Montana Post-Construction Storm Water BMP Design Guidance Manual

September 2017


Produced for:
Montana's MS4 Municipalities


Billings
Bozeman
Butte
Great Falls
Helena
Kalispell
Missoula




Prepared by
HDR

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In cooperation with:

Montana Department of Environmental Quality

First Edition

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Acknowledgments

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Foreword

This *Montana MS4 Post-Construction Best Management Practice Design Guidance Manual* has been prepared to provide guidance to assist professionals with selecting, designing, constructing, inspecting, and maintaining post-construction storm water management controls. The information presented in this manual is the result of research of up-to-date storm water management practices and the combined expertise of storm water management professionals in Montana and throughout the United States.

This manual is a guidance document. The information in this manual is intended to provide professionals with general information on the subject concerned. It is not intended to be an exhaustive review of all applicable practices or a comprehensive summary of all regulatory and local requirements. Additionally, best known storm water practices are evolving, along with regulatory and local requirements, all of which are subject to change and may involve subjective interpretation. With the exception of referenced permit language, this manual does not convey requirements for storm water management practices in the state of Montana. However, it is expected that municipalities or other governing entities may adopt this manual in full or in part to convey requirements for conducting development or redevelopment activities in their jurisdictions. The professional is responsible for identifying all applicable requirements for each specific project.

The professional using this manual is responsible for the proper design of a functioning system that meets all the applicable requirements and considers all unique conditions of individual sites. It is the professional who is responsible for proper installation of an approved design. Ultimately, it is the property owner or operator's responsibility to ensure that all permanent best management practices (BMPs) function as designed at all times.

This manual does not cover every aspect of engineering necessary for proper BMP design, construction, and implementation, nor does it cover every possible design scenario. Where the designer determines that conformance to this manual would be technically or financially infeasible, alternative design approaches, materials, and methods should be evaluated while consulting local jurisdictions.

> Note: Throughout this manual, the words "should" and "recommended" are used for items that are suggested for good design practice and optimal performance. The words "shall," "must," and "required" convey guidance and/or criteria that, when adhered to, are expected to meet the Post-Construction Performance Standard (see Section 1.3) based on resources reviewed during this manual's development.

> Note: This Manual is not intended to supersede existing procedures and policies for the review of site, drainage, or infrastructure plans for local jurisdictions. Local policy and ordinances specific to MS4 jurisdictions must be consulted to guide or dictate permanent storm water management planning and design. Examples of these include land use codes, right-of-way easements, roadway setbacks, impervious surface ratios, and a suite of other policies that affect how development is distributed. Coordinate with the local jurisdiction for more information on site design and storm water management policies.

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Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
BMP	Best management practice
BOD	Biological oxygen demand
COD	Chemical oxygen demand
Construction General Permit	General Permit for Storm Water Discharges Associated with Construction Activity
CN	Curve Number
DEQ	Department of Environmental Quality
DNRC	Department of Natural Resources and Conservation
EDB	Extended detention basin
EISA	Energy Independence and Security Act
General Permit	General Permit for Storm Water Discharges Associated with Small Municipal Separate Storm Sewer Systems (MS4s): Permit Number MTR040000
HDPE	High-density polyethylene
HSG	Hydrologic soil group
H:V	Horizontal:vertical
ICPI	Interlocking Concrete Pavement Institute
Ksat	Saturated hydraulic conductivity
LID	Low-impact development
L:W	Length:width
MBOGC	Montana Board of Oil and Gas Conservation
MCM	Minimum control measure
MS4	Municipal separate storm sewer system
NRCS	Natural Resources Conservation Service
PICP	Permeable interlocking concrete pavers
RRV	Runoff Reduction Volume
RTF	Runoff Treatment Flow
RTV	Runoff Treatment Volume
TMDL	Total maximum daily load
TSS	Total suspended solids
UDFCD	Urban Drainage and Flood Control District
UIC	Underground Injection Control
US EPA	U.S. Environmental Protection Agency
WDB	Wet detention basin
WSDOT	Washington State Department of Transportation
WSE	Water surface elevation

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1 Introduction to the Manual

1.1 Purpose of the Manual

This *Montana MS4 Post-Construction Best Management Practice Design Guidance Manual* provides guidance for selecting, designing, constructing, inspecting, and maintaining post-construction storm water management controls, hereafter referred to as best management practices (BMPs), in accordance with the provisions of Montana's General Permit for Storm Water Discharges Associated with Small Municipal Separate Storm Sewer Systems (MS4s): Permit Number MTR040000 (General Permit). The General Permit is part of the Montana Pollutant Discharge Elimination System, under which the Montana Department of Environmental Quality (DEQ) issues and enforces permits to control point source discharges to protect water quality in the state's surface waters. Following federal discharge permit regulations, the General Permit contains the following six minimum control measures (MCMs) that must be addressed in an MS4's storm water management program:

1. Public education and outreach
2. Public involvement and participation
3. Illicit discharge detection and elimination
4. Construction site storm water management
5. Post-construction site storm water management in new and redevelopment projects
6. Pollution prevention/good housekeeping for permittee operations

This manual provides guidance for addressing the performance standard for new and redevelopment projects within MCM 5. This manual also provides tools that may be used to address other portions of an MS4's storm water management program, such as impaired waterbodies with approved total maximum daily load (TMDL) waste load allocations. Specific pollutant considerations are addressed in Chapter 5 in the summary sheet for each BMP.

1.2 Audience for the Manual

Table 1-1 suggests uses of this manual for specific intended audiences.

Table 1-1. Suggested Uses of the Manual for Intended Audiences

Intended Audience	Suggested Use[1]
MS4 Program Manager	To assist with implementation of a storm water management program: ▪ The manual may be adopted and/or adapted for use with local storm water management program implementation.
MS4 Plan Reviewer	To review plans for compliance with the Post-Construction Performance Standard:[2] ▪ Chapter 3 provides guidance for hydrologic analyses. ▪ Chapter 4 describes the BMP selection process. ▪ Chapter 5 provides guidance for BMP design and implementation.

Chapter 1 – Introduction to the Manual

Intended Audience	Suggested Use[1]
MS4 BMP Inspector	To effectively inspect BMPs: ▪ Chapter 5 provides maintenance considerations for the BMPs included in this manual. ▪ Appendix F provides example inspection forms specific to each BMP that may be adapted and/or adopted by local jurisdictions.
Design Professionals/ Consultants	To develop storm water designs that can meet the Post-Construction Performance Standard:[2] ▪ Chapter 1 provides background and an overview of permitting requirements. ▪ Chapter 2 provides site development guidance. ▪ Chapter 3 provides guidance for hydrologic analyses. ▪ Chapter 4 provides BMP selection guidance. ▪ Chapter 5 provides design and implementation guidance for the eight BMPs included in this manual.
Contractors	To be informed of construction considerations: ▪ Chapter 5 discusses construction considerations for the BMPs included in this manual.
Project Owners/ Operators	To effectively operate and maintain BMPs: ▪ Chapter 5 discusses maintenance considerations for the BMPs included in this manual. ▪ Appendix F provides example inspection forms specific to each BMP that may be adapted and/or adopted by local jurisdictions.
Montana DEQ Staff	To provide technical assistance to local programs: ▪ The manual allows Montana DEQ to gauge how site plans translate to achieving performance standards.
Non-MS4 Local Government or Other Entity	To assist with implementation of an effective storm water management program: ▪ The manual may be adopted and/or adapted for use with local storm water management program to communicate design standards to local stakeholders.
Interested Stakeholders (Businesses, Watershed Groups, Citizens)	To be informed: ▪ The manual is an education, outreach, and technical assistance tool for stakeholder use as guidance in BMP selection, site development, and public education.

