted stormwater can also impair rural waterways. As a result, many smaller counties and towns that do not currently fall under the purview of the EPA Phase 1 or 2 regulated MS4[1]'s are either preparing to become Phase 2 MS4's, or understand and want to mitigate future detrimental impacts of unplanned development and poor stormwater management. There is also a need for solutions to mid-range stormwater problems, i.e., cities below Phase 1 and 2, such as the Port Townsend stormwater system and commercial properties with shared stormwater infrastructures, such as that in Port Hadlock at the intersection of Hwy 119 and Chimacum Rd. These are likely the most impactful to water quality in that county; however, such stormwater systems are outside this project's scope. Additionally, individual landowners might want to learn more about how they might manage stormwater on their properties or just limit standing water on their properties. This document aims to provide a basic outline of how the top three stormwater management practices (based on the stakeholder survey) might be used.

[1] Municipal Separate Storm Sewer System - https://www.epa.gov/npdes/stormwater-discharges-municipal-sources-developing-ms4-program

Understanding Site Conditions

Creating a site map is the first step in determining the best options for managing stormwater at the lot scale. A map showing the current pathways, or a ’drainage map’ does not have to be very complicated or even to perfect scale – however, keeping to an approximate scale is essential (see Figure 1 adapted from Clark County[2]). Creating a site map is a critical step that needs to be taken and a valuable tool to communicate how water flows on your parcel of land. The availability of space, the type of soils, the gradient of the landscapes, presence of adjacent critical areas – are all critical factors that need to be considered when developing a plan to manage stormwater on a site. A site drainage map must include the following.

[2] Clark County. Clark county stormwater manual. URL https://clark.wa.gov/sites/default/files/dept/files/environmental-services/Stormwater/Code/ccsm2015-book-1.pdf

The following are a list of critical pieces to a suitable drainage map (adapted from Fairbanks North Star Borough - Dept. of Community Planning)[3]

[3] Fairbanks North Star Borough - Department of Community Planning. How to draw a residential plan. URL https://www.fnsb.gov/DocumentCenter/View/885/Site-Plan-Guide---Residential-PDF?bidId=

1. Scale at which site plan is drawn (for example 1" = 20’)
2. Show a North arrow
3. Show all property lines and their dimensions
4. Location, type (i.e., house, garage, shop, shed, carport, etc.), and dimensions of all existing structures
5. Location, type, and dimensions of all proposed structures and/or additions
6. Setback distances of all proposed structures and/or additions to all property lines
7. Buildable area of the lot inside required setbacks (only required if the proposed structures and/or additions are within five feet from the required setback line)
8. Names of adjacent roads
9. Existing and/or proposed driveways
10. Well location (optional)
11. Septic location (optional)

It is also often necessary and helpful to briefly describe the adjacent land uses on the map. A simple example of such a map is presented in Figure 1.

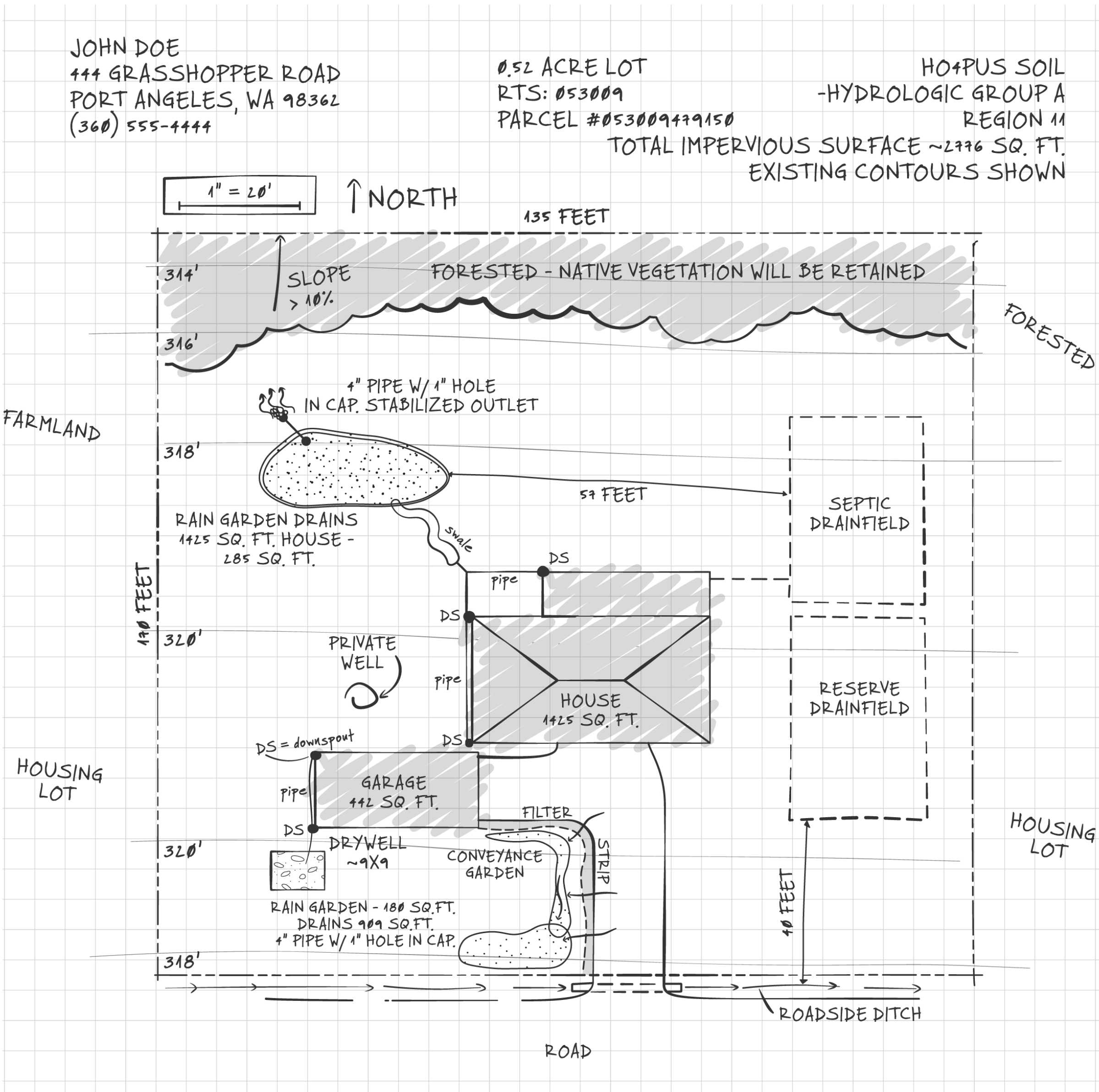

Illustration by Andrew Mack, Washington State University

Figure 1: An example of a drainage plan drawn to scale on gridded paper

Determining which best management practice (Best Management Practice (BMP)) is most appropriate to manage stormwater on a parcel of land requires consultation with an expert or after attending some basic training offered by the local county, university, or conservation district. This document seeks to outline some options but is not written as a substitute for professional advice. Please consult with your local county engineer, and be familiar with the stormwater ordinances in place in your area. Here is a simple hierarchy that might be useful in determining what Best Management Practice (BMP) options best fit the job – an example is reproduced below in Figure 2 adapted from Oregon State University Extension[4].

[4] Oregon State University Extension. Stormwater solutions for green infrastructure. URL `https://extension.oregonstate.edu/stormwater-green-infrastructure`

We have chosen to highlight three types of Best Management Practice (BMP)s for this document. These are

- Surface dispersion systems – Level 3 from Figure 2.
- Gravel infiltration trenches – Level 4 from Figure 2.
- Bioinfiltration swales – Level 5 from Figure 2.

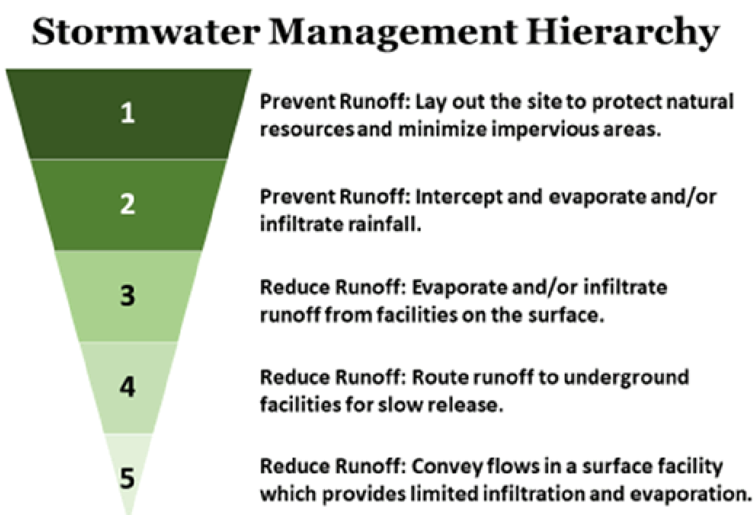

Figure 2: An example of a stormwater management hierarchy that prioritizes how BMPs might be chosen.

Surface Dispersion Systems

Introduction

Surface dispersion systems primarily utilize the existing landscape to slow down and process stormwater. The stormwater moves across the landscape's surface using the vegetation and topography to assist with, and encourage, infiltration. The most simplistic dispersion systems use unaltered native vegetated areas that can accommodate additional water generated from impervious surfaces (roofs, driveways, roadways). Other dispersion systems include additional components to gently direct stormwater flow to landscape areas designated for stormwater accumulation and attenuation. Systems such as level spreaders and flow spreaders enable breaking up flow occurring in channeled or narrow pathways, spreading the flows across a wider area, thereby improving the chances of infiltration into the ground. Generally, however, dispersion systems aim to slow the velocity of water and spread it more evenly across the landscape, giving it a better chance of infiltrating into soils. Native soils vary significantly in infiltration capabilities and are vital for surface dispersion systems' success and usability—several dispersion systems are described in further detail below.

Complete Dispersion (BMP T5.30, volume V, V-3) The goal of full dispersion is to preserve and utilize the original landscape where possible to take on additional stormwater generated by impervious or cleared surfaces. "Rural single-family residential developments should use this BMP wherever possible to minimize effective impervious surfaces." In other words, there are enough untouched areas left on the property that can handle the additional stormwater created by an impervious or cleared area. The designated dispersion areas rely on soils that do not get compacted, allowing for as much stormwater infiltration as possible. An example of a dispersion plan is presented in Figure 3; the figure is adapted from the Clallam County Small Drainage Manual[5].

Definition[5]: This Best Management Practice (BMP) allows for

[5] Clallam County. Clallam county small drainage manual. URL http://www.clallam.net/realestate/assets/applets/FINAL_BMP_Manual_Draft.pdf

"fully dispersing" runoff from impervious surfaces and cleared portions of the project sites into areas preserved as forest, native vegetation, or cleared area[6]." Washington State Department of Ecology accepts Full Dispersion as meeting Minimum Requirements for onsite stormwater management, runoff treatment, and flow control.

[6] Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm

Sheet Flow Dispersion (BMP T5.12, volume V, V-3) Definition[7]: "Sheet flow dispersion is the simplest method of runoff control. This BMP can be used for any impervious or pervious surface that is graded to avoid concentrating flows. Because flows are already dispersed as they leave the surface, they need only traverse a narrow band of adjacent vegetation for effective onsite stormwater management[7]". Sheet flow dispersion is a simple type of dispersion to utilize on flat or moderately sloping surfaces. The example below depicts how runoff sheet-flowing from a reasonably flat driveway can be dispersed with a simple gravel transition zone, leading to a vegetated strip. For surface dispersion BMPs to successfully manage stormwater, a full property needs assessment must be completed. Slopes, soil types, erosion, or flooding potential, are a few aspects that factor into whether these BMPs are appropriate. An adapted[7] schematic of sheetflow dispersion for driveways is presented in Figure 4.

[7] Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm

Concentrated flow (BMP T5.11, volume V, V-3) Definition[7]: "Dispersion of concentrated flows from driveways or other pavement through a vegetated pervious area attenuate peak flows by slowing entry of runoff into the conveyance system, allowing for some infiltration, and providing some water quality benefits." Sites having steeper slopes will result in more concentrated flow patterns. Surface dispersion can still be a helpful tool; however, working within the constraints that slopes pose will need to be addressed in the design plans. An adapted[7] schematic of concentrated flow dispersion for steep driveways is presented in Figure 5.

