Voluntary Clean Water Guidance for Agriculture Chapters

The purpose of this guidance is to describe best management practices (BMPs) that agricultural producers can use to protect water quality. It is intended to both support healthy farms while helping producers meet clean water standards. The Voluntary Clean Water Guidance introduction[1] provides overall goals and objectives, as well as information on how the guidance will be used. Readers are encouraged to read the overall introduction before this chapter.

This report is available on the Department of Ecology's website at https://apps.ecology.wa.gov/publications/SummaryPages/2010008.html[2]

[1] https://apps.ecology.wa.gov/publications/documents/2010008.pdf

[2] https://apps.ecology.wa.gov/publications/SummaryPages/2210002.html

Chapter 9—Draft

Runoff Control for Agriculture Facilities

Voluntary Clean Water Guidance for Agriculture

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Washington State Department of Ecology
Water Quality Program

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Introduction

Managing runoff from agricultural facilities involves the use of best management practices to collect, disperse, and infiltrate runoff from buildings and other impervious surfaces to prevent erosion and the mixing of runoff with pollutants that can be carried to surface waters or infiltrated to groundwater. Along with limiting the potential for polluted runoff from agricultural facilities, stormwater control practices also reduce the potential for flooding of farm infrastructure such as barns, feed and chemical storage areas, manure storage facilities, and livestock confinement areas making them easier to use and manage.

Scope of Guidance

The purpose of this chapter is to outline best management practices (BMPs) that can be used to capture, disperse, and infiltrate runoff to help prevent runoff from interacting with pollution sources associated with agricultural facilities. Practices outlined in this chapter are primarily source control BMPs meant to prevent the generation of polluted runoff and should be implemented in combinations to ensure runoff is properly conveyed, dispersed, and infiltrated.

The Department of Ecology has developed stormwater management manuals for western and eastern Washington. These stormwater guidance manuals provide information, specifications, and standards for stormwater BMPs that are used widely across Washington. Contact your local municipality when planning a new development or redevelopment project to make sure you follow local requirements for stormwater management.

NRCS Practices

- Waterspreading (640)
- Underground Outlet (620)
- Water and Sediment Control Basin (638)
- Vertical Drain (630)
- Sediment Basin (350)
- Grassed Waterway (412)
- Roof Runoff Structure (558)
- Diversion (362)

Commonly Associated Practices

- Chapter 5: Soil Stabilization & Sediment Capture (Vegetative)
- Chapter 6: Soil Stabilization & Sediment Capture (Structural)
- Chapter 6: Irrigation Management
- Chapter 7: Field Drainage & Subsurface Drainage Management
- Chapter 11: Animal Confinement & Manure Handling & Storage
- Chapter 12: Riparian Areas and Surface Water Protection

Recommendations

The following are recommendations for managing runoff from agricultural facilities. These practices focus on methods that can be used to disperse and infiltrate runoff before it interacts with pollution sources. While recommended practices generally fall into these two categories, most practices are implemented in combinations. Below are brief descriptions of dispersion and infiltration.

- **Dispersion** - dispersion involves the spreading out of stormwater over an area to reduce flow and facilitate gradual infiltration into the soil before reaching a natural or artificial waterway. Dispersion BMPs are commonly used to redirect and infiltrate runoff so that it doesn't reach agricultural facilities such as barns, feed and chemical storage areas, equipment store areas, manure storage facilities, and livestock confinement areas and generate polluted runoff.
- **Infiltration** - infiltration is the downward movement of water from the land surface to the subsoil. Infiltration BMPs are used to reduce the volume and rate of surface runoff and facilitate infiltration into the ground.

Best Management Practices (BMPs)

Roof Runoff Structures

Roof runoff structures are practices used to convey runoff from roofs and outlet collected water away from pollution sources to a stable location for infiltration or dispersion. At a minimum, roof runoff structures should include gutters and downspouts. When properly sized and installed, roof runoff structures can prevent the generation of polluted runoff, concentrated flows and erosion, and reduce ponding and flooding.

- Roof runoff structures should be installed on all buildings and other agricultural structures where runoff is likely to interact with pollution sources and generate polluted runoff and/or when roof runoff will cause erosion.
- Roof runoff structures should also be installed on all buildings and other agricultural structures when runoff is likely to cause flooding at or near agricultural facilities and limit their proper use and maintenance or impact their structural integrity.

- At a minimum, roof runoff structures should include gutters and downspouts that facilitate the dispersion and infiltration of runoff prior to reaching surface waters. Downspouts are practices used to disperse and infiltrate roof runoff without causing erosion or generating polluted runoff.
- Collected runoff from agricultural buildings and structures must be directed away from facilities such as barns, livestock areas, manure storage locations, equipment and chemical storage areas, and bare soils.
- Roof runoff structures should have adequate capacity for anticipated water runoff volumes.
- Gutter construction may vary by region, particularly for areas of Washington that receive a significant amount of snow, as the weight of snow could be damaging. Ensure gutter supports can withstand the anticipated loading from precipitation including loads from snow and ice, where applicable.
- Use Downspout Dispersion Systems, Downspout Full Infiltration, or Perforated Stub-out Connections to disperse and infiltrate roof runoff. Ecology's Stormwater Management Manuals should be used to properly design and implement these practices.
- Do not discharge collected or rerouted water directly to streams.
- Whenever feasible, do not discharge collected or redirected water directly to constructed ditches.

Underground Outlets

Underground outlets are non-perforated conveyance pipes buried in the ground used to convey collected runoff to an infiltration area or infiltration system.

- Use underground outlets when a surface outlet is impractical due to stability problems, topography, land use, or equipment traffic.
- Underground outlets should be used in conjunction with dispersion and infiltration BMPs, and not outlet directly to surface waters.
- The end of the underground outlet must provide sufficient space to incorporate dispersion and infiltration BMPs.
- Size outlets to handle the design flow from the gutter system.
- Provide accessible cleanouts for routine maintenance.
- Use Ecology's Stormwater Management Manuals when designing Roof Downspout BMPs including Downspout Full Infiltration, Downspout Dispersion Systems and Perforated Stub-out Connections.

Berms

Vegetated berms can be used to redirect water away from agricultural facilities and vulnerable areas that can be a source of polluted runoff. They can also be used to protect agricultural facilities from being flooded. Berms should be used in conjunction with dispersion and infiltration BMPs, especially when redirected water is likely to cause erosion or is unlikely to be naturally infiltrated. Berms should only be used to redirect water and are not intended to be an edge of field practice used to reduce nonpoint source pollution.

- Berms must be designed to contain and redirect anticipated runoff volumes and velocities. Runoff volume and velocity will vary based on factors such as area of drainage, slope, slope length, and vegetative cover.
- Berms are most effective when used in combination with dispersion practices and infiltration practices. Berms must include a safe and stable outlet with capacity to convey and infiltrate the design storm volume.
- Berms must outlet as sheet flow over a vegetated, pervious area large enough for dispersion and/or infiltration BMPs. Outlets must be stable enough to reduce erosion and have capacity to facilitate infiltration. Examples of Natural Resource Conservation Service (NRCS) infiltration practices include Grassed Waterways, Vegetated Treatment Areas, Sediment Basins, and Water and Sediment Control Basins.
- Berms should be oriented on slopes in a manner that prevents concentrated flows and facilitates infiltration while limiting ponding or pooling of water which can negatively affect soil quality or create the potential for overflow, high velocity concentrated flows or structural failure. It is important for berms to be designed to perform as desired and not exacerbate runoff issues. Some sizing considerations from NRCS:
    - When used as a temporary measure, design berms to convey the peak discharge from the 2-year frequency, 24-hour duration storm.
    - When used to protect agricultural land, design berms to convey the peak discharge from a 10-year frequency, 24-hour duration storm.
    - When used to protect buildings, roads, animal waste management and feed lots, design berms to convey the peak discharge from a 25-year frequency, 24-hour duration storm with a minimum freeboard depth of 0.3 feet. Increase the capacity when additional hazards and conditions necessitate greater protections.
    - Use criteria outlined in NRCS Conservation Practice Standard for Diversion (Code 362) when designing a berm.
- Use criteria outlined in NRCS Conservation Practice Standard for Critical Area Planting (Code 342) to establish and maintain berm vegetation.
    - Select species suited to local site conditions and the intended use.

    - Use plant species that can provide adequate density, height, and vigor within an appropriate timeframe to stabilize the berm.

- If the soils or climatic conditions preclude the use of vegetation for erosion protection, non-vegetative linings such as concrete, gravel, rock riprap, cellular block, turf reinforcement mats, or other approved manufactured lining systems may be used. See the Lined Waterway section below for more information.

Diversion Channels

Diversion channels are used to convey surface water runoff away from vulnerable areas and agricultural facilities to prevent erosion and the generation of polluted runoff. Channels are constructed across slopes and include a supporting ridge on the downslope side. Redirecting water away from agricultural facilities can help prevent the transport of sediment, pathogens, nutrients, and other pollutants. Diversion channels are often vegetated but can be lined, especially when conditions are not conducive for the use of vegetation only or when conditions are likely to result in channel erosion.

- Diversion channels must be designed to contain and redirect anticipated runoff volumes and velocities. Runoff volume and velocity will vary based on factors such as area of drainage, slope, slope length, and vegetative cover.

- Diversion channels are most effective when used in combination with dispersion practices. Diversion channels must include a safe and stable outlet with capacity to convey the design storm volume.

- Diversion channels must outlet as sheet flow over a vegetated, pervious area large enough for dispersion and/or infiltration BMPs. Outlets must be stable enough to reduce erosion and have capacity to facilitate infiltration. Examples of NRCS infiltration practices include Grassed waterways, Vegetated Treatment Areas, Sediment Basins, Water and Sediment Control Basins.
    - When used as a temporary measure, design diversion channels to convey the peak discharge from a 2-year frequency, 24-hour duration storm.
    - When used to protect agricultural land, design diversion channels to convey the peak discharge from a 10-year frequency, 24-hour duration storm.
    - When used to protect buildings, roads, animal waste management and feed lots, design diversion channels to convey the peak discharge from a 25-year frequency, 24-hour duration storm with a minimum freeboard depth of 0.3 feet, at a minimum. Increase the capacity when additional hazards and conditions necessitate greater protections.
    - When using vegetation, diversion channels should be designed to include a stable channel to limit stress on soil and vegetation such that soil particles will not be

detached, and the vegetation will not be damaged. The capacity of a vegetated diversion should be based on the densest and longest vegetation resulting in the highest expected resistance.

- Use criteria outlined in NRCS Conservation Practice Standard for Diversion (Code 362) when designing a diversion channel.
- Use criteria outlined in NRCS Conservation Practice Standard for Critical Area Planting (Code 342) to establish and maintain vegetation.
  - Select species suited to local site conditions and the intended use.
  - Use plant species that can provide adequate density, height, and vigor within an appropriate timeframe to stabilize the channel.
- If soils or climatic conditions preclude the use of vegetation for erosion protection, channels should be lined. Common lining materials include concrete, stone, synthetic turf reinforcement fabrics, or other flexible permanent material. See the Lined Waterway section for additional information.
- Use Ecology's Stormwater Management Manuals for design criteria for Interceptor Dike and Swale when considering the use of a lined waterway.

Lined Waterways

Lined waterways are constructed conveyance channels with an erosion resistant lining used to convey runoff. Lined waterways may be used in cases when land use practices or conditions such as highly erosive soils or climatic conditions preclude the use of vegetation only. Lined waterways are also used when concentrated runoff, high flows, prolonged flows, and steep grades require lining to prevent erosion. Common lining materials include concrete, stone, or other flexible permanent materials.

- Use lined waterways when needed to prevent erosion, especially when site or climatic conditions limit the use of vegetation to stabilize the conveyance.
- The minimum capacity of a lined waterway must be adequate to carry the peak rate of runoff from a 10-year frequency, 24- hour duration storm. Design capacity may be reduced when the lined waterway is less than 1 percent.
- Provide a stable outlet with adequate capacity to prevent erosion and flooding damages.
- Lined waterways must outlet as sheet flow over a vegetated, pervious area large enough for dispersion and/or infiltration BMPs. Outlets must be stable enough to reduce erosion and have capacity to facilitate infiltration.
- Conduct routine maintenance to prevent lining damage.
- Use criteria outlined in the NRCS Conservation Practice Standard for Lined Waterway or Outlet (468) when designing a diversion channel.

- See the design criteria for Riprap Channel Lining within Ecology's Stormwater Management Manuals when considering the use of a lined waterway.

Grassed Waterways

Grassed waterways, sometimes referred to as grassed swales, are shaped and graded shallow channels planted with dense, rough grass used to convey surface water runoff at a reduced velocity to a stable outlet without causing erosion. Grassed waterways are often used where added conveyance capacity and vegetative protection are necessary to prevent erosion and improve infiltration.

- Design grassed waterways to convey the peak runoff expected from the 10-year frequency, 24- hour duration storm. Increase the capacity as needed to account for potential sedimentation between planned maintenance activities.
- The waterway must be large enough to provide the capacity necessary to ensure water remains in the channel.
- Protect the waterway from concentrated flow by using flow spreader or mechanical means of stabilization.
- Use a dense and hydraulically rough grass cover to slow runoff and increase water infiltration.
- Consider the depth to groundwater table, climatic factors, and vegetative roughness when selecting an effective vegetative species.
- Include a stable outlet that facilitates dispersion and prevents erosion.
- Avoid vehicle traffic in the waterway and exclude livestock.
- Use NRCS specifications for Grass Waterways (NRCS code 412) when designing and installing a grassed waterway.

Subsurface Underdrains

Subsurface drains are perforated pipes installed beneath the ground surface used to manage soil moisture conditions. Subsurface drainage may be used to reduce excessive soil moisture near farm buildings and other agricultural structures to address adverse conditions that cause ponding, flooding, or increased potential for polluted runoff and to increase the usability and trafficability of agricultural facilities.

- Prior to implementing subsurface drainage, evaluate whether other practices can be used to address adverse conditions. For example, gutters, downspouts and underground outlets may be sufficient to address saturated areas.
- To limit excessive drainage of soil moisture and associated flows, limit the installation of subsurface drainage only to those areas where adverse (e.g., saturated) conditions occur.
- Subsurface drainage must not be installed in locations that receive polluted surface runoff from agricultural facilities such a barnyard, livestock feeding and confinement

areas, feed and waste storage facilities, equipment storage locations, chemical storage and handling areas, or other areas where runoff can transport pollutants to the drained area.

- Polluted runoff or collected polluted runoff must not be connected to subsurface drains.
- Water collected by subsurface drains must not outlet directly to surface waters and should outlet to an appropriate dispersion and/or infiltration BMP. Outlets must be stable enough to reduce erosion and have capacity to facilitate infiltration. Examples of NRCS infiltration practices include Grassed Waterways, Vegetated Treatment areas, Sediment Basins, Water and Sediment Control Basins.
- Subsurface drainage cannot be used to drain wetlands. If wetlands are present or if it's unknown whether an area contains a wetland, a wetland determination must be conducted.
- Protect drainage areas from root clogging that can result from root penetration by water-loving shrubs and grasses.
- Use criteria outlined NRCS Conservation Practice Standard for Subsurface Drain (606) when implementing subsurface drains.

Infiltration Ponds and Rain Gardens

Infiltration ponds and rain gardens are used to temporarily store and infiltrate runoff; however, they differ slightly in approach. Infiltration ponds are earthen impoundments, typically between 2 and 6 feet deep often stabilized with grass. Rain gardens are non-engineered, shallow, landscaped depressions with amended soils and adapted plants used to temporarily store and infiltrate runoff. Runoff that exceeds the storage capacity of a rain garden is designed to overflow to an adjacent drainage system.

Choosing between an infiltration pond and a rain garden will depend on the capacity needed to store and infiltrate runoff, area available, desired aesthetic, cost, maintenance requirements and other site-specific factors.

- Use Ecology's Stormwater Management Manuals to design and implement infiltration ponds and rain gardens.
- For additional information about rain gardens, refer to the *Rain Garden Handbook for Western Washington: A Guide for Design, Installation, and Maintenance* (Hinman et al., 2013[3])for rain garden specifications and construction guidance.

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[3] Curtis Hinman et al., *Rain Garden Handbook for Western Washington: A Guide for Design, Installation, and Maintenance*, Washington State Department of Ecology/Washington State University Extension/Kitsap County, June 2013.

Additional Infiltration Practices and Underground Injection Controls

Runoff can be infiltrated in many additional ways and the method used is often site-specific. Examples include rock-lined swales and trenches, buried perforated pipe and dry wells such as vertical drains. Consult Ecology's stormwater manuals when considering additional infiltration practices to manage runoff to ensure practices are properly designed, sited, implemented, and maintained.

It's important to know that some infiltration practices are considered underground injection control (UIC) wells and are required to be registered with the state of Washington. According to state regulations, all underground injection control (UIC) wells receiving runoff, except those located on tribal lands and UIC wells at single-family homes receiving only residential roof runoff or used to control basement flooding, must be registered with the state of Washington. The following is a detailed definition of UIC wells and examples.

- A UIC well is defined as a structure built to discharge fluids from the ground surface into the subsurface; a bored, drilled, or driven shaft whose depth is greater than the largest surface dimension; or a dug hole whose depth is greater than the largest surface dimension; or an improved sinkhole, which is a natural crevice that has been modified; or a subsurface fluid distribution system that includes an assemblage of perforated pipes, drain tiles, or other similar mechanisms intended to distribute fluids below the surface of the ground.
- Examples of UIC wells for subsurface infiltration systems include drywells, drain fields, infiltration trenches with perforated pipe, storm chamber systems with the intent to infiltrate, french drains, bioretention systems intended to distribute water to the subsurface by means of perforated pipe installed below the treatment soil, and other similar devices that discharge to the ground.

Considerations for All Infiltration Practices

- When planning an infiltration BMP, determine and apply the appropriate level of runoff treatment.
- When runoff is not suitable for dispersion BMPs, use infiltration BMPs.
- Use Ecology's Stormwater Management Manuals to properly design and implement dispersion and infiltration BMPs.
- Rainfall intensity varies greatly by season and region in Washington. Consider precipitation timing, duration, and intensity of runoff when selecting and designing infiltration BMPs.
- The selection of practices to manage runoff from agricultural facilities will be site specific. However, factors such as soil type, slope, surrounding drainage, and proximity to surface waters or conduits to surface waters should, at a minimum, be considered when evaluating potential solutions.

Definitions as Used in this Document

Berm – a constructed practice used to redirect runoff flow away from pollution sources to prevent the generation of polluted runoff.

Dispersion – the spreading out of stormwater over an area to reduce flow and facilitate gradual infiltration into the soil before reaching a natural or artificial waterway.

Dispersion outlet - practices used to spread out concentrated runoff to facilitate sheet flow and promote infiltration.

Diversion channel - are constructed conveyance waterways used to redirect surface water away from vulnerable areas and agricultural facilities to prevent erosion and the generation of polluted runoff.

Grassed waterway - shaped and graded shallow channels planted with dense, rough grass used to convey surface water runoff at a reduced velocity to a stable outlet without causing erosion.

Infiltration - downward movement of water from the land surface to the subsoil.

Lined waterway - constructed conveyance channels with an erosion resistant lining used to transport runoff.

Roof runoff structures - systems used to convey runoff from roofs and outlet collected water away from pollution sources to a stable outlet or infiltration area.

Subsurface drain - perforated pipes installed beneath the ground surface used to manage soil moisture conditions.

Underground outlets - pipes buried in the ground used to convey collected runoff to a suitable outlet.

Infiltration pond - earthen impoundments used to temporarily store and infiltrate runoff.

Rain gardens - non-engineered, shallow, landscaped depressions with amended soils and adapted plants used to temporarily store and infiltrate runoff

UIC well - structure built to discharge fluids from the ground surface into the subsurface. See the additional information section for a complete definition.

Chapter 9 Appendix Part A: Effectiveness Synthesis (Runoff Control for Agricultural Facilities - Stormwater)

Effectiveness Synthesis

Introduction

Precipitation events present a challenge to all producers and communities. Even small amounts of precipitation can lead to surface runoff from impervious and semi-impervious surfaces, which can carry manure, sediments, debris, and pollutants into nearby water bodies when uncontrolled. Resulting runoff can present even greater challenges in the event of intense and long-lasting precipitation. Practices that prevent runoff from agricultural facilities can be critical in maintaining water quality. Water that contacts manure and other pollutants from agricultural facilities should be dispersed, infiltrated, and/or diverted to limit negative impacts. The runoff control practices in this chapter are intended to (1) minimize erosion and sedimentation; (2) reduce the quantity and improve quality of runoff leaving developing or developed sites, and (3) divert and maintain clean water. Though there are many practices that can be implemented to control, divert, and infiltrate runoff, the following practices for managing runoff from agricultural facilities are covered in this chapter:

- Roof runoff structures
- Subsurface Drain
- Underground Outlets
- Grassed Waterways
- Lined Waterways
- Infiltration Basins
- Retention Ponds
- Vegetative Treatment Areas
- Rain Gardens

This document's purpose is to identify best management practices (BMPs) that can be implemented by agricultural producers and livestock managers to protect and improve water quality. This chapter examines different BMPs related to runoff control and diversion and their relative effectiveness at protecting water quality with regard to sediments, nutrients, and pathogens.

Uncontrolled runoff has the potential to transport sediment, nutrients, and bacteria to surface waters through erosion and surface runoff and contribute pollutants to groundwater via infiltration. BMPs included in this section are organized by those that:

1. **Divert** runoff water before coming into contact with pollutant sources and impacted areas.
2. **Disperse** rainwater from non-permeable surfaces (i.e., roofs) to reduce erosion and prevent contact with impacted areas.
3. **Infiltrate** runoff from locations that are potential sources of pollutants to filter out contaminants before the runoff is transported to ground water and surface water.

Nutrients, bacteria, and sediment can be carried via runoff from all areas associated with agricultural operations. Practices that can be implemented to address potential runoff impacts from crops, fields and grazing lands are covered in Chapters 1, 2, 12, 5, 6, 8, 10 and 12. This chapter specifically considers agricultural facilities and areas with impervious or semi-imperious surfaces, with a particular focus on areas associated with animal confinement due to the additional pollutant potential associated with animal waste. These areas include, but are not limited to:

- Barns and other buildings
- Waste storage facilities
- Livestock feeding and confinement areas
- Feed, fertilizer, and chemical storage locations
- Equipment storage areas
- Heavy traffic areas where runoff can transport pollutants to the drained area.

For a list of covered BMPs and their organization within the chapter, see Table 1. Though these practices are individually reviewed for effectiveness, they are typically part of a larger runoff control and diversion system. This chapter, to the extent possible, considers the relative effectiveness of combined BMPs in different settings with a lens towards the differing contexts of rainfall and precipitation across Washington state. Information in this chapter is based on NRCS Field Office Technical Guides (FOTG) and guidance and the effectiveness of practices in this section significantly relies on proper implementation and maintenance, which will be discussed in more detail in the implementation section. Ultimately, each landowner scenario is unique and practices from this section should be considered on a case-by-case basis. Consider local stormwater ordinances when selecting and implementing BMPs (Jayakaran et al. 2022). Some of these practices may require assistance from an engineer.