[1] These are suggested uses for various parties, but not exhaustive, because many types of users will find various sections of the manual to be helpful for particular purposes.
[2] See Section 1.3 for discussion on the Post-Construction Performance Standard.

1.3 Post-Construction Storm Water Criteria in the Montana MS4 General Permit

MCM 5 in the General Permit requires MS4s to develop, implement, and enforce a program to address storm water runoff from new development and redevelopment projects that disturb greater than or equal to 1 acre, including projects less than 1 acre that are part of a larger common plan of development or sale and that discharge into a permitted small MS4. This program must ensure that controls are in place that would prevent or minimize water quality impacts. MCM 5 has multiple General Permit requirements; however, this manual primarily focuses on the performance standard for new and redevelopment projects.

1.3.1 Post-Construction Performance Standard

For new and redevelopment projects regulated by the General Permit, the Post-Construction Performance Standard presented in Part II.A.5.b.iii of the General Permit—which was issued on November 30, 2016, and became effective on January 1, 2017—is as follows:

Require that all regulated projects implement post-construction storm water management controls that are designed to infiltrate, evapotranspire, and/or capture for reuse the post-construction runoff generated from the first 0.5 inches of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation. For projects that cannot meet 100% of the runoff reduction requirement, the remainder of the runoff from the first 0.5 inches of rainfall must be either:

a. *Treated onsite using post-construction storm water management control(s) expected to remove 80 percent total suspended solids (TSS);*
b. *Managed offsite within the same sub-watershed using post-construction storm water management control(s) that are designed to infiltrate, evapotranspire, and/or capture for reuse; or*
c. *Treated offsite within the same subwatershed using post-construction storm water management control(s) expected to remove 80 percent TSS*

Permittees allowing offsite treatment shall do the following:

a. *Develop and apply criteria for determining the circumstances under which offsite treatment may be allowed.*
   - *The criteria must be based on multiple factors, including but not limited to:*
     i. *Technical or logistic infeasibility (e.g. lack of available space;*
     ii. *High groundwater;*
     iii. *Groundwater contamination;*
     iv. *Poorly infiltrating soils;*
     v. *Shallow bedrock;*
     vi. *Prohibitive costs; and*
     vii. *A land use that is inconsistent with capture and reuse or infiltration of storm water).*
   - *Determinations may not be based solely on the difficulty and/or cost of implementation.*
   - *The permittee must develop a formal review and approval process for determining projects eligible for offsite treatment.*
   - *The offsite treatment option is to be used only after all onsite options have been evaluated and documented through the permittee's developed formal review and approval process.*

1.3.2 Montana MS4 Standard Terminology

The following terms and definitions are used in this manual to address components of the Post-Construction Performance Standard presented above:

Post-Construction Performance Standard

The BMP design requirement presented in Part II.A.5.b.iii of the General Permit.

Runoff Reduction Requirement

The portion of the Post-Construction Performance Standard requiring that all regulated projects implement BMPs that are designed to infiltrate, evapotranspire, and/or capture for reuse the post-construction runoff generated from the first 0.5 inch of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation.

Runoff Treatment Requirement

The portion of the Post-Construction Performance Standard requiring that, for regulated projects that cannot meet 100 percent of the Runoff Reduction Requirement, the remainder of the runoff from the first 0.5 inch of rainfall be treated using BMPs expected to remove 80 percent total suspended solids (TSS).

Offsite Treatment Evaluation

An evaluation that must be conducted to determine whether a project is eligible for offsite treatment.

> Note: In accordance with the General Permit, MS4s allowing offsite treatment shall develop and apply criteria for determining the circumstances under which offsite treatment may be allowed. These criteria must be part of a formal review and approval process developed by the MS4 for determining whether projects are eligible for offsite treatment. Refer to the local jurisdiction for additional guidance because the General Permit allows each MS4 to develop its own offsite treatment criteria and approval process.

1.4 Regulatory Considerations for Storm Water Management in Montana

For many sites, there are overlapping regulations at the local, state, and federal levels. In addition to controlling runoff, new and redevelopment projects may have to comply with other requirements related to storm water, such as floodplains, wetlands, natural streams, and dam safety, among others. For instance, any new or redevelopment project that disturbs 1 acre or more of land will also be required to obtain coverage under the Montana DEQ General Permit for Storm Water Discharges Associated with Construction Activity (Construction General Permit), which provides the requirements for controlling storm water runoff associated with construction activities.

Table 1-2 outlines the more common regulatory programs/drivers that may intersect with local storm water programs. While the table is not exhaustive in this regard, it does highlight the degree of coordination that may be necessary.

Table 1-2. Common Regulatory Programs that Influence Design and Storm Water Management in Montana[1]

Permit or Regulatory Program	Description
Local Construction/ Development Permits **Local Jurisdiction**	In accordance with the MS4 General Permit, an MS4 must have a program to address storm water runoff from construction sites and post-construction development. Coordinate with the local jurisdiction to determine applicable standards, submittals, and permits that may be required for development within the local jurisdiction's regulated boundary.
General Permit for Storm Water Discharges Associated with Construction Activity **Montana DEQ**	This permit applies to all construction activities that result in land disturbance of greater than or equal to 1 acre and projects disturbing less than 1 acre that are part of a larger common plan of development or sale that would disturb 1 acre or more. Coverage under this permit is obtained through Montana DEQ. Additional details are provided on Montana DEQ's webpage, entitled "MPDES Permits for Storm Water Discharges" (http://deq.mt.gov/Water/WPB/mpdes/stormwater). Note that some local jurisdictions may require submittal of the Construction General Permit package in order to conduct construction activities within their regulated boundaries.

Permit or Regulatory Program	Description
Multi-Sector General Permit for Storm Water Discharges Associated with Industrial Activity **Montana DEQ**	This permit applies to storm water discharges associated with various categories of industrial, mining, and oil and gas activities as defined in Administrative Rule of Montana 17.30.1102 (29 and 30). Coverage under this permit is obtained through Montana DEQ. Additional details are provided on Montana DEQ's webpage, entitled "MPDES Permits for Storm Water Discharges" (http://deq.mt.gov/Water/WPB/mpdes/stormwater).
Other NPDES Permits – Non-Storm Water General Permits and Individual Permits **Montana DEQ**	Montana DEQ requires coverage under other general and/or individual permits for surface water discharges associated with a variety of activities other than storm water. Examples of such activities include construction dewatering and disinfected water. A list of individual and general permits can be found on Montana DEQ's webpage, entitled "Montana Pollutant Discharge Elimination System" (http://deq.mt.gov/Water/WPB/mpdes#GP).
Circular DEQ 8: Montana Standards for Subdivision Storm Drainage **Montana DEQ**	Circular DEQ 8 defines Montana's minimum standards for subdivision storm drainage and provides guidance for designing and submitting storm drainage plans for subdivision development. Note that some local jurisdictions may have storm drainage standards that are more stringent than the requirements of Circular DEQ 8.
Surface Water Permits **Multiple Agencies**	A Joint Application is required for proposed work in Montana's streams, wetlands, floodplains, and other waterbodies to protect water quality and aquatic habitats. The Joint Application allows applicants to apply for the following local, state, or federal permits: 310 Permit, SPA 124 Permit, Floodplain Development Permit, Section 404 Permit (Clean Water Act), 318 Authorization, 401 Certification, and Navigable Rivers Land Use License, Lease or Easement. Additional information can be found on the Montana Department of Natural Resources and Conservation Stream Permitting webpage (http://dnrc.mt.gov/licenses-and-permits/stream-permitting).
Underground Injection Control (UIC) Program **U.S. Environmental Protection Agency (US EPA)** **Montana Board of Oil and Gas Conservation (MBOGC)**	US EPA has minimum requirements for UIC with respect to Class I to VI injection wells. In Montana, US EPA has primary enforcement authority for Class I and Class III to VI injection wells, while the MBOGC has primary enforcement authority for Class II wells. Generally, BMPs such as infiltration basins will be classified as Class V injection wells (storm water drainage wells) if the basins are deeper than their largest surface dimension. Class V storm water drainage wells are authorized by rule, which means they can operate without an individual permit as long as the injection does not endanger underground sources of drinking water and the owner/operator submits basic inventory information to US EPA. Additional information can be found on US EPA's UIC webpage (https://www.epa.gov/uic/stormwater-drainage-wells).
Section 438 of the Energy Independence and Security Act (EISA) **US EPA**	Section 438 of EISA states that "the sponsor of any development or redevelopment project involving a Federal Facility with a footprint that exceeds 5,000 ft^2 shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to temperature, rate, volume, and duration of flow." In 2009, US EPA issued technical guidance for implementing this provision of EISA (1).
Dam Safety Program **Montana Department of Natural Resources and Conservation (DNRC)**	To build a new dam or alter an existing dam, either of which has an impoundment capacity of 50 acre-feet or more, the owner must apply to the DNRC Dam Safety Program for a hazard classification. Dams classified as *high hazard* and containing over 50 acre-feet of water are required to obtain additional permits from the DNRC Dam Safety Program.