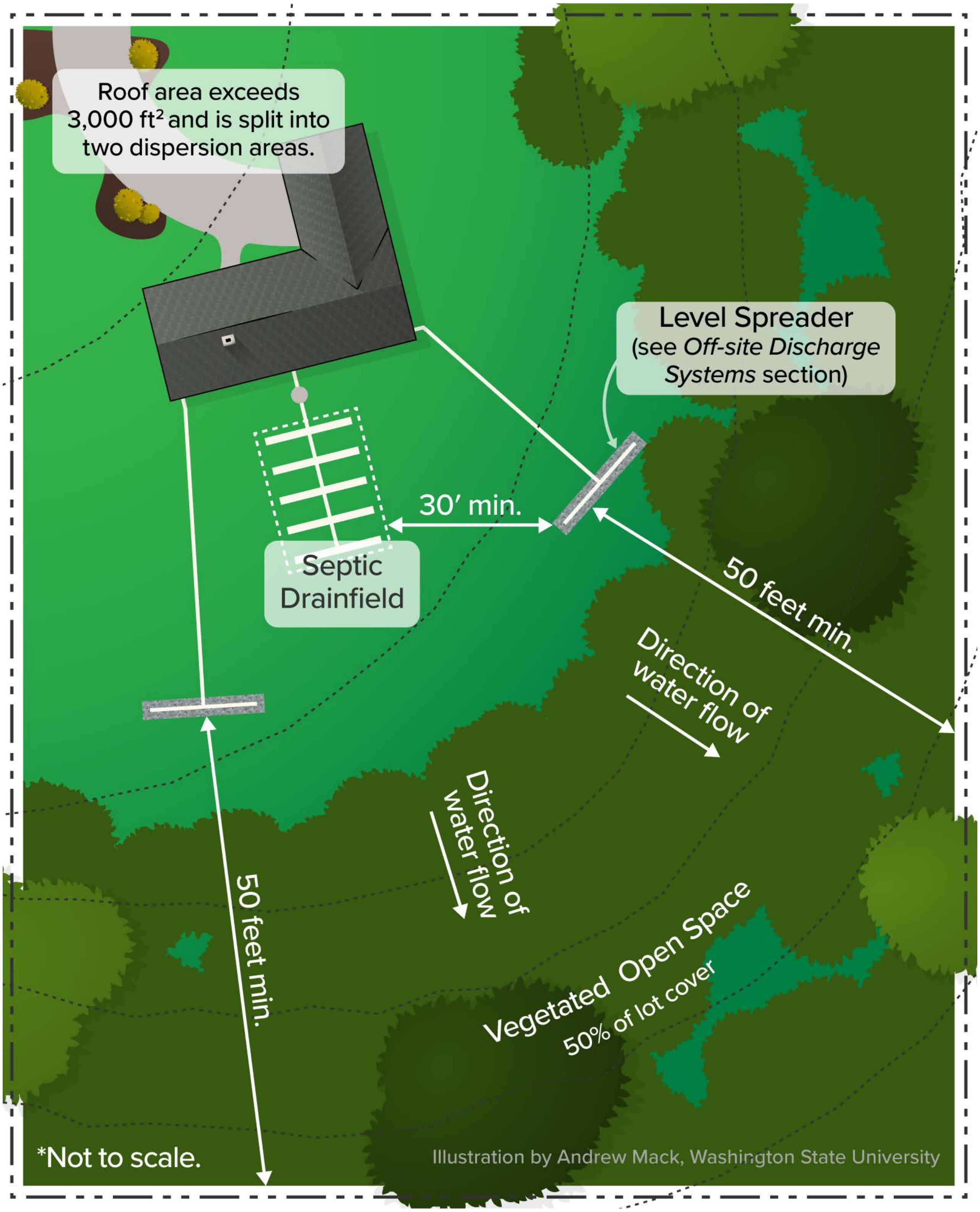

Figure 3: An example of a dispersion plan.

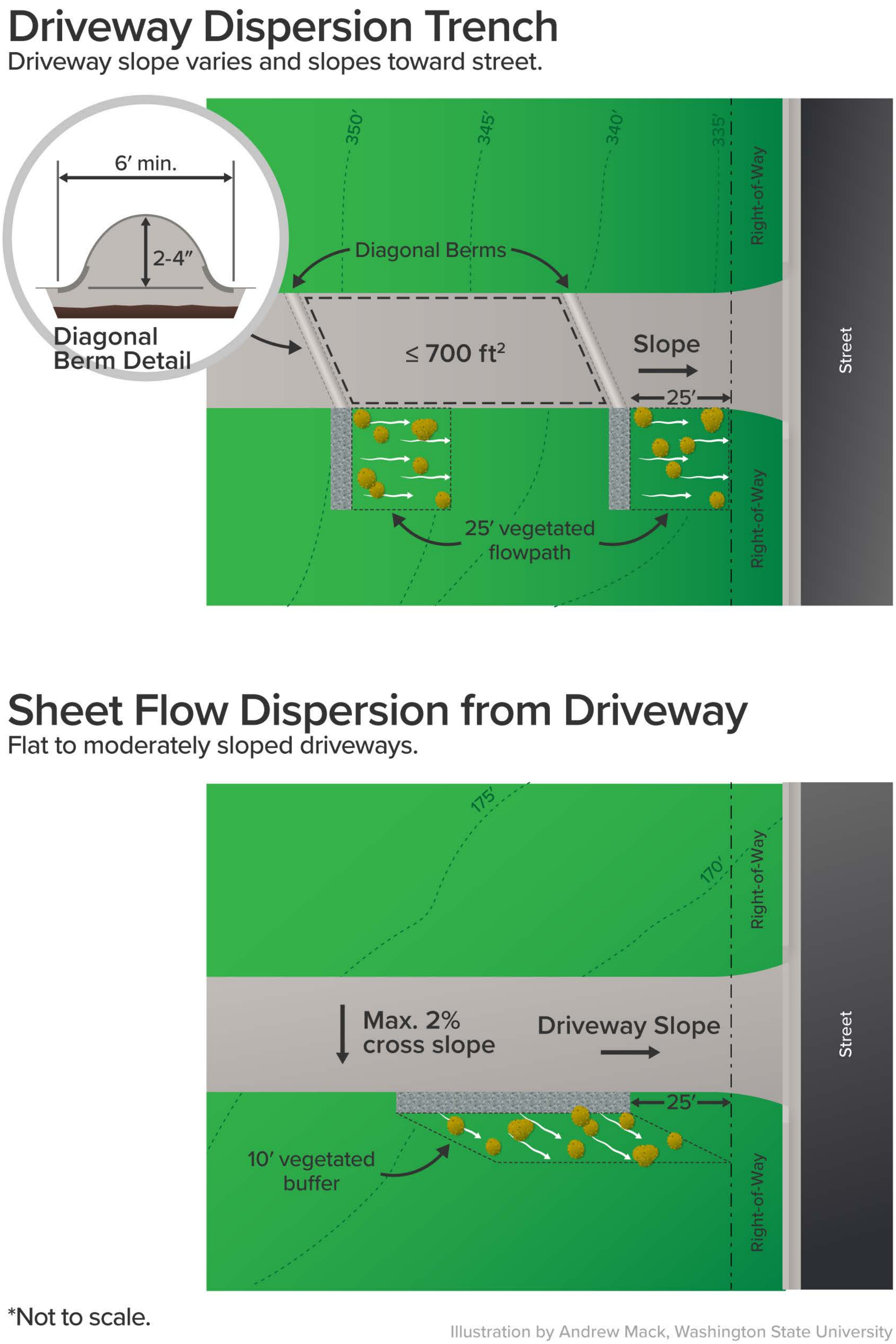

Figure 4: Sheetflow dispersion for driveways

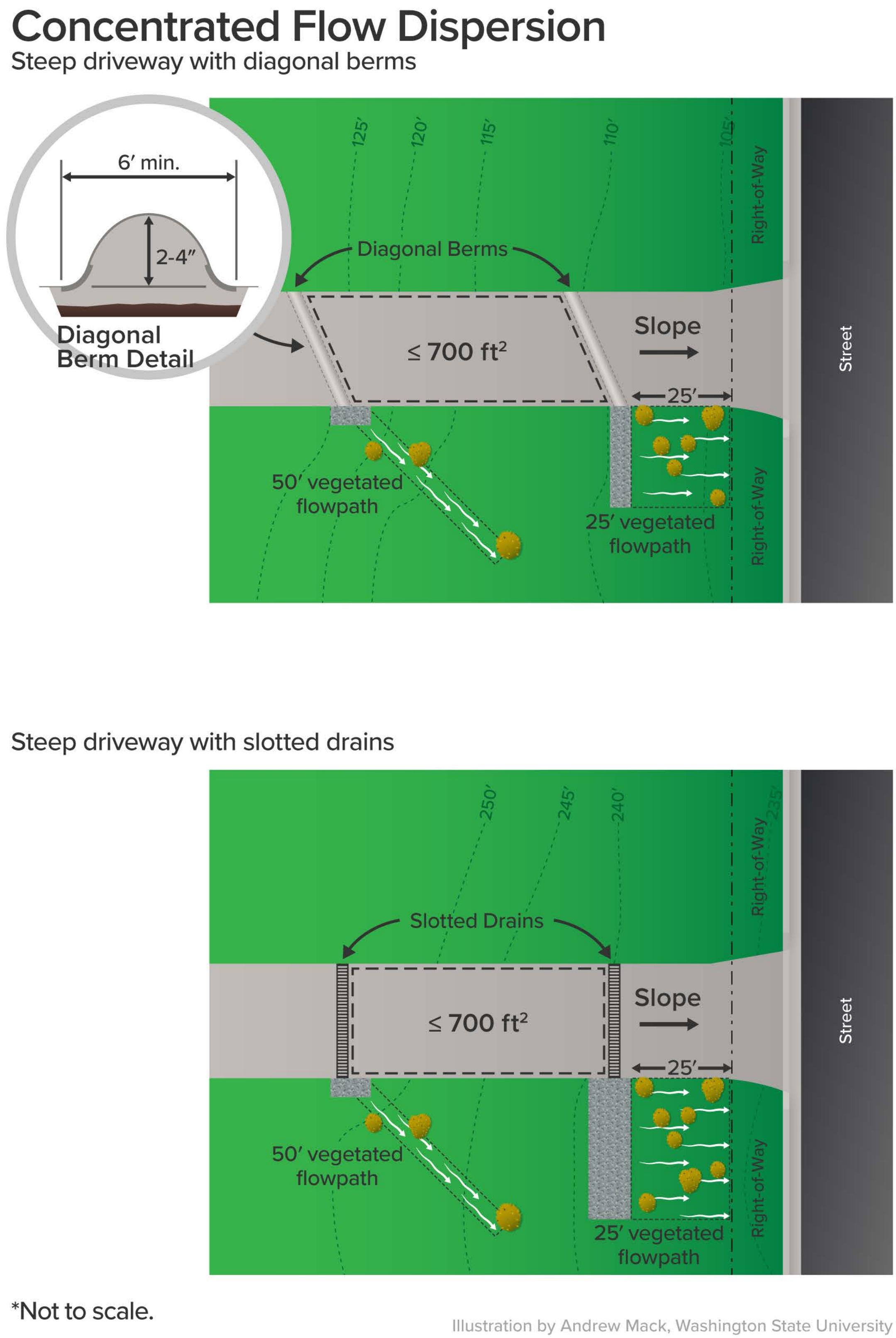

Figure 5: Concentrated flow dispersion for steep driveways.

DOWNSPOUT DISPERSION Definition[8]: "Roof downspout BMPs are simple, pre-engineered designs for infiltrating and dispersing runoff from roof areas to increase opportunities for groundwater recharge and reduction of runoff volumes from development." Stormwater emerging from downspouts have three different BMPs:

1. Downspout full infiltration (BMP T5.10A, Volume V, V-4)
2. Downspout Dispersion Systems (BMP T5.10B, Volume V, V-4)
3. Perforated Stub-out Connections (BMP T5.10C, Volume V, V-4)

There is no one size fits all on which downspout Best Management Practice (BMP) to utilize; it may be site-specific as to which type or types will work best. Downspout full infiltration and perforated stub-out connections are not covered in this document. Downspout dispersion systems work well to spread roof runoff over vegetated pervious areas on large urban lots. The three types of downspout dispersion systems include downspout splashblock dispersion, downspout dispersion trench, and a trench with a notched grade board.