Table 1: BMPs organization and focus of Chapter 9.

Purpose of Practice/Section	Practice Name	NRCS FOTG Code
Dispersal/Infiltration	Roof runoff structures (Includes gutters, downspouts and outlets)	558
Diversion	Berms	362
Diversion/Infiltration	Subsurface Drain	606
Diversion	Underground Outlets	620
Diversion/Infiltration	Grassed Waterways	412
Diversion	Lined Waterways	468
Infiltration	Infiltration Basins	N/A
Infiltration	Retention Ponds	N/A
Infiltration	Vertical Drain (Underground Injection Control)	630
Infiltration	Rain Gardens	N/A

In general, site layout is the first step to preventing runoff by laying out facilities in a manner that prevents or reduces the likelihood of runoff. Following this, producers should consider implementing practices that infiltrate runoff prior to reaching facilities. In the event runoff does travel through facilities and comes into contact with pollutants, practices can be implemented that infiltrate runoff to reduce the potential pollutant load to surface waters. Lastly, runoff may be dispersed and slowed via dispersal and diversion practices or conveyed to storage facilities. This order of importance or "hierarchy" is demonstrated by Figure 1.

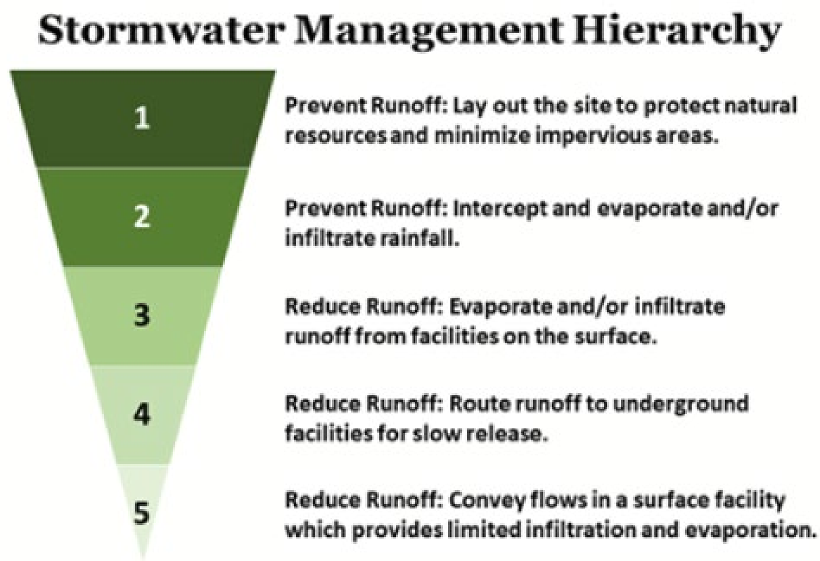

Figure 1: The stormwater management hierarchy demonstrates to order of importance for implementing different types of BMPs to support clean water (Jayakaran et al. 2022).

Relevance in Washington: Focus and Value

Runoff control context in Washington state

In a natural, unimpacted setting, runoff is a function of rainfall rate and infiltration capacity of soil. The hydrologic soil types range from A (lowest runoff potential, highest infiltration) to D (highest runoff potential, lowest infiltration) (Table 2). Washington has a range of hydrologic soil types across the state (Hipple, 2022; Kitsap County, n.d.). NRCS has expanded beyond a basic calculation of runoff and established a runoff curve number (RCN) to estimate direct runoff from rainfall by incorporating land use and management practices (USDA 2009a). Land use and land management practices play a large role in soil quality, runoff potential of a given area, and the quantity and types of nutrients that could potentially be transported by runoff.

Table 2: Soil hydrologic groups, runoff potential, and relationship to Washington regions (NRCS 2009a)

Soil Hydrologic Group	Runoff Potential	Water Transmission Rate (inches/hour)	Description
A	Low	Greater than 0.30	Sand, loamy sand or sandy loam types of soils; primarily deep, well to excessively drained sands or gravels.
B	Moderately low	0.15 to 0.3	Silt loam or loam; primarily soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.
C	Moderately high	0.05 to 0.15	Sandy clay loam; primarily soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.
D	High	0 to 0.05	Clay loam, silty clay loam, sandy clay, silty clay, or clay; primarily clay soils with a high swelling potential, soils with a permanent high-water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material.

Additional soil properties that can inform infiltration capacity are electrical conductivity (EC) and cation exchange capacity (CEC). EC is a measure of soil salinity and soils with lower EC has higher infiltration and drainage as compared to those with high EC (NRCS 2014). CEC refers to a soil particle's ability to react with and attach to positively charged molecules (e.g., nutrients, water, herbicides, etc.). Conversely to EC, a low CEC is indicative of sandy soils while high CED is indicative of soils containing more silt, clay and organic matter which tend to have higher water holding capacity and lower infiltration rates (Goldy 2011). Understanding the soil properties at or near agricultural facilities, including areas surrounding roofed facilities, heavy use areas, and outlet areas can be particularly important to informing effectiveness of practices within a given landowner's context.

Uncovered animal confinement areas and other facilities associated with livestock production can either be surfaced (e.g., with concrete or other materials) or unsurfaced. The NRCS estimates the runoff curve number (RCN) for paved/surfaced confinement areas to be 97 versus 90 for unpaved/unsurfaced confinement areas, wherein an area with a higher RCN has higher runoff potential. The amount of runoff that could come from a confinement areas if left uncontrolled can be estimated by utilizing the RCN. The annual runoff from unsurfaced confinement areas in Washington can be anywhere from <10% of annual precipitation for eastern Washington to >20% of annual precipitation for western Washington. For concrete surfaced areas, runoff can equate approximately 30-50% of mean monthly precipitation (USDA 2009b). Implementing BMPs can reduce the amount of untreated or uncontrolled runoff leaving farming operations that are utilized for livestock production, or other activities such as fertilizer storage and equipment storage.

Regional differences influence the risk of surface runoff. An inch of precipitation in eastern Washington will lead to different outcomes as compared to western Washington due to differing land and soil properties. Eastern Washington is more likely to receive precipitation in the form of snow, which can lead to snowmelt runoff depending on fluctuations in air temperature. Timing, duration, and intensity are important to consider when preparing for excess moisture.

Rainfall rate influences the effectiveness of practices to control and divert stormwater on agricultural lands. Practices in this chapter should be designed in accordance with NRCS recommendations for rainfall capacity. Design specifications and information on maintenance for each practice is expanded upon in the implementation section of this chapter. While some practices should be designed with enough capacity for 25-year, 5-minute rainfall rates in mind, other practices may need to be designed for 25-year, 24-hour rainfall events. See Figure 2 for the 25-year, 5-minute rainfall estimates for the United States (USDA 2009b). Note that the data represented in Figure 2 is from 1995, and with changing climatic patterns, may differ.

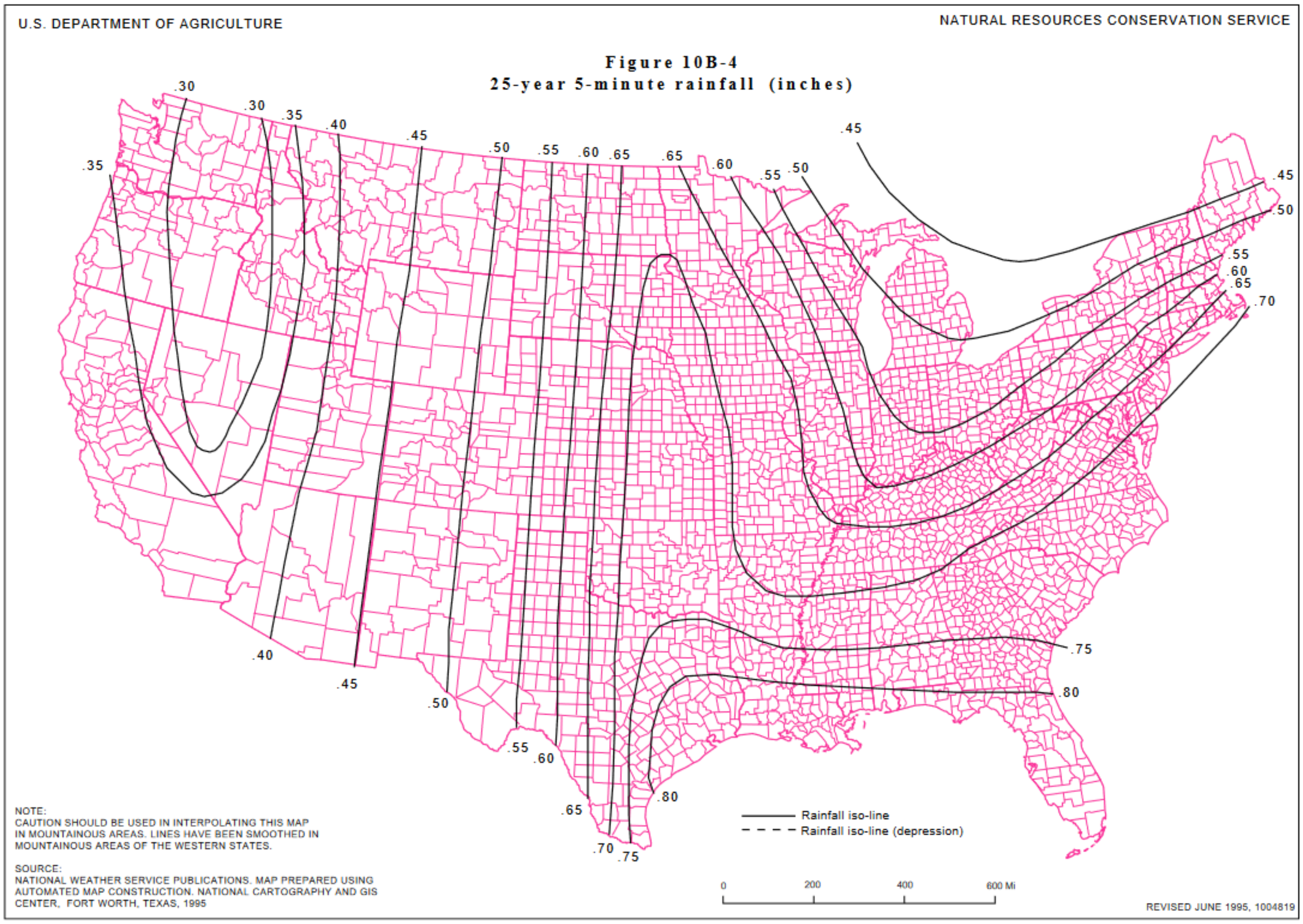

Figure 2: The 25-year, 5-minute rainfall estimates according to the USDA (1995). While eastern Washington 25-year, 5-minute rainfall events are about .30 inches, western Washington's is slightly higher, between .30 and .35 inches.

The more stormwater generated per increment of time can increase the management challenge, though prolonged average precipitation (e.g., one inch of storm per day for multiple days) can also challenge stormwater control systems and practices. See Figure 3 for the average total precipitation in Washington state. Rainfall intensity varies greatly by season and region in Washington and designing practices to meet site-specific needs will enhance effectiveness across all BMPs.

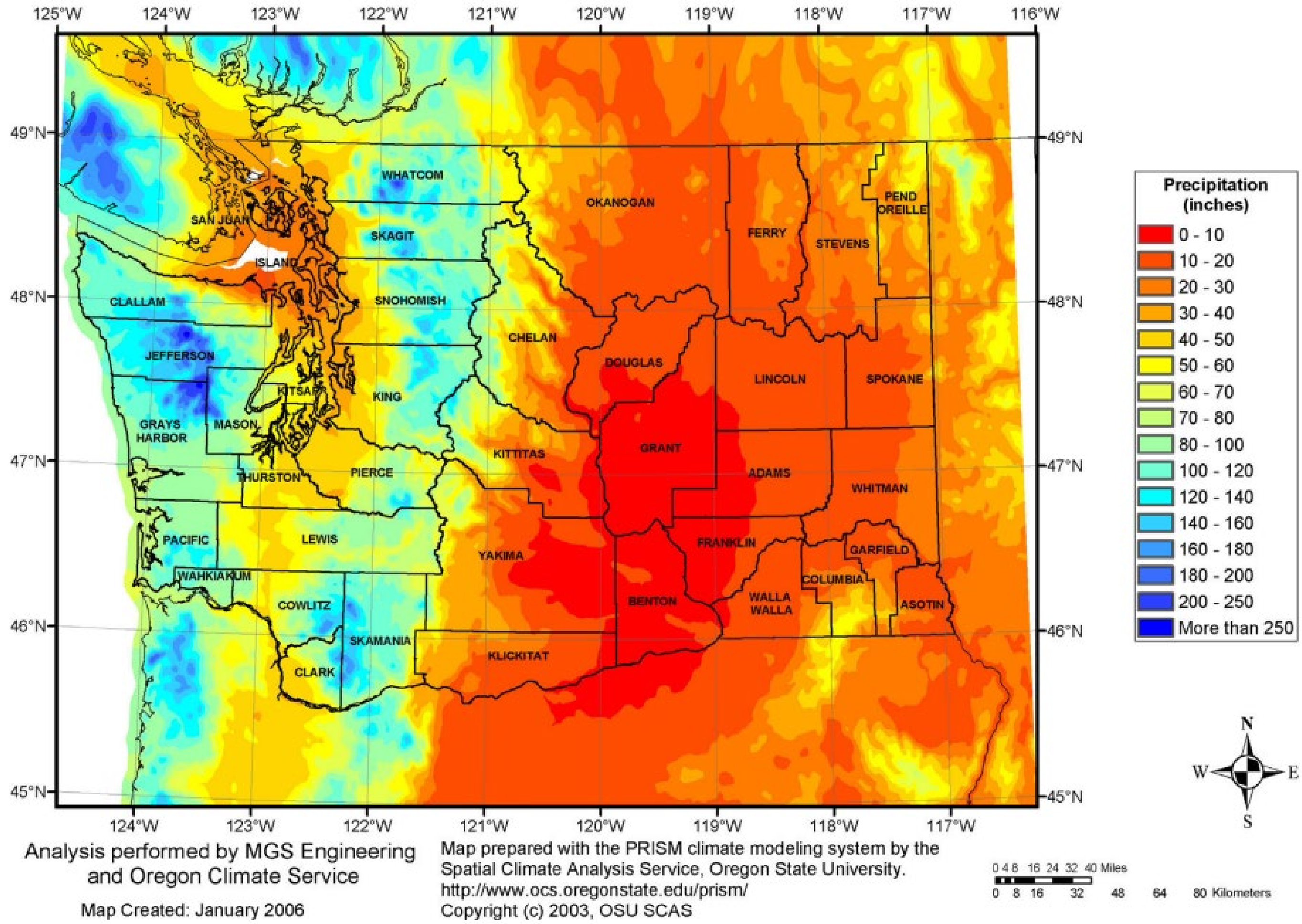

Figure 3: Mean annual precipitation for Washington state (Wallis et al. 2007).

Precipitation, Climate Change, and Stormwater Control and Diversion

Regional and local weather patterns and precipitation events are changing due to climate change. Summer precipitation is expected to decrease in the Pacific Northwest, although winter precipitation is expected to increase (Climate Change Impacts in the Northwest, n.d.). Additionally, extreme events, including heavy rainfall due to atmospheric rivers, are expected to become more frequent. Some research projects that atmospheric rivers are expected to be 25% longer and wider, leading to more rain over larger areas, for longer periods of time (Climate change may lead to bigger atmospheric rivers, 2023). Given that atmospheric rivers are more common in winter months while soils can be frozen or saturated, longer events can present challenges. These change in precipitation pattern, intensity, and frequency, has the potential to impact the long-term viability and effectiveness of runoff control and diversion practices due to a mismatch between capacity design and actual rainfall. Though NRCS recommends designing for 25-year, 5-minute rainfall events to ensure adequate capacity, this is a minimum requirement. Planning for more intense, frequent rainstorms can ensure longer-term use of practices to manage and divert stormwater.

Nutrients and Pollutants of Concern in Washington

A range of pollutants can be transported by runoff from agricultural facilities, including those associated with animal manure (e.g., nutrients, pathogens), sediments from erosion, and others related to operations, including lubricants, oil and other petroleum products, fertilizers and pesticides. It should be noted that the practices presented in this chapter can assist in reducing pollutant transport from impervious and semi-impervious surfaces across all farmland operations and contexts. Sediment, nitrogen, phosphorous, and pathogens are the primary pollutants this chapter considers in its effectiveness review.

Sediment

Sediment is composed of soil particles, varying in size, that have detached from land via erosion and can be dislodged by rainwater or snow melt (Rhea 2022). Impacts of snowmelt on sediment runoff can be influenced by the hill slope, angle, and soil texture. Severity of sediment detachment is based on hill slope and soil texture. Higher soil organic matter and perennial ground cover (e.g. rangelands, pasturelands, alfalfa fields) can help retain sediments. Approximately 38% of rivers in the U.S. that are impacted by sedimentation have increased turbidity (Montakhab et al. 2012). Turbidity decreases light for aquatic plants, increases water temperature through heat absorption, and reduces available oxygen (Rhea 2022). Sediment contains and transports organic matter, nutrients, including phosphorous (P) and nitrogen (N), and pollutants. When accumulated in water ways, sediments can lead to eutrophication, algal blooms, and increased turbidity (Longmore 2008; EnviroAtlas 2018). While erosion is a natural process, the EPA estimates that only 30% of sedimentation in U.S. is from natural erosion processes, whereas 70% comes from human land use activities, including agriculture (Kitsap County, n.d.). Practices that disperse clean water and slow its transport from impermeable surfaces (i.e., barn roofs), divert runoff, and increase infiltration can limit erosion and sedimentation in nearby waterbodies.

Phosphorous

Phosphorous (P) (an essential nutrient for crop and animal production) in freshwater bodies can accelerate eutrophication leading to increased growth of algae and aquatic weeds, and ultimately oxygen shortages after their death and decomposition. Eutrophication can result in harmful algal blooms leading to fish deaths, drinking water contamination, and other environmental issues. Only a small amount of P in water bodies can lead to these detrimental environmental impacts (Rodriquez et al., 2004; Yorgey et al. 2014).

Land application of P is common on agricultural land. In the case of feed production, P is applied to feed crops which is then provided to livestock (i.e., cattle, pig, and poultry) and is deposited via manure. The number of livestock produced in the last 10 years has increased and the number of farms rearing livestock has decreased, leading to increased land use intensity for animal rearing. P in feed is not effectively utilized by livestock and much of it provided in feed is excreted in manure (Yorgey et al. 2014). The P concentration of manure can vary within species depending on their feed, age, and other factors (Table 3).

Table 3: Annual Phosphorous Loss Estimator (APLE) model assumptions for daily dry mass dung production and dung total P content for cattle in Wisconsin pastures (Vadas et al. 2014).

Animal Type	Daily manure production (kg)	Manure total P (kg. P/kg. manure)
Lactating dairy cow	8.9	0.0088
Dairy heifer	3.7	0.0054
Dairy dry cow	4.9	0.0061
Dairy calf	1.4	0.0054
Beef cow	6.6	0.0067
Beef calf	2.7	0.0092

When precipitation comes into contact with manure, particulates can be transported via runoff. Phosphorous can then either deposit with sediments; adsorb to suspended solids, surface soil and vegetation; assimilate with plants and microorganisms; move downslope with runoff, or infiltrate into the soil profile (WA Department of Ecology 2023). Once accumulated within runoff, P is at risk of entering water bodies either attached to the soil particles or dissolved into the surface runoff. Phosphorous has less potential to leach through soil into groundwater given the soils ability to adsorb phosphorus. However, filtration can be reduced in under certain conditions (e.g., compaction) or in soils with poor infiltration rates (e.g., soil groups C and D). Infiltration can also be excessive, such as in sandy soils, or bypassed when soils have cracks or channels or when the water table is close to the soil surface (Lory 1994). Simultaneous management of runoff and manure is therefore essential to reduce P loss and transport.

Table 4: Estimated P produced from animal manure in 2017 in Washington state. Inclusive of cattle, swine, poultry, sheep, and horses (EPA 2023).

Estimated animal manure in 2017 (1000 kg of P)	Estimated animal manure per farmland area in 2017 (kg of P/km^2)
17,816	300

Nitrogen

Animal agriculture is a primary source of nitrogen (N) to surface and groundwater via surface runoff and infiltration from rain events and snow melt. Like P, N can lead to eutrophication in water bodies. N can be lost or transported via a variety of pathways, including soil erosion, ammonia volatilization, denitrification, leaching, and runoff.

Most research on N runoff from agriculture is focused on fertilizer field application, with less information on runoff from discrete animal use areas or agricultural facilities more broadly. However, all water that contacts manure carries the possibility of transporting dissolved N (generally nitrate) to surface water bodies and is a primary concern when it does not have an opportunity to infiltrate (Ribaudo, 2011). Soil erosion from concentrated animal areas is of concern since N can attach to soil particles and erosion can increase with uncontrolled runoff.

Proper land management practices and stormwater BMPs explored in this section for concentrated animal areas help to reduce the likelihood of sediment erosion, which tends to be more of a concern in drier, arid areas such as eastern Washington.

Table 5: Estimated N produced from animal manure in 2017 in Washington state. Inclusive of cattle, swine, poultry, sheep, and horse (EPA 2023).

Estimated animal manure in 2017 (1000 kg of N)	Estimated animal manure per farmland area in 2017 (kg of N/km^2)
69,943	1,177

The USDA estimates that 5% of nitrogen excreted by livestock is released into runoff. While 50% of N in runoff is likely retained after solids separation, 50% of nitrogen in runoff is plant available and can be attenuated through capture in vegetated areas (Table 6).

Table 6: Estimated nitrogen in runoff for livestock (USDA, 2004a).

Species	Typical Nitrogen Excretion per Animal (lb. N/ day)	5% assumed release in runoff from open lot	Assumes 25% of N is plant available
Beef – Cow	0.42	0.021	0.0053
Beef – Growing calf	0.29	0.015	0.0036
Dairy – Lactating cow	0.98	0.049	0.012
Dary – Dry cow	0.5	0.025	0.0063
Dairy – Calf (330 lbs.)	0.14	0.007	0.0018
Dairy – Heifer (970 lbs.)	0.26	0.013	0.0033
Horse – Sedentary (1,100 lbs.)	0.2	0.01	0.0025
Horse – Intense exercise (1,100 lb.)	0.34	0.017	0.0043

Pathogens

Surface runoff and subsurface flow can carry pathogens from animal manure, including, but not limited to, fecal coliform, *Campylobacter, Salmonella,* and *Escherichia coli (E. coli)*. Even small amounts of pathogens can negatively impact water quality and subsequently human health. For example, only 10 cells of *E. coli spp.* are required for infection (Manyi-Loh et al. 2016). Bacterial pathogens can survive in manure from a few days to months depending on the environmental conditions and the species (Manyi-Loh et al. 2016). Manure-borne pathogens are primarily transported via flowing water, where they are then transported via surface or subsurface flow. Generally, these microorganisms move suspended freely in water or attached to soil or manure particulates (Pachepsky et al. 2006).