[1] This table is not intended to communicate every potential regulatory requirement. The project owner and/or design professional are responsible for determining the applicable regulatory requirements and associated permits for each individual project.

1.5 Best Practices for Storm Water Management

Modern-day best practices for land development employ various land planning techniques, design practices, and technologies to simultaneously conserve and protect natural resource systems. This multistep storm water management approach uses thoughtful site planning and manages rainfall at its source by using integrated and distributed small-scale BMPs. This approach is also referred to as low-impact development (LID). While this may not be feasible or the preferred approach for every project, nationally, LID is becoming increasingly popular as the standard for storm water management. It is encouraged in Montana's General Permit. As such, considerations for LID have been incorporated into this manual. Table 1-3 identifies some of the more common LID principles, along with their benefits and suggested application. Additionally, LID principles are incorporated into the site development and BMP selection techniques presented in Chapters 2 and 4, respectively.

Every site is unique and should be assessed on a case-by-case basis to determine whether the LID BMP would be feasible or beneficial, given the site's characteristics. Examples of these characteristics include soil infiltration rates, frost depth, local precipitation and hydrology, vegetation suitability, winter maintenance considerations, maintenance responsibilities, and regulatory conflicts. The BMP screening guidance presented in Chapter 4 of this manual may prove helpful when considering the use of LID principles for a given site.

Table 1-3. LID Planning Principles

LID Principle	Example Application	Benefits
Preserve natural site features	Implement designs that preserve features such as wetlands, floodplains, woodlands, riparian areas, and highly permeable soils.	▪ Improved habitat ▪ Reduced storm water runoff ▪ Improved aesthetics
Minimize and disconnect impervious areas	Minimize runoff by using techniques such as permeable pavement systems on sidewalks and parking areas, routing downspouts away from impervious surfaces, and using street layouts that reduce the site's impervious area.	▪ Reduced storm water runoff ▪ Improved water quality ▪ Increased groundwater recharge
Disperse small-scale integrated BMPs throughout the site	Design sites with multiple small BMPs (ponds, bioretention, permeable pavers, etc.) as opposed to one large pond.	▪ Improved aesthetics ▪ Improved water quality ▪ Protect/restore local watersheds
Control storm water as close to its source as possible	Design sites to create many small sub-watersheds and manage runoff close to where it is created in small decentralized structures.	▪ Increased groundwater recharge ▪ Reduced flooding
Create multifunctional landscapes	Create multifunctional landscapes using BMPs that provide filtration, treatment, and infiltration. Design features that function as open space, wildlife habitat, and snow storage areas, in addition to storm water management.	▪ Improved aesthetics ▪ Reduced cost of storm water infrastructure

2 Site Development

2.1 Recommended Site Development Process and Design Approach

As discussed in Section 1.3, the General Permit requires implementation of a program that addresses storm water runoff from new and redevelopment projects that disturb greater than or equal to 1 acre, including projects less than 1 acre that are part of a larger common plan of development or sale and that discharge into a permitted small MS4. The site development process is a key component of this program, which includes elements such as submittal, review, and approval of site plans as well as construction, inspection, and maintenance of BMPs.

Figure 2-1 illustrates a typical pathway through the site development process. The left side of the figure refers to activities or actions undertaken by the local jurisdiction (MS4), and the right side refers to activities and actions by the project owner/applicant. Since each local jurisdiction may have other plan review and inspection procedures and policies that take precedence, the owner/applicant is responsible for identifying and following all applicable local engineering standards that pertain to each phase of design and project implementation. A thorough understanding of the local jurisdiction's engineering standards, submittal requirements, and review process will save significant time, money, and staff resources during design and permitting.

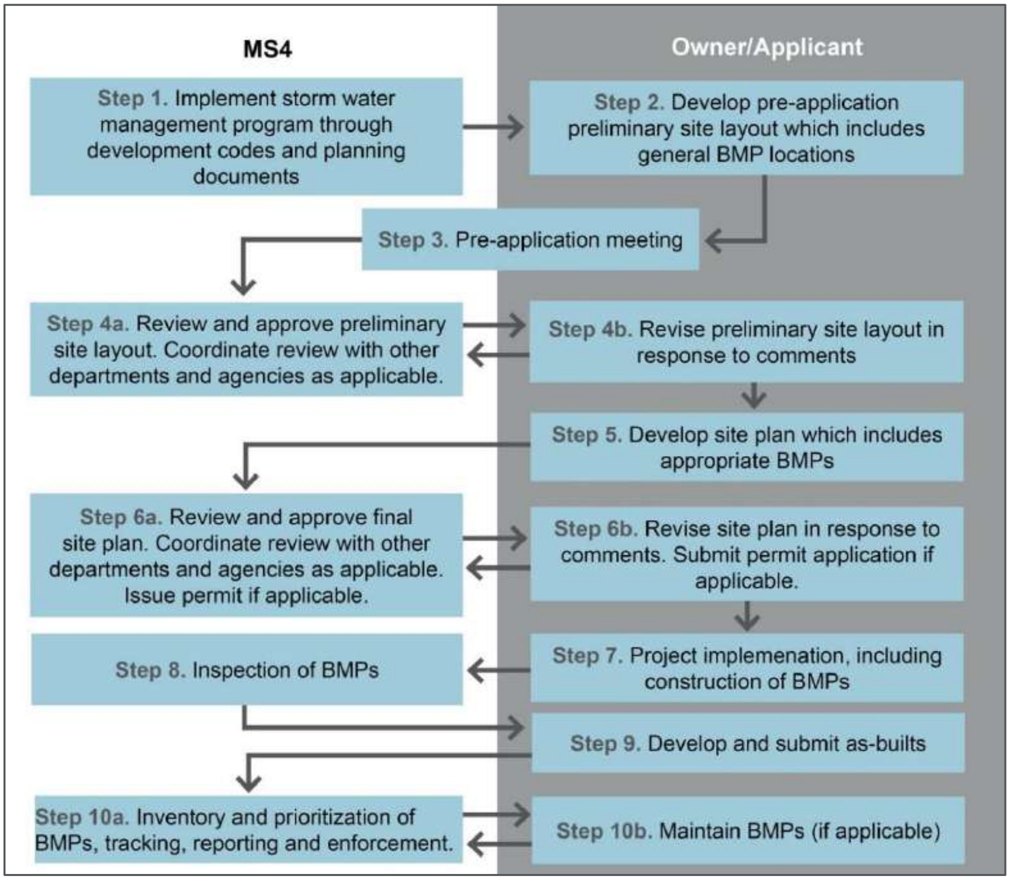


Figure 2-1. Typical Site Development Pathway for Regulated New and Redevelopment Projects
Source: West Virginia Department of Environmental Protection (2)

Note: Figure 2-1 is a typical depiction of the site development process. Local jurisdictions are encouraged to adapt or modify the components of the process in this figure to develop a local site development process that reflects their requirements. The local jurisdiction should also consider how this process will be modified for city-owned developments (e.g., library, city roads).