[8] Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm

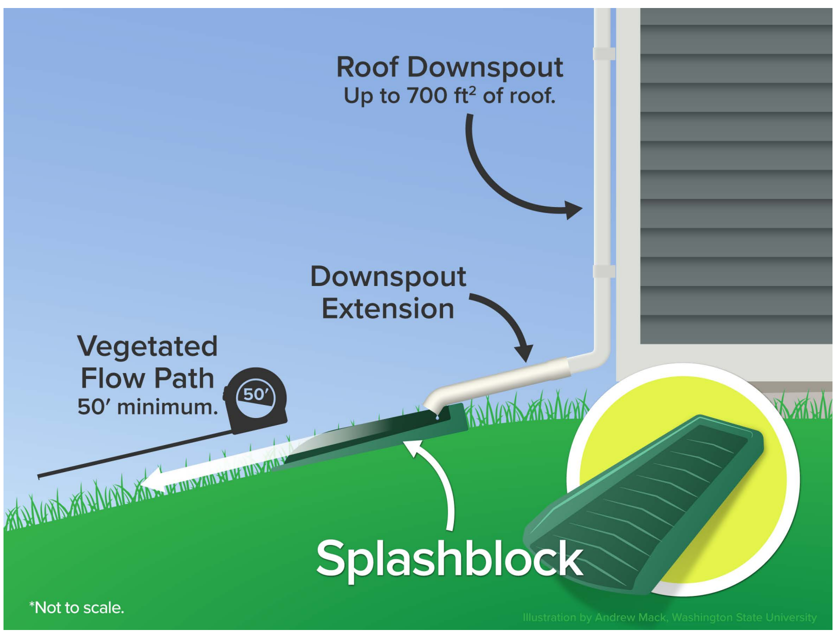

Figure 6: Downspout dispersion[8].

Applications & limitations

As noted in the introduction to surface dispersion systems, these Best Management Practice (BMP)s primarily rely on vegetated landscapes that contain enough room for stormwater to "naturally" disperse and infiltrate onsite. Clearing away the native landscape of vegetation or

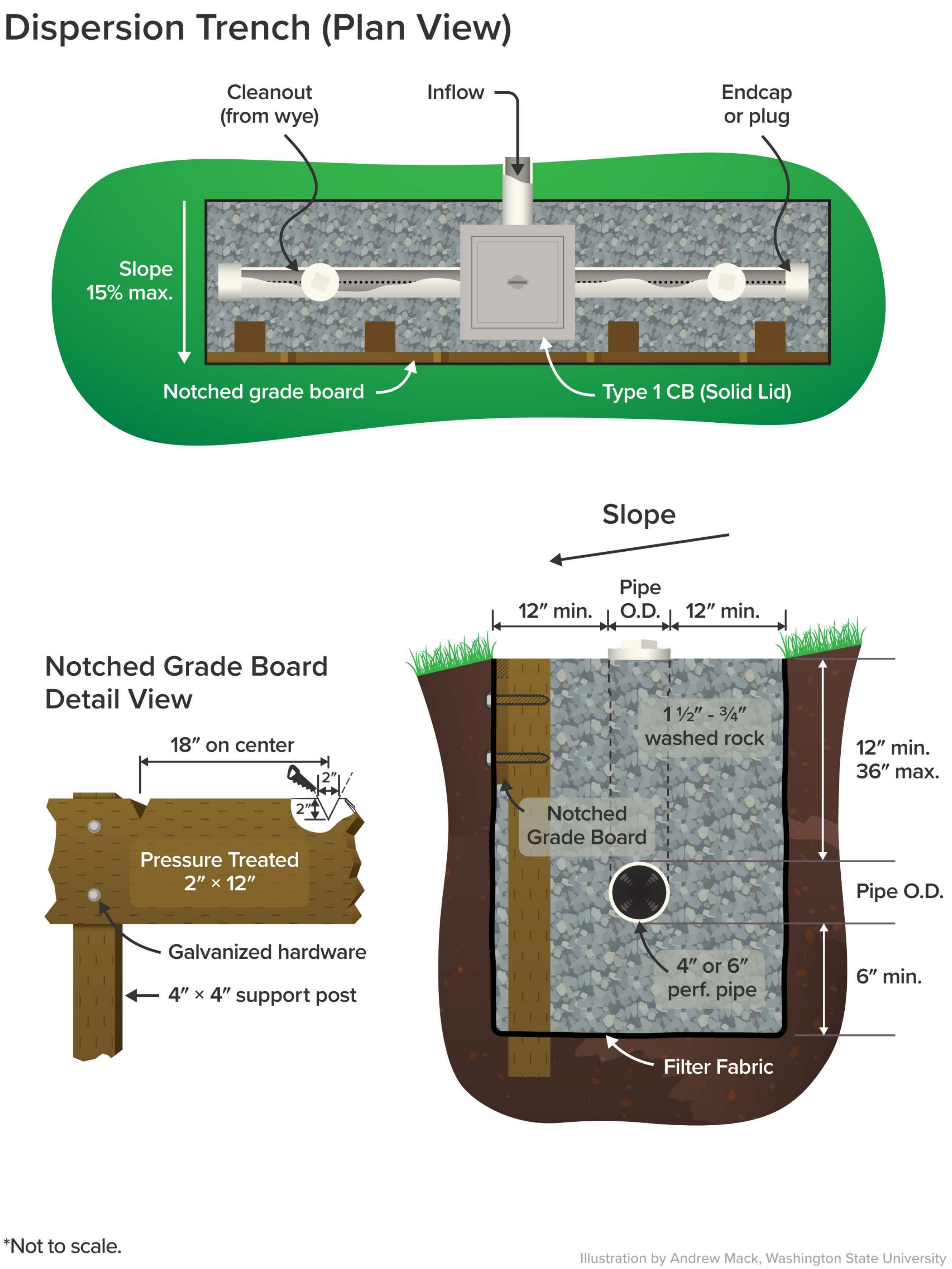

Figure 7: Standard dispersion trench with notched grade board.

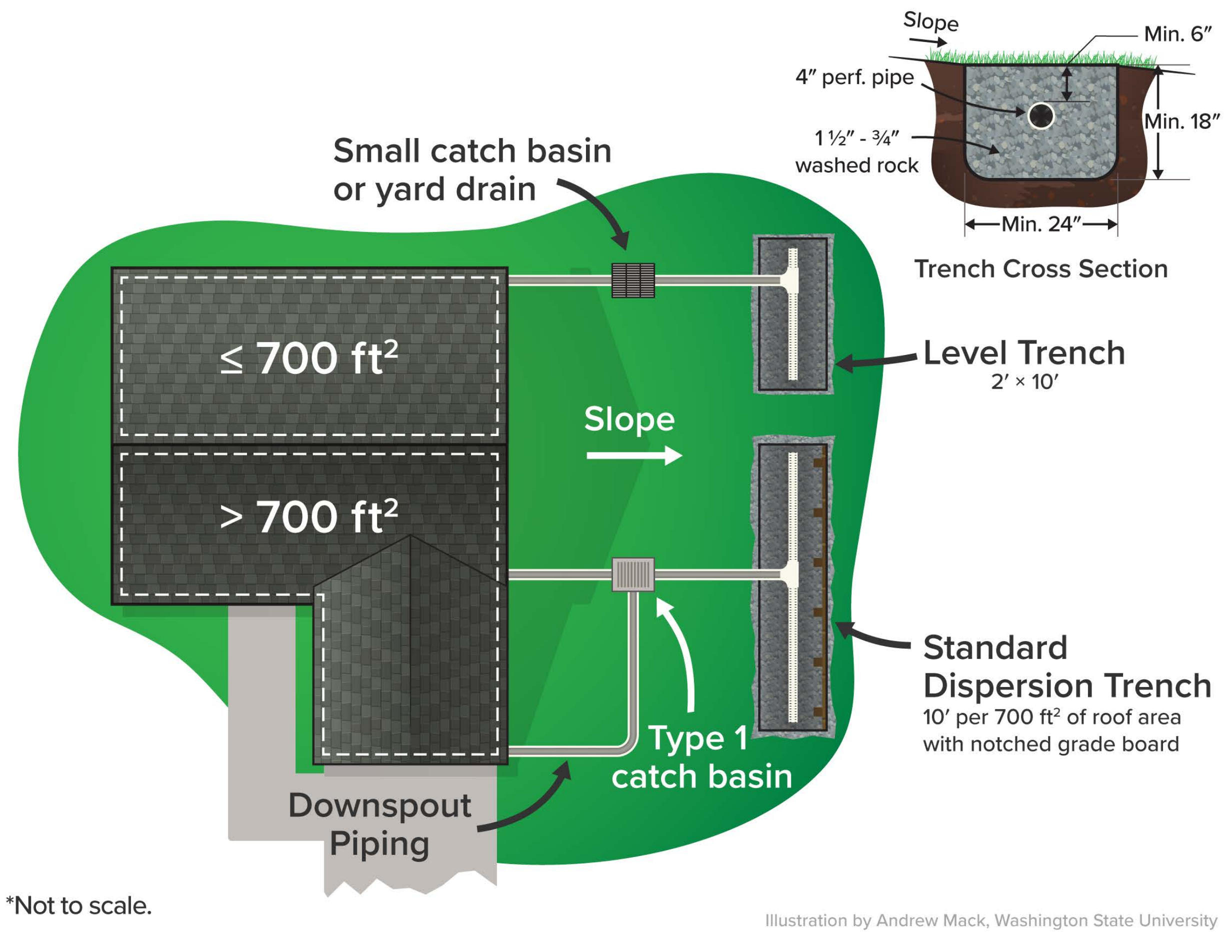

Figure 8: Layout of dispersion systems on a home parcel.

adding additional impervious surfaces such as driveways changes the water patterns on the property. Large and relatively flat vegetated lots can often absorb the altered water flow patterns with mostly minor modifications. There are situations when altering or changing surface dispersion flow patterns make these dispersion BMPs not feasible, though, because there is the potential to impact adjacent properties adversely. Horizontal setbacks and site constraints can be limiting factors for dispersion BMPs (6). Horizontal setbacks add a layer of protection to prevent stormwater from flowing onto adjacent properties, but these setbacks will also reduce the available space to factor into the dispersion areas. In addition, site constraints, such as landslide-prone areas or septic systems/drain fields, will also reduce the potential useable property for dispersion areas. Dispersion BMPs have flow path length or dispersion area requirements that can only be attainable on larger properties but limit smaller projects. For example, a typical downspout splashblock dispersion system requires "a vegetated flow path of at least 50 feet between the discharge point and any property line... [9]"

The 2019 Stormwater Management Manual for Western Washington (SWMMWW)[9] discusses each of these surface dispersion BMPs and potential reasons why they may or may not work on a property. In addition, possible issues that limit the use of surface dispersion BMP (infeasibility criteria) are outlined below.

[9] Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm

Dispersion Infeasibility Criteria

The following infeasibility examples are sourced from the Kitsap County Stormwater Best Management Practice Infeasibility Worksheet for Onsite Stormwater Management [10]. Other counties might have slightly different infeasibility criteria in place. These are infeasibility criteria that apply to **all** Dispersion Best Management Practice (BMP)s in Kitsap County:

[10] Kitsap County. Bmp infeasibility worksheet. URL https://www.kitsapgov.com/dcd/FormsandBrochures/StormwaterBestManagementPractice(BMP)InfeasibilityWorksheet.pdf

- A professional geotechnical evaluation recommends against glsdispersion due to erosion, slope failure, or flooding concerns.
- The only available dispersion flow path is within 10 feet uphill of a septic system or drain field.
- The only available dispersion flow path is within an erosion hazard of a landslide hazard area.
- The only available dispersion flow path is in a critical area, steep slope (over 15%), or a setback to a steep slope.
- The only available dispersion flow path is within 100 feet uphill of a contaminated site or abandoned landfill.