Pathogens are primarily removed from surface runoff through entrapment within the soil matrix through physical and chemical absorption in the soil. For more information on pathogens, see Voluntary Clean Water Guidance for Agriculture Chapter 12 : Riparian Areas & Surface Water Protection[4]. The rate by which pathogens infiltrate soil is primarily influenced by soil type (Table 1), water volume, and flow. However, soil pH, temperature, plant presence, microbial soil properties, and the type of waste can also impact infiltration. Land with impermeable soil or soil with high water content infiltrate poorly and are more susceptible to transporting pathogens during rainfall events (Mawdsley et al. 1995).

Department of Ecology Stormwater Management Manuals

The Department of Ecology has developed stormwater management manuals (SWMMs) for western and eastern Washington which provide information, specifications, and standards for stormwater BMPs that are used widely across Washington. Practices outlined in the SWMMs are effective practices that can be used to disperse and infiltrate stormwater and should be consulted whenever planning and implementing stormwater management best management practices. It's also recommended to contact your local municipality when planning a new development or redevelopment project to make sure you follow local requirements for stormwater management.

Effectiveness of Practices for Dispersing Clean Water

All roofed structures on agricultural land and operations should have some form of runoff control to reduce erosion and transport of pollutants. Lots with larger amounts of roofed structures or impervious or semi-pervious surfaces will need enough area to disperse and/or infiltrate roof runoff, whereas small lots, or lots that have a risk of negatively affecting adjacent property, can utilize perforated stub-out connections to direct rainwater to a stormwater management facility (WA Department of Ecology, 2019). According to NRCS, roof runoff dispersal practices can achieve one or more of the following:

[4] https://apps.ecology.wa.gov/publications/parts/2010008part6.pdf

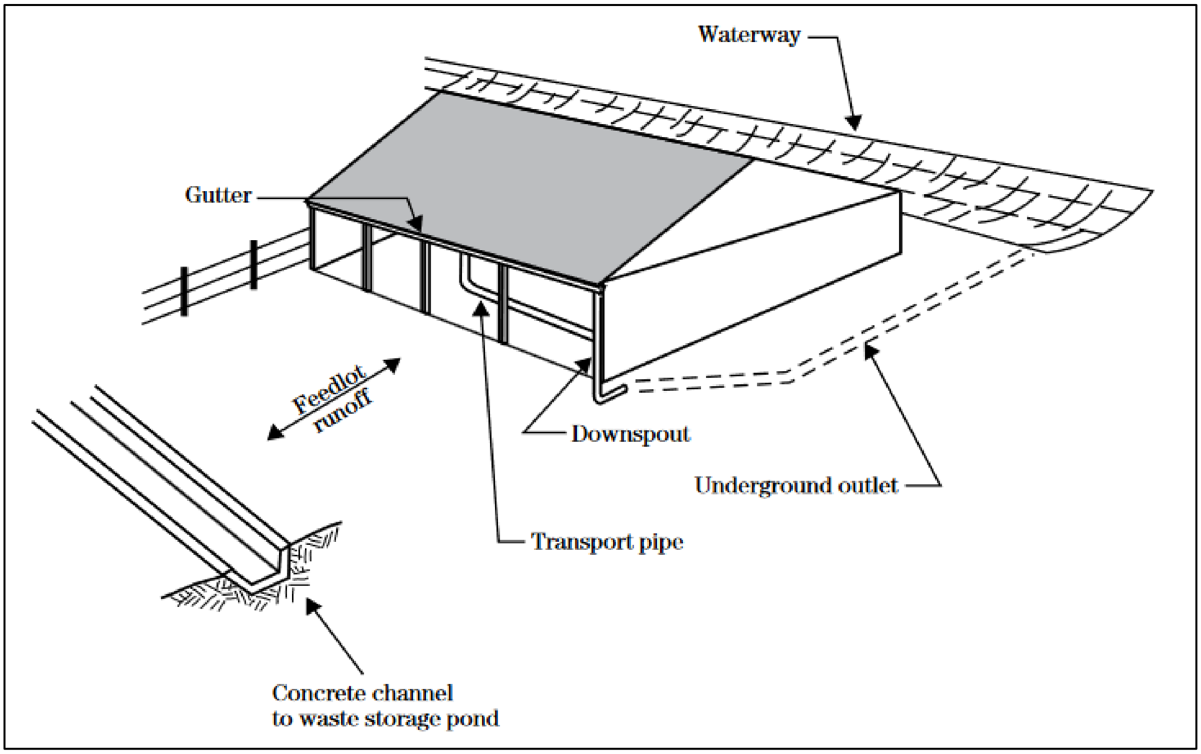

Figure 4. Diagram of roof gutter and downspout system. Water should exit through downspouts into underground outlets to be transported to other diversion BMPs. Any water that runs off feedlot surfaces should be transported to waste storage (NRCS 2009).

- Protect surface water quality by excluding roof runoff from contaminated areas;
- Prevent erosion from roof runoff;
- Increase infiltration of roof runoff;
- And capture roof runoff for on-farm use.

Roof runoff structures consist of gutters, downspouts, and outlets to controlled areas to disperse, infiltrate, and/or transport water away from roofed facilities. Gutter construction may vary by region, particularly for areas of Washington that receive a lot of snow, as the weight of snow could be damaging. If runoff from roofs is uncontrolled, the water has the potential to come into contact with areas containing animal manure, nutrients, or other pollutants (e.g., petroleum from equipment maintenance facilities) and migrate to surface water or infiltrate into groundwater. Additionally, the force of uncontrolled water from roofs can lead to erosion around a facility and potentially lead to sediment transport to surface water. Collecting roof runoff through a series of gutters, downspouts, and outlets is assumed effective at protecting water quality if the structures have adequate capacity for water volumes equal to or greater than peak flow expected during a 25-year, 5-minute rainfall event (NRCS, 2021a). A basic equation below allows producers to calculate precipitation and subsequent runoff to properly design roof runoff systems.

$$Area\ of\ roof\ (ft^2) \times precipitation\ (inches) \times\ .62 \\ = Total\ runoff\ from\ impermeable\ surfaces\ annually$$

As an example, if the average rainfall in a location is 55 inches of rain per year and a farmer has a 2100 ft^2 roof, the calculation would be 2100 x 55 x 0.62 = 71,160 gallons per year of runoff from that roof. An effective solution would divert this water from the roof, through gutters and downspouts, into an underground outlet and away from the facility and any livestock, heavy use area, or manure storage facility (Stienbarger, 2004). Producers should design the capacity of downspouts to exceed the capacity of gutters to prevent overflow from roofs and ensure effectiveness. NRCS utilizes Manning's equation with additional considerations and inputs to determine the capacity design of roof gutters and downspouts (USDA, 2009b). Manning's equation is included in Appendix C.

Ultimately, having a well-managed roofed area over semi-impervious and impervious surfaces, areas animals congregate, and where manure is stored lowers the need to manage runoff in other ways, such as through runoff basins and settling ponds. Maintenance, including removal of accumulated debris, checking for damage, and ensuring outlets are freely operating and not causing erosion, also ensures effectiveness.

Outlets for Dispersal Systems

Downspout diversions can include a splashblock, trench, or a dispersion trench with notched grade board (Jayakaran et al. 2022). A splashblock is a device that sits at the base of downspouts to aid distribution of precipitation and reduce likelihood of pooling. Once rainwater has travelled through the series of gutters and downspouts, it can then be dispersed to slow down velocity and increase infiltration across a wider area. Examples of dispersal BMPs associated with roof runoff structures include:

- Full dispersion: The dispersion area is 6.5x greater than the area of the impervious surface draining to it and allows for 100% infiltration of runoff.
- Sheet flow dispersion: Inclusive of a transition zone and vegetated buffer or dispersion area. The transition zone promotes transport of rainwater to a dispersion area or vegetative buffer.
- Concentrated flow dispersion: Specially adapted concentrated flow dispersions with features such as rock pads or dispersion trenches and level spreaders to ensure dispersal of concentrated flows from impervious surfaces.

Following collection of water via roof runoff systems, water can also be aided in infiltration via an underground infiltration system (UIC). Primary types of UICs include dry wells, infiltration trenches, dispersion trenches, and perforated stub-outs (Snohomish County, 2023). Design and construction of common UICs will be described in detail in the Implementation Section of this chapter. The effectiveness of a given type of UIC is dependent on site-specific conditions, including soil conditions, groundwater conditions, and placement in relation to the building, groundwater, and surface water. The State of Washington regulates some UIC wells and they may need to be registered.

Additional guidance on Roof Downspout BMPs and Infiltration BMPs can be found in Ecology's Stormwater Management Manual for Western Washington (V-4 and V-5) and the Stormwater Management Manual for Eastern Washington (6.4 and 6.5).

Effectiveness Considerations

There is limited research to draw upon that measures effectiveness of roof runoff systems. However, roof runoff structures are a commonsense practice, and the total amount of pollution prevented from escaping an impacted agricultural area by a roof structure is equivalent to the potential amount that would run off in an uncontrolled scenario since the rainwater is fully prevented contacting the ground. As such, roof structures in or adjacent to confinement areas are particularly important as they can be a significant contributor of N, P, and sediment runoff in uncontrolled scenarios.

We did not find calculations of P and N loss via runoff. However, if clean water is successfully diverted from contaminated areas, there is a baseline assumption that the water will remain free of contaminants. A master's thesis from the University of Nebraska found that anywhere between 5-21% of total N in cattle manure can be lost from runoff, depending on cattle diet (Baerman 1995). P is also primarily transported via runoff and erosion – both of which are reduced via installation of roof runoff structures (Ritter and Shirmohammadi 2001). In a study on the effectiveness of reducing P through animal waste management in two watersheds in Vermont, barnyard runoff control (inclusive of a suite of BMPs associated with reduced runoff from livestock areas) resulted in the higher P loss reduction and was found to be cost effective in comparison to milkhouse waste treatment and waste storage facilities BMPs (Table 6) (USDA 2006). The watersheds investigated in this study were high dairy production areas, and the BMPs were selected based on the highest contributing factors for P.

Table 7: P reduction and cost effectiveness of suites of BMPs in two watersheds of LaPlatte River Basin, Vermont from 1980 - 1989 (Data from Meals 1990).

Best Management Practices	Watershed 1: P Reduction (kg)	Watershed 1: Cost effectiveness ($/kg P)	Watershed 2: P Reduction (kg)	Watershed 2: Cost effectiveness ($ kg/P)
Barnyard runoff control	311	4	78	14
Milkhouse waste treatment	34	12	11	32
Waste storage facility	154	269	14	1963
Total	567	77	103	282

Effectiveness of Practices for Diverting Clean Water

When surface water runoff is transported through or near agricultural facilities, runoff can become contaminated with nitrogen, phosphorous, sediment, other pollutants, and agricultural products (e.g. petroleum and pesticides). This can cause significant environmental and human health impacts. Overland water flow increases transport of these contaminants, stream velocity, erosion, and sediment loading. The farther contaminants travel, the more likely they will have detrimental effects on water quality. Practices that divert clean water around livestock and manure handling areas to contain contaminants at their source are an effective component of an agricultural operation's runoff control systems (WA Department of Ecology, 2015).

Effectiveness Considerations

A wide variety of practices may be implemented to divert clean water. The maximum effectiveness of these practices is highly dependent on proper implementation, which will be covered in the Implementation Section of this chapter. The NRCS FOTGs are a starting point to ensure diversion practices are effective. Producers can work with Conservation Districts (CD), and/or private sector consultants, to implement effective diversion systems. Determining which practices are most effective will depend on site conditions. All clean water diversion mechanisms discussed in this chapter should consider the following variables:

- Location
- Maximization of diversion infiltration to limit surface water runoff and increase nutrient treatment and attenuation
- Containment load
- Proper outlet
- Proper maintenance

Location

Diversion location should be carefully chosen to maximize its effectiveness. The ideal location for a diversion is dependent on the geography and size of the land. Consider maximizing distance between the diversion and surface water, and between the diversion and the human, manure, and livestock operations. Topography and spacing between individual diversions are also important to consider when designing diversion systems (WA Department of Ecology, 2015). Clean water diversion locations with soil types that allow for water infiltration and vegetation growth are ideal. Non-erodible areas should be chosen to prevent clean water from carrying soil particles with excess nutrients, as well as any potential pollutants into water bodies (Cesti et al. 2003). The most effective location to install a diversion practice should consider land use and whether the diversion needs to be on the edge of the field versus in-field. A diversion is more effective if located in an area that does not need to be crossed by equipment to prevent any potential transfer of pollutants and manure via the equipment, and to avoid complicating navigation across diversion methods, such as ditches.

Maximization of infiltration during diversion to limit surface water runoff and increase nutrient treatment and attenuation

Surface runoff occurs when excess rain accumulates on the soil surface and creates runoff. Calculating runoff quantity and velocity is complex. An effective diversion will hold excess rainfall which is determined as the total amount of rainfall minus water infiltration and interception. Depending on a producer's location, diverting snowmelt runoff may also need to be considered. Runoff is influenced by many factors including slope, vegetation presence, surface roughness, infiltration rate and capacity, evapotranspiration, and interception of water. Retained water will eventually evaporate or infiltrate (Ritter and Shirmohammadi 2001). Maximizing infiltration of the runoff during diversion will help reduce its overall quantity and therefore lower the capacity of water that needs to be transported.

Properly grown and maintained vegetation can increase infiltration and prevent erosion in some diversion methods. Vegetation porosity or density, shape, flexibility, and height affect sediment deposition rate and flow turbulence. Stiffer grasses increase drag on soil and water, slow water velocity, and improve stability which decreases the likelihood of erosion and sediment transport (Montakhab et al. 2012). A range of environmental factors effect perennial vegetation growth, including day length, air temperature, soil temperature, water, and nutrients. Pasture calendars show that vegetation growth may only be effective during portions of the year depending on the vegetation type and location. Consider the PNW 699 Western Oregon and Washington Pasture Calendar[5] or PNW 708 Inland Pacific Northwest Pasture Calendar[6] to understand how to most effectively monitor, maintain, and account for vegetation growth.

An effective diversion will allow for nutrient treatment and attenuation, which is how much of each type of nutrient and/or possible pollutants can infiltrate within the diversion, and over what distance the nutrients and/or pollutants need to travel to infiltrate. It is important to keep nutrients in the soil, minimizing movement of sediment to water bodies. Water moves into soil through infiltration and capillary movement from groundwater. Soil texture, type of clay, organic matter content, depth of wetting and antecedent moisture, presence of impeding layers, and evapotranspiration all affect infiltration (Ritter and Shirmohammadi 2001). The more nutrients that are attenuated along the way, the more effective the diversion is at keeping clean water clean.

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[5] https://pubs.extension.wsu.edu/the-western-oregon-and-washington-pasture-calendar

[6] https://pubs.extension.wsu.edu/inland-pacific-northwest-pasture-calendar

Maintenance of Diversion Practices

Clean water diversion practices should be properly maintained to effectively manage runoff capacity, correctly direct water transport, and promote infiltration. Maintenance will vary by practice and location and will be described in more detail in the implementation section of this chapter. Considerations include prevention of clogging, trampling by livestock or machinery, maintaining pipes or any lining (e.g. geotextile fabric, weed cloth, gravel, plastic) applied to the diversion, and limiting erosion. It is critical to prevent erosion with proper maintenance so that water does not overflow from the diversion mechanism and create alternative paths of travel that can lead back to livestock areas, manure storage areas, or other water bodies (Hardwood, 2005). As soon as there is erosion in a channel, it is difficult to control new paths of water flow, decreasing the channel's effectiveness (Montakhab et al. 2012). Practices that involve vegetation must also consider proper maintenance and timing of vegetation growth (Fransen et al. 2017).

Containment Load

A diversion mechanism is most effective when designed to address the volume and velocity of runoff and can be influenced by the soil type of a given area (Table 2). The diversion mechanism must be designed to the proper depth, width, or pipe capacity (Cestti et al. 2003). Climate change and increased storm events may increase the frequency, rate, and total volume of precipitation of peak storm events in the future and create an increased need for diversion systems that can handle larger water capacity than currently needed. NRCS guidance and the Implementation Section of this chapter will provide more specific design criteria to meet peak storm events for each diversion mechanism.

Proper Outlet

Runoff should be diverted to a proper outlet that can infiltrate the water (see section below on infiltration). A suitable outlet is an area that can receive redirected runoff without causing erosion or other problems such as water buildup that could lead to continued runoff. Water can be collected or directed for storage, spreading, water harvesting systems, or treatment. Other options include rain gardens, dry wells, existing swales, or gently sloping vegetated land (Northern Virginia Soil and Water Conservation District, 2023).

Diversion Mechanisms

Diversion mechanisms covered in this chapter include:

- Ditch diversions
- Underground outlets
- Subsurface drains
- Grassed and lined waterways

According to NRCS guidelines, each method is effective when properly implemented and with consideration of the effectiveness factors discussed above. NRCS provides a Conservation

Practice Physical Effects information sheet (CPPE). CPPE is a relative assessment of how a practice addresses a "resource concern". In general, CPPE shows that the diversion practices discussed in this section provide a moderate to substantial improvement in reducing runoff, flooding, and ponding. In doing so, diversion practices may slightly worsen surface or groundwater depletion by impacting the depth or time of infiltration. See the CPPE Matrix[7] for more information on particular practices.

Type of Diversions

NRCS' Field Office Technical Guide for Diversions (Code 362) describes diversions as channels, often across slopes, with a supporting ridge on the lower side. Diversion channels are effective at intercepting shallow surface and subsurface water to reduce runoff and erosion by directing water away from sensitive areas including agricultural facilities and either direct or collect water for storage, water spreading, water-harvesting systems, or treatment (NRCS, 2023a). There are three main diversion types: channels in which it is excavated at the base of a slope, ridge (diversion berms) where an earthen ridge is constructed on a slope to create a channel, and combination diversions where material is pushed from a channel to form a ridge (Herbert 2009).

Channels

Diversion channels reduce runoff and erosion by intercepting surface and shallow subsurface flow, directing runoff away from sensitive or eroding areas and agricultural waste systems, and/or collecting or directing water for storage, spreading, or treatment. Moving and redirecting water away from agricultural facilities can prevent transportation of sediments, pathogens, nutrients, and other pollutants. Diversion channels are often vegetated and can be lined to prevent erosion and can transport different volumes of water depending on the size, soil type of the area, slope, and vegetation planted (NRCS, 2023a). The permissible velocity for soil type and vegetative cover within the diversion will determine maximum grade for an effective diversion (Massachusetts Department of Environmental Protection, 2023). The water must properly drain to a safe and stable outlet that is stable enough to reduce erosion and has capacity to convey the runoff volume being transported. Potential outlets include grassed or lined waterways, vegetated or paved areas, grade stabilization structures, underground outlets, stable watercourses, sediment basins, or a combination (NRCS, 2023a). Diversions can also outlet to water and sediment control basins (NRCS 638). Water and sediment control basins are earth embankments or ridge and channel combinations constructed across the slope of a minor drainageway to reduce gully erosion, trap sediment, and reduce and manage runoff. Refer to

[7] https://www.nrcs.usda.gov/resources/guides-and-instructions/conservation-practice-physical-effects

Chapter 6: Sediment Control: Soil Stabilization & Sediment Capture[8] for more information.

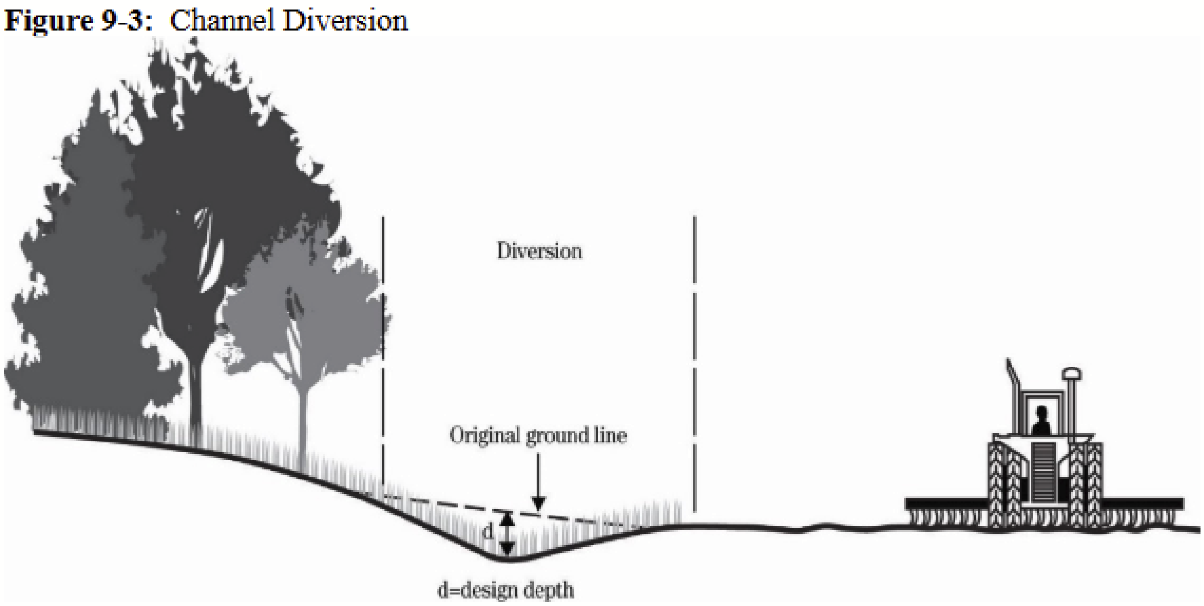

Figure 5. Diagram of channel diversion (Herbert et al. 2009)

Berms

Diversion berms may be used to divert water away from impacted areas, reduce erosion, and slow surface water runoff, allowing for more infiltration away from agricultural facilities. However, berms are not intended to be an edge of field practice to reduce nonpoint source pollution. Berms are impractical as the only BMP method used to retain a large water volume due to their limited height. Berms are more effective in combination with other types of diversion practices, require proper maintenance, and design variations should consider soil permeability, grade, vegetative cover, placement, and compaction. Berms should be designed for the proper containment load which varies based on size, length, and soil type (Pennsylvania Department of Environmental Protection, 2006). Berms can hold water volumes in a ponding area so it is important to properly divert water and prevent ponding or pooling of water when the water may negatively affect soil quality or create the potential for overflow. If a berm overflows, the built-up water can lead to high water velocity, resulting in an increased risk of surface runoff and erosion (Lake Champlain Committee, 2019).