To effectively address the Post-Construction Performance Standard and other storm water management objectives, consideration of storm water runoff should be integrated into the site planning and design process. The remainder of this chapter provides an overview of the recommended approach to site design, which involves a more comprehensive approach to site planning and requires a thorough understanding of the site's physical characteristics and resources. The three primary phases in this recommended approach are shown in Figure 2-2 and are further illustrated in Figure 2-3. These figures provide an overview of the site planning and design process. Iteration between phases will likely be necessary.

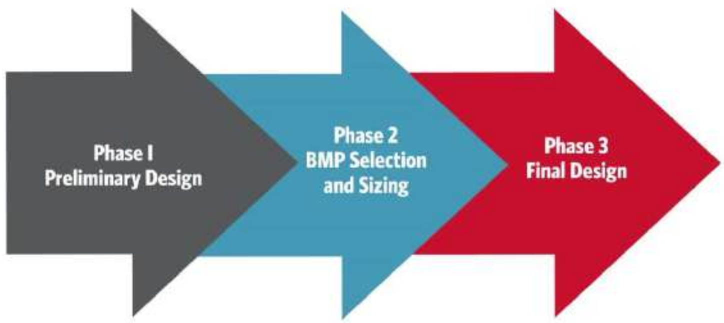


Figure 2-2. Recommended Design Approach Steps

This design approach provides the site planner with an extensive tool kit to develop a site plan that meets the Post-Construction Performance Standard and mitigates negative impacts on receiving waters by managing volume, discharge frequency, and peak flow rates. The remainder of this chapter primarily focuses on the preliminary design phase. Information regarding phases 2 and 3 in this chapter is provided only to the extent necessary for the reader to understand how these steps fit into the overall design process. More details on these phases are described in the subsequent chapters.

Note: To support the long-term success of site designs, a multidisciplinary design team is recommended that includes qualified and experienced professionals in land use planning, landscape architecture, vegetation ecology, geotechnical engineering, soils science, and water resources engineering.

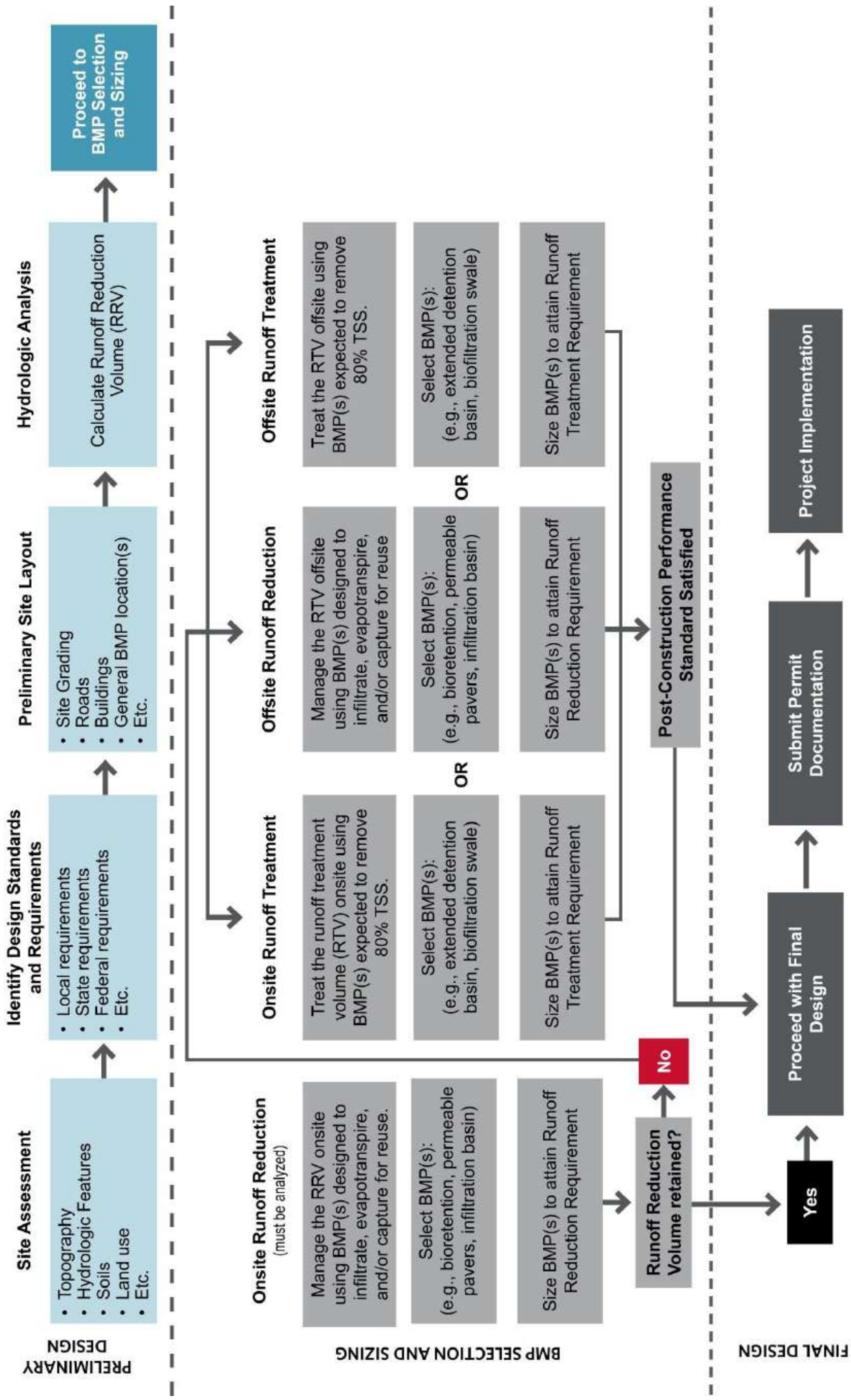
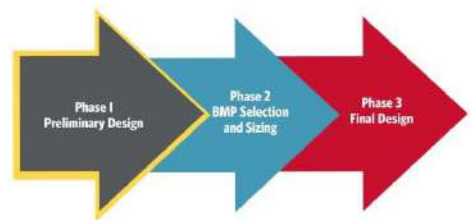


Figure 2-3. Recommended Design Approach Flowchart

2.2 Preliminary Design



The primary objectives of the preliminary design phase are to gather key information and develop a preliminary site layout that considers all the site characteristics and constraints.

2.2.1 Site Assessment

The site development process typically begins with a site assessment that provides information about the site and its surroundings, forming the basis to make decisions about BMP placement and selection. The site assessment should include an inventory and analysis of on- and offsite natural and developed conditions that would affect the project design. Information typically collected during the site assessment includes:

- Topography
- Hydrologic patterns and features
- Soil and geotechnical assessment
- Native vegetation and soil protection areas
- Environmentally sensitive features
- Site access
- Land use controls
- Utility availability and conflicts

The remainder of this section provides details and recommendations for site assessments and documentation of the information to be collected. Since every site will have a unique set of characteristics to be considered, additional information can be added to the list, as necessary (3).

Topography

Understanding the topography of the existing site, surrounding areas, and upgradient areas is important for delineating drainage basins, siting BMPs, and implementing design principles that promote runoff reduction, such as minimizing grading and preserving existing flow paths. The data gathered during this step should be used to create a contributing drainage area map which delineates the offsite runoff flowing to the site and a detailed topographic map of the site and immediate surrounding areas. Depending on local jurisdiction requirements, projects may require a topographic survey prepared by a registered land surveyor.