Additional infeasibility criteria for full dispersion:

- The minimum 100-foot flow path through native vegetation cannot be met.
- A 65 to 10 ratio of native vegetation area to impervious area is unachievable.

Additional infeasibility criteria for sheet flow dispersion:

- For flat to moderately sloped areas, a minimum 10-foot wide vegetated flow path is not possible.
- For variably sloped areas, a minimum 25-foot wide vegetated flow path is not possible.
- Positive drainage is not possible.
- The contributing area has a slope of 15% or more.

Additional infeasibility criteria for concentrated flow dispersion:

- Horizontal setbacks cannot be met.
- Dispersion and flow path requirements cannot be met:
  - A minimum 10-foot dispersion trench followed by a 25-foot minimum flow path, OR a 3-foot rock pad with a minimum 50-foot minimum flow path.
  - A maximum of 700 square feet contributing area to any dispersion device.

Additional infeasibility criteria for downspout dispersion:

- The flow path cannot be properly vegetated.
- For dispersion trenches:
  - The minimum dispersion trench length cannot be met (10 feet of trench for every 700 square feet of contributing area).
  - The minimum 25-foot flow path for dispersion trenches cannot be met.
  - A vegetated flow path of 50 feet between the trench and a slope over 15% cannot be met.
- For splashblock dispersion:
  - The minimum 50-foot flow path for splashblocks cannot be met.
  - The contributing area to any splashblock exceeds 700 square feet.

Design Criteria

Each surface dispersion BMP will have specific design requirements and may vary by jurisdiction. Broadly, all dispersion BMPs will have two key components:

1. Contributing area.
2. Dispersion area.

The contributing area at a location is the pervious and impervious areas, such as a driveway, roof or cleared area, which will generate stormwater runoff to that location. The dispersion area is the area of land designated for the stormwater to be redistributed to.

Critical design criteria may need to be included to ensure that the dispersion area can accommodate the additional stormwater. Check with local jurisdictions or refer to the stormwater manual for specific requirements. Below are some example design requirements for each surface dispersion BMP.

Full Dispersion: The "full dispersion" BMP focuses on preserving as much of the site as possible - the dispersion area shall have a minimum area of 6.5 times the area of the impervious surface draining to it [11]. Forested landscapes or those with native vegetation are best equipped to process additional stormwater. However, the construction process should not impact untouched landscapes, and soil infiltration should be preserved in these locations. Some allowances for passive recreation within the designated dispersion areas are allowed, but preventing soil compaction is vital.

[11] Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL `https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm`

Sheet Flow Dispersion: Sheet flow dispersion systems generally have a transition zone and a vegetated buffer or dispersion area. The transition zone is primarily a 2-foot-wide area of material, such as drain rock, which is next to the impervious surface (i.e., driveway). The transition zone discourages stormwater channeling and encourages flow to the dispersion area or designated vegetative buffer[11]. The vegetated buffer size is related to the size of the impervious surface. Therefore, a larger driveway requires a larger vegetated buffer. Specifically, a driveway that is up to 20 feet wide requires a 10-foot vegetated buffer. For a wider driveway, An additional 10 feet of vegetated buffer width is needed for every additional 20 feet of impervious surface width or fraction thereof[11]. A 30-foot wide driveway, for example, would require a vegetated buffer with a width of 20 feet.

Concentrated Flow Dispersion: Stormwater generated from impervious surfaces on sloped properties tends to flow along concentrated or channeled pathways. Therefore, specially adapted concentrated flow dispersion BMPs include additional features like a rock pad or a dispersion trench to ensure that concentrated flows are well dispersed. The rock pad or dispersion trench are types of level spreaders– they slow down the water and spread it out over a wider area. Downstream of the level spreader, there needs to be an unobstructed vegetated flow path of at least 25 feet free of rigid structures, steep slopes, water bodies, or other impervious surfaces to ensure proper dispersion. Additionally, "for sites with septic systems, the discharge point must be ten feet downgradient of the drain field and primary reserve areas[11]." The steepness of the property determines the length of the flow path and what type of level spreader is necessary. Concentrated flow dispersion BMPs need to have a dispersion trench or a crushed rock pad installed at a location upstream of the vegetated flow path [12].

[12] Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm

DOWNSPOUT DISPERSION: There are three different types of roof downspout dispersion BMPs:

1. Typical downspout splashblock dispersion.
2. Typical downspout dispersion trench.
3. Standard dispersion trench with notched grade board.

Downspout dispersion using splashblocks is the simplest to implement of the three options listed above. If there is adequate vegetation, room for effective dispersion, and the ground is sloped away from the foundation, splashblocks work well to disperse storm runoff[12]. Additionally, splashblock dispersion requires a vegetated flow path free of obstructions for at least 50 feet from the discharge point. If this distance is not attainable, downspout dispersion can be supplemented with the addition of a dispersion trench, shortening the vegetated flow path down to 25 feet - this is also known as a typical downspout dispersion trench. Depending on the site, the trench may also require a notched board to dissipate the concentrated flow - also known as a standard dispersion trench with a notched grade board. Finally, if the vegetated flow path is shorter than 25 feet, another Best Management Practice (BMP) called a perforated stub-out connection is appropriate for use. Please refer to T5.10C in SWMMWW[12].

Construction Notes

The emphasis of dispersion BMPs is to reallocate water from the impervious surface to locations within the property that can adjust and accommodate additional stormwater. Ensuring that construction practices do not impact the newly designated dispersion areas is critical. Heavy equipment can compact soils and reduce infiltration rates. Where possible, construction access and sequencing should be planned to preserve the dispersion area and the flow paths to those areas. Marking clearly where these components are on the site helps with any potential communication issues. A map of the site is also a valuable reference for the construction crew and the homeowner. If the property changes ownership, the new homeowner needs to know about the dispersion area and flow path. The map could look something like Figure 9 adapted from Mason County[13].

[13] Mason County. Managing storm drainage on small sites. URL https://www.co.mason.wa.us/forms/Community_Dev/small_site_storm_drainage.pdf

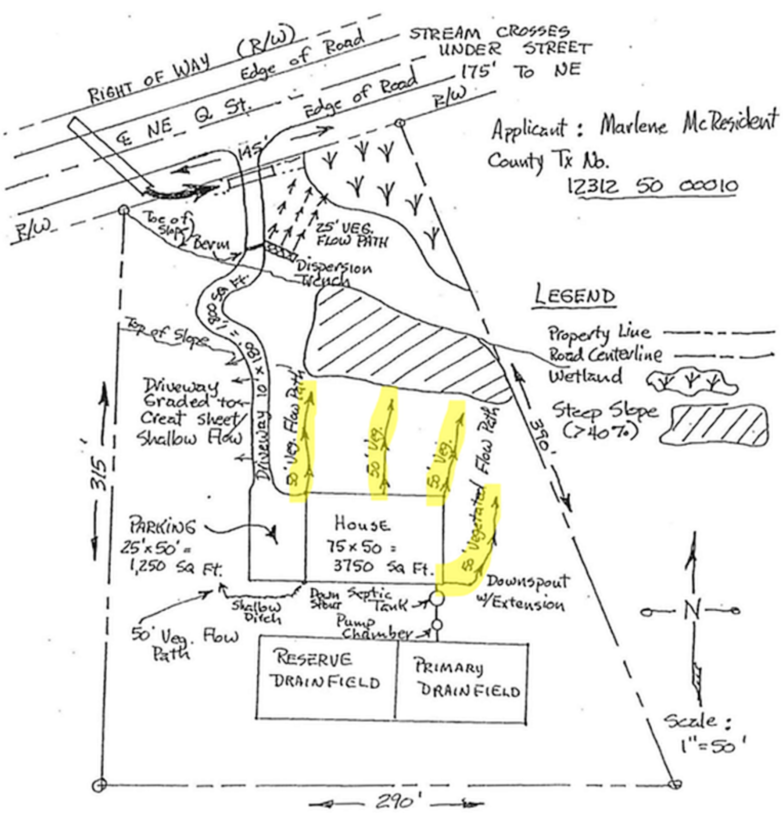

Figure 9: Map showing where dispersion areas, flow paths, and other assets on a site are can help communicate and ensure those assets are not impacted by construction or construction traffic. Flow paths are highlighted.

Maintenance

Surface dispersion BMPs primarily employ vegetation and vegetated landscapes to manage the additional stormwater. Just like any other vegetated landscape, surface dispersion BMPs require maintenance to continue to manage stormwater effectively.

The main component, the dispersion area, needs to remain covered with dense, well-established vegetation. Also, preventing soil compaction in the dispersion area is critical [14]. Avoid using the dispersion area for other purposes, such as for livestock or heavy equipment storage. These activities tend to reduce soil infiltration rates and the overall success of the dispersion area significantly.

Regular inspections of vegetated flow paths to ensure they are not obstructed are required for surface dispersion BMPs, especially before significant rain events. Other components, such as rock pads or splashblocks, should also be routinely checked for any issues that may prohibit flow.

[14] Vermont Department of Environmental Conservation. Vermont guide to stormwater management for homeowners and small businesses. URL https://dec.vermont.gov/sites/dec/files/wsm/erp/docs/2018-06-14VT_Guide_to_Stormwater_for_Homeowners.pdf

MAINTENANCE TASKS: Herrera Environmental Consultants[15] created a comprehensive table of all the components or issues that may occur with a surface dispersion system as well as corrective actions to take. Readers are directed to that resource for more information.

[15] Herrera Environmental Consultants. Western washington low impact development operation and maintenance. URL https://ecology.wa.gov/DOE/files/0b/0b070df2-4aff-4e74-821a-152e3fcb4ff5.pdf

Gravel Infiltration Trenches

Introduction

Infiltration trenches are narrow, stone-filled channels situated over well-draining soil. These trenches utilize the voids between stones to act as a temporary reservoir for stormwater as it infiltrates into the surrounding soil. Infiltration trenches, like other infiltration BMPs, utilize physical filtration and the biological and sorptive properties of native soils to remove pollutants[16]. There are two general types of infiltration trenches- open and closed. Open infiltration trenches collect stormwater that flows from the surface of impervious areas such as a driveway through a vegetated filter strip and into the top of the trench[17]. A closed or subsurface infiltration trench directs stormwater through a pipe into a sedimentation basin and eventually into the subsurface of the trench through a perforated pipe[17]. Adapted illustrations[16] of open and closed infiltration trenches are presented in Figures 10 & 11.

[16] Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm

[17] Michigan Department of Environmental Quality. Infiltration trench. URL https://www.michigan.gov/documents/deq/deq-wb-nps-it_250882_7.pdf

Applications and Limitations

Gravel infiltration trenches provide several benefits to land users. These trenches are effective in reducing runoff volumes as well as treating several common stormwater contaminants. Infiltration trenches have been shown to filter out suspended solids, provide a high level of treatment of metals, oils, and grease, along with a moderate level of treatment of total nitrogen and total phosphorus[18].

[18] Minnesota Pollution Control Agency. Minnesota stormwater manual – bmps for stormwater infiltration. URL https://stormwater.pca.state.mn.us/index.php/BMPs_for_stormwater_infiltration

Along with their ability to remove pollutants from stormwater, infiltration trenches also have hydrological benefits. They act as a peak flow control helping mitigate flood risk and preventing streambank erosion while helping recharge groundwater[16].