[8] https://apps.ecology.wa.gov/publications/parts/2010008part3.pdf

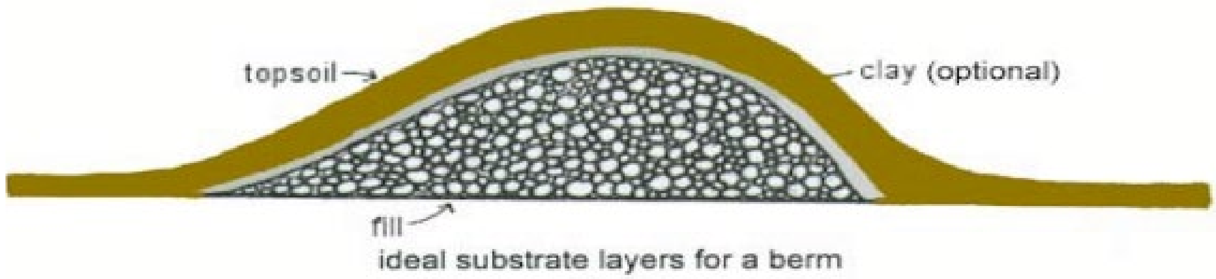

Figure 6: A typical berm includes a layer of substrate covered by topsoil with an option layer of clay (Pennsylvania Department of Environmental Protection, 2006).

Underground Outlets

Underground outlets (NRCS Code 620) are pipes buried in the ground to convey surface water and often extend from roof structures to a suitable outlet. Underground outlets maintain water quality, manage flooding and ponding, and prevent concentrated flow erosion (NRCS, 2024). Underground outlets are beneficial to install when a surface outlet is impractical due to stability problems, topography, land use, or equipment traffic. Underground outlets are also helpful in lowering excessive sediment in surface water. An additional type of outlet is often needed for continued diversion or storage of water (e.g., water and sediment control basin). Otherwise, it is best to locate the end of the outlet where the diverted clean water can infiltrate back into the ground. A 4-inch corrugated plastic pipe can divert rainwater from a 5400 ft^2 roof area if properly (Stienbarger, 2004)

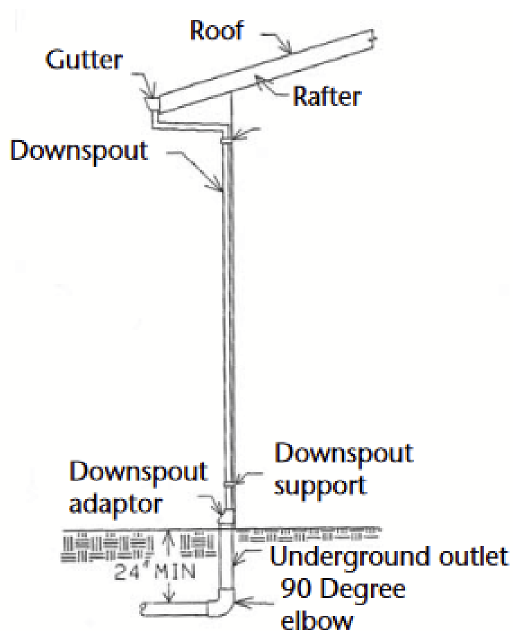

Figure 7. A typical downspout associated with an underground outlet (Stienbarger, 1996).

Subsurface drains

Subsurface drains (NRCS Code 606) are perforated pipes beneath the ground surface that manage soil moisture conditions. They remove or distribute soil water, remove salts and contaminants from the soil profile, and can mitigate degraded plant health and undesirable plant productivity resulting from to saturated soil, ponding, and flooding (NRCS, 2022a). Subsurface drains can also reduce sediment and phosphorous surface runoff. Note that subsurface drains are not the same as underground outlets. This practice is especially effective at managing the water table level by removing excess groundwater from the crop root zone system to prevent excess groundwater that may lead to pooling and seeping of water. The drains are most effective when placed outside the groundwater table and should be designed with proper spacing and depth based on soil texture classification (Tiwari and Goel 2017).

Subsurface drains are a more expensive diversion option used in areas with high water tables, where lowering the water table and controlling groundwater and surface water runoff is worth the expense. Subsurface drains may work better for smaller livestock farms because they often require more intensive maintenance and component repair to be effective, which can become especially costly and labor intensive for larger areas of land. This is especially true if subsurface drains are installed under heavy use areas where large animals or equipment can damage drains and manure can get into pipes. The water should drain to another method of diversion, storage, or infiltration, such as a grassed or lined waterways, grade stabilization structures, or underground outlets (Hardwood, 2005). The drainage outlet must be adequate for the quantity and quality of water to be discharged and are not recommended to be submerged (NRCS, 2022a).

Grassed Waterways

Grassed waterways (NRCS Code 412), sometimes referred to as grassed swales, are shaped or graded broad and shallow channels, with vegetation to convey surface water runoff at a reduced velocity to a stable outlet without causing erosion (MDEQ, 2015)., Grassed waterways prevent gully formation and protect and improve water quality. Grassed waterways are effective in areas where added water conveyance capacity and vegetative protection are necessary to prevent erosion and improve runoff due to concentrated surface water (NRCS, 2021b). A dense and hydraulically rough grass cover creates less soil compaction and sealing, and slows down runoff velocity, allowing for prolonged and increased water infiltration, as well as a higher surface storage capacity than drainage ways. Grassed waterways are widely used on larger farm areas. While grassed waterways have been proven to be beneficial, they are not as widely used as simply placing vegetated filter strips at downslope ends of fields or along bodies of water. Grassed waterways are often less expensive than installing subsurface drains and are used over other methods because of their ability to prevent gullies that pose obstacles during field operations (Fiener and Auerswald 2017).

In order to be effective, grassed waterways require proper seeding, mulching, sodding, soil saturation, and maintenance to allow for vegetation establishment and growth to effectively control runoff and prevent erosion (Hardwood, 2005). Vegetation should be planted at the proper time and established as soon as possible using NRCS CPS Critical Area Planting Code 342 (NRCS, 2017). Seeking guidance from a soil scientist or an agronomist for recommendations on specific site locations is beneficial for maximizing effective vegetation growth. Effective vegetative species for grassed waterways can be determined by assessing the depth to groundwater table, climatic factors, and vegetative retardance.

If designed properly, grassed waterways will effectively convey peak runoff expected from the 10-year frequency, 24-hour duration storm. The grass will slow down runoff and capture potential sediment which could accumulate in the waterway between maintenance periods. The greater the width of established vegetation above the flow area, the more effective the grassed waterway (MDEQ, 2015). Fiener and Auerswald (2003) found that over an eight-year period, average runoff was reduced by 10% with the implementation of grass waterways with a small incision along a drainage way, compared to 90% runoff reduction with flat-bottomed grassed waterways.

A grassed waterway should have a stable outlet with adequate capacity such as another vegetated channel, an earthen ditch, a grade stabilization structure, a filter strip, lined waterway, or other suitable outlet depending on what works best on a case-by-case basis (NRCS, 2021b). Use NRCS guidance (Code 606 and 620), or other suitable measures in waterway designs for proper drainage. If drainage practices are not adequate to solve seepage problems, use guidance from NRCS CPS Lined Waterway or Outlet (Code 468) in place of NRCS CPS Grassed Waterway (Code 412). The NRCS National Engineering Handbook Title 210 Part 650, Chapter 7 can also be referred to for proper implementation practices.

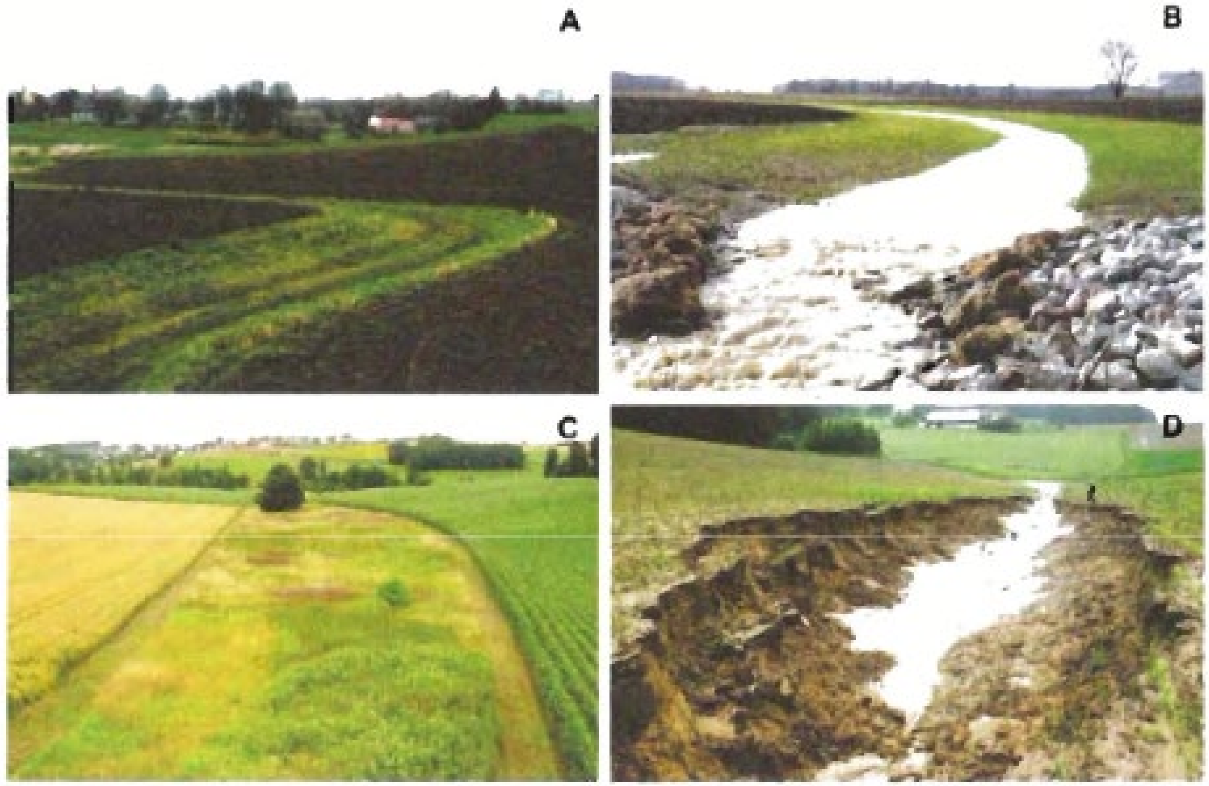

Figure 8: Examples of grassed waterways. (A) Narrow, subsurface grassed waterway in Belgium. (B) Wide, flat-bottomed grassed waterway for large runoff rates. (C) Successional grassed waterway in Germany with hydraulic roughness and high biotic value. (D) Massive gullying initiated by a single runoff event due to lack of grassed waterway (Fiener et al., 2017).

Lined Waterways

Lined Waterways (Code 468) are broad and shallow constructed channels, shaped and graded to required dimensions, with an erosion-resistant lining (NRCS, 2023b). Lined waterways are often chosen as a diversion method for conditions including highly erosive soils, prolonged or extreme water velocities, concentrated runoff, a water outlet width that needs to be controlled, or when activity causes trampling of the land that prevents only using suitable vegetation cover. The practice effectively creates safe runoff conveyance in a desired direction away from contaminant sources, prevents erosion and flooding, and protects and improves water quality (NRCS, 2023b). If vegetation is established, it acts as a filter to remove sediment-attached pollutants, nutrients, and other potential chemicals from runoff (Cestti et al., 2003). The purpose of lined waterways is not to infiltrate water. Rather, water should outlet to another diversion, infiltration, or storage method. Lined waterways must be able to carry the peak runoff rate from a 10-year, 24-hour frequency storm to be effective, with several exceptions determined by NRCS Code 468 guidance. Lined waterways must also be periodically maintained to remain effective by preventing material lining damage.

Figure 9. Example of a lined waterway (USDA NRCS 2020).

Note on Terraces, Surface Drain Field Ditches & Other In-Field Practices.

Terraces (Code 600) and Surface Drain Field Ditches (Code 607) are additional practices that are used to reduce erosion from runoff and convey water (NRCS, 2020). Terraces slow water velocity and reduce erosion. Surface drain field ditches are graded channels on the field surface for collecting and conveying excess water (NRCS, 2022a). In-field practices such as tillage and residue management, contour farming, cover crops and other vegetative cover practices can also be used to reduce runoff and erosion and facilitate infiltration. These types of approaches are discussed in other chapters of the Clean Water Guidance for Agriculture.

Effectiveness of Practices for Infiltration of Stormwater

Runoff control practices for infiltration are intended to do the following (NRCS, 2021c):

- Minimize erosion and sedimentation during and following construction activities
- Reduce the quantity of stormwater leaving developing or developed site
- Improve the quality of stormwater leaving developing or developed sites
- This practice does not include runoff from areas of livestock facilities

Practices for managing runoff from impacted areas that are covered in this section include:

- Stormwater basins
- Vegetative treatment areas
- Rain gardens

Structural practices to manage stormwater nutrients and pathogens rely on constructed features such as detention ponds, rain gardens, or permeable pavers (Yang and Lusk 2018).

Stormwater Basins

Stormwater basins include retention ponds and infiltration basins. Retention ponds control stormwater by retaining and treating contaminated runoff and removing pollutants. These ponds are often surrounded by natural vegetation which helps prevent erosion. Bioretention systems and drains carry stormwater away in pipes, but this may be costly and not a feasible option for landowners. Infiltration basins reduce stormwater discharge volume by enhancing groundwater recharge (EPA, 2021). Infiltration basins reduce the volume of stormwater and pollutants that directly discharge to surface waters. Infiltration basins use soil as a filter for removing pollutants (e.g., sediment, phosphorous, metals), and effectively increase groundwater recharge and baseflow to nearby streams. The effectiveness of stormwater basins depends on storage volume, catchment area, and hydraulic residence time.

Water Containment

Performance of infiltration runoff controls are related to (1) the volume of runoff that the basin captures and infiltrates and (2) the level of filtration provided by soil (EPA, 2021). The effectiveness of infiltration basins can be hindered by soil infiltration rates, groundwater contamination concerns, spatial limitations, and shallow groundwater tables (EPA, 2021). Soils should be significantly permeable to ensure that basins can efficiently infiltrate stormwater (See Table 2). Soils that infiltrate too rapidly could result in groundwater contamination. The infiltration rate should range between 0.5 and 3 inches per hour. Textural and hydraulic properties are critical determinants of soil moisture retention capacity and affect nutrient infiltration. In some cases, stormwater basins will use sandy soil which is packed by machinery and has low infiltration. The structure of organic matter influences the leaching of nutrients and pollutants into soil. Therefore, monitoring activities to assess soil types and infiltration is critical.

Nutrient Infiltration

The ability of retention ponds to treat runoff varies and depends on the drainage area, design factors, and maintenance. Typically, retention ponds provide some water quality treatment, but they are typically a source rather than a sink of N and P. Soil media is a key factor in the efficacy of bioretention to treat stormwater nutrients. Bioretention cells perform best for nutrient treatment when constructed with sand to sandy loam soils with clay content kept to 5-8%, which is important for phosphorous removal (Yang and Lusk 2018). The settling process is very important for removal of sediment in retention ponds. The denitrification process drives N reduction, and the phosphorous removal processes involve adsorption by sediment particles and uptake by plants (Yang and Lusk, 2018). There is limited evidence of how effective stormwater basins are with nutrient infiltration during different seasons. More monitoring is needed to better understand the cycles of N and P in stormwater basins.

Outlets

The “outlet” of infiltration basins is underlying soil, which hinders the ability to measure effluent concentrations. Retention ponds can hold a large percentage of inflow for a certain amount of time before gradually releasing it and allowing suspended sediments and pollutants to settle (Yazdi et al. 2021). Retention ponds are fed by underground pipes, which allows high quantities of water to fill the pond. A small outlet allows some water to flow out so that the pond does not overflow. A detention or drainage easement allows others to access and/or use other properties for drainage purposes to protect homes and surrounding areas from water damage. In response to rainfall and basin water depth, one study actively adjusted the outflow gate which increased the total suspended solids removal efficiency by 44%. Research on designing active controls in stormwater basins to meet hydrologic objectives remains limited (Parolari et al. 2018).

Rain Gardens

Green stormwater infrastructure (often called low impact development) addresses runoff by using vegetation and soil to filter and cleanse rainwater where it falls. By weaving natural processes into the built environment, green infrastructure provides runoff management and supports flood mitigation, groundwater recharge, stream and wetland replenishment, and water quality management. There are many types of green stormwater infrastructure practices, including bioswales, rain gardens, planters, and green roofs (Sound and Council, n.d.).

Low impact development stormwater BMPs, such as rain gardens and bioretention facilities, are commonly used to infiltrate stormwater, reduce stormwater runoff volume, and improve water quality via filtration and other processes. Rain gardens collect, absorb, and filter runoff from impervious surfaces and can be sized to accommodate temporary ponding after rainfall. Rain gardens are not intended to be permanent ponds, but rather shallow depressions (Hinman, 2013).

Effectiveness of comparable rain gardens varies across the U.S. due to the amount and pattern of precipitation. Rain gardens can add retention capacity to sewer sheds and the hydrologic effectiveness of a rain garden depends on the amount and timing of runoff volume delivered, transmitted, and stored in the different layers of a rain garden. Total inflow volume and intensity, evapotranspiration losses, and soil formation can impact retention in rain gardens (Shuster et al. 2017).

Typical ponding depths for rain gardens range from 6 inches to 12 inches. Deeper ponding areas will take longer to drain and require water-tolerant plants, unless there are sandy, well-draining soils. Performance of rain gardens are grouped into the following categories:

- **Good performance** captures 80% of water from contributing areas.
- **Better performance** captures 95% of water from contributing areas.
- **Best performance** captures all the water from contributing areas.

Refer to the Rain Garden Handbook for Western Washington: A Guide for Design, Installation, and Maintenance (Hinman et al., 2013) for rain garden specifications and construction guidance.

Nutrient Infiltration

Underlying soils contribute to effective nutrient infiltration in rain gardens. Rain gardens provide benefits including decreased surface runoff, increased groundwater recharge, and pollutant treatment. Past studies on laboratory prototypes of rain gardens found high concentration reductions (greater than 90%) for copper, lead, and zinc. In laboratory prototypes, nutrient concentrations were reduced and the only nutrient that was not well retrained by a rain garden system was NO_3-N (Dietz 2007). Field studies yielded similar results with nutrient retention. Nutrient retention by soil media was lower in some cases. In one field study, the rain gardens successfully managed flow retention, but had little impact on pollutant concentrations which suggests that if an underdrain is not connected to the stormwater system, there may be high flow and pollutant retention (Dietz and Clausen 2005). The same study found that total N and NH_3-N concentrations were significantly reduced in the rain garden (Figure 10). NH_3-N tends to be retained by rain gardens, although retention of NO_3-N is much lower because NO_3-N does not absorb well to soil particles. Further research is needed to assess pollutant retention in rain gardens with underdrains.

Phosphorous export from rain gardens seems to be more common and an initial export of P can be attributed to high phosphorous content in the soil. When designing a rain garden, the P content of the soil media in rain gardens should be first determined with a complete laboratory soil test. If the P content in rain garden soil media is very high, then that could result in P export moving into an underdrain then connecting to a stormwater system.

Table 7: Summary of geometric means and ANOVA results for pollutants measured in rain gardens in Haddam, CT (Dietz et al. 2005).

Variable	N	Detection Limit	Unit	Bulk Deposition	Roof Runoff	Garden 1: Underdrain	Garden 2: Underdrain
NO3-N[ns]	47	0.2	mg L^{-1}	0.5 a ±0.5	0.5 a ±0.6	0.3 a ±0.4	0.4 a ±0.5
NH3-N***	47	0.01	mg L^{-1}	0.03 a ±0.12	0.04 a ±0.19	0.01 b ±0.01	0.01 b ±0.14
TKN[n]	47	0.1	mg L^{-1}	0.5 a ±0.7	0.7 a ±0.8	0.4 a ±0.3	0.6 a ±0.4
TN*	47	0.1	mg L^{-1}	1.2 a ±0.8	1.2 a ±1.1	0.8 b ±0.6	1.0 ab ±0.6
ON[ns]	47	0.1	mg L^{-1}	0.4 a ±0.6	0.5 a ±0.7	0.4 a ±0.3	0.6 a ±0.4
TP***	47	0.005	mg L^{-1}	0.012 a ±0.018	0.019 b ±0.038	0.058 c ±0.036	0.060 c ±0.064

*p = 0.05
***p = 0.001
Ns = Anova comparison non-significant.

DL = Detection Limit.

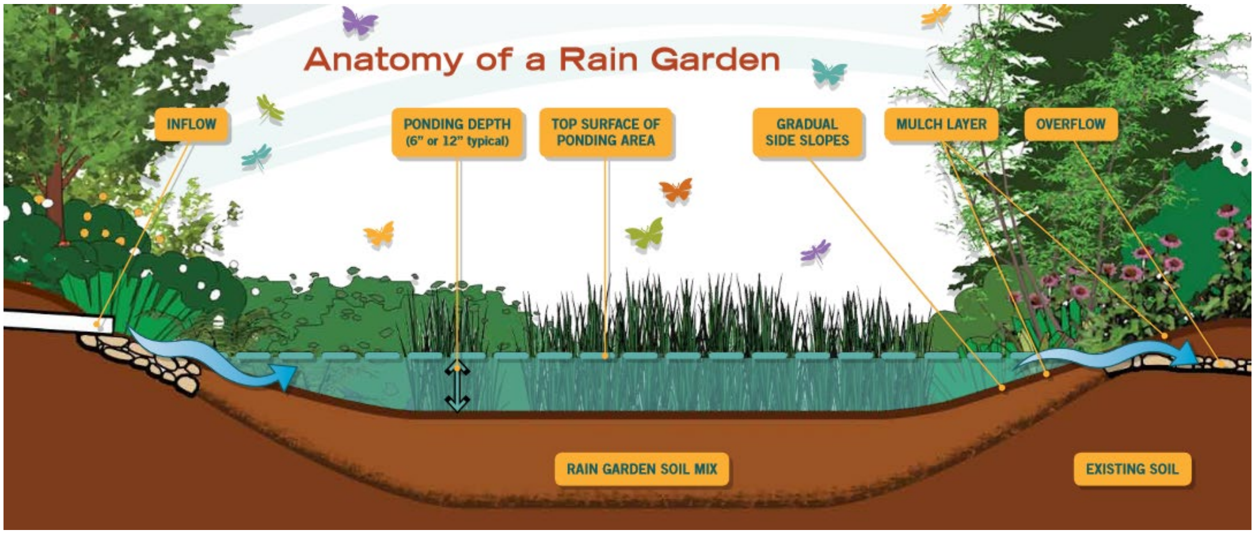

Figure 10. Anatomy of a Rain Garden (Hinman, 2013).

Outlets

Stormwater in rain gardens will either move through underdrains into broader stormwater treatment systems or soak into the ground, which is the intended purpose of rain gardens. The size of the rain garden, soil type, slope, and distance from a downspout will affect the movement of stormwater in and out of the rain garden. Sandy soils drain quicker and can handle small and deep rain gardens. Whereas clay soils drain slower and require larger and shallower rain gardens (University of Wisconsin, 2015). Rain gardens, along with other structural practices to manage stormwater may capture stormwater for later reuse, but typically rain gardens hold stormwater for some time then slowly release into a receiving water body or underlying soils (Yang and Lusk, 2018). Infiltrating stormwater with underlying soil allows for some pollutant attenuation before the stormwater is released to the surface or groundwater.