Hydrologic Patterns and Features

Identifying hydrologic patterns and features such as ponds, wetlands, creeks, and swales allows the designer to determine drainage patterns, evaluate the condition of various drainage features, determine whether they can be incorporated into the project, and select storm water management measures to protect ecologically sensitive areas. It may be necessary to divide the site into multiple subwatersheds, especially if small-scale BMPs will be used to manage storm water runoff.

Soil and Geotechnical Assessment

Understanding the soil and subsurface hydrology is critical to storm water management planning and design. Typically, the goals of the soil and geotechnical assessment are to evaluate the site's feasibility for infiltration and, where appropriate, to determine long-term native soil design infiltration rates. Soil characterization is also important to help specify materials to be used in design. For example, geotextile layers for separation may not be needed on the sides or bottom of excavations for bioretention or permeable pavement if the native site soils are not expected to migrate into the various BMP layers based on grain size distributions.

During the preliminary design phase, obtaining soil data from sources such as the Natural Resources Conservation Service (NRCS) Web Soil Survey may be an appropriate approach to make initial judgments about a site's suitability for infiltration and the placement of site features and BMPs. One key piece of information to be obtained during this phase is the hydrologic soil group (HSG), which provides general information regarding the infiltration rate of the soils, summarized as follows:

- Group A: Low runoff potential, high infiltration rate, well-drained sands and gravels
- Group B: Moderate infiltration rate, well-drained sandy loam and fine to coarse gravels
- Group C: Slow infiltration rate, silty loam and moderately fine to fine texture types
- Group D: High runoff potential, slow infiltration rate, clay and soils with high water table

Detailed onsite geotechnical assessments such as infiltration test pits and soil borings should be conducted as early as possible to determine infiltration rates and depth to groundwater. These assessments should be conducted by a qualified professional such as a certified soil scientist, professional engineer, geologist, hydrogeologist, or engineering geologist. See Appendix C, Evaluating Soil Infiltration Rates, for detailed discussion of recommended methods for evaluating native soil infiltration rates.

Native Vegetation and Soil Protection Areas

Protecting onsite native vegetation and soil helps reduce runoff, increase evapotranspiration, and reduce erosion from the site, which can reduce the size of BMPs necessary to achieve the Post-Construction Performance Standard. Vegetation surveys are recommended to determine baseline conditions, establish long-term management strategies, and determine appropriate application of dispersion techniques if storm water is directed to a protection area.

Environmentally Sensitive Features

It is important to identify environmentally sensitive features early in the design process because these features typically need to be avoided or mitigated, both for habitat protection and permitting reasons. Some of the typical features that should be identified and mapped during the site assessment include wetlands, streams, riparian areas, floodplains, and cultural resources.

Site Access

Vehicular and pedestrian access areas are project elements that should be identified during the site assessment because access can often represent a controlling element for the site's design. Consult the local jurisdiction to determine the street classification and site access requirements, which will identify constraints such as the number of allowed access points, the width of the access, the spacing of access points between sites on the same or opposite side of the adjacent street right-of-way, and pedestrian circulation requirements along and through the site. The designer can use this information to complete the access assessment, which typically includes mapping the location of roads, driveways, and other points of ingress and egress within 50 feet of the site.

Land Use Controls

It is important to understand land use regulations to determine the allowable land uses and development standards for the project site. Coordination with the local jurisdiction's planning department—along with a review of the local planning standards, comprehensive plans, and zoning classifications—will reveal whether land use controls will place limitations on development, such as limits on the amount of impervious surface coverage, minimum landscaping and lot area requirements, setback requirements, parking requirements, and site design standards associated with building placement and orientation.

Utility Availability and Conflicts

The location of wet (e.g., water, sewer, storm water) and dry (e.g., power, phone, cable) utilities should be identified and the adequacy or concurrency of these utilities should be confirmed. Where utilities already exist on the site, easements or other covenants that may stipulate onsite restrictions should be identified and mapped. The county auditor or recorder's office or a title company is often a good source for finding restrictions and easements that may be recorded against the title of the property. Also consider directly contacting the utility purveyors for this information.

If new utilities need to be extended to the site, the designer will need to understand where the utility will come from, and potentially extend to, and the impact that easements and restrictions may have on the site design. Existing utilities and utility easements, including any applicable setbacks, should be mapped on the site plan. Existing utilities that may need to be moved and any new utilities to be extended to the site should also be mapped.

Site Mapping Process

Through the site assessment process, map layers can be produced to delineate important site features. These map layers may be combined to provide a composite site map that guides the layout of streets, structures, and other site features (see Figure 2-4). This composite site map may be used for all development types and will form the basis for the site layout, discussed in Section 2.2.3.

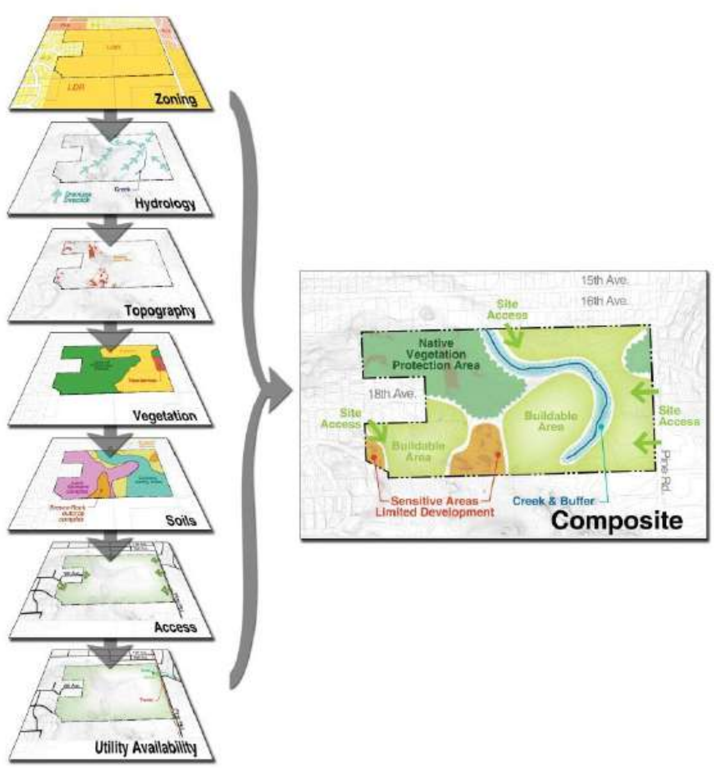


Figure 2-4. Composite Site Map
Source: Courtesy of AHBL, Inc. (3)

2.2.2 Identify Design Standards and Requirements

The next step is identifying and reviewing the local jurisdiction's engineering and development standards and any applicable state and federal requirements that will influence the design. This step typically involves meeting with the local jurisdiction to discuss the proposed project and approach to meeting the standards and requirements. This meeting, often in the form of a pre-application meeting, usually occurs concurrent with the site assessment. Local standards and requirements that may influence site design include:

- Storm water regulations and design standards, including post-construction water quality and flow control requirements
- Setback requirements for infiltration facilities
- Setback requirements for structures
- Soil and subsurface hydrology evaluation and reporting requirements
- Sizing methodologies to be used to demonstrate compliance with applicable storm water requirements
- Street network design standards
- Maintenance agreement requirements for storm drainage systems and BMPs

A list of potential state and federal requirements is provided in Table 1-2 in Chapter 1. During this review of design standards and requirements, the design team should also confirm local jurisdiction requirements for design submittal preparation. By understanding all of the requirements and their relative importance at the start of design process, the team can develop a site plan that efficiently prioritizes and achieves all applicable objectives (3).