Due to their long and narrow shape, infiltration trenches can be utilized into areas where little space is available or in spaces with a footprint too small for other stormwater BMPs. The surface of infiltration trenches can be left as stone, covered with a grating, a layer of sand, or even a vegetated layer of grass in some closed infiltration

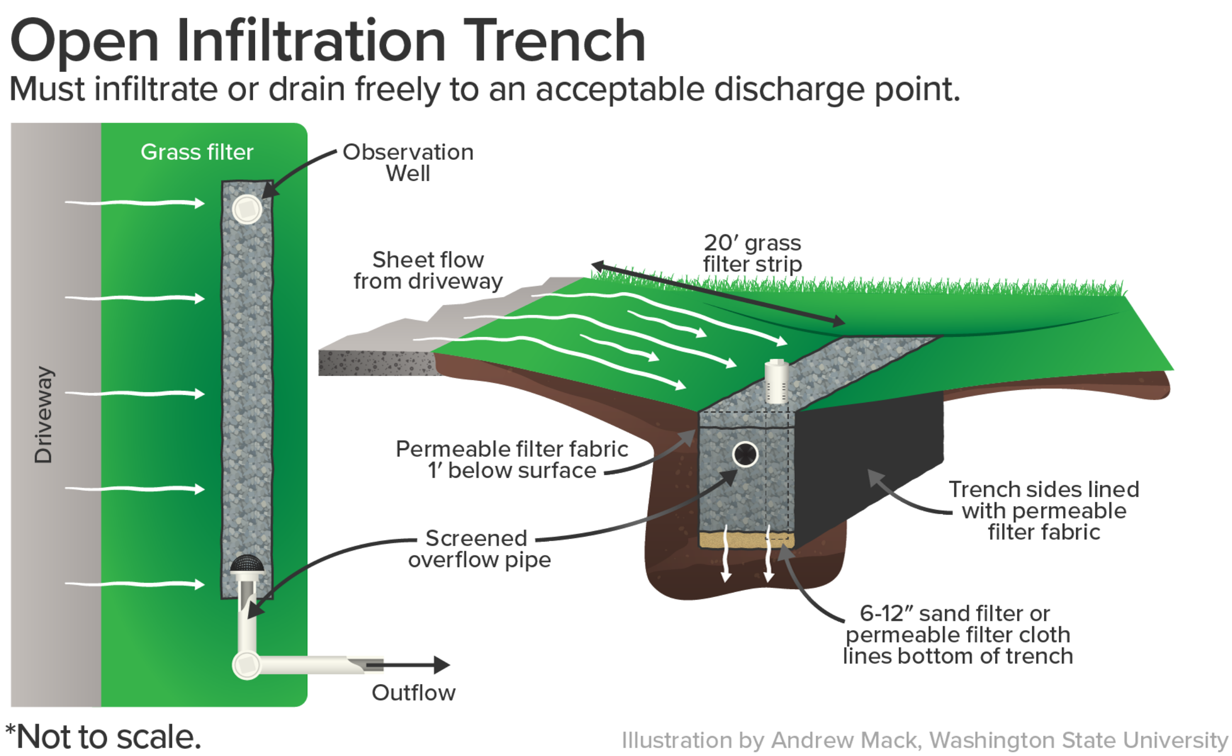

Figure 10: An example of an open infiltration trench.

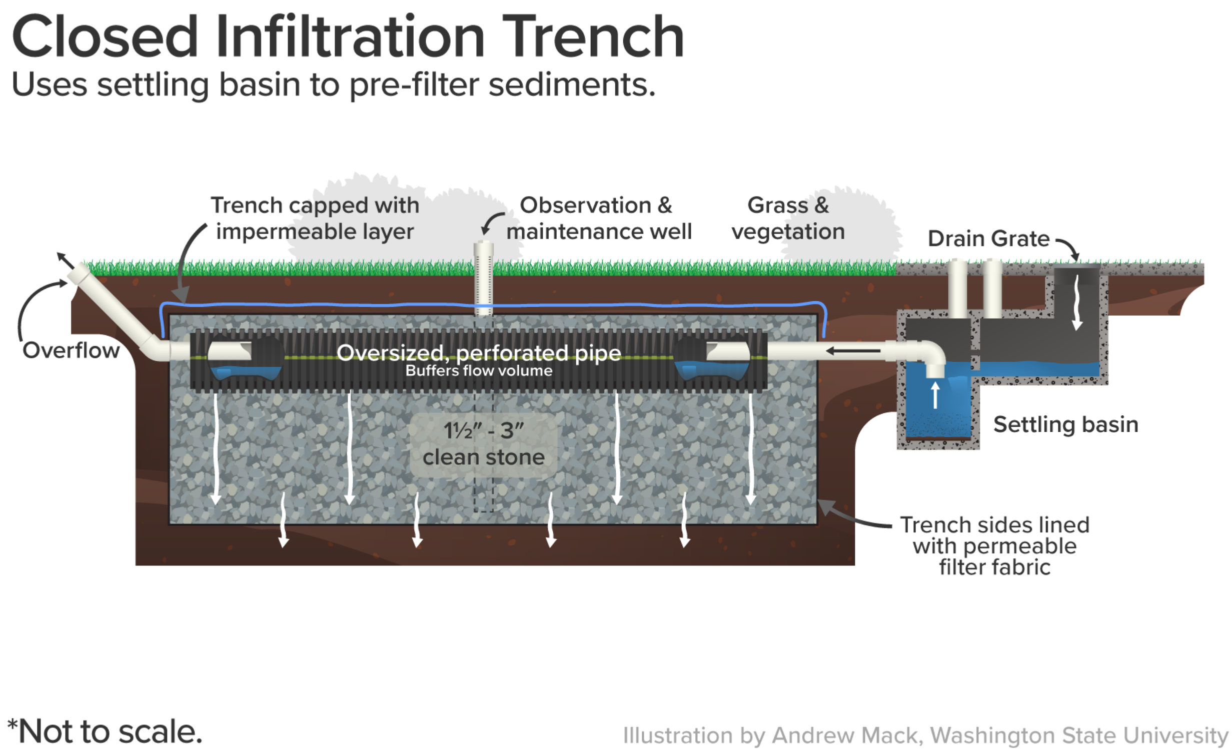

Figure 11: An example of a closed infiltration trench.

Figure 12: Infiltration trenches can be implemented without comprising aesthetics.

trench applications[19]. These options allow gravel infiltration trenches to be easily integrated into the existing landscape with little to no aesthetic impacts[20] - Figure 12[21].

While infiltration trenches have several benefits, some limitations should be carefully considered. One of the significant limitations is that infiltration trenches can be prone to clogging[22]. Clogging of the trench can prove to be an expensive issue to correct, as fixing a clogged infiltration trench often involves removing some or all the gravel layer and geotextile fabric for cleaning or replacement[23]. However, there are several design considerations mentioned in section 5.3 that help reduce the likelihood of clogging.

Infiltration trenches can also have limitations if the surrounding soil has poor infiltration. For example, poor soil infiltration can lead to water accumulating near the surface and prevent the stormwater from being treated. In addition, removing and replacing poor underlying soil is likely unfeasible and cost-prohibitive[23], so other management options should be considered when poor soil infiltration is found.

Infiltration trenches can also lead to groundwater contamination if improperly designed or the stormwater contains high concentrations of soluble contaminants, such as nitrates[20, 22]. If the water being treated has high levels of soluble contaminants, pretreatment or other Best Management Practice (BMP)s should be considered[24]. Because of this contamination risk, closed infiltration trenches that use perforated pipes are subject to Underground Injection Control (UIC) regulations[19].

[19] Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm

[20] Michigan Department of Environmental Quality. Infiltration trench. URL https://www.michigan.gov/documents/deq/deq-wb-nps-it_250882_7.pdf

[21] Minnesota Pollution Control Agency. Minnesota stormwater manual – bmps for stormwater infiltration. URL https://stormwater.pca.state.mn.us/index.php/BMPs_for_stormwater_infiltration

[22] SUNY College of Environmental Science and Forestry. Infiltration trenches. URL https://www.esf.edu/ere/endreny/GICalculator/InfiltrationIntro.html

[23] New Jersey Stormwater. Best management practices manual. URL https://www.njstormwater.org/bmp_manual/NJ_SWBMP_9.3print.pdf

[24] Washington Department of Ecology. Design requirements for infiltration trenches with solids considered a treatment bmp, b. URL https://ecology.wa.gov/DOE/files/7a/7a90167f-371b-4fd2-937e-fc01db3f30c0.pdf

Design Criteria

Design considerations include determining location, sizing, and ensuring that clogging will not become an issue later.

LOCATION CONSIDERATIONS: When deciding on a location to construct an infiltration trench, several considerations should be taken. The first consideration for the location of an infiltration trench is the soil into which the trench will be constructed. Infiltration trenches should be constructed on uncompacted, well-draining soils[25]. The native soil underneath your infiltration trench should have an infiltration rate slow enough to allow the treatment of the stormwater but not so slow that it leads to ponding. A local geologist, hydrogeologist, or engineer with geotechnical experience can be consulted to help determine the suitability of native soil[19].

[25] Stormwater PA. Pennsylvania best management practices manual. URL https://www.stormwaterpa.org/assets/media/BMP_manual/chapter_6/Chapter_6-4-4.pdf

Due to the potential for groundwater contamination, infiltration trenches should be constructed away from wells. The bottom of the trench should also be at least 5 feet above the top of the seasonal high groundwater table to allow adequate infiltration and treatment[24].

Infiltration trenches should also always be downslope from the house, driveway, or other impervious catchment areas the trench is designed to treat. This ensures that the stormwater flows to the infiltration trench as intended[26]. It is also essential to keep infiltration trenches at least 20 feet downslope and 100 feet upslope from buildings-, particularly those with basements, to prevent potential flooding or damage to foundations [27].

Design Considerations: After a suitable location is found, several design criteria should be followed. Proper sizing, sediment control, construction materials, and design will allow for an infiltration trench that is easy to maintain with a lifespan of up to 15 years[28].

Properly sizing an infiltration trench is essential. When sizing an infiltration trench, the designing engineer will take stock of the contributing area the trench will treat, the infiltration rate of the native soil, the maximum trench depth, and the water quality design volume of a 6-month 24-hour storm [29]. The SWMMWW provides multiple resources to help size an infiltration trench appropriately, including a process for sizing trenches that handle roof runoff based on soil type.

One of the most common failure points in infiltration trenches is clogging through sediment buildup. Clogging can be controlled through several design features. For open infiltration trenches, A vegetative strip of at least 20 feet should be included in the design to provide a buffer that traps sediment before it enters the trench [30]. For closed trenches piped directly from a roof or other impervious surface, a sedimentation basin or large catch basin should be used to settle sediment before entering the trench.

A geotextile fabric liner is another crucial design feature of an infiltration trench. The geotextile liner should encase the sides and bottom of the trench. The addition of this liner prevents soil intrusion into the trench[27a]. The geotextile liner can also be added on the top of the infiltration trench and kept under a thin layer of stones. Adding a liner on top allows for easier maintenance and helps prevent the inflow of clogging sediment from the surface and reduce repair costs when clogging becomes an issue[27a]. In cases where a trench clogs without a top layer of geotextile liner, the entire trench may need to be excavated, and the entirety of stones would need to be washed or replaced. The addition of a top liner makes it so only the stones placed above the liner would need replacing.

Along with a top layer of geotextile liner, the addition of perforated PVC observation wells can help determine when maintenance

[26] Pierce County. Single family residential infiltration dispersion system design guide. URL https://www.piercecountywa.gov/DocumentCenter/View/4424/Residential-Infiltration-Design-Guide?bidId=

[27] Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm; and Washington Department of Ecology. Design requirements for infiltration trenches with solids considered a treatment bmp, b. URL https://ecology.wa.gov/DOE/files/7a/7a90167f-371b-4fd2-937e-fc01db3f30c0.pdf

[28] US Environmental Protection Agency. Storm water technology fact sheet infiltration trench. URL https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=91018M1F.txt

[29] New Jersey Stormwater. Best management practices manual. URL https://www.njstormwater.org/bmp_manual/NJ_SWBMP_9.3print.pdf; and Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm

[30] Michigan Department of Environmental Quality. Infiltration trench. URL https://www.michigan.gov/documents/deq/deq-wb-nps-it_250882_7.pdf; and Washington Department of Ecology. 2019 stormwater management manual for western washington, a. URL https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm

of the infiltration trench is needed. In addition, these PVC observation wells provide an access point to see water levels, check for sediment accumulation, and monitor water quality.