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Summary: This source is a short guide for managing water runoff from buildings and runoff on pasture lands. It discusses the negative impacts of erosion and sediment particle runoff. It focuses on French drains, berms, grassy swales, and dry wells as best management practices to manage runoff.

Cestti R., Srivastava J., Jung, S. (2003). *Agriculture Non-Point Source Pollution Control: Good Management Practices – The Chesapeake Bay Experience*. The International Bank for Reconstruction and Development / The World Bank: World Bank Working Paper No. 7.

Summary: This publication focuses on the wide range of on-farm measures used in Chesapeake Bay Watershed to reduce nutrient loads from non-point source pollution, discuss their benefits from the farmers and Bay's health points of view, and identify factors that affect farmer adoption of best management practices. The publication reviews costs and benefits of diversions, terraces, and grassed waterways. It compares best management practices and highlights the importance of preventing soil erosion.

Department of Ecology, 2015. Clean Water and Livestock Operations: Assessing Risks to Water Quality. *Washington State Department of Ecology*, State Publication Number: 15-10-020.

Summary: This publication provides information on livestock related water quality impacts to help landowners and producers make informed management decisions. It discusses how livestock and manure handling practices have potential to deposit manure and associated pollutants when exposed to water. Bacteria and pathogens can cause significant human and health environmental impacts. It discusses the importance of landowners containing pollutants at their source and away from groundwater due to potential negative water quality impacts.

Fransen et al., 2017. The Western Oregon and Washington Pasture Calendar. PNW 699. Accessed 12/27/2023 at: https://extension.oregonstate.edu/catalog/pub/pnw-699-western-oregon-washington-pasture-calendar

Summary: This publication provides information on the Washington and Oregon Pasture Calendar for how to best manage and plan for perennial forage growth. It takes environmental and internal plant factors and functions into consideration for positive and negative growth effects. It provides detailed calendars and maps, and scientific reasoning behind the timeline and growth factors.

Fiener P. and Auerswald K., 2003. Effectiveness of Grassed Waterways in Reducing Runoff and Sediment Delivery from Agricultural Watersheds. Journal of Environmental Quality, 32 (3): 927-936. doi.org/10.2134/jeq2003.9270

Summary: This publication evaluated whether maintenance of a grassed waterway can be reduced if on-site erosion control is effective, measured the effectiveness of the grassed waterway, and analyzed underlying mechanisms of effectiveness. The study indicated that grassed waterways have high potential to reduce runoff volume and velocity and sediment loss. Success of grassed waterways is largely dependent on the length of side slopes and shape of cross section in concentrated flow areas of grassed waterways as well as infiltration ability.

Fiener P. and Auerswald K. 2017. Grassed Waterways. *Precision Conservation: Geospatial Techniques for Agricultural and Natural Resources Conservation*: 131-150.

Summary: This publication reviews the background and effectiveness of grassed waterways. It reviews grassed waterway implementation as a BMP from an agricultural, ecological, and political perspective. It reviews costs and benefits from both these perspectives and focuses on the benefits of runoff, sediment, nutrient, and agrochemical delivery. It discusses potential groundwater effects as well as effects on plant and faunal diversity. It highlights a lack in proper ecological studies on grassed waterways.

Herbert, N. et al. 2021. Diversions. *USDA NRCS Engineering Field Handbook, Part 650* (Chapter 9):3-4. Accessed 12/27/2023 at: https://directives.sc.egov.usda.gov/46275.wba

Summary: This Engineering Handbook is an in-depth guide to diversions following NRCS guidance. It discusses the purpose, suitability, types, planning considerations, design, capacity, vegetation cover, construction layout, and maintenance considerations of diversions. Most of the guide is focused on implementation considerations but some effectiveness considerations are included.

Jayakaran, A. D., C. Thompson, B. Boyd, and A. Mack. 2022. Rural Property Surface Water Management -

Surface Dispersion, Infiltration Trenches & Bio infiltration Swales. Washington State University Extension. Accessed online 3/5/2024 at: https://ruralstormwater.wsu.edu/documents/2022/02/rural-stormwater-white-paper.pdf/

Summary: This publication reviews the role of sustainable stormwater management practices in mitigating negative impacts of unmanaged rural stormwater. It provides a broad introduction to three stormwater management practices: surface dispersion, infiltration trenches, and bioinfiltration swales. It provides information on advantages and disadvantages of these three systems, an overview of construction and maintenance considerations, and essential conditions for feasibility. It also discusses the need to understand site conditions and how best management practices can be prioritized using a stormwater management hierarchy.

Montakhab, A., Yusuf, B., Ghazali, A.H. *et al.* 2012. Flow and sediment transport in vegetated waterways: a review. *Rev Environ Sci Biotechnol,* **11**: 275–287. https://doi.org/10.1007/s11157-012-9266-y

Summary: This publication discusses the importance of vegetation in waterways, particularly in controlling flow and sediment transport. It reviews research on vegetated open channels and discusses vegetation environment and characteristics affected in vegetated channels.

Lake Champlain Committee. 2019. Lesson #1 Berms create a false sense of security. *Lessons from the Floods:* 7-8*.* Accessed 12/27/2023 at: https://www.lakechamplaincommittee.org/fileadmin/files/Photo%20Archive/Learn/Lessons_from_the_Flood_-_Lake_Champlain_Committee.pdf

Summary: This publication resulted from a study on the effects of flood damage from a 2011 flood at Lake Champlain, Vermont. The Lake Champlain Committee interviewed members of communities particularly vulnerable to flood damage and identified eight lessons to be considered by communities seeking to increase resilience to flood damage. One main lesson was that berms create a false sense of security by creating more issues than benefits if damaged.

Pennsylvania Department of Environmental Protection. 2006. BMP 6.4.10: Infiltration Berm & Retentive Grading. *Pennsylvania Stormwater Best Management Practices Manual,* Chapter 6.4.10: 113-122. Accessed 12/27/2023 at: https://www.stormwaterpa.org/assets/media/BMP_manual/chapter_6/Chapter_6-4-10.pdf

Summary: The Pennsylvania Stormwater Best Management Practices Manual considers effectiveness of infiltration berms and retentive grading in creating a barrier to flow, retaining flow and allowing infiltration for volume control, directing flows, and preventing erosion. It provides in depth descriptions on berms and its applications, stormwater functions, design considerations, and maintenance and cost considerations.

Ritter, W.F. and Shirmohammadi, A. (2001). *Agricultural Nonpoint Sources Pollution, Watershed Management and Hydrology.* Lewis Publishers.

Summary: This publication provides a range of information on hydrology, controlling soil erosion and sedimentation, impacts of nitrogen, phosphorous, and pesticides on water quality. It reviews best management practices for nonpoint source pollution control including related to livestock manure management. It discusses how to limit surface runoff, the importance of nutrient infiltration, proper containment load and location as factors to consider for diversion, and the effectiveness of diversions.

Stienbarger, D. 2004. *Managing Roof Runoff.* WSU Extension Clark County, from Snohomish CD "Easy BMP" series. Accessed 12/27/2023 at https://extension.wsu.edu/clark/naturalresources/smallacreageprogram/managing-roof-runoff/

Summary: This source reviews the best management practice of installing and/or maintaining properly functioning gutters, downspouts, and outlets. It provides calculations for the capacity of water that can be handled by roof surfaces, pipes, and gutters. It also provides calculation methods for determining the amount of water an area can receive per year based on average rainfall amounts.

Tiwari P., Goel A. 2017. An overview of impact of subsurface drainage product studies on salinity management in developing countries. *Appl Water Sci 7:* 569-580.

Summary: This review, focused in India, provided information on installing subsurface drains based on design parameters including drain depth and spacing, installation area, and type of outlet used. Drain depth and spacing is dependent on soil texture classifications. Subsurface drainage is an approach that can help manage ground water levels, which can be helpful in preventing surface water buildup and water runoff.

Chapter 9 Appendix Part B: Implementation Considerations (Runoff Control for Agricultural Facilities)

Introduction

As described in the Effectiveness Section of this chapter, uncontrolled stormwater runoff from agricultural land and facilities can transport sediment, nutrients, and pathogens to nearby surface water and groundwater. This chapter primarily deals with impermeable or semi-impervious surfaces, with a particular focus on areas associated with animal confinement due to the additional pollutant potential associated with animal waste, including, but not limited to:

- Barns and other buildings
- Waste storage
- Heavy use areas/confinement areas
- Food storage areas
- Livestock and other operations

To reduce environmental impacts, producers can implement a variety of best management practices (BMPs). The decision of which BMPs to use to control runoff is extremely site-specific. In many cases, producers are encouraged to talk to their local Conservation Districts (CDs) and NRCS offices about what could work best for their situation and property.[9]

The Implementation section of this guidance provides practical information for implementing individual BMPs articulated in Table 1. However, BMPs for runoff control are multi-step and operate within a full management system. A full runoff management system for facilities and other impermeable areas reduces the likelihood of clean water contacting polluted areas, and would include mechanisms for dispersal (i.e., roof runoff management structures), diversion, and infiltration of clean water. Combinations of practices will depend on a producer's goals and site-specific conditions of the land.

Below are challenges, opportunities, and information on application of full runoff system BMPs in Washington state which are relevant across all dispersal, diversion, and infiltration BMPs.

[9] Stienbarger, D. 2004. *Living on the Land: Keeping Clean Water Clean & Reducing Mud – Managing Roof Runoff*. Washington State University Extension Clark County, from Snohomish Conservation District "Easy BMP" series. Retrieved from: https://s3.wp.wsu.edu/uploads/sites/2079/2014/02/roof-runoff.pdf

Information on challenges, opportunities, and application for individual BMPs are detailed in applicable sections.

Adoption of Runoff Systems in Washington State

Requirements for agricultural runoff systems in Washington State can be based on a facility's size and whether lots could be considered a part of animal feeding operations. Before planning for additional BMPs, check local and state regulatory requirements to ensure runoff control systems align.

Western Washington and eastern Washington have differing climates, topographies, soil types, and annual precipitation rates. Even within regions, conditions can vary and as such, the application of BMPs for runoff will differ.

Climatic Conditions

Given the climatic differences between eastern and western Washington, the water volume capacity of BMPs will need to account for different peak storm events. Western Washington experiences more rainfall on average, so BMPs need to accommodate more consistent, larger volumes of flow. Eastern Washington experiences more snow and a broader range of temperatures. BMPs in Eastern Washington may need to account for larger volumes of snow melt runoff, pipes and outlets freezing, building any structural elements to withstand weight of snow and ice, and ensuring surface water is still available for vegetation during drier summers.[10]

Soil Type and Vegetation Selection

Soil types vary across Washington, influencing erosion potential and infiltration rate and capacity. Soil type will influence selection of BMPs based on their applicability and ease of installation. Soil type can also affect vegetation species and growth. Multiple BMPs in this chapter include the use of vegetative cover. There are resources available to producers in Washington to assist selection of appropriate vegetation for an area, including the PNW 699 Western Oregon and Washington Pasture Calendar and PNW 708 Inland Pasture Calendar These resources also articulate how to effectively monitor and maintain vegetated areas, including nutrient analysis, harvest guidelines, plant tissue tests, and ideal timing to establish vegetation .

Challenges Associated with Runoff Systems

There are logistical and practical challenges associated with implementing runoff systems on agricultural land. Below are a few of these challenges, and where applicable, potential solutions or opportunities to remediate.

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[10] Western Washington Climate Center. 2024. "Climate of Washington" https://wrcc.dri.edu/Climate/narrative_wa.php

Costs

Firstly, costs of implementing new BMPs can be high, particularly those that require contractors and use of heavy equipment for digging and leveling of land, which can be the case for diversion and infiltration BMPs. Implementation costs vary by practice and size. See specific practice tables below for more details on costs. Costs can be reduced by producers conducting their own work with their own equipment where possible, though producers should still consider receiving additional support from designers and engineers to ensure the practices will meet the needs of their property. Additionally, costs can increase depending on federal, state, and local permitting requirements. Cost-share programs can help bring total costs to producers down. Some ways to reduce costs include accessing local county or Conservation District programs and federal programs such as the NRCS Environmental Quality Incentives Program (EQIP) or Conservation Stewardship . NRCS offers technical assistance at no cost and can learn more through the Technical Service Provider Program (TSP) or Conservation Technical Assistance (CTA) Program.

Permitting

Permitting requirements should be considered when planning the installation of BMPs as this could extend the time needed to start and complete a project, and bring associated costs. For example, property owners implementing a BMP which utilizes heavy equipment on or disturbs soil may need a Cultural Resources Permit (Washington Administrative Code 25-48-060[11]) if disturbing land with historic cultural significance. Local building permits may also be needed for certain types of BMPs. Plan for extra time of installation if permits are required. Permits and requirements may include:

- Cultural Resources Permit if disturbing land with historic cultural significance. This includes any alterations such as using heavy equipment on or disturbing soil. Complete permit requirements can be found in the Washington Administrative Code 25-48-060.
- Construction Stormwater Pollution Prevention Plan Elements[12] pertaining to the project site for projects that result in 2,000 square feet or more of new or replaced hard surface area. Projects disturbing 7,000 square feet or more of land must prepare a Construction Stormwater Pollution Prevention Plan (Stormwater Management Manual for Western Washington, p 116[13]).

[11] https://app.leg.wa.gov/WAC/default.aspx?cite=25-48-060
[12]https://fortress.wa.gov/ecy/ezshare/wq/SWMMs/2024SWMMWW/Content/Resources/DocsForDownload/2024SWMMWW_6-14-24.pdf#%5B%7B%22num%22%3A1541%2C%22gen%22%3A0%7D%2C%7B%22name%22%3A%22XYZ%22%7D%2C72%2C735.75%2C0%5D
[13]https://fortress.wa.gov/ecy/ezshare/wq/SWMMs/2024SWMMWW/Content/Resources/DocsForDownload/2024SWMMWW_6-14-24.pdf

- Local building permits may be required when implementing structural changes or alterations to existing buildings, or for new construction.

Maintenance

Like all activities on agricultural land, BMPs for runoff management require maintenance activities to ensure their operability and effectiveness over time. Producers will need to account for time and money of ongoing maintenance. Maintenance activities may include:

- Manual labor, including sheering of vegetative growth, planting, and weeding in vegetated systems
- Removal of debris in roof runoff systems
- Purchasing of new parts, as needed
- Routine checks for operability following winter season and high precipitation events.

Producers should consider the maintenance needs and additional time required to maintain runoff systems in relation to their routines and workload and select a series of BMPs that work best within their existing responsibilities. Doing so provides the highest likelihood of maintaining BMPs over time.

Site Specific Requirements

Implementation and design of BMPs is extremely site-specific. In the case of runoff management BMPs, site characteristics such as topography and slope, land layout, lot size, and presence of manmade features should be considered to most effectively implement BMPs. Though there are some practices that could be constructed and developed by producers it is still recommended to work with engineers and other technical professionals at your local conservation district or NRCS office. Obtaining a second opinion can ensure the system will work properly and that it meets all regulatory requirements and maximizes effectiveness. Additionally, local offices may have insight into how to plan systems with increased extreme events (due to climate change) in mind. [14] Doing so can limit challenges in the future and reduce the likelihood of having to re-do any BMPs.

Benefits Associated with Runoff Systems

Despite the challenges and barriers associated with implementing runoff BMPs, they also provide a significant number of benefits to producer's land.

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[14]EPA. 2024. "Climate Adaptation and Stormwater Runoff". https://www.epa.gov/arc-x/climate-adaptation-and-stormwater-runoff

Environmental benefits

Diverting and infiltrating water away from potential pollutants provides an obvious benefit to surface and groundwater quality by reducing transport of sediment, nutrients (including phosphorous and nitrogen), and pathogens (See: Effectiveness Section). It is important to collect and control water near its source to reduce the likelihood that runoff will transport pollutants to surface waters.[15]

However, there are additional environmental benefits, particularly for practices which utilize native vegetation. Increasing native vegetation on land promotes water infiltration and can also bring beneficial insects which could then, in turn, provide pollination benefits to crops in the surrounding area.

Reduced Erosion

BMPs in this chapter primarily deal with runoff from impermeable and semi-permeable land and not on fields, where erosion and runoff can lead to loss of valuable soil and nutrients. However, controlling runoff on impermeable and semi-permeable areas on a property can control, direct, and divert water away from other areas where additional runoff would be undesirable.

Particularly for the case of facilities and buildings, uncontrolled runoff can lead to erosion and other water issues around foundations, weakening structures. Consistent erosion, and resulting pooling of water, can lead to costly repairs and render facilities unusable as issues are resolved. Structures help prevent runoff collecting around foundations of barns and other buildings and therefore prevent soil erosion and significant damage over time.[16]

Beneficial water reuse

If appropriate, and desired, a runoff system can be designed to collect rainwater which can then be used based on a producer's needs. Water is a valuable, sometimes expensive resource. Non-potable water can potentially be collected and used for irrigation and watering. If producers would like to use rainwater for potable purposes, it would require treatment before use.

Practical Benefits

Best management practices can save time and money associated with handling polluted runoff, muddy soils and erosion. Gutters and downspouts can increase chore efficiency by reducing

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[15] NRCS. 2022. *Small Scale Solutions for your Farm: Runoff Management*. USDA. Retrieved from: https://www.farmers.gov/sites/default/files/2022-12/farmersgov-small-scale-factsheet-runoff-mangement-12-14-2022.pdf

[16] Washington State University Extension, Clark County. *Improving Drainage:* Keeping Clean Water Clean and Reducing Mud. Small-Acreage Program. Retrieved from: https://extension.wsu.edu/clark/naturalresources/smallacreageprogram/improving-drainage/

muddy areas and by preventing runoff water from entering animal confinement areas, water storage facilities or other locations that need to be dry and mud-free. Reducing mud makes work easier, quicker, and safer for producers, reduces potential health conditions and pathogens, keeps animals clean improving their quality of life, keeps equipment clean, reduces erosion issues.[17]

Installing roof runoff structures on facilities where runoff is likely to enter livestock confinement or waste facilities is particularly important. Eliminating water from the manure stream can bring down costs as a producer does not have to store manure-contaminated water, pay to pump it, or need to apply it later.

Department of Ecology Stormwater Management Manuals

The Department of Ecology has developed stormwater management manuals (SWMMs) for western and eastern Washington which provide information, specifications, and standards for stormwater BMPs that are used widely across Washington. Ecology's SWMMs should be consulted whenever planning and implementing stormwater BMPs. It's also recommended to contact your local municipality when planning a new development or redevelopment project to make sure you follow local requirements for stormwater management.

The following sections outline stormwater management practices applicable to agricultural facilities along with accompanying implementation considerations. For Clean Water Guidance practices that have an corresponding SWMM practices, the equivalent SWMM practice will be identified in the tables below.

Best Management Practices for Runoff Control

This section provides practical information for the implementation of BMPs used to control runoff semi-impermeable and impermeable surfaces on agricultural land and key implementation considerations such as use cases, cost, technical requirements, and operational and maintenance requirements. BMPs are separated into three topics:

1. **Dispersal of Clean Water**, including roof runoff structures
2. **Diversion of Clean Water**, including subsurface drains, underground outlets, ditch diversions, and grassed waterways
3. **Infiltration of runoff**, including vegetated treatment areas, infiltration basins, and rain gardens.

[17] Pierce Conservation District. *Mud prevention*. Pierce Conservation District. Retrieved from: https://piercecd.org/704/Mud-Prevention

Dispersal of Clean Water

Roof Runoff Structures

Definition: Structures to collect, control, and convey precipitation runoff from a roof, including gutters and downspouts. Roof runoff structures, inclusive of gutters and downspouts, are the first step in a series which enable diversion of water from roofed structures to outlets which can allow for infiltration.[18]

Use Cases: Use on any roofed structure - gutters and downspouts should empty into an area that is well suited for infiltration, or transported the distance required to do so. Many buildings on agricultural properties likely already have roof runoff structures, particularly those associated with livestock, manure or feed storage. New structures should refer to local ordinances and requirements that include permitting considerations.[19]

[18] NRCS. 2021. Conservation Stewardship Program FY 21. https://www.nrcs.usda.gov/sites/default/files/2022-09/Roof_Runoff_Structure_558_NHCP_CPS_2021.pdf

[19] King County Department of Natural Resources and Parks. *King County Livestock Management Ordinance*. King County WLR GIS, Visual Communications & Web Unit. https://your.kingcounty.gov/dnrp/library/2009/kcr2621.pdf

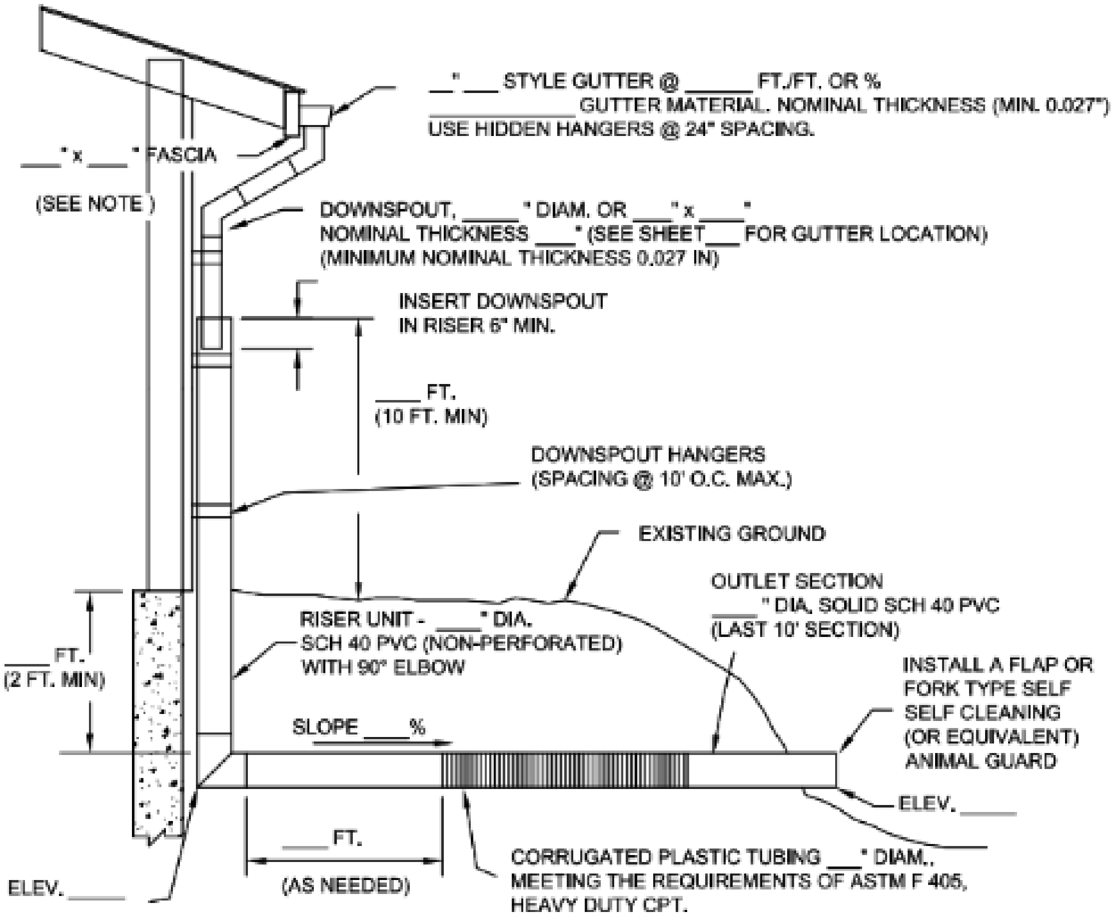

Figure 11. Roof runoff structure shows the connection between a roof gutter, downspout, and underground outlet with example sizing dimensions and materials (NRCS CPS 558 Training).