2.2.3 Preliminary Site Layout

Developing the preliminary site layout is an iterative process intended to optimize site development and ensure that the site requirements and constraints are considered, including water quality considerations. This process typically takes place after the majority of the site assessment has occurred. Some of the standard content and general guidance to consider when developing a preliminary site layout is provided in this section.

Preliminary Site Layout Content

Local jurisdictions usually have specific requirements for the contents of a preliminary site layout; some of the more standard components are as follows:

- Site grading (existing and proposed topography)
- Roads
- Buildings
- Drainage facilities (conveyance, flood control facilities, maintenance access, and BMPs)
- Recreational areas (parks, trails, etc.)
- Utilities (water, sewer, gas, etc.)
- Parcel boundaries
- Natural resource protection areas (wetlands, floodplains, etc.)

Storm Water Management Strategies

This section identifies strategies that can be employed during the preliminary design phase to promote the natural hydrology. Implementation of such recommendations typically reduces the Runoff Reduction Volume (RRV) (see Section 3.2.1) and results in smaller BMPs (4).

Conserve Existing Site Features

During the preliminary site layout process, identify portions of the site that should be protected or improved. Such areas may include:

- Natural wetlands
- Floodplains
- Steep slopes
- Woodlands
- Wildlife habitats
- Open spaces
- Streams and riparian areas
- Soils with high infiltration rates
- Aquifers and their recharge areas

Some areas are generally legally or logistically unbuildable and therefore must be avoided; consult the local jurisdiction for additional information.

Minimize Impervious Area

Multiple strategies may be used to reduce the site's impervious area. A few options include:

- Consider using cluster development to conserve open space.
- Confine construction traffic to areas where structures, roads, and right-of-ways will exist after construction, which limits compaction of native soils.
- Reduce paved areas and compacted soils.
- Use non-impervious drainage conveyances where appropriate.

Figure 2-5. Permeable Interlocking Concrete Pavers Walkway Application
Source: Courtesy of the City of Bozeman

Permeable interlocking concrete pavers in Bozeman create an aesthetically pleasing walkway and provide storm water management by reducing the effective impervious area.

Strategically Locate BMPs

Consider the following recommendations when selecting locations for BMPs:

- Select BMP areas that promote greater infiltration.
- Where practical, consider combining flood control facilities with water quality BMPs to achieve multiple storm water management objectives.
- BMPs can sometimes be located in areas that promote multiple uses. An example includes permeable surfaces, which may be ideal in areas where space constraints are a concern.

2.2.4 Hydrologic Analysis

The hydrologic analysis is an iterative process that should be initiated during the preliminary site layout step. The delineation of subwatersheds and approximation of impervious areas within each subwatershed provide critical information for this analysis. Once this information has been determined, calculate the RRV using Equation 3-1 in Section 3.2 and the Runoff Treatment Flow (RTF) rate using the procedure described in Section 3.3 for each subwatershed delineated. Each of these values should be recalculated as the site layout is adjusted throughout the design process.

Note: Additional hydrologic analysis will likely be required to address flow control in accordance with the local jurisdiction's requirements (see the local jurisdiction's engineering and development standards).

2.3 BMP Selection and Sizing

Each project has unique design goals and constraints. As such, there is no one-size-fits-all BMP which meets the Post-Construction Performance Standard. Some of the many items that should be considered when selecting a BMP for a given site include land use, target pollutants, performance capabilities, and physical site capabilities. For sites that are not conducive to runoff reduction, documentation of the BMP selection process is important, especially if offsite treatment will be used. For these projects, coordinate with the local jurisdiction to determine whether offsite treatment is allowed and to work through the offsite treatment evaluation process. See Chapter 4 for additional guidance on BMP selection and use of offsite treatment.

Preliminary sizing of BMPs will be necessary to determine if the Post-Construction Performance Standard can be achieved with any given BMP or if several BMPs need to be applied in series, using a "treatment train" approach. The selection and sizing process will likely be iterative because multiple options may need to be considered to determine the most efficient and effective BMP(s) for the site. See Chapter 5 for BMP sizing guidance.

2.4 Final Design

After the preliminary design phase has been completed and the proposed BMPs have been preliminarily sited and sized, the design team should transition to the final design phase. Coordination with the local jurisdiction is recommended prior to beginning the final phase to verify that the preliminary site layout and proposed BMPs adequately address the local jurisdiction's design standards and requirements. Development of a final design for BMPs should include components such as final siting and sizing, landscaping plans, construction considerations, and operation and maintenance considerations. See Chapter 5 for guidance on BMP sizing and final design considerations.

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3 Hydrologic Analysis Methodology

3.1 Hydrologic Basis of the Post-Construction Performance Standard

The overall goals of MCM 5 within the General Permit are to have the hydrology associated with new development reflect the predevelopment hydrology and to improve redeveloped sites' hydrology. Pre-development hydrology, in terms of permit compliance, is defined as the natural conditions where runoff from approximately 90 percent of the annual rainfall is either infiltrated, taken up by plants, or conveyed by shallow subsurface flow (or interflow) to streams and rivers.

Historical rainfall data support the characterization that, on average, 90 percent of the rainfall events occurring across Montana's MS4 areas are 0.5 inches or less; therefore, the General Permit requires that all regulated projects implement BMPs that are designed to infiltrate, evapotranspire, and/or capture for reuse the post-construction runoff generated from the first 0.5 inches of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation (5).

3.2 Runoff Reduction and Runoff Treatment Volume

3.2.1 Runoff Reduction Volume

In accordance with the Runoff Reduction Requirement (see Section 1.3.2), the RRV is the volume of storm water runoff generated from the first 0.5 inches of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation. Montana DEQ requires that when calculating the RRV, at a minimum, designers must use impervious areas from new and redevelopment projects, and including contiguous drainage areas that may contribute storm water (6). Equation 3-1 is recommended to calculate the RRV (7).

$$RRV = \frac{PR_vA}{12} \qquad \text{Equation 3-1}$$

Where:

- RRV = Runoff Reduction Volume (acre-ft)
- P = Water quality rainfall depth (use 0.5 inches)
- R_v = Dimensionless runoff coefficient, $R_v = 0.05 + 0.9(I)$
- I = Percent impervious cover draining to the facility, converted to decimal form
- A = Site drainage area (acres)

3.2.2 Runoff Treatment Volume

The Runoff Treatment Volume (RTV) is defined as the remainder of the RRV that was not infiltrated, evapotranspired, or captured for reuse onsite; hence, this volume must be treated onsite or managed offsite (see Section 1.3). Equation 3-2 is recommended to calculate the RTV.

$$RTV = RRV - V_{i,e,c} \qquad \text{Equation 3-2}$$

Where:

- RTV = Runoff Treatment Volume (acre-ft)

RRV = Runoff Reduction Volume (acre-ft)
$V_{i,e,c}$ = Volume of water infiltrated, evapotranspired, or captured for reuse onsite

3.3 Runoff Treatment Flow Rate

The RTF is the peak flow rate associated with the RRV or RTV, which is used to size flow-based systems such as a biofiltration swale and flow diversion structures for offline storm water management practices. The following procedure is recommended to calculate the RTF. This procedure relies on the volume of runoff computed using Equation 3-1 and uses an adaptation of the NRCS TR-55 Graphical Peak Discharge Method (7). Users are encouraged to refer to TR-55 for more discussion on procedures and limitations.

Step 1: Determine the Runoff Curve Number

Determine the NRCS Runoff Curve Number (CN) using Equation 3-3, which is derived from the CN method described in Chapter 2 of TR-55:

$$CN=\frac{1000}{\left[10+5P+10Q-10(Q^2+1.25QP)^{1/2}\right]}$$ Equation 3-3

Where:

CN = Runoff Curve Number
P = Rainfall depth (use 0.5 inches)
Q = Runoff depth (watershed inches)

Compute the runoff depth (Q) in watershed inches using Equation 3-4:

$$Q=\frac{RRV*12}{A}$$ Equation 3-4

Where:

A = Total area (acres)

> Note: The RTV should be used in place of the RRV in Equation 3-4 in cases where a Runoff Treatment BMP will be used.