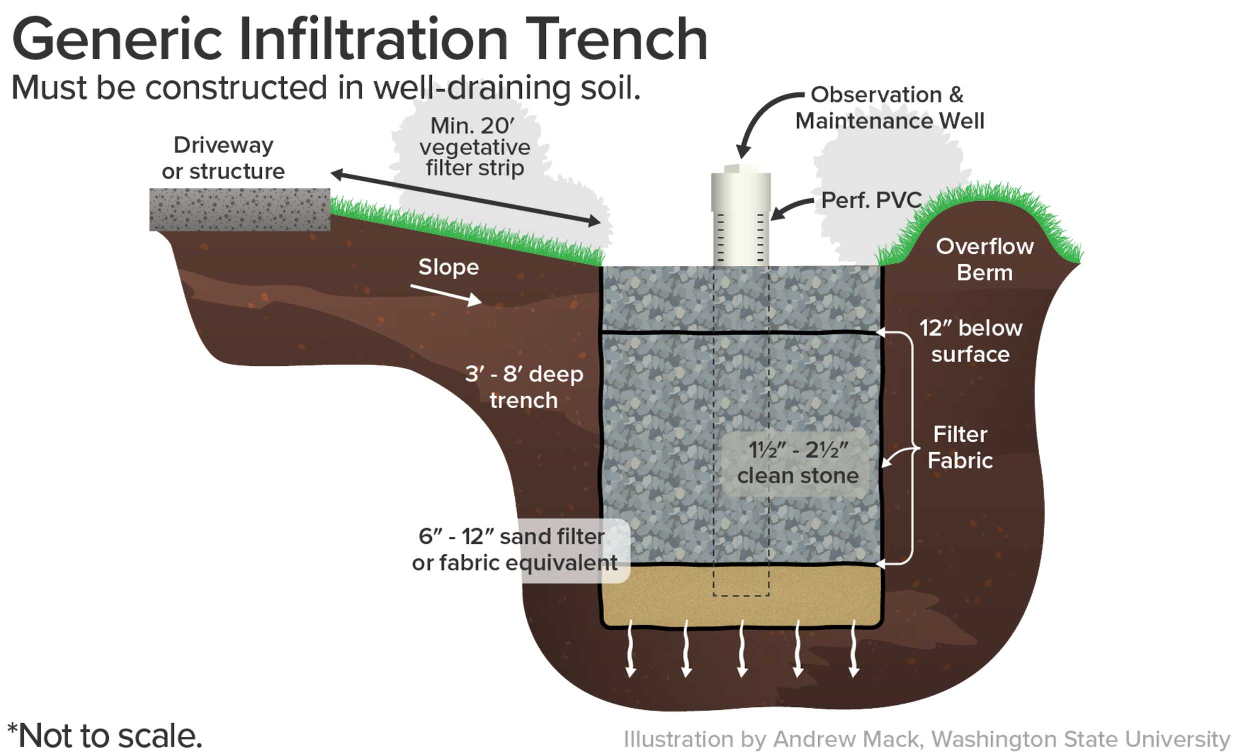

Figure 13: Example showing the design features of an infiltration trench.

Construction Notes

Several steps should be taken during the construction of an infiltration trench to ensure the trench performs as designed and doesn't suffer from long-term maintenance issues.

When constructing an infiltration trench in conjunction with various other construction projects, it is essential to delay trench installation until all other projects that may drain to the trench are stabilized. This helps prevent disturbed soil from washing into the trench and creating clogging issues[31]. Another strategy would be to ensure that water does not flow to the infiltration trench until the projects that drain to it are stabilized.

Other steps should be taken during construction to prevent clogging of infiltration trenches. For example, placing material stockpiles away from the infiltration trench contributing area will help prevent sediment from running off and clogging the infiltration trench.

[31] New Jersey Stormwater. Best management practices manual. URL https://www.njstormwater.org/bmp_manual/NJ_SWBMP_9.3print.pdf

Stormwater should also be diverted away from a newly constructed infiltration trench until after the area around the vegetated filter strip is established and stabilized[31]. Failure to wait until vegetation becomes established can result in sediment buildup and eventual clogging of the trench.

It is essential to prevent heavy equipment from driving over the trench area during trenching and other nearby construction. Heavy equipment can compact the subgrade soils, reducing infiltration rates and the infiltration trench's performance[31].

Maintenance Considerations

Proper maintenance is a critical component of keeping an infiltration trench working correctly. Most of the maintenance considerations revolve around preventing excessive clogging. During the first few months after construction, the observation well should be checked frequently to ensure sediment isn't building up and that water is infiltrating properly. The observation well should then be checked at least annually at a minimum[32]. During the spring and summer, any weeds should be manually removed from the trench, and the surrounding vegetative filter strip should be mowed as needed, ensuring that grass clippings are removed. During the fall and winter, leaves and other debris should be removed[33]. Three days after significant storms, infiltration trenches should be checked for standing water and inspected for unwanted debris or erosion in the flow path surrounding the trench[33]. Standing water is a sign of poor infiltration and can lead to untreated water and mosquito problems. In addition, any barren or eroded areas should be revegetated to stabilize the area and prevent sediment from filling the infiltration trench[34].

[32] Michigan Department of Environmental Quality. Infiltration trench. URL https://www.michigan.gov/documents/deq/deq-wb-nps-it_250882_7.pdf

[33] Chesapeake Bay Foundation. Infiltration trench maintenance. URL https://www.cbf.org/document-library/presentation-webinar-materials/CBF_Infiltration_Trench_011614.pdf

[34] Michigan Department of Environmental Quality. Infiltration trench. URL https://www.michigan.gov/documents/deq/deq-wb-nps-it_250882_7.pdf

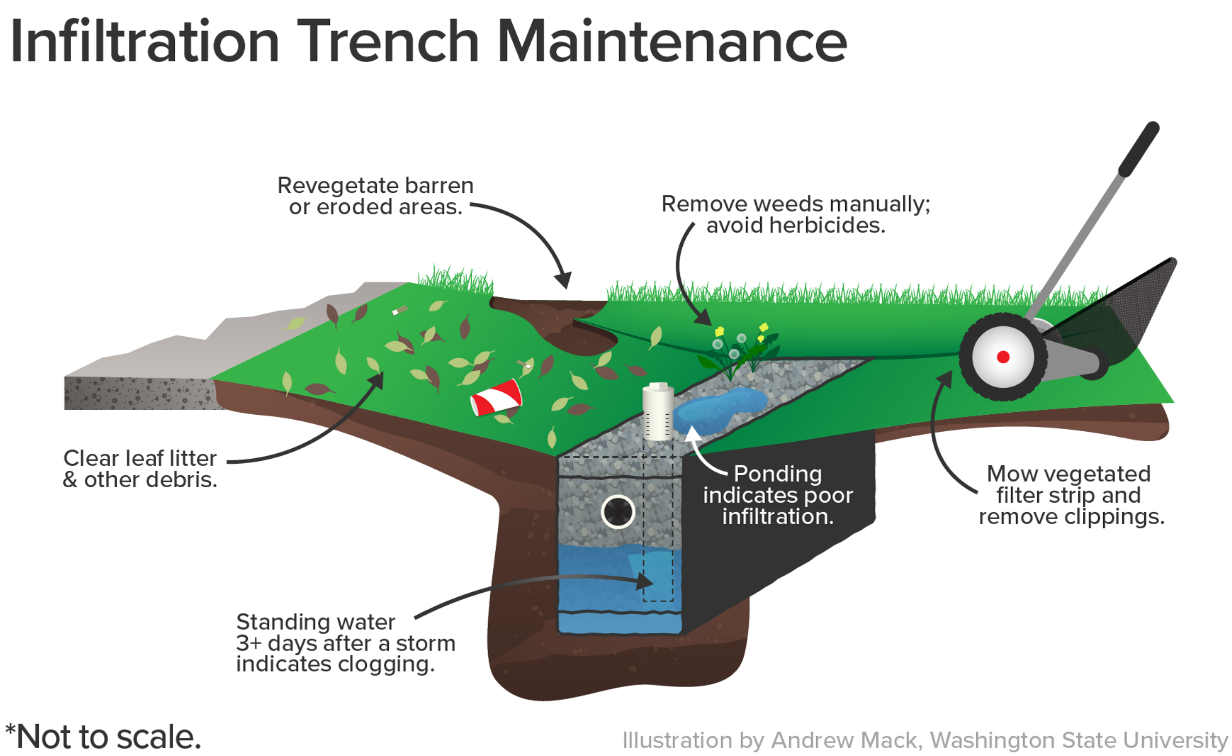

Figure 14: Common maintenance practices for an infiltration trench.

Table 2: Common Maintenance Practices for Infiltration Trenches

Maintenance Item	Frequency	Notes
Inspect observation well for clogging	Several times during the first months after construction, then annually.	If sediment buildup is evident or infiltration rates are low, the trench may need to have stones removed and the bottom few inches of soil excavated.
Mow vegetated filter strip.	Seasonally - As needed	Grass should be removed from the surrounding area and prevented from entering the trench.
Inspect trench for standing water	3 days after a significant rainfall.	Standing water can lead to mosquitos and is a sign of a clogging issue. It may be possible to remove and the top layer of geotextile fabric and stones to fix the clog.
Inspect surrounding trench area for barren areas or erosion.	After significant rainfall- As needed	Stabilize any erosion issues and revegetate any barren areas to prevent sediment from running off into the trench.
Inspect trench inlets and outlets for debris.	After major rainfall	Remove any debris.
Manually remove weeds and debris from the trench.	As needed	Remove weeds and root structure from trench.
Remove leaves and other debris from the trench and surrounding area.	Seasonally-As needed	Leaves can cause clogging and flow issues into the trench.
Inspect settling basin or other pretreatment structures	Semi-annually.	Remove sediment buildup as needed - usually pertains to a closed infiltration trench.

Bioinfiltration Swales

Introduction

A bioinfiltration swale is a stormwater conveyance system that comprises an excavated channel for stormwater, with gentle slopes and vegetation on the channel bottom and sides. They are an excellent alternative to standard ditches or traditional piped stormwater conveyance systems. They are explicitly designed to move water to locations that can handle excess stormwater while treating and infiltrating the water as it moves through the bioinfiltration swale. Bioinfiltration swales are different from bioretention systems in that the bioinfiltration systems are linear flow systems were the majority of stormwater flows along the length of the system from upstream to downstream. Bioretention systems are vertical flow systems were the system is designed to allow most of the water to infiltrate vertically from surface to the parent soils below, or to an underdrain.

The primary mechanism through which water quality is improved in a bioinfiltration swale is through sedimentation. The gentle channel slopes and the preponderance of vegetation ensure that the flow velocity is low, and sediment and associated particulate pollutants are slowed down and trapped within the bioinfiltration swale. However, the performance of bioinfiltration swales in the remediation of water quality pollution is poor for dissolved pollutants. Therefore, both King County and Washington State's Department of Ecology recommend considering other treatment methods upstream of a bioinfiltration swale.

Bioinfiltration swales soils are commonly amended to increase their organic matter content and promote stormwater infiltration into the bottom of the channel. Amending the soils helps to promote infiltration of the first most polluted flush of runoff – thereby facilitating pollutant removal[35]. The most common form of amendment is incorporating compost into the soils at the bottom of the bioinfiltration swale. Typically, compost is tilled into a depth of about six inches, ensuring that the compost does not get washed out.

[35] King County, Washington. King county surface water design manual 2021, a. URL https://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/surface-water-design-manual/2021/2021-kcswdm-chapter-6-water-quality-design.pdf

The design and construction of bioinfiltration swales require professional expertise from a licensed engineer and should not be attempted by an individual homeowner on their own. The following section provides general concepts about when bioinfiltration swales might help manage onsite stormwater, providing general design, construction, and maintenance guidelines. Please consult with your local county or city engineer's office after reading this document.

Applications and Limitations

The advantages of bioinfiltration swales are replacing existing constructed drainage ditches[36] and treating stormwater – especially 'first flush' pollutants[37]. However, modifying an existing drainage ditch to a bioinfiltration swale can pose challenges because drainage ditches are designed to move large volumes of water that could severely reduce the pollutant treatment capacity of the bioinfiltration swales[38]. It is therefore recommended that only small drainage ditches be converted to a bioinfiltration swale. Since bioinfiltration swales are also conveyance systems (i.e., they move stormwater from one location to another), they can provide a small amount of flood storage depending on design, thereby reducing downstream flooding[39]. Beyond conveyance and flood storage, groundwater recharge can also be accomplished when the bottom of a bioinfiltration swale comprises high infiltration soils[40].