Benefits of Water Dispersal:

- Prevents erosions around structures, reducing pooling and the need for repairs.
- Water collected from roofs can be used for other, non-potable purposes, such as irrigation. If treated for residual pollutants (e.g., airborne manure particles, bird feces[20]), it can be stored and used for potable purposes.

[20] Chang et al., 2004. Roofing as a source of nonpoint water pollution. *Journal of Environmental Management,* 73(4): 307 – 315. https://doi.org/10.1016/j.jenvman.2004.06.014

Table 8: Information synthesis for Roof Runoff Structures

<table>
<tr><th>Considerations</th><th>Details</th></tr>
<tr><td>Capital Cost</td><td>Materials
Roof gutter
Less than 50ft in length: $2.67/ft
Roof gutter, medium: $2.09
Roof gutter, small: $1.1721
Aluminum gutter: Small (4”-6” width w/ hangers) - $3.34/ft, medium (7”-9” w/ hangers) - $14.69/ft, large (10”-12” width w/ hangers) - $25.46/ft.
Aluminum downspouts: 3”-5” width w/ hangers - $3.40/ft.
Tanks (If using): The cost of tanks range in terms of volume, where gallons with less than 1,000-gallon capacity are $0.36/gal and those greater than 1,000 gallons are $0.28/gal. If a volume greater than 2,000 gallons is needed, NRCS includes gutters and downspouts, and the cost is $0.21/gal. Tanks with less than 2,000 gallons capacity and gutters and downspout, the cost is $0.42/gal.
Labor
Labor performed with basic tools that do not require extensive training (e.g. pipe layer, concrete placement, materials spreader, flagger, etc.): $33.98 per hour.
Heavy equipment operators including cranes, hydraulic excavators, dozers, paving machines, rock trenchers, dump trucks, agricultural equipment, scrapers, water wagons, etc.: $51.15 per hour.</td></tr>
<tr><td>Operational and maintenance requirements</td><td>Regular inspection and cleaning to freeing of obstructions that reduce flow and prevent organic material from entering into downspouts.</td></tr>
<tr><td>Technical requirements</td><td>Placement
Gutters and downspouts are placed on structural facilities.
Materials
Materials for gutters and downspouts: May be made of aluminum, galvanized steel, plastic, or wood.</td></tr>
</table>

[21] NRCS. 2023. Conservation Stewardship Program FY 23. https://www.nrcs.usda.gov/sites/default/files/2022-11/Washington-CStwP-23-payment-rates.pdf

Considerations	Details
Technical requirements (cont.)	○ Aluminum: Gutters must have a minimum nominal thickness of 0.027”; downspouts of 3”x4” must have minimum nominal thickness of 0.024”. ○ Galvanized steel: Gutters and downspouts must be a minimum of 28 gauge. ○ Plastic: Must contain ultraviolet stabilizers. ○ Wood: Must be made of rot-resistant wood free of knots. ○ Reinforced or non-reinforced concrete may be applicable.22 Design • Build roof runoff systems to withstand weight of snow and ice if conditions are applicable. • Downspouts can be attached to columns with steel braces. • The design of roof gutters and downspouts can be properly sized using equations from Chapter 10 of the Agricultural Waste Management Field Handbook23 and must follow four steps: ○ Compute the capacity of the selected gutter size. ○ Compute the capacity of the downspout. ○ Determine whether the system is controlled by the gutter capacity or downspout capacity and adjust number of downspouts if desired. ○ Determine the roof area that can be served . Conveyance Capacity • Design to convey peak flow from a 25-year, 5-minute rainfall event. Outlet • Outlet water into a subsurface drain, underground outlet, storage tank, dry well, or energy dissipation device.
Lifespan	At least 15 years[24]
Land area requirements	Land area should allow roof runoff structures to convey water to a stable outlet.

[22] NRCS. Conservation Practice Standard: Roof Runoff Structure. USDA: 558-CPS-1. https://www.nrcs.usda.gov/sites/default/files/2022-09/Roof_Runoff_Structure_558_NHCP_CPS_2021.pdf

[23] https://irrigationtoolbox.com/NEH/Part651_AWMFH/awmfh-chap10.pdf

[24] NRCS. Conservation Practice Standard: Roof Runoff Structure. USDA: 558-CPS-1. https://www.nrcs.usda.gov/sites/default/files/2022-09/Roof_Runoff_Structure_558_NHCP_CPS_2021.pdf

Considerations	Details
Other implementation factors	• When installing gutters and downspouts, avoid contact between components of dissimilar metals to prevent corrosion[25]. • If roof runoff is being channeled towards underground injection control (UIC) systems, the UIC must be registered with the State of Washington[26] More information about UIC system requirements can be found by visiting https://ecology.wa.gov/regulations-permits/guidance-technical-assistance/underground-injection-control-program . • Protect downspouts and exposed pipes from damage by equipment or livestock. • If a producer is looking to collect water as part of a liquid manure system during a set time of year, consider using valves or equivalent approaches to design a system that allows for easy and quick changes between water collection and diversion.
Resources	• Consult Ecology's Stormwater Management Manuals to properly design and implement these practices. . ○ Use practices such as Downspout Dispersion Systems, Downspout Full Infiltration, or Perforated Stub-out Connections to disperse and infiltrate roof runoff. • NRCS Conservation Practice Standard 558 • NRCS USDA Training Presentation for detailed implementation guide and step-by-step implementation process[27]

Diversion of Clean Water

Water diversion methods transport water from roofed structures or water collecting on fields to infiltration methods, diverting the water away from sources of contamination such as livestock facilities or manure storage areas. More than one diversion method can be used in combination. As discussed in the introduction, implementation will vary by land type, location, and conditions. Diversion methods explored in this section include

- Ditch diversions

[25] NRCS. Conservation Practice Standard: Roof Runoff Structure. USDA: 558-CPS-1. https://www.nrcs.usda.gov/sites/default/files/2022-09/Roof_Runoff_Structure_558_NHCP_CPS_2021.pdf

[26] WA Department of Ecology. 2019. Stormwater Management Manual for Eastern Washington. Publication Number 18-10-044. https://apps.ecology.wa.gov/publications/documents/1810044.pdf

[27] https://www.nrcs.usda.gov/sites/default/files/2022-09/CB-RoofRunoffStructureCPS558-Training.pdf

- Underground outlets
- Grassed waterways.

Diverting clean water around potential sources of contamination, such as livestock areas, manure storage facilities, or heavy use areas, reduces the likelihood of polluting surface water sources, and reduces the need for on-site management of runoff. [28] Reduced mud, as a result, has an added benefit of chore efficiency. Without diversion BMPs, runoff can cause erosion and land saturation, leading to muddy conditions and impacts to animal health.[29] Alternatively, uncontrolled water flow can create new channels without remediation. Diversion methods slow the velocity, reduce uncontrolled runoff volumes, and traps sediments.[30] Implementation of any surface water diversions should be mindful of state requirements for water diversions. See Washington administrative code 220-660-250 [31]for more information.

Underground Outlets, Subsurface Drains, and French Drains

Subsurface drains, French drains, and underground outlets are often used interchangeably but are distinctly different. Subsurface drains are conduits installed beneath the ground to manage soil moisture and convey soil water and shallow groundwater from an area. French drains are a type of subsurface drain and are trenches filled with rock or gravel, with or without a perforated pipe to convey water from an area or structure. Underground outlets are a system of conduits installed beneath the surface use to transport collected water and outlet that water to stable location.

Subsurface Drains

Subsurface drains are conduits installed below the ground to used manage soil water conditions by removing or distributing soil water. In most cases, subsurface drainage is more effective than open drains, allowing for incremental removal of excess moisture and does not require ditches.[32]

Use Cases: Areas upslope from relevant areas (i.e., barns, livestock operations, manure storage) to reduce surface runoff and avoid contact with surface pollutants before reaching them.

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[28] WSU. n.d. “Animal Agriculture: Protecting the water on your small farm”. https://extension.wsu.edu/animalag/content/protecting-the-water-on-your-small-farm/

[29] WSU Extension. 2005. Keeping Clean Water Clean and Reducing Mud: Improving Drainage. Small-Acreage Program. https://s3.wp.wsu.edu/uploads/sites/2079/2014/02/water-diversion.pdf

[30] Sharpley, A.N. et al. 2006. Best Management Practices to Minimize Agricultural Phosphorus Impacts on Water Quality. USDA: ARS – 163. https://www.ars.usda.gov/is/np/bestmgmtpractices/best%20management%20practices.pdf

[31] https://app.leg.wa.gov/wac/default.aspx?cite=220-660-250

[32] Herzon, I. and J Helenius. 2008. Agricultural drainage ditches, their biological importance and functioning. *Biological Conservation*, 141(5): 1171 – 1183. https://doi.org/10.1016/j.biocon.2008.03.005

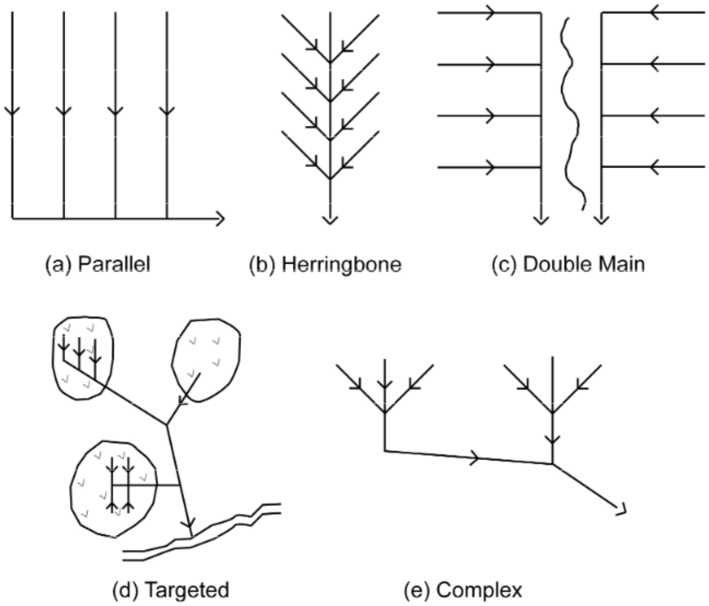

Figure 12. Subsurface drain system can spread water diverted water into a field in a number of patterns in a way that is best given the land characteristics (Koganti et al., 2020).

Additional Benefits of Subsurface Drains:

- Benefits soil health upslope of operations by removing excess moisture, increasing aeration of soil, increasing responses to fertilizer, and reducing mineral imbalances and salinity.
- If draining from an area that is growing fodder for animal feed, hay and other feed species can be harvested earlier than in undrained soils
- Pre-emptive effort than can reduce reliance on other types of runoff BMPs.

Table 9: Information Synthesis for Subsurface Drains

Considerations	Details
Capital Cost	Cost-share programs are available to support implementing these practices (designing a whole roof runoff system). For example, King County offers 50% of total cost for gutters, downspouts, and outlet piping, up to $7 per foot, on buildings built prior to 1994.[33] Costs below are estimated per unit based on NRCS Washington Practice Scenarios for FY24. Materials • Corrugated pipe: $2.85 - $4.23 per pound. • Drainage lateral connection: $33.88 for 6” drainage lateral to main drain, including excavation to 6’ depth, installation of and material for tee on main line, connect lateral, and backfill. • Gravel: $47.06 per cubic yard. Construction and Installation • Trenching: $2.48 - $3.78 per ft. • General Labor: Approximately ~33.98 per hour. • Large equipment rental (if required): $761.41 - $919.30. • Equipment operators (if required): $51.15 per hour.
Operational and maintenance requirements	• A winterization plan can help protect shallow drains from freezing or thawing damage. • Provide a specific plan accounting for periodic inspection and prompt component repair. • Outlets should be kept free of debris and rodents. • Inspect systems in spring, late fall, and after significant rainfall events and record maintenance and repairs.[34]

[33] King County. 2024. “Cost-sharing guidelines for livestock best management practices (BMPs)”. https://kingcounty.gov/en/legacy/services/environment/water-and-land/agriculture/bmp-cost-sharing-guidelines.aspx

[34] Ontario. 2024. “Maintenance of a subsurface drainage system”. https://www.ontario.ca/page/maintenance-subsurface-drainage-system

Considerations	Details
Technical requirements	Technical requirements for implementing subsurface drains depends on site and design (e.g., single pipe vs a series of pipes; piper material is flexible vs rigid). The following aspects should be considered. Placement • Ideally locate in areas where large equipment will not cross the pipes and where trees are not close enough to cause damage from roots. • Install across a slope on a continuous grade to drain in the direction of the slope[35]. • Ensure the placement of underground outlets are away from buried utilizes, drainage tiles, and other structural materials[36]. Materials • Conduits can be flexible or rigid. • Flexible conduit materials include plastic, bituminized fiber, or metal. • Rigid conduits include clay or concrete. • Materials must meet American Society for Testing and Materials, American Association of State Highway Transportation Officials, or American Water Works Association standards. • Stable bedding of granular envelope, filter material, or a treated plank (for rigid conduits or flexible conduits with bedding layer) can be used to stabilize the foundation conduit foundation. Design • Prepare detailed plans that include location relative to livestock and utilities, spacing, dimensions, protections, elevations, installation requirements, materials, and outlets. • Depth: ○ The depth of subsurface drains depends on the soil type and water table. The maximum burial depth should be based on conduit manufacturer recommendations but is typically ~6 feet.

[35] Massachusetts Department of Environmental Protection. 2003. Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas: Subsurface Drain (p. 201). https://megamanual.geosyntec.com/npsmanual/source/ES%20Control%20Guidelines%20for%20Urban%20and%20Suburban%20Areas.pdf

[36] NRCS. Conservation Practice Standard: Subsurface Drain (Code 606). USDA: 606-CPS-1. https://www.nrcs.usda.gov/sites/default/files/2022-10/Subsurface_Drain_606_NHCP_CPS_2022.pdf

Considerations	Details
Technical requirements (cont.)	o In mineral soils, minimum depth of cover over subsurface drains is 2ft. o In organic soils, minimum depth of cover is 3ft, unless structures are installed to limit oxidation and subsidence of soil, in which case they can be 2.5ft deep. • Drain size: o Use Manning's formula (included in effectiveness section of this chapter) to calculate size and utilization of roughness coefficients by conduit manufacturer. o The Diameter of drain should be a minimum 3 inches . o Plan for a 10-20 ft. pipe section length. • Conduit outlets: o The minimum length of outlet pipe sections depends on the pipe diameter, and ranges from 10ft for 8" diameter pipes, to 20ft for pipes larger than 18" in diameter. o Ensure drain outlets to another diversion or infiltration system by gravity or pumping; empty to sediment trapping BMP or receiving channel/vegetated area. o Outlets should be continuous sections of pipe with the stiffness required to withstand water volumes and velocity. • The internal hydraulic pressure of the drain should remain at or below limits recommended by the conduit manufacturer • Consider maximum equipment load crossing over conduits in the design. • Wrap conduit joints with a nonwoven geotextile. • Encase the conduit in sand and gravel that is filter-compatible with joint openings and surrounding soil. • Place conduits on bedding with grooves to provide stabilization. Avoid exposed rock. • Apply proper filter and hydraulic envelops and materials, as well as auxiliary structures and protection in accordance with NRCS Code 606 standards. Conveyance Capacity • Allow for water velocity of 1.4 ft/sec – 12ft/sec; Corrugated plastic pipe under open channel flow allows for the greatest water velocity. With open-joint pipe (clay or concrete), maximum velocity depends

Considerations	Details
Technical requirements (cont.)	on the soil texture of the surround area, ranging from 3.5ft/sec (for sand and sandy loam) to 9ft/s (for coarse sand or gravel). • Maximum flow velocities should be limited to 12 ft/sec. for perforated corrugated plastic pipe drainage. • Maximum flow velocities vary by soil texture in open-joint clay or concrete pipes: ○ Sand and sandy loam: 3.5 ft/sec. ○ Silt and silt loam: 5 ft/sec. ○ Silty clay loam: 6 ft/sec. ○ Clay and clay loam: 7 ft/sec. ○ Coarse sand or gravel: 9 ft/sec. Outlets • Outlet to another diversion, infiltration, or water storage system.
Lifespan	100-year maximum life span for pipes[37], total system lifespan indefinite assuming proper design, installation, and maintenance.
Land area requirements	• Surface and area requirements are minimal following installation and drainage ditch digging. Underground area requirements will depend on the system design. Junction boxes and other maintenance structures may require a 2ft-by-2ft surface area. (NRCS 606)
Other implementation factors	• Under certain conditions, thrust control may be needed. Pipe manufacturers' recommendations should be followed. • Consider effects of drainage system on limiting availability of surface water needed for plant growth. • Use GPS to record coordinates of outfalls, inlets, and other structures during installation.[38] • Drains may need protection from a range of clogging hazards, including bacteria, minerals, and roots. • Subsurface drains can be a conduit for nutrients and other pollutants to reach surface waters. Careful management above and near

[37] https://www.plasticpipe.org/Drainage/Drainage/Resources/Service-Life.aspx

[38] Ontario. 2024. "Maintenance of a subsurface drainage system". https://www.ontario.ca/page/maintenance-subsurface-drainage-system

Considerations	Details
	subsurface drains may be needed to prevent pollutants from leaching into subsurface drains.
Resources	• NRCS Code 606 • USDA NRCS. 2021. National Engineering Handbook (Title 210), Part 650, Chapter 14, Water Management (Drainage). Washington, D.C. • USDA NRCS. 2008. National Engineering Handbook (Title 210), Section 16, Chapter 4, Subsurface Drainage. Washington, D.C. • NRCS National Engineering Handbook (NEH) (Title 210), Part 636, Chapter 52, "Structural Design of Flexible Conduits"[39]. • Maintenance of a subsurface drainage system[40]. • Washington State Stormwater Management Manuals[41].

Underground Outlets

Underground outlets are a conduits or systems of conduits installed beneath the ground surface to convey surface water to a suitable outlet.

Use Cases: Water diverted from areas such as barns, pens and manure storage or roof runoff where pooling or runoff cause erosion or transport pollutants to surface waters.

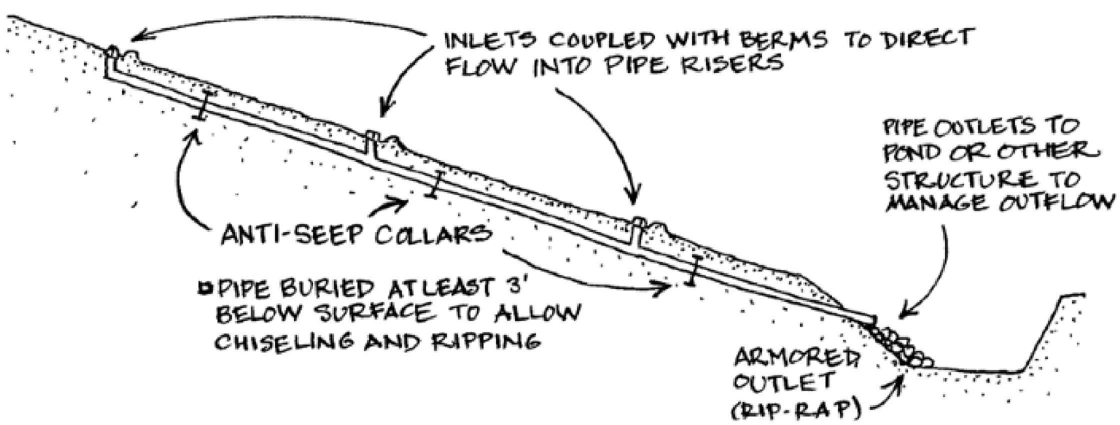

Figure 13. Underground outlets can transport water via pipes directly to an outlet or other diversion or infiltration structure. Underground outlets can be beneficial to take water away

[39] https://directives.nrcs.usda.gov/sites/default/files2/1720463435/Chapter%2052%20-%20Structural%20Design%20of%20Flexible%20Conduits.pdf
[40] https://directives.nrcs.usda.gov/sites/default/files2/1720463435/Chapter%2052%20-%20Structural%20Design%20of%20Flexible%20Conduits.pdf
[41] https://ecology.wa.gov/regulations-permits/guidance-technical-assistance/stormwater-permittee-guidance-resources/stormwater-manuals

from an area that the water should or could not infiltrate into the soil. (Hillslope Management Practices Guide[42])

Additional Benefits of Underground Outlets:

- Prevents clean water from mixing with pollutions sources and minimizes their transport.
- Helps keep high-traffic areas drier and easier to manage and use.
- Reduces the potential for muddy conditions and erosion.

Table 10: Implementation information synthesis for Underground Outlets

Considerations	Details
Capital Cost	Costs for underground outlets range significantly depending on the use case and design. This section provides an idea of potential costs based on the NRCS Washington Scenarios for FY24. More complicated designs may incur high costs, such as those including concrete catch basins with particularly large pipes and conveyance systems. Equipment Installation • Excavation costs depend on the type of equipment and earth types. Costs including equipment and labor, range from: $1.52 for common earthen soil to $4.82 per cubic yard for rock • Hydraulic excavator with ~1 cubic yard capacity range including equipment and power costs: $129.96 per hour (if required). • Compaction costs approximately $2.81 per cubic yard Labor • Supervisor or manager: ~ $55.32 per hour • General labor using basic tools that do not require extensive training (if required): ~ $33.98 per hour • Light - heavy equipment operators (if required): $32.21 to $51.15 per hour Materials • Rock riprap placed with geotextile, including materials and local delivery within 20 miles of the quarry: $153.20 per cubic yard • Graded and washed sand (if required): $44.73 per cubic yard • Gravel including materials and local delivery (if required): $47.06 per cubic yard

[42] https://www.rcdmonterey.org/images/docs/publications/underground-outlets.pdf

Considerations	Details
	• Pipe costs range depending on the type used: At the low end is HDPE, single walled corrugated pip (12” diameter) at $2.85. At the high end is HDPE corrugated double wall pipe with ≥15” in diameter at $3.24. Both are priced per pound. • (If needed) Precast concrete catch basin (square or round) including materials, equipment, and labor: $981 each for 2 ft to $1,912.98 for 3 ft. Mobilization • Mobilization equipment ranges by size from $181.31 to $919.30
Operational and maintenance requirements	• Prepare an operation and maintenance plan. • Conduct periodic inspections, especially after significant runoff events. • Keep inlets, trash guards, and collection boxes and structures free of sediment and materials that could reduce flow. • Promptly repair damaged components, inlets damaged by farm equipment, and eroded areas at the pipe outlet. • Maintain permeability of surface materials of blind inlets by periodically scouring or replacing the soil surface layer.
Technical requirements	Placement • Underground outlets are ideal for land with a slope to allow for water to travel through the outlet. • Underground outlets often connect to downspouts. Materials • Install flexible conduits that are made of plastic, metal, or other materials of acceptable quality to meet site-specific requirements for leakage, external loading, and internal pressure. Heavy duty perforated plastic risers are the most common material. ○ Conduits must follow requirements by the American Society for Testing Materials (ASTM), American Association of State Highway Transportation Officials (AASHTO) or American Water Works Association (AWWA). Design • Refer to soil survey data as a preliminary planning tool to assess areas. Consult the Web Soil Survey to obtain soil properties and qualities information.