Step 2: Calculate Time of Concentration

The time of concentration (t_c) is the time it takes for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed. Water generally flows through a watershed as sheet flow (overland), shallow concentrated flow, open channel flow, or some combination of these. The minimum t_c is 5 minutes, even when the calculated t_c is less than 5 minutes.

Time of Concentration

A component of t_c is travel time (T_t), which is the time it takes water to travel from one location to another in a watershed. T_c is computed by summing all the travel times for consecutive components (that is, sheet flow, shallow concentrated flow, and open channel) of the drainage conveyance system, as shown in Equation 3-5:

$$t_c=T_{t_1}+T_{t_2}+. . . T_{t_m}$$ Equation 3-5

Where:

t_c = Time of concentration (hrs)

m = Number of flow segments

Travel time for sheet flow is calculated directly using Equation 3-7. For shallow and open channel flow, travel time is calculated based on the ratio of flow length to flow velocity using Equation 3-6:

$$T_t = \frac{L}{3600 * V} \qquad \text{Equation 3-6}$$

Where:

T_t = Travel time (hrs)

L = Flow length (ft)

V = Average velocity (ft/sec)

3600 = conversion factor from seconds to hours

Sheet Flow

Sheet flow is shallow flow over land that usually occurs in the uppermost portion of a watershed and occurs for very short distances in urbanized conditions. The maximum allowable sheet flow is 300 feet; however, most sheet flow distances will be shorter. Calculate the sheet flow travel time using Equation 3-7:

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}} \qquad \text{Equation 3-7}$$

Where:

T_t = Sheet flow travel time (hrs)

n = Manning's roughness coefficient (see Table B-1 in Appendix B)

L = Flow length (ft)

P_2 = 2-year, 24-hour rainfall (in) (refer to local jurisdiction for rainfall depths)

s = Slope of hydraulic grade line (land slope, ft/ft)

Shallow Concentrated Flow (i.e., Street Gutter Flow)

After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow. Calculate the average velocity for this flow using Equation 3-8 or Equation 3-9, depending on the watercourse slope and type of channel. After determining average velocity, use Equation 3-6 to estimate travel time for the shallow concentrated flow segment.

Unpaved: $V=16.1345*(s)^{0.5}$ Equation 3-8

Paved: $V=20.3282*(s)^{0.5}$ Equation 3-9

Where:

V = Average velocity (ft/sec)

s = Slope of hydraulic grade line (watercourse slope, ft/ft)

Open Channel Flow and Pipe Flow

The velocity in open channels and pipes can be determined using Manning's equation if the shape, flow depth, slope, and channel type are known. Channels can be in either natural or improved conditions. Calculate the velocity for open channel flows using Equation 3-10. After determining average velocity, use Equation 3-6 to estimate travel time for the open channel and/or pipe flow segments.

$$V=\frac{1.49}{n}R^{2/3}\sqrt{S} \qquad \text{Equation 3-10}$$

Where:

V	= Average velocity (ft/sec)
n	= Manning's roughness coefficient (see Table B-2 in Appendix B)
R	= Hydraulic radius (ft)
S	= Slope of the channel (ft/ft)

> Note: The hydraulic radius, R, depends on the depth of flow in the channel or pipe. The depth of flow associated with the RTF should initially be assumed, and should be confirmed upon final calculation of the RTF.

Step 3: Calculate RTF

The RTF is computed using the following procedures, based on Chapter 4, "Graphical Peak Discharge Method," of TR-55.

- Calculate the initial abstraction (I_a) using Equation 3-11.

$$I_a=0.2*\left(\frac{1000}{CN}-10\right) \qquad \text{Equation 3-11}$$

- Compute the ratio I_a/P where P = 0.5 inches.
- Use the calculated values for t_c and I_a/P to read the unit peak discharge (q_u) from TR-55 Exhibit 4-I or Exhibit 4-II as recommended by the local jurisdiction (see Appendix B). Accuracy of peak discharge estimated by this method will be reduced if I_a/P values are used that are outside the range given in Exhibit 4-I or Exhibit 4-II. In such cases, the limiting I_a/P values are recommended for use.
- Compute the RTF using Equation 3-12:

$$RTF=q_uAQ \qquad \text{Equation 3-12}$$

Where:

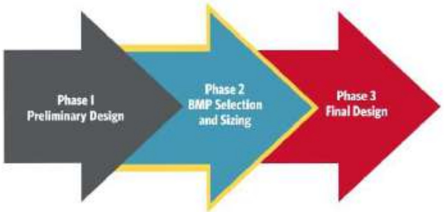
RTF	= Runoff treatment flow rate (cfs)
q_u	= Unit peak discharge (cfs/mi^2/inch)
A	= Drainage area (mi^2)
Q	= Runoff depth (in watershed inches) (see Equation 3-4)

3.4 Flood Control

Flood protection controls are designed based on a design storm with a specific return frequency that is identified by local regulating jurisdictions. Generally, a 10- or 25-year return design storm is used to size storm drainage infrastructure and a 100-year return design storm is used to address upstream and downstream flooding, including restrictions and backwater conditions. Coordinate with the local jurisdiction for flood control regulations and associated hydrologic analysis procedures (8).

4 Selection of Post-Construction BMPs

4.1 BMP Selection Process



The selection of suitable BMPs for any given project is based on a review of the available BMPs, their performance capabilities and design criteria, and screening factors such as physical site constraints, treatment objectives, aesthetics, safety, maintenance requirements, and cost. The guidance provided in this chapter builds on the preliminary design phase discussed in Chapter 2 and is based on the presumption that the designer has already conducted a site assessment (Section 2.2.1) and identified the design standards and requirements (Section 2.2.2) for the project.

As discussed in Chapter 1, the General Permit requires that all regulated new and redevelopment projects use onsite runoff reduction to satisfy the Post-Construction Performance Standard. In cases where this cannot be achieved, the remainder of runoff must be addressed using one of the following approaches, listed in the order of priority for selection: (1) treated onsite prior to discharge using BMPs expected to remove 80 percent of TSS; (2) managed offsite within the same subwatershed using BMPs that are designed to infiltrate, evapotranspire, and/or capture for reuse; or (3) treated offsite within the same subwatershed using BMPs expected to remove 80 percent TSS (see Figure 4-1).

The selection of BMPs, regardless of the option selected, should include a feasibility analysis to verify that the selected BMP will safely and efficiently meet performance objectives. The remainder of this chapter discusses the types and functions of BMPs available for use, along with the recommended screening factors that should be reviewed when selecting a BMP for a given site.