The limitations of bioinfiltration swales are that if too much sediment accumulates in the swale, water cannot flow through the soil/plant interface, limiting the swale's ability to remove stormwater pollutants[41]. The sediment load entering a bioinfiltration swale is dependent on the types of land uses that feed stormwater to the system. Bioinfiltration swales are also prone to be taken over by invasive plants if not planted or maintained correctly. As stated earlier, pollutant removal performances of bioinfiltration swales are somewhat varied; improperly designed bioinfiltration swales can yield little to no pollutant removal. Bioinfiltration swales cannot treat stormwater with high pollutant loads[40] and are inappropriate where local water table levels are high[39]. Because high plant density ensures that particulate trapping is a critical design feature of bioinfiltration swales, arid regions are unsuitable for bioinfiltration swale installation. If bioinfiltration swales are installed in the dry season, temporary irrigation systems must be provided to ensure plants survive. A minimum vegetation cover of about 70% is recommended[42].

Bioinfiltration swales are also inappropriate when located downstream of runoff sources carrying pollutants that might kill vegetation in the bioinfiltration swale – like oils and greases. The ability of a bioinfiltration swale to remain dry between storms ensures the

[36] King County, Washington. King county drainage maintenance standards for commercial and multifamily drainage facilities, b. URL https://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/Drainage-Maintenace-Standards-Commercial-Multifami09_ComDrainBook.pdf

[37] City of Bothell. Bioswales. URL https://www.bothellwa.gov/1283/Bioswales

[38] King County, Washington. King county surface water design manual 2021, a. URL https://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/surface-water-design-manual/2021/2021-kcswdm-chapter-6-water-quality-design.pdf

[39] Clemson Cooperative Extension. An introduction to bioswales. URL https://hgic.clemson.edu/factsheet/an-introduction-to-bioswales/

[40] Capital Regional District. Bioswales. URL https://www.crd.bc.ca/education/stormwater-wastewater-septic/green-stormwater-infrastructure/bioswales

[41] Rebecca A Purvis, Ryan J Winston, William F Hunt, Brian Lipscomb, Karthik Narayanaswamy, Andrew McDaniel, Matthew S Lauffer, and Susan Libes. Evaluating the hydrologic benefits of a bioswale in Brunswick County, North Carolina (NC), USA. *Water*, 11(6):1291, 2019. URL https://www.mdpi.com/2073-4441/11/6/1291

[42] CalRecycle. Biostrips and bioswales. URL https://www.calrecycle.ca.gov/organics/compostmulch/toolbox/biostripbioswal

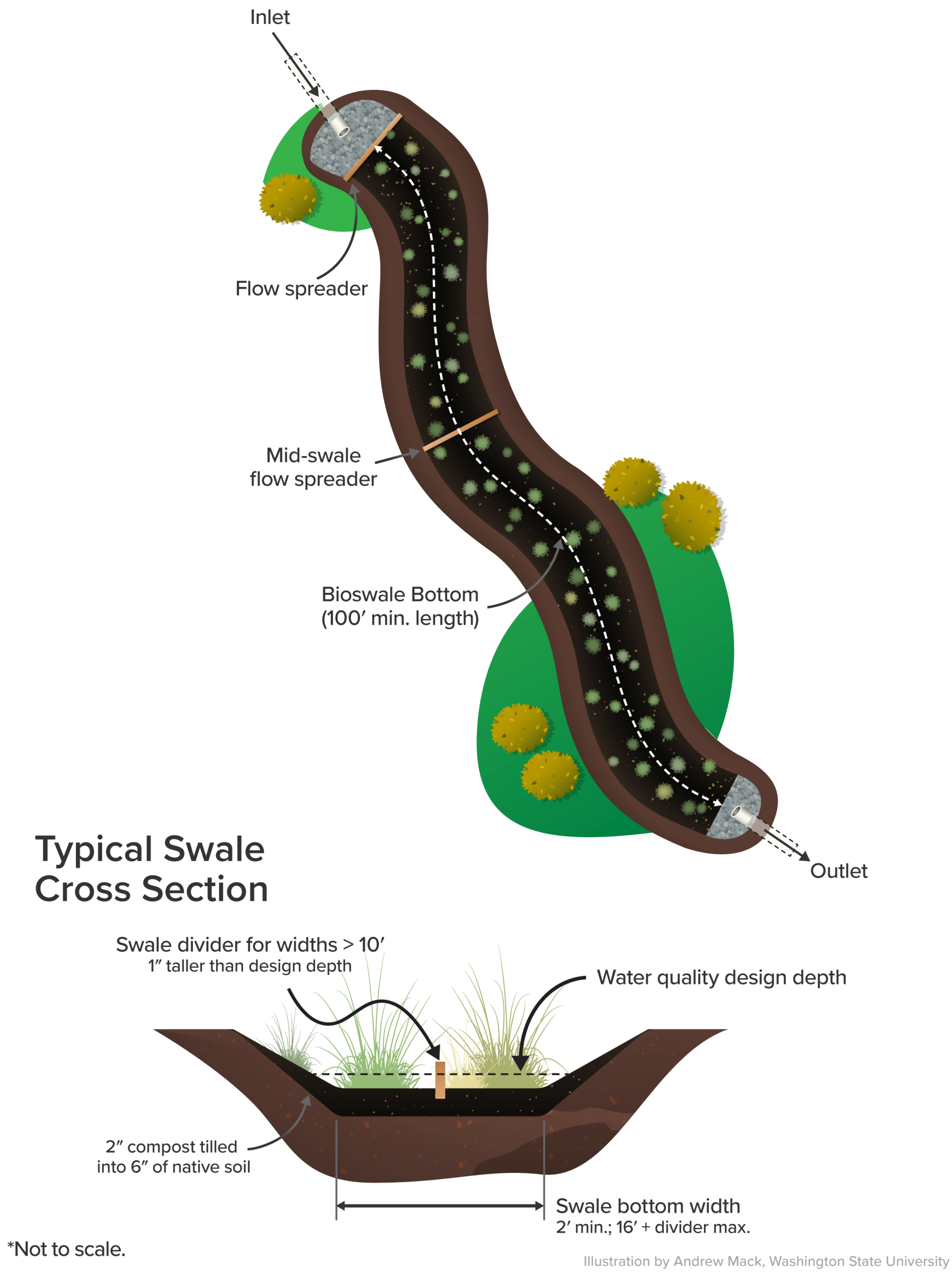

Figure 15: The anatomy of a bioinfiltration swale.

survival of the plants. Hence, sites with high natural groundwater tables or groundwater seeps are not suitable locations for bioinfiltration swales. A couple of bioinfiltration swale refinements might be employed when building bioinfiltration swales where soils are saturated for extended periods – see sections below on wet bioinfiltration swales and bioinfiltration swales with underdrains.

Design Criteria

Of the three practices in this document, bioinfiltration swales are the most complex to design. They must be able to transport stormwater continuously and are designed using open channel hydraulic principles. In addition, bioinfiltration swales are designed to convey the most prominent peak flows based on upstream conditions[43] and ensure that the "water quality design flow" is treated. The water quality design flow is the basis for calculating the dimensions of a bioinfiltration swale. This flow rate is at or below which 91% of the total runoff volume, as estimated by an approved continuous runoff model, will be treated[44]. If the bioinfiltration swale will be installed downstream of a detention facility, then the "2-year release rate" from that detention facility is used to estimate the water quality design flow. Once the water quality design flow is calculated, the bioinfiltration swale's bottom width and length can be calculated. As stated earlier, these design calculations should be made by a practicing civil/water resources engineer.

The bottom width and length of the bioinfiltration swale define the 'bioinfiltration swale area'; this should be between 10-20% of the contributing area[45] feeding stormwater to the system. While the size of a bioinfiltration swale is dependent on the size of the contributing area and site constraints, typical dimensions of a bioinfiltration swale are:

- The minimum swale length is 100 ft[46] if all the water enters at one end of the swale. However, if a swale gets continuous inflow, a minimum of 200 ft is needed[47].
- Minimum bottom width 2 ft[43].
- If the bottom width exceeds 10 ft, a lengthwise flow divider across the swale should be incorporated for at least ¾ of the swale's length. In addition, that flow divider must be made of a strong material that can resist weathering[44].
- Minimum longitudinal slope 0.25%. (1% to 2% preferred, 6% max)[43].
- If the longitudinal slope exceeds 6%, check dam with vertical

[43] CalTrans (California DOT). Biofiltration swale design guidance, 2012. URL `https://dot.ca.gov/-/media/dot-media/programs/design/documents/dg-biofiltration-swale-092712-a11y.pdf`

[44] King County, Washington. King county surface water design manual 2021, a. URL `https://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/surface-water-design-manual/2021/2021-kcswdm-chapter-6-water-quality-design.pdf`

[45] Capital Regional District. Bioswales. URL `https://www.crd.bc.ca/education/stormwater-wastewater-septic/green-stormwater-infrastructure/bioswales`

[46] King County, Washington. King county surface water design manual 2021, a. URL `https://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/surface-water-design-manual/2021/2021-kcswdm-chapter-6-water-quality-design.pdf`

[47] Swale length is being evaluated at the time of writing by the Washington Department of Transportation.

drops that do not exceed 12 inches are required. The spacing between check dams should be such that the slope does not exceed 6% between drop sections[48].

[48] King County, Washington. King county surface water design manual 2021, a. URL https://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/surface-water-design-manual/2021/2021-kcswdm-chapter-6-water-quality-design.pdf

The bioinfiltration swale area below the water quality design depth is known as the "swale treatment area." Specific design and planting requirements pertain to this zone. For example, the side slopes of the bioinfiltration swale must be between around 3H:1V but cannot exceed 2H:1V. Above the treatment area, slopes can be steeper, but they must be protected against erosion and slope failure[48].

If locating the bioinfiltration swale away from trees is not an option, removal of leaf litter should be incorporated into regular maintenance protocols. While leaf litter from nearby trees could fall into the swale and impede the flow of water[48], it is vital to ensure that leaf litter clogging the system is periodically removed. This also implies that volunteer tree species should be removed as part of maintenance, if they threaten the system.

Bioinfiltration swales in flat terrain: When the terrain is flat, a typical bioinfiltration swale with a slope less than 0.25% will not meet the goals of water quality treatment; some basic refinements to the design are therefore needed. Two refinements that help install bioinfiltration swales in flat terrains are bioinfiltration swales with underdrains and wet bioinfiltration swales. These two refinements are broadly described below.

Bioinfiltration swales with underdrains ensure that water in a bioinfiltration swale with a gentle slope will flow through the plant-soil interface to achieve some level of water quality treatment. A perforated pipe encased in drain rock is installed about a foot below the bioinfiltration swale bottom. Ensuring that the underdrain pipe can flow freely is critical.

Wet bioinfiltration swales are appropriate when drainage is needed in flat terrain, and the water table is close to the ground surface resulting in wet or saturated soils. This condition usually occurs when there are compacted till soils on the site or when the bioinfiltration swale receives water from an upstream stormwater detention facility[48]. Therefore, plants Plants have to be chosen that can survive saturated soil conditions.