Considerations	Details

Technical requirements (cont.)	• Inlet:
	    ○ Inlets include but are not limited to a collection box, blind inlet (gravel), or perforated riser or conduit. They must not restrict flow and must have a guard to prevent debris from clogging or rodents.
	    ○ Blind inlets can be used to prevent soil movement into the conduit.
	Conduit
	• Conduits must have a minimum 4-inch diameter.
	• Design using continuous solid or perforated pipe depending on the site conditions. The outlet must have a section of heavy duty pipe and may have a headwall[43].
	• The conduit must be smooth and prevent soil particle movement into the outlet.
	• Provide thrust blocking or anchoring where needed to prevent undesired conduit movement.
	Outlet
	• Locate the outlet at least one foot above the channel bottom.
	• Minimum outlet lengths are dependent upon the diameter and range from 8 inches and smaller for a 10-foot section length, to an 18 inch or larger pipe diameter with a 20-foot length.
	• Bury two-thirds of the rigid outlet pipe section.
	• Design to a minimum velocity no less than 0.8 ft./second where fine silts/sands are not a hazard, or 1.4 ft / second if a sedimentation potential exists. Design to no more than 12 ft/second under open channel flow.
	• Reshape and stabilize all disturbed land.
	Conveyance *Capacity*
	• Design to hold capacity of water based on requirements of the structure it serves.
	• Account for water surface conditions at the outlet.

[43] NRCS. 2023. Conservation Practice Overview: Underground Outlet (Code 620). USDA. https://www.nrcs.usda.gov/sites/default/files/2023-08/620_NHCP_PO_Underground_Outlet-Riser_2023.pdf

Considerations	Details
	• Design for either pressure or gravity flow. Pressure relief wells if necessary to allow for excess flow to escape over the ground surface, only when there is a stable outlet for discharge. Outlets • Divert water to another diversion, infiltration, or water storage method. Vegetation *Selection and Establishment* • Revegetation is often needed above ground where the underground outlet is installed. Follow NRCS Conservation Practice Standard Critical Area Planting (Code 342) and the PNW 699 Western Oregon and Washington Pasture Calendar (Fransen et al. 2017) or PNW 708 Inland Pasture Calendar.
Lifespan	Lifespan is indefinite assuming proper design, material selection, and maintenance. Pipes are often made perforated HDPE Corrugated Plastic which vary in lifespan based on environmental conditions, soil and traffic loads, and the capacity of the product. The pipes can have a 100-year life span.[44]
Land area requirements	Surface and area requirements are minimal following installation. Underground area requirements will depend on the system design.
Other implementation factors	Direct outlet to an infiltration method or water capture method, or to another diversion method.
Resources	• Use Ecology's Stormwater Management Manuals when designing Roof Downspout BMPs including Downspout Full Infiltration, Downspout Dispersion Systems and Perforated Stub-out Connections. • See NRCS 620 for more details. • See USDA Practice Scenarios p. 1299- 1335[45] for cost estimates • Follow NRCSS CPS Subsurface Drain (Code 606) in absence of manufacturers data, or follow NRCS Title 210 National Engineering Handbook Part 636, Chapter 52, Structural Design of Flexible Conduits

[44] PPI. 2024. "HDPE Corrugated Pipe: Predicting Service Life". https://www.plasticpipe.org/Drainage/Drainage/Resources/Service-Life.aspx

[45] https://www.nrcs.usda.gov/sites/default/files/2024-01/fy24-washington-scenarios.pdf

Ditch Diversions

Ditch diversions are channels, usually constructed across a slope with a supporting ridge on the lower side.

Use Cases: Water coming from underground outlets or other dispersal or diversion methods that should be diverted away from relevant livestock areas (e.g. livestock facilities, heavy use areas, manure storage). Ditch diversions may be chosen for land with steeper slopes.

Additional Benefits of Ditch Diversions:

- Prevents clean water from mixing with pollution sources and minimizes their transport.
- Transports desired water capacity in a controlled manner, allowing infiltration, preventing erosion, and reducing surface water build-up.

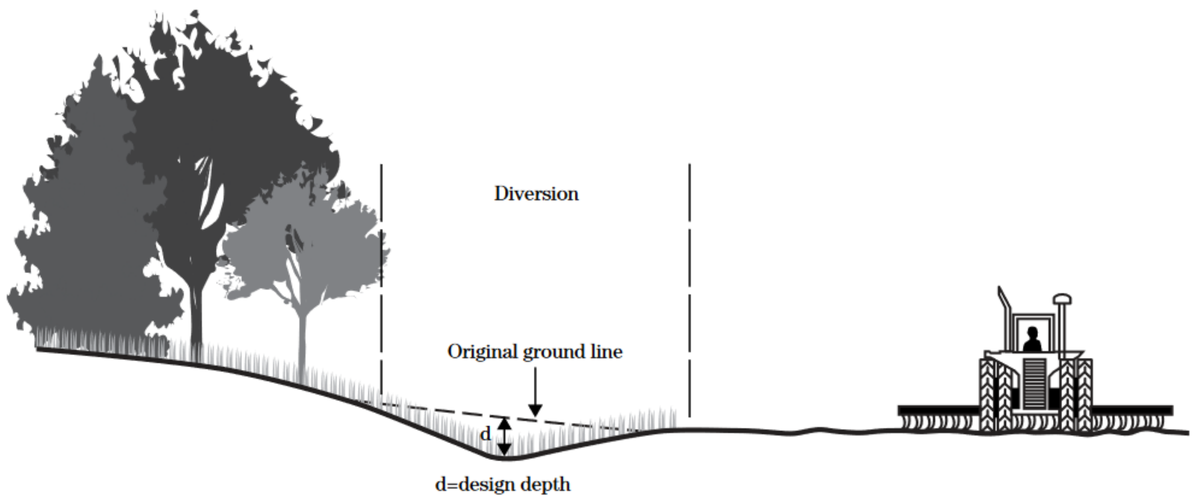

Figure 14: Channel Diversions can be designed along slopes with different depths based on the water carrying capacity required to divert (NRCS Part 650 Engineering Field Handbook, Chapter 9 Diversions).

Table 11: Implementation information synthesis for Ditch Diversions/Diversion Channel

Considerations	Details
Capital Cost	Diversion costs vary based on the depth and material required to excavate to install the required diversion to meet water capacity needs. Equipment Installation • Excavation and side casting of earth with hydraulic excavator including equipment and labor: $2.53 per cubic yard • Excavation of earth including sand and gravel for large diversions (>2cubic yards per linear foot) with dozer >1000 HP, including equipment and labor: $3.68 per cubic yard • Earthfill, roller or machine compacted including equipment and labor: $4.02 per cubic yard Labor • General labor: Approximately ~33.98 per hour • Supervisor or manager including crew supervisors, foreman and farm/ranch manager time: Approximately ~$55.32 per hour Mobilization • Medium Equipment with 70-150 horsepower or typical weights between 14,000 and 30,000 pounds: $761.41 per piece of equipment • Large Equipment greater than 150 horsepower or typical weights greater than 30,000 pounds or loads requiring over width or over length permits: $919.30 per piece of equipment
Operational and maintenance requirements	• Prepare a plan that accounts for diversion capacity, storage of water runoff, ridge height, and outlets. • Conduct periodic inspections, especially for erosion following significant storms. • Promptly repair any damage to the channel. • Establish necessary cleanout requirements to ensure proper capacity, ridge height, and outlet elevations. • Clean out sediment so the outlet remains at the lowest point in the channel. • Periodically mow for desired vegetation height and design. • Apply supplemental nutrients as needed for proper vegetative species and stand density.

<table>
<tr><th>Considerations</th><th>Details</th></tr>
<tr><td></td><td>Control trees, brush and noxious weeds, and pests that interfere with proper vegetation establishment.</td></tr>
<tr><td>Technical requirements</td><td>Placement

If protecting flatland from upland runoff, locate diversion at or near the base of an upland slope.
Divert away from any livestock or heavy use areas.
Locate the diversion so water does not travel to any important landscape elements such as trees or adjacent land uses.

Materials

Vegetative Establishment:

Follow NRCS CPS Critical Area Planting (Code 342) to establish vegetation with proper density, height, and vigor in an appropriate timeframe to reduce flow.
Consider the PNW 699 Western Oregon and Washington Pasture Calendar or PNW 708 Inland Pasture Calendar to understand how to most effectively monitor, maintain, and account for vegetation growth. Vegetative establishment largely depends on soil conditions including soil moisture.
Protect vegetation (e.g. with mulch, rock, straw, etc.) until it is established and ensure the crop is close-growing (e.g. small grains or millet)

Lining (if applicable): If vegetation cannot be used due to erosion, use nonvegetative linings such as concrete, gravel, rock riprap, cellular block, turf reinforcement mats, or other approved manufactured lining systems. Follow NRCS CPS Lined Waterway or Outlet (Code 468) for more information.

Design

Construct a parabolic, V-shaped, or trapezoidal channel
Include supporting ridges to contain flow with a minimum top width of 3 feet plus room for overfill sediment. Slopes for farmable land should not be steeper than a 5 (horizontal) to 1 (vertical) ratio. Non farmable slopes should follow a 2:1 ratio.
Design a plan that demonstrates NRCS practice standards have been met. See WA NRCS Diversion (362) design and installation deliverables and compliance protocols for a full list of inclusions.
</td></tr>
</table>

Considerations	Details
	• A typical diversion scenario is 1000 cubic yards but can be constructed as long as desired as long as depth and width standards are met. • Add vegetation to prevent erosion. • Ditch diversions are a method more ideal for assisting on land with steeper slopes than other diversion methods such as grassed waterways. Conveyance Capacity • Design for enough capacity to protect from 2-year (temporary diversion), 10-year (protecting agricultural land), or 25-year (protecting urban, buildings, roads, animal waste), 24-hour duration storms. • Provide a minimum freeboard depth of 0.3 feet. Outlets • Water will likely have some infiltration during the course of the diversion. Remaining water should outlet to another diversion or infiltration method such as a grassed waterway, underground outlet, vegetated treatment area, sediment basin, or combination of practices.
Lifespan	Indefinite assuming proper design and maintenance
Land area requirements	Diversion channels should take up a minimum of 3-feet wide of land but can be wider dependent upon planned water capacity and land slope. They can be as long as needed to divert the water.
Other implementation factors	• A vegetated lining should be considered • Inform operators of potential hazards. • Channel diversions are not meant to be crossed by equipment.
Resources	• See the design criteria for riprap Channel Lining within Ecology's Stormwater Management Manuals when considering the use of a lined waterway. • NRCS National Engineering Handbook (Title 210), Part 650 • NRCS Practice 362 • USDA Cost Estimates

Grassed Waterways

Grassed waterways are shaped or graded channels with a broad and shallow cross section that is established with suitable vegetation to convey surface water at a nonerosive velocity to a stable outlet.

Use Cases: As a conveyance for runoff during storm events. They can be combined with other dispersal or diversion methods. Grassed waterways require flatter land that is ideal for vegetative growth to allow for both controlled water transport and infiltration, and where equipment may need to cross the diversion.

Additional Benefits of Grassed Waterways:

- Provides a non-erosive pathway for uncontaminated water to slow and infiltrate into the soil.
- Provides a conveyance and infiltration method that is less disruptive to land (does not require deep ditches or pipes), allowing more efficient land use.
- Vegetation filters out soil, nutrients, and pollutants creating cleaner water runoff and allowing nutrients to remain in soil for continued vegetative growth.

Figure 15. Grassed Waterways are wider and flatter than channel diversions and are more ideal on flatter land that supports vegetative growth and allows for infiltration to not erode the channel bottom (K. McKague, P.Eng. Ontario Ministry of Agriculture Food)

Table 12: Implementation information synthesis for Grassed Waterways

<table>
<tr><th>Considerations</th><th>Details</th></tr>
<tr><td>Capital Cost</td><td>Costs are dependent on the best scenario to apply to the situation for installing a grassed waterway:

Equipment Installation (including equipment, power unit, and labor costs)
Excavation, depending on distance and type of earth: $1.57 - $2.35 per cubic yard
Stripping and stockpiling topsoil adjacent to the stripping area: $0.87 per cubic yard
Manually compacted earthfill: $6.27 per cubic yard
Light tillage: $14.20 per acre
Fertilizer application performed by ground equipment: $7.58 per acre
No till or grass drill for seeding: $21.25
Cultipacking: $10.14 per acre
Labor
Supervisor or manager: ~$55.32 per hour
General labor using basic tools that do not require extensive training (if required): ~33.98 per hour
Materials
Nutrients
Nitrogen supplied by Urea: $0.77 per pound
Phosphorous supplied by Superphosphate: $1.02 per pound
Potassium: K2O supplied by Muriate of Potash: $0.80 per pound
Limestone Fertilizer spread on field: $80.77 per ton
Non-woven geotextile (less than 8 oz/square with staple anchoring): $2.08 per square yard
Introduced perennial grasses, legumes, and/or forbs planted at high density (>60 live seeds per square foot) including material and shipping: $88.70 per acre
Mobilization
Equipment costs depend on type used and can range from $181.31 - $302.66 per truck haul</td></tr>
</table>

Considerations	Details
	• (If required) Medium Equipment with 70-150 horsepower or typical weights between 14,000 and 30,000 pounds: $761.41 per piece of equipment
Operational and maintenance requirements	• Establish a maintenance program to maintain waterway capacity, vegetative cover, and outlet stability. Promptly repair damaged vegetation, and fill, compact, and reseed damaged areas. • Ensure nothing will interfere with design flow once vegetation is established. • Exclude livestock and only permit grazing if a grazing system is implemented. • Avoid herbicides and pesticides, especially adjacent to waterways. • Mow vegetation to maintain capacity, reduce sediment deposition, and maintain suitable plant composition and vigor. • Apply supplemental nutrients as needed to maintain desired vegetation. • Control noxious weeds • Do not use waterways as a field road and avoid crossing with heavy equipment when wet. • Inspect regularly especially after heavy rains and ensure waterways are clear of any sediment trapping.
Technical requirements	Placement • Ensure grassed waterways are on flatter land that is ideal for vegetative establishment. • Locate to divert away from facilities and areas with livestock or manure storage. • Materials • Provide materials such as mulch, nurse crop, rock, straw, hay bale dikes, fabric, rock checks, or filter fences to protect vegetation until it is established. • Provide seed required for vegetative establishment. Design • Width: The bottom of a trapezoidal waterway should remain less than 100 feet. Increasing width allows for increased filtering of sediment and infiltration.

Considerations	Details
Technical requirements (cont.)	• Side slopes: Keep side slopes flatter than a 2 horizontal to 1 vertical ratio. Flatten side slopes as needed to allow for equipment maintenance. Grassed waterways are flatter and wider than diversion channels. • Depth: Consider a 0.5 feet freeboard above the designed depth when excess flow must be contained. • A typical practice is 1200 ' long, 12 ' bottom, 8:1 side slopes, 1.5 ' depth. • Vegetation: This practice is extremely reliant upon successful vegetative growth. Establish vegetation as soon as possible and design with consideration of soil and climatic conditions. Plant close-growing crops nearby to construction of grassed waterway to help reduce flow. Select species that can achieve adequate density, height, and vigor within an appropriate time frame to stabilize the waterway. Follow NRCS Conservation Practice Standard Critical Area Planting (Code 342) and the PNW 699 Western Oregon and Washington Pasture Calendar (Fransen et al. 2017) or PNW 708 Inland Pasture Calendar Conveyance Capacity • Design to convey peak runoff and withstand a 10-year frequency, 24-hour duration storm • Account for potential sediment accumulation between planned maintenance. • *Outlets* • Use NRCS Conservation Practice Standards (CPSs) Subsurface Drain (Code 606), Underground Outlet (Code 620) or other suitable measures in waterway design to account for drainage. Use CPS Lined Waterway or Outlet (Code 468) in place of NRCS CPS Grassed Waterway (412) when drainage practices are not practical or adequate. • Provide a stable outlet such as another vegetated channel, an earthen ditch, grade stabilization structure, filter strip, or lined waterway with adequate capacity.
Lifespan	• Grassed waterways will continue to be effective as long as they are properly maintained.

Considerations	Details
	• A minimum expected lifespan is 10 years.[46]
Land area requirements	• Seek recommendations from a soil scientist for where to best locate the grassed waterway for best placement or consider adding topsoil to facilitate vegetative establishment. • Grassed waterways should be installed on slightly slopped (mostly flat) land (ideally 1-5% slope)[47]. They are not ideal on steeply graded land.
Other implementation factors	• Use a soil health management system in conjunction with the grassed waterway to minimize upstream runoff • Use irrigation in dry regions or supplemental irrigation as necessary to promote vegetation establishment. • Advantages include carrying large flows, the ability for farm machinery to cross it, and relatively low maintenance after vegetative establishments. Difficulties can include vegetative establishment and sediment accumulation if erosion rates are not controlled on adjacent land.[48]
Resources	• NRCS Practice Code 412 • USDA Cost Estimates • NRCS National Engineering Handbook (Title 210) Part 650, Chapter 7, "Grassed Waterways[49]" • Agricultural Research Service Agriculture Handbook 667, Stability Design of Grass-Lined Open Channels."

Infiltration of Runoff

Infiltration methods have been promoted as a way to avoid direct water conduit to streams and creeks. Infiltration methods collect water from diversion mechanisms and allow water to be absorbed into the soil. Unless spillover practices are applied, water can only be applied a rate lower than the soil infiltrability so that water is controlled and does not runoff.[50] Infiltration ability depends on the rate and duration of water application, soil properties, slope, vegetation, and soil roughness. Infiltration methods covered in this section include:

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[46] https://efotg.sc.egov.usda.gov/api/CPSFile/28433/412_VT_OM_Grassed_Waterway_2021
[47] https://www.ontario.ca/files/2024-01/omafra-grassed-waterways-23-083-en-2024-01-10.pdf
[48] https://www.ontario.ca/files/2024-01/omafra-grassed-waterways-23-083-en-2024-01-10.pdf
[49] https://irrigationtoolbox.com/NEH/Part650_EngineeringFieldHandbook/H_210_650_07.pdf
[50] EPA. 2024. "Infiltration Models." https://www.epa.gov/water-research/infiltration-models

- Infiltration basins
- Rain gardens

References to other materials for additional infiltration BMPs are included in the appendix. Though not an official NRCS practice standard, rain gardens have increasingly become recognized as a method of infiltrating water from impervious surfaces on agricultural operations. They can, along with infiltration basins and vertical drains, be utilized by producers in Washington as method to infiltrate runoff from facilities, roofs, and other impervious areas.

Infiltration Basins

Infiltration basins, or infiltration ponds, are a type of stormwater basin without outlets that slowly draw down collected water volume by infiltration.

Infiltration Basins vs Water and Sediment Control Basins

Infiltration basins are very similar to water and sediment control basins, which address similar issues, including addressing runoff and sediment capture. However, one key difference is infiltration basins do not have an outlet, instead allowing the total runoff collected to infiltrate into the ground. Water and sediment control basins typically have an outlet whereas infiltration basins do not. For effectiveness and implementation information on water and sediment control basins, see Chapter 3.

Use Cases: Infiltration basins (or stormwater basins) should be used in conjunction with other BMPs to manage runoff downslope of diversion methods (e.g. ditch diversion, grassed waterway, underground outlet, or subsurface drain) and is generally only able to be used when soil conditions are suitable for infiltration and the land area can accommodate a basin sized for the relevant runoff volume.

Additional Benefits of Infiltration Basins:

- Can help to recharge groundwater
- If planted with bushes, trees, and other foliage, areas around infiltration basins can support native species and wildlife

Figure 16. Infiltration Basins are more common in urban setting as shown here but can be applied to agricultural settings as well where they can effectively draw water into the ground with vegetation and gravel. The image shows the flattened gravel before being covered with soil and vegetation (EPA, Credit Massachusetts Dep. of Transportation)

Table 13: Implementation information synthesis for Infiltration Basins

Considerations	Details
Capital Cost	Cost estimates for infiltration basins range greatly. Below are a few estimates: • $15,000 for a 5-acre commercial site[51]. • $1.30 per cubic foot for a typical .25-acre infiltration basin[52]. • $19 - $63/sq ft.[53]
Operational and maintenance requirements	• Maintenance should be conducted annually after spring snowmelt to remove material and debris from the basin and confirm any conveyance facilities are still functional (TRPA) • Regular inspections for clogging and other blockages • Vegetation management • Inlet/outlet cleaning
Technical requirements	Placement • Comprehensive investigation of soil suitability is essential to ensure the area is appropriate for infiltration[54]. • Suggested soil infiltration rates range from 0.5" – 2.5" per hour[55,56]. • Drainage areas less than 5 acres is typically ideal, but if designed properly and with the right conditions, infiltration basins can be utilized for drainage areas of up to 10 acres[57] • Should be at least 600' away from a drinking water source (TRPA). • Should be located away from building foundations – infiltration basins should be at least 10' down gradient and 50' up gradient of a structural feature (TRPA) – basins can be closer if approved if an

[51] EPA. n.d. Chapter 6: Costs and Benefits of Storm Water BMPs. https://www3.epa.gov/npdes/pubs/usw_d.pdf
[52] EPA. n.d. Chapter 6: Costs and Benefits of Storm Water BMPs. https://www3.epa.gov/npdes/pubs/usw_d.pdf
[53] Greay, M., D. Sorem, C. Alexander, and R. Boon. 2013, February 13. "The Costs of LID". Stormwater Solutions. https://www.stormwater.com/bmps/article/13007772/the-costs-of-lid
[54] Susdrain. n.d. "Component: Infiltration Basins". https://www.susdrain.org/delivering-suds/using-suds/suds-components/infiltration/infiltration-basin.html
[55] Susdrain. n.d. "Component: Infiltration Basins". https://www.susdrain.org/delivering-suds/using-suds/suds-components/infiltration/infiltration-basin.html
[56] TRPA. 2014. Chapter 4: BMP toolkit, 4.1-b Infiltration Basin. https://tahoebmp.org/Documents/BMPHandbook/Chapter%204/4.1/b_InfBas.pdf
[57] EPA. 2021. Stormwater Best Management Practice: Infiltration Basin. EPA-832-F-21-031B. https://www.epa.gov/system/files/documents/2021-11/bmp-infiltration-basin.pdf

Considerations	Details
Technical requirements (cont.)	engineer thinks it's appropriate and measures have been taken to mitigate damages from seepage. • Installing as close as possible to the source of the runoff improves capture. Sizing • Size of infiltration basins should be based on runoff volume estimates. • To calculate runoff volume estimates, use an approved continuous runoff model, such as WWHM, MGSFlood, or KCRTS for calculations. Infiltration basins should successfully infiltrate 91% of the influent – the remaining 9% can bypass the infiltration facility[58]. Design and Construction • Ensure bottom of basin is flat to allow for infiltration. Side slopes should be flat enough to prevent erosion. • Maximum ponded water depth should be between 2-6 feet with at least one foot of freeboard – See the Stormwater Manual for Western Washington for more information on how to size infiltration basins • Remove and stockpile native topsoil after grading basin dimensions – the bottom of the basin should be flat • After grading, till back topsoil or other soil to at least 12" deep amendments which may have been compacted during grading to improve infiltration capacity.
Lifespan	Indefinite, assuming proper maintenance
Land area requirements	Infiltration basins require a large, flat area – the land area requirements depend on the design and sign of the basin[59]
Other implementation factors	• High failure rates are possible without proper siting, design, and maintenance of the infiltration basin.

[58] WA Department of Ecology. 2012. Stormwater Management Manual for Western Washington: Vol. III Hydrologic Analysis and Flow Control BMPs. WA Department of Ecology Water Quality Program. Publication No. 12-10-030. https://apps.ecology.wa.gov/publications/parts/1210030part4.pdf
[59] Susdrain. n.d. "Component: Infiltration Basins". https://www.susdrain.org/delivering-suds/using-suds/suds-components/infiltration/infiltration-basin.html

Considerations	Details
	• Contributing drainage area, conveyance channels, and all inlets to basin should be stabilized or pretreatment to prevent sediment discharge[60].
Resources	• Use Ecology's Stormwater Management Manuals to design and implement infiltration ponds.

Rain Gardens

Rain gardens are areas that collect, absorb, and filter stormwater runoff via a shallow depression landscaped with a variety of plants determined by the surrounding area. They are sized to hold temporary ponding after rain but are not permanent ponds.

Use Cases: Rain gardens should be used in conjunction with other BMPs to manage runoff from downspouts. Rain gardens are used for smaller areas of land and closer to structures to handle a smaller quantity of water than infiltration basins or vegetative treatment areas.

Additional Benefits of Rain Gardens:

- Can replenish groundwater, which can be particularly beneficial to producers with wells
- Provide additional habitat for pollinators which can benefit nearby crops
- Can be considered more visually appealing than other BMPs

[60] California Department of Transportation. 2020. Infiltration Basin Design Guidance. https://dot.ca.gov/-/media/dot-media/programs/design/documents/8_dg-infiltration_basins_ada.pdf

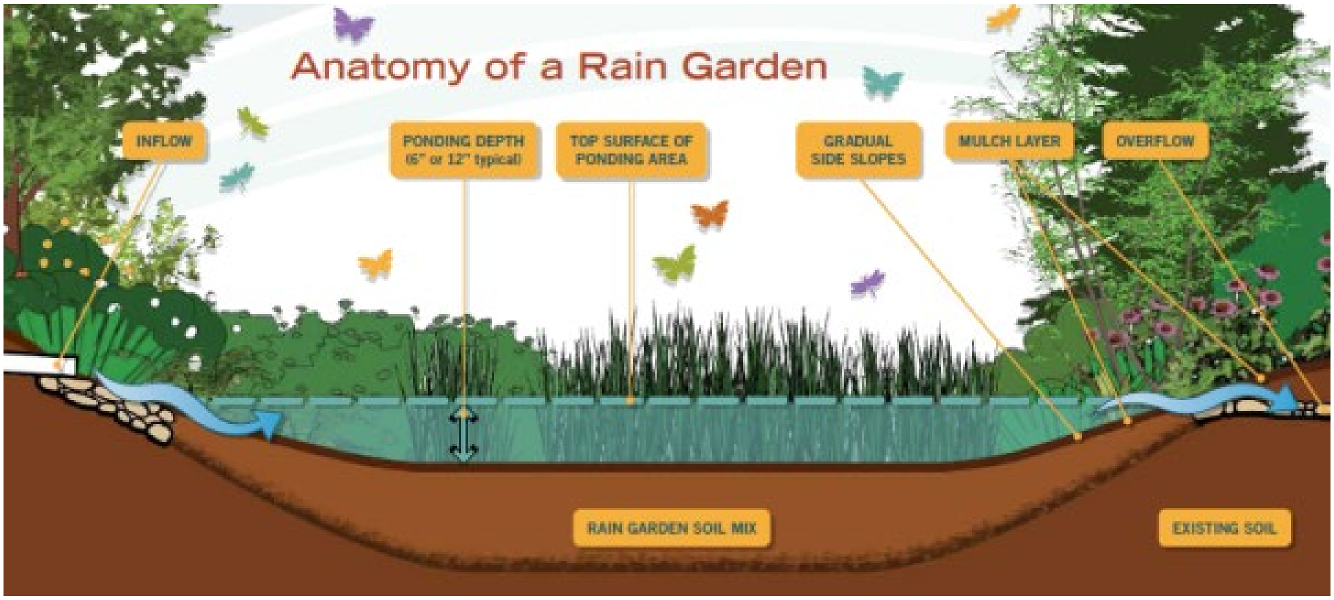

Figure 17: Rain gardens are smaller and less commonly used but have great abilities to infiltrate clean water and keep it clean with the extensive vegetation they are composed of. (WSU Extension).

Table 14: Implementation information synthesis for Rain Gardens

Considerations	Details
Capital Cost	Estimates of rain garden installation costs range greatly due to variations in size and complexity that can occur. A number of conservation districts in Washington have mini-grants and cost share programs available to support installation of rain gardens for individuals, businesses, and organizations. Eligibility and amount provided vary so please refer to your local Conservation District for more information. • Self-Installation: If a producer installs and plants a rain garden themselves, estimates range from \$3 to \$5 per square foot[61,62]. • Utilizing a Contractor: If a producer contracts out for installation of a rain garden, cost estimates range from \$10 - \$35 per square foot[63,64]. • Rain gardens can be expensive take more effort to cover larger areas of land than other methods. They are not used as often and are less

[61] Groundwater Foundation. n.d. “All About Rain Gardens: What is a rain garden?” https://groundwater.org/rain-gardens/
[62] Three Rivers Rain Garden Alliance. “Rain Gardens FAQs”. http://raingardenalliance.org/what/faqs
[63] Prince George County Department of the Environment. n.d. Rain Garden Fact Sheet. https://cbtrust.org/wp-content/uploads/Fact-Sheet-and-Guidelines_Rain-Garden_030922.pdf
[64] Three Rivers Rain Garden Alliance. “Rain Garden FAQs”. http://raingardenalliance.org/what/faqs

Considerations	Details

Capitol Cost (cont.)	likely to be funded with a cost share program. They do provide significantly effective benefits in promoting clean water.
	• The exact cost of a rain garden will depend on the following:
	  ○ Material costs, such as landscaping, seed, stone, and plants
	  ○ Size of the rain garden
	  ○ Whether heavy equipment and machinery will be required
	  ○ Ease of access to the site (applicable to contractors)
	  ○ Whether soil will need to be disposed of offsite (applicable to contractors)
	  ○ Duration of construction (applicable to contractors)

Operational and maintenance requirements	Because rain gardens are meant to contain established perennials, they should require less maintenance as compared to traditional gardens. Maintenance includes:[65] • Plant Care • Provide water and additional mulch as needed. • Weed control • Infiltration maintenance: keep inlet and overflow clear of debris and well protected with rock. See Section 4 of the Rain garden Handbook for Western Washington for complete details on maintenance and see page 61 for a Maintenance Checklist.
Technical requirements	Placement • For rain gardens installed adjacent to roofs and lawns, NRCS has a rain garden site and soil assessment[66] that may help determine proper sizing and location, though is not considered a substitute for detailed, on-site investigations by professionals. Note that this is not applicable for runoff that may contain animal waste, pesticides, or other residential/commercial uses which discharge water. • Proximity to trees should be considered – tree roots may be damaged by installation of rain gardens. Ideally, the distance from the nearest trees to rain gardens should be more than 10 feet.

[65] Rain Garden Alliance. 2009. “Rain Garden FAQs”. http://raingardenalliance.org/what/faqs
[66] https://www.nrcs.usda.gov/sites/default/files/2022-10/RAIN_GARDEN_SITE_ASSESSMENT_CARD.pdf

Considerations	Details

Technical requirements (cont.)	Additionally, the area should receive some sun. Species selected for planting should be appropriate for the sun/shade conditions of the site.
	• See Step 1 of Design below
	Materials
	• Mulch and proper vegetation as described in Vegetation below
	Design
	Step 1: Siting a rain garden
	• Distance from foundation of a structure: Ideally more than 20 feet to prevent seepage or causing frost damage
	• Distance from a downspout (if runoff is derived from a roofed structure): Ideally 20-30 feet distance.
	• If downspout is more than 30 feet from the site, producers can consider using a grass swale or PVC pipe to move to garden to prevent erosion.
	• Slope from structure: Between 1% and 15% and land slopes down from structure to garden. Rain gardens located upslope from the runoff source would be impractical and would require pumping.
	• Slope of land at the rain garden site: Lower than 12% grade is ideal.
	  ○ If slope is less than 4%, garden should be 3”-5” deep
	  ○ If slope is between 5% and 7%, garden should be 6” to 7” deep
	  ○ If slope is between 8% and 12%, garden should be 8” deep
	Step 2: Examine the soils
	• Exposed bedrock is not suitable for rain garden installation – you should be able to dig a hole at least 2’ deep without hitting solid bedrock.
	• Loose soil is ideal for at least 2’
	• Soil Type: Loamy sand, sandy loam, loam, silt loam, silty clay loam, and sandy clay loam.
	• Standing rainwater should last less than 24 hours, even after heavy rain. If ponding lasts for more than 72 hours, it may provide breeding habitat for mosquitoes
	• Drainage speed should allow water to move down faster than 1” per hour. To test this, you can dig a 6” – 10” hole, fill it with water, and time how fast the water moved down 1”.

<table>
<tr><th>Considerations</th><th>Details</th></tr>
<tr><td></td><td>Step 3: Determine the size and shape
Size of drainage area: Less than 3000 ft2 for a single rain garden. More than 3000 ft2 may necessitate multiple rain gardens or additional infiltration options.
Identifying the exact size of a rain garden includes considering the size of the drainage area, slope of the garden, and soil texture. A worksheet provided in the NRCS Rain Garden Site Assessment Guide can help give a rough idea of the area of a rain garden. Ideally an individual rain garden should be less than 300 ft2.
Width and positioning: If the slope of the garden is more than 8%, the width should be less than 15ft, though 10ft wide is ideal to enable access into the garden. The longer side of a rain garden should face upslope.
Timing
Plan and design the raingarden December to May, which is a prime time to test soil drainage. Build the rain garden from May to September, and plant the raingarden September through November.
Vegetation
See Section 2 of the Raingarden Handbook for Western Washington for information on preparing the landscape, planting zones, mulching information, and sample planting plans for a rain garden. Follow NRCS Conservation Practice Standard Critical Area Planting (Code 342) and the PNW 699 Western Oregon and Washington Pasture Calendar or PNW 708 Inland Pasture Calendar for more information on planting vegetation in Washington.</td></tr>
<tr><td>Lifespan</td><td>Raingardens can stay in operation for as long as they are needed, assuming proper maintenance of the area including vegetation and soil.</td></tr>
<tr><td>Land area requirements</td><td>Locate the raingarden on lands with less than 10% slope, where there is enough space for the rain garden and where water flows to the garden but will overflow or outlet to contaminated areas or water bodies.
Do not locate rain gardens near sources of contamination, by water bodies, by utilities or septic areas, near the edge of steep slopes, in low spots that do not drain well, in areas that would disturb already healthy vegetation, or where there is already high groundwater in the winter.</td></tr>
</table>

Considerations	Details
Other implementation factors	• Rain gardens can be "enhanced" to support specific types of animal life. For example, the USDA offers guidance to support establishment of Monarch, pollinator, and beneficial insect habitat through Conservation Enhancement Activity E570A[67]. Activities that are considered "enhancements" are designed to maintain or exceed the quality criteria, or stewardship level, for the resource concern. Estimated cost of enhancements is $0.23 per square foot[68].
Resources	• Use Ecology's Stormwater Management Manuals to design and implement rain gardens. • For additional information about rain gardens, refer to the *Rain Garden Handbook for Western Washington: A Guide for Design, Installation, and Maintenance* (Hinman et al., 2013[69])for rain garden specifications and construction guidance.

[67] https://www.nrcs.usda.gov/sites/default/files/2024-01/E570A_WA_010424.pdf
[68]NRCS. 2023. Conservation Stewardship Program FY 23. https://www.nrcs.usda.gov/sites/default/files/2022-11/Washington-CStwP-23-payment-rates.pdf
[69] Curtis Hinman et al., *Rain Garden Handbook for Western Washington: A Guide for Design, Installation, and Maintenance*, Washington State Department of Ecology/Washington State University Extension/Kitsap County, June 2013.

Additional Practices and Resources for Producers

Practice	Sources	Notes as needed
Lined Waterways	NRCS Practice 468 on Lined Waterways or Outlet	If site conditions are not ideal for vegetative growth, or producers want to retain water on fields, consider adding a liner to the waterway. This will add additional maintenance requirements. See NRCS Practice 468 on Lined Waterways or Outlet for more information. Lined waterway materials include nonreinforced concrete, hand-placed screeded concrete or mortared-in-place flagstone, flip form concrete, rock riprap, synthetic turf reinforcement fabrics, and grid pavers. Use geotextiles as a separator between materials and to keep soil particles in place, and use filters or bedding as a leveling base.
Berms	Berms do not have an NRCS practice standard. Santa Cruz Permaculture[70]	A raised bank that helps intercept and trap water running down slopes and infiltrate in a localized area via a swale, which is an excavation basin.
Retention Ponds	EPA: Stormwater Technology Factsheet On-Site Underground Retention/Detention[71] NRCS Practice Code 378	A water impoundment made by constructing an embankment, excavating a dugout, or a combination of both. A retention pond is designed to permanently hold water.
Water and Sediment Control Basin	NRCS Practice Code 638	An earth embankment or combination ridge and channel constructed across the slope of a minor drainageway used to reduce gully

[70] https://santacruzpermaculture.com/2019/08/berms-swales/

[71] https://nepis.epa.gov/Exe/ZyNET.exe/P100IL5C.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2000+Thru+2005&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C00thru05%5CTxt%5C00000032%5CP100IL5C.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

Practice	Sources	Notes as needed
		erosion, trap sediment, or reduce and manage runoff (see Chapter 3).
Vertical Drains	NRCS Practice Code 630 Prefabricated Vertical Drains[72]	A well, pipe, pit, or bore in porous underground layers of rock or soil into which drainage water can be discharged without contaminating groundwater resources. Base the capacity of the vertical drain system on determination of depth, permeability, porosity, thickness, and extent of strata. Determine the proper number, size and location of vertical drain adequate to discharge the flow into the underlying stratum. Ensure the vertical drain has a minimum 4" diameter and has suitable filters to remove sediment to keep the drain unclogged.
Rain Barrels	Soak Up the Rain: Rain Barrels | US EPA[73] Rainwater Collection | Department of Ecology[74]	Captures and stores water from roofs to use at a later time for other needs such as lawns, gardens, or livestock. Conserving water can help reduce landowner water expenses. No water right permit is needed to collect rainwater. Note that roof water can pick up pollutants from roofs and so landowners should be careful if using water on edible plants. Some counties allow rainwater for drinking while others do not. The Washington Department of Health's Office of Drinking Water considers rainwater to be subject to requirements of the Surface Water Treatment Rule[75].

[72] https://www.geoengineer.org/education/web-class-projects/cee-542-soil-site-improve-winter-2014/assignments/prefabricated-vertical-drains
[73] https://www.epa.gov/soakuptherain/soak-rain-rain-barrels
[74] https://ecology.wa.gov/water-shorelines/water-supply/water-recovery-solutions/rainwater-collection
[75] https://doh.wa.gov/sites/default/files/legacy/Documents/Pubs/331-085.pdf

Definitions

- **Algal Blooms** – Rapid growth or excessive accumulation of algae in marine or freshwaters commonly caused by the overabundance of nutrients such as nitrogen and phosphorus. Algae that reaches high concentrations can negatively affect water quality and produce toxic effects on humans and wildlife.
- **Ammonia Volatilization** – when significant amounts of nitrogen are lost to the atmosphere as ammonia, if nitrogen source is does not immediately incorporated into soil. Warm temperatures accelerate conversion of manure and inorganic nitrogen fertilizers to ammonia gas.
- **Biogeochemical transformations –** Natural pathways that convey fundamental nutrients and chemical elements between living organisms and the environment and transform chemical compounds within the environment.
- **Bioswales** – Planted or mulched channels that slow water, allowing it to infiltrate into the soil.
- **Critical Area** – An area to be treated with special consideration because of inherent site factors, size, location, condition, values, or significant potential use conflicts.
- **Denitrification** – When oxygen levels in the soil are low, nitrogen is converted to nitrogen gas and nitrous oxide gas by microorganisms called denitrifiers. Nitrous oxide is a greenhouse gas.
- **Dry Wells** – A well used to transmit water underground, and is deeper than its width at the surface.
- **Eutrophication –** A process of an increase in the rate of supply of organic matter to an ecosystem.
- **Erosion** – The removal of land surface due to water, wind, ice, or other geological causes.
- **Evapotranspiration** – The actual total loss of water by evaporation from soil, waterbodies, and transpiration from vegetation over a given area with time.
- **Filter Strip –** A strip or area of herbaceous vegetation that removes contaminants from overland flow (NRCS 393).
- **Grassed Waterways** – A shaped or graded channel that is established with suitable vegetation to convey surface water at a nonerosive velocity using a broad and shallow cross section to a stable outlet (NRCS Code 412).
- **Green roofs –** Vegetated roofs with a waterproofing membrane, soil, and vegetation, overlaying a traditional roof.
- **Heavy Use Area (HUA) Protection** – Stabilization or protection of an intensely used area (NRCS Code 561).
- **Infiltration Basins** – reduce stormwater discharge volume by enhancing groundwater recharge.
- **Infiltration Berm** – built-up earthen embankments with sloping sides to divert, retain, and promote infiltration, slow down, or divert stormwater flows.

- **Waste Treatment Lagoon –** A waste treatment impoundment made by constructing an embankment and/or excavating a pit or dugout (NRCS Code 359).
- **Leaching –** When there is sufficient rain and/or irrigation to move dissolvable nitrates into below the roots zone of plants. Nitrates end up in underground aquifers or surface water due to drains and underground flow.
- **Lined Waterways** – A waterway or protected outlet section having an erosion-resistant lining of concrete, stone, synthetic turf, reinforcement fabrics, or other permanent material (NRCS Code 468).
- **Nutrients** - Nitrogen (N) and Phosphorous (P) are elements and essential building blocks for plant and animal growth.
- **Pathogen** – Any small organism such as a virus or bacterium that can cause disease.
- **Permeable Paver** – A type of pavement with high porosity that allows rainwater to pass through to the ground.
- **Pond (Retention and Detention)** – (See NRCS Code 378 – Pond) - A water impoundment made by constructing an embankment, excavating a dugout, or a combination of both. It can be used for to store water for flow detention, and is used to improve water quality. Water detention ponds temporarily store runoff while retention ponds permanently hold runoff.
- **Surface runoff** – when the infiltration capacity of soil is exceeded by rainfall rate.
- **Rain gardens** – can help clean polluted stormwater runoff, by acting like a native miniature forest that collects, absorbs, and filters stormwater runoff.
- **Retention ponds** – control stormwater by retaining and treating runoff.
- **Roof runoff structures -** consist of gutters, downspouts, and outlets to controlled areas to infiltrate or be transported away from livestock.
- **Runoff** – The movement of water from a watershed including surface and subsurface flow, usually expressed in acre-feet of water yield.
- **Sediment Load –** The amount of sediment being transported in water runoff or in a river. There is dissolved, suspended, and bed load.
- **Sedimentation** – When wind or water runoff transports soil particles to a stream or body of water.
- **Subsurface Drain –** A conduit, or system of conduits, installed beneath the ground surface to manage soil water conditions (NRCS Code 606).
- **Surface Drain Field Ditch** – A graded channel on a field surface for collecting and conveying excess water (NRCS Code 607).
- **Terrace –** An earth embankment or combination ridge and channel constructed across a sloped field (NRCS Code 600).
- **Underground Outlet** – A conduit or system of conduits installed beneath the ground surface to convey surface water to a suitable outlet (NRCS Code 620).
- **Waste Storage Facility –** An agricultural waste storage impoundment or containment structure (NRCS Code 313).

- **Water Table –** The boundary between the unsaturated and saturated zone underground. Below the water table, groundwater fills spaces between sediment and rock.

Manning's Equation to determine gutter capacity

Step 1: Compute and select gutter size, utilizing recommended gutter gradient of 1/16 inch per foot and a Manning's roughness coefficient of 0.012.

$$q_g = 0.01185 \times A_g \times r^{.67}$$

Where:

q_g = capacity of gutters (ft^3/s)
A_g = cross-sectional area of gutter (in^2)
R = A_g / wp (in)
wp = wetted perimeter of the gutter (in)

Step 2: Computer capacity of downspout with an orifice discharge coefficient of .65. Orifice equation is as follows:

$$q_d = 0.010456 \times A_d \times h^{0.5}$$

Where:

q_d = capacity of downspout (ft^3/s)
A_d = cross-sectional area of downspout (in^2)
h = head (in)

Step 3: Determine whether the system is controlled by gutter capacity or downspout capacity and adjust number of downspouts, if desired.

$$N_d = \frac{q_g}{q_d}$$

Where:

N_d = number of downspouts

If N_d is less than 1, the system is gutter-capacity controlled and the producer should add additional downspouts. If it is equal to or greater than 1, the system is downspout-capacity controlled, and the downspouts can handle peak flow from the gutters.

Step 4: Determine the roof area that can be served by the following equation:

$$A_r = \frac{q \times 3{,}600}{P}$$

Where:

A_r = area of roof served (ft^2)

Q = capacity of system, either q_g or q_d, whichever is smallest (ft^3/s)
P = 5-minute precipitation for 24-year storm event (in)