Construction Notes

If design flow velocity exceeds 4 ft/sec, use a turf reinforcement mat[49]. High design flow velocities are expected when the bioinfiltration swale has a steep gradient. It is critical to provide erosion control

[49] CalTrans (California DOT). Biofiltration swale design guidance, 2012. URL https://dot.ca.gov/-/media/dot-media/programs/design/documents/dg-biofiltration-swale-092712-a11y.pdf

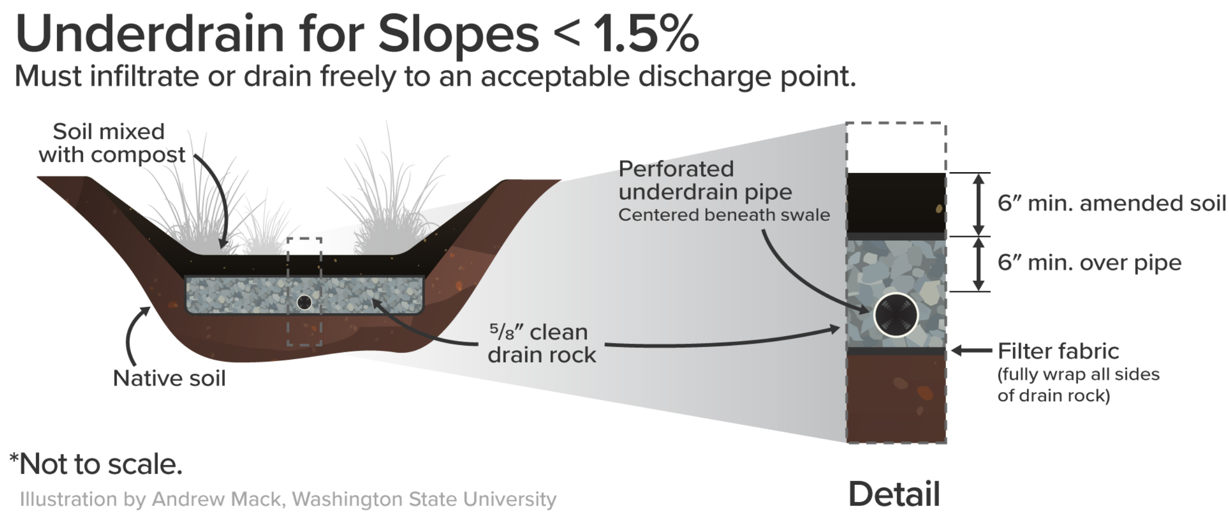

Figure 16: The details of a bioinfiltration swale with an underdrain.

after construction[50] and ensure that vegetation is well established in the newly constructed swale before runoff is allowed to flow into the bioinfiltration swale. It is also essential that weed sources are not introduced in the newly exposed soils of a bioinfiltration swale; existing weed roots should be thoroughly removed from the subsoils.

[50] Oregon Department of Environmental Quality. Biofilters for stormwater discharge pollution removal. URL https://www.oregon.gov/deq/FilterPermitsDocs/biofiltersV2.pdf

Planting Considerations

Grass is to be established across the whole worksite, with grass seed applied in spring or fall by hydroseeding or broadcast application[51]. The treatment area needs plants that provide a dense cover to limit erosion[51]. A minimum 70% planting coverage should be the goal of any bioinfiltration swale planting design. The plants must withstand (remain upright) the forces exerted on them by the design water quality event[51]. The plants should be chosen to withstand the soil conditions within the bioinfiltration swale in terms of pH, compaction, soil moisture, or lack of moisture[52]. Newly planted bioinfiltration swales must be protected from runoff until the grasses are well established[51]. King County approved two seed mixes for the treatment area for use in typical bioinfiltration swales; those mixes are detailed in Chapter 6 of the 2021 King County Surface Water Design Manual[51] and reproduced below in Table 3. Please consult with a landscape or erosion control specialist for regions outside King County to recommend grass mixes, fertilizer, and mulch.

For regions above the treatment zone, standard lawn mixes or landscape plantings can be used. Plants that can bind the bank soils

[51] King County, Washington. King county surface water design manual 2021, a. URL https://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/surface-water-design-manual/2021/2021-kcswdm-chapter-6-water-quality-design.pdf

[52] Clemson Cooperative Extension. An introduction to bioswales. URL https://hgic.clemson.edu/factsheet/an-introduction-to-bioswales/; and Oregon Department of Environmental Quality. Biofilters for stormwater discharge pollution removal. URL https://www.oregon.gov/deq/FilterPermitsDocs/biofiltersV2.pdf

Table 3: Grass seed mixes suitable for a typical bioinfiltration swale's treatment area – King County Surface Water Manual - TABLE 6.3.1.C (all percentages are by wt.)

Mix 1		Mix 2	
75-80 percent	Tall or Meadow Fescue	60-70 percent	Tall Fescue
10-15 percent	Seaside Creeping Bentgrass or Colonial Bentgrass	10-15 percent	Seaside Creeping Bentgrass or Colonial Bentgrass
5-10 percent	Redtop	10-15 percent	Meadow Foxtail
		6-10 percent	Alsike Clover
		1-5 percent	Marshfield Big Trefoil
		1-6 percent	Redtop

to prevent erosion are critical in bioinfiltration swales that are likely to see high flows. A list of suitable ground covers and grasses for the regions above the treatment area zone is reproduced from Chapter 6 of the 2021 King County Surface Water Design Manual[53] and presented in Table 4.

A list of suitable plants for a wet bioinfiltration swale and the appropriate planting spacing between plants specified by the King County Surface Water Design Manual[53] is presented in Table 5.

[53] King County, Washington. King county surface water design manual 2021, a. URL https://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/surface-water-design-manual/2021/2021-kcswdm-chapter-6-water-quality-design.pdf

Maintenance Considerations

Periodic inspections[54] of bioinfiltration swales are critical for ensuring their proper functioning; semiannual[55] inspections are recommended. Deposited sediments and trash must be periodically removed[56]. In the sections of the bioinfiltration swale above the water quality treatment zone, grasses should be mowed. Monthly mowing should occur during the growing season - grass clippings from mowing should be removed and disposed of or composted[53]. Irrigate, and prune plants[56]. Ensure there is no standing water after a storm event – regrade if standing water persists[57] or if channelization or erosion has occurred[53]. If regrading is needed annually, there may be a more significant, more systemic issue with the bioinfiltration swale that might need to be addressed. Remove accumulated sediments upstream of check dam (if any[59]) and from the head of the swale[53]. Finally, in the first two years after planting, check frequently during the growing season for excessively tall or nuisance vegetation[55]. After the first two years, check annually. Monitor plant health and identify causes for plant stress[55].

[54] Naturally Resilient Communities. Bioswales. URL http://nrcsolutions.org/bioswales/

[55] King County, Washington. King county drainage maintenance standards for commercial and multifamily drainage facilities, b. URL https://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/Drainage-Maintenace-Standards-Commercial-Multifami09_ComDrainBook.pdf

[56] CalRecycle. Biostrips and bioswales. URL https://www.calrecycle.ca.gov/organics/compostmulch/toolbox/biostripbioswal

[57] City of Bothell. Bioswales. URL https://www.bothellwa.gov/1283/Bioswales

Table 4: Groundcovers and grasses suitable for the upper slopes of a bioinfiltration swale – King County Surface Water Manual - TABLE 6.3.1.E

Groundcovers - *Native Species	
Kinnikinnick*	Arctostaphylos uva-ursi
Epimedium	Epimedium grandiflorum
—	Euonymus lanceolata
Strawberry*	Fragaria chiloensis
—	Genista
St. John's-Wort	Hypericum sempervirens
Broadleaf Lupine*	Lupinus latifolius
White Sweet Clover*	Melilotus alba
Creeping Forget-Me-Not	Omphalodes verna
—	Rubus calycinoides
White Lawn Clover	Trifolium repens
Yellow-Root	Xanthorhiza simplissima
Grasses (drought-tolerant, minimum mowing - *Native Species)	
Buffalo Grass	Buchloe dactyloides
Tufted Fescue	Festuca amethystina
Tall Fescue *	Festuca arundinacea
Hard Fescue	Festuca ovina duriuscula (e.g., Reliant, Aurora)
Red Fescue*	Festuca rubra
Dwarf Tall Fescues	Festuca spp. (e.g., Many Mustang, Silverado)
Blue Oatgrass	Helictotrichon sempervirens
Low-growing turf mix:	Notes:
· 40% dwarf tall fescue	Many other ornamental grasses which require only annual mowing are suitable.
· 30% dwarf perennial rye "Barclay"	Ivy is not permitted because of its tendency to spread.
· 25% red fescue	
· 5% colonial bentgrass	

Table 5: Recommended plants for a wet bioinfiltration swale swale – King County Surface Water Manual - TABLE 6.3.2.A

Common Name	**Scientific Name**	**Spacing (on center)**
Shortawn foxtail	Alopecurus aequalis	seed
Water foxtail	Alopecurus geniculatus	seed
Spike rush	Eleocharis spp.	4 inches
Slough sedge*	Carex obnupta	6 inches or seed
Sawbeak sedge	Carex stipata	6 inches
Sedge	Carex spp.	6 inches
Western mannagrass	Glyceria occidentalis	seed
Velvetgrass	Holcus mollis	seed
Slender rush	Juncus tenuis	6 inches
Watercress*	Rorippa nasturtium-aquaticum	12 inches
Water parsley*	Oenanthe sarmentosa	6 inches
Hardstem bulrush	Scirpus acutus	6 inches
Small-fruited bulrush	Scirpus microcarpus	12 inches

* Good choices for swales with significant periods of flow, such as those downstream of a detention facility.

Note: Cattail (Typha latifolia) is not appropriate for most wet swales because of its very dense and clumping growth habit, which prevents water from filtering through the clump

Figure 17: An image of a fully planted bioinfiltration swale -Wikimedia Commons – File:Bioswale @first.jpg.

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Glossary

anthropogenic originating from human activity. Used in this document in the context of pollution or environmental change caused by human activity. 6

attenuate to reduce the force, effect, or value of. 12

Best Management Practice (BMP) a practice, or a combination of practices, that prevent or reduce the release of pollutants and other limit adverse impacts to waterbodies. 10, 11, 16, 19, 22, 28

check dam a check dam is a small, sometimes temporary, dam constructed across a swale drainage ditch or waterway to counteract erosion by reducing water flow velocity. 37, 41

closed infiltration trench a type of infiltration trench that receives stormwater through an inlet pipe that brings water from the surface to the subsurface of the trench. 25, 28

contributing area the total area, including pervious and impervious surfaces, contributing runoff to a BMP. 20, 29, 30, 37

dispersion the process of spreading the flow of water over a wide area to ensure lower flow depths and lower velocities. 10–12, 16, 19–22, 24

dispersion area area of land designated for stormwater runoff from an impervious area to be spread out over. This area should be pervious and covered with vegetation to ensure that the water flows slowly and infiltrates into the soils. 11, 19–22, 24

dispersion trench a facility designed to receive stormwater runoff and disperse it evenly through vegetated areas. Trenches are typically 2 feet wide and 18 inches deep — length is determined by the size of contributing area. 16, 21, 22 *flow path* the path that water takes as it flows from one point to another. 19, 21, 22, 24, 31

flow spreader a device or system that helps to spread water flowing in a narrow-concentrated path, into a wider, slower, and shallow manner. Flow spreaders are typically installed between a pipe inlet and a stormwater runoff treatment BMP. An example of a flow spreader is a notched board. 11

groundwater table Water in a saturated zone or stratum beneath the land surface or a surface waterbody. 29, 37

impervious surface a solid (usually artificial) surface that prevents the infiltration of water into the soil (e.g., roads, roofs, pavements, parking lots). 11, 12, 19, 21, 22, 29

infiltration rate the rate at which water moves downward (percolates) through the soil surface to lower layers. It is usually expressed as inches/hour or millimeters/hour. 22, 24, 28, 29, 31

level spreader similar to flow spreaders, level spreaders are designed to alter concentrated runoff to sheet flow runoff. However, they are typically used upstream of vegetated flow paths or dispersion areas. 11, 21, 22

open infiltration trench an infiltration trench that receives stormwater in the form of sheet flow that enters from the top of the trench. 29

runoff water originating from rainfall and other precipitation that flows off the landscape and ends up in drainage facilities like rivers, streams, springs, seeps, ponds, lakes, and wetlands . 6, 12, 16, 20, 22, 25, 29, 34, 35, 37, 39

sorptive properties properties that affect sorption, or the physical and chemical process by which one substance becomes attached to another. 25

stormwater runoff stormwater runoff is generated from rain and snowmelt events that flow over land or impervious surfaces, such as paved streets, parking lots, and building rooftops, and does not soak into the ground. The runoff picks up pollutants like trash, chemicals, oils, and dirt/sediment that can harm our rivers, streams, lakes, and coastal waters. 6

transition zone an approximately 2-foot-wide zone that discourages channeling of water between the edge of the impervious surface and the downslope vegetation. This zone is usually composed of crushed rock (extension of subgrade material), drain rock, or something similar that meets the local planning authority. 12, 21

water quality design flow the flow rate at or below which 91% of the total runoff volume, as estimated by an approved continuous runoff model, will be treated. 37

watershed the region of the landscape that drains water to a particular location. Similar concept to *contributing area*, however watersheds are usually recognized at the landscape level. 6, 7