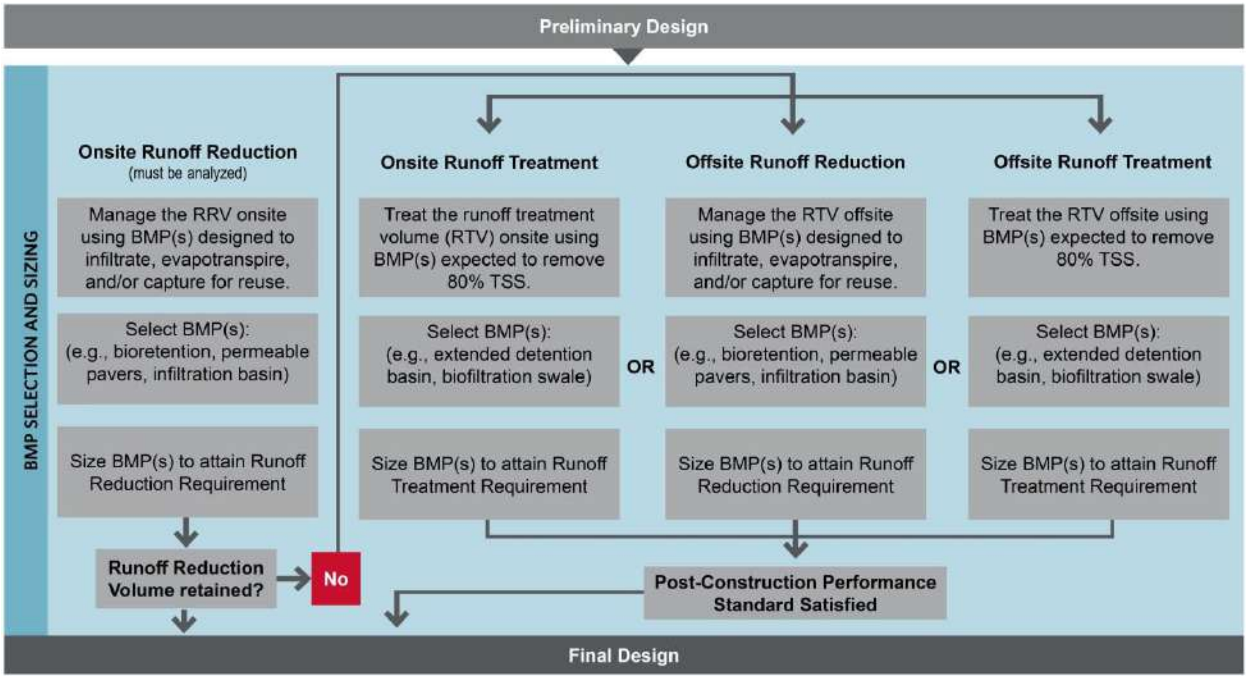


Figure 4-1. BMP Selection and Sizing Flow Chart

4.2 Types and Functions of BMPs

No one-size-fits-all BMP exists. In particular, the types of treatment provided by a BMP and how BMPs receive runoff can vary. This section introduces the primary functions of BMPs associated with this manual, differentiates the two ways in which BMPs can receive runoff, and defines the pollutant removal processes by which BMPs provide treatment.

4.2.1 Primary Function

The BMPs addressed in this manual have been placed into one of two categories, based on the primary function they provide: runoff reduction or runoff treatment. For the purposes of this manual, these terms are defined as follows:

- **Runoff Reduction**: Implementation of a BMP (or series of BMPs) designed to infiltrate, evapotranspire, or capture for reuse the RRV.
- **Runoff Treatment**: Implementation of a BMP (or series of BMPs) expected to remove 80 percent TSS from the RTV.

4.2.2 Online Versus Offline BMPs

Storm water BMPs can be designed as either online or offline facilities. Online BMPs are designed to intercept and manage all runoff generated from the contributing watershed. They provide treatment for the RRV or RTV, and any additional runoff from larger storms is conveyed through an outlet structure and/or overflow spillway. Offline BMPs are designed to receive only a portion of the runoff generated from the contributing watershed. A flow regulator (diversion structure, flow splitter, etc.), located upstream of the BMP, intercepts all the contributing runoff and then diverts a specified volume or flow rate, such as the RRV or RTV, to the BMP, while the remaining volume of runoff bypasses the BMP (9).

Note: Use of online BMPs in a natural drainage way may be discouraged or prohibited by the local jurisdiction or applicable regulatory entities. Early coordination with applicable regulatory personnel is highly recommended when considering the use of an online BMP in a natural drainage way.

4.2.3 Pollutant Removal Process

Some BMPs remove pollutants from runoff through a variety of physical, chemical, and biological processes. The pollutant removal processes associated with a BMP dictate which pollutants the BMP will be effective at removing. Primary processes include biological uptake, filtration, infiltration, density separation, and sorption. For sites subject to the Post-Construction Performance Standard, the primary objective of BMPs is to remove gross solids and suspended sediment. For meeting these treatment goals, BMPs that provide the following processes are effective: filtration, infiltration, and density separation. When other pollutants are targeted, such as dissolved metals, other processes such as biological uptake and adsorption/absorption may be necessary. Table 4-1 provides a brief overview of the more common physical, chemical, and biological processes by which the BMPs remove pollutants (10). This table will be useful for MS4 program managers when considering management strategies in areas that discharge to an impaired waterbody and will aid designers when selecting BMPs for sites located upstream of impaired waterbodies.

Table 4-1. Storm Water Pollutant Removal Processes

Removal Process	Description and Pollutants Affected	BMPs
Biological Uptake	**Definition:** Broadly referred to as the transfer of pollutants from runoff by plants or microbes; can include evapotranspiration. **Pollutants**: hydrocarbons, nutrients, metals, organics, biological oxygen demand (BOD), particulate chemical oxygen demand (COD)	▪ Bioretention ▪ Dispersion ▪ Biofiltration swale ▪ Wet detention basin
Chemical Transformation	**Definition:** Process by which pollutants react with other compounds to change structure and are removed from the runoff. **Pollutants:** nitrogen (ammonia, nitrate, nitrite), organics, hydrocarbons	▪ Bioretention ▪ Biofiltration swale
Filtration	**Definition:** Straining of pollutants by passing storm water through a media (sand, natural soil, vegetation, etc.) finer than the target pollutants. **Pollutants:** solids, pathogens, particulate nutrients, particulate metals, BOD, particulate COD	▪ Bioretention ▪ Permeable surfaces ▪ Biofiltration swale ▪ Mechanical treatment[1]
Infiltration	**Definition:** Pollutant reduction is achieved through runoff volume reduction, such as infiltrating storm water through existing soils below the surface grade. **Pollutants:** solids, pathogens, nutrients, metals, organics, BOD, particulate COD	▪ Infiltration basin ▪ Bioretention ▪ Permeable surfaces[2] ▪ Dispersion
Density Separation	**Definition:** Uses density differences between pollutants and storm water for removal. This includes sedimentation and flotation. Sedimentation is the gravitational settling of solids denser than water. Alternatively, floatation is removal of those lighter than water. **Pollutants:** sediment, solids (particulates associated with other pollutants such as nutrients and metals), oil (hydrocarbons), BOD, particulate COD	▪ Biofiltration swale ▪ Extended detention basin ▪ Wet detention basin ▪ Mechanical treatment
Sorption	**Definition:** Includes adsorption and absorption. Absorption occurs when a substance of one state is incorporated into another substance of a difference state (that is, liquids being absorbed by solids). Adsorption is the adherence or bonding of a pollutant onto the surface of media or soil particles. **Pollutants:** dissolved phosphorus, dissolved metals, oil (hydrocarbons), and organics	▪ Bioretention ▪ Dispersion

Source: West Virginia Department of Environmental Protection (11)
[1] *Some proprietary treatment BMPs use filtration. See Section 5.9 for more information.*
[2] *Permeable surfaces use infiltration when there is not an underdrain system. See Section 5.4 for more information.*

4.3 Screening Factors

Screening factors are characteristics and constraints of the project site and surrounding areas that should be reviewed to help evaluate which BMPs are suitable for use. This section discusses some of the screening factors that should be reviewed and considered during the BMP selection process.

4.3.1 Land Use

The first screening factor in BMP selection is identifying the land use from which the BMP will receive runoff. This is because typical land use characteristics can provide the designer with important information, such as the pollutants to be expected in storm water runoff from the site and design strategies and limitations that should be considered. This section provides a general description of each land use, along with strategies and limitations for BMP selection (11).

Rural

- Rural development consists of low-density projects generally occurring on lot sizes of greater than 1/3 acre. Impervious cover is typically widely dispersed, and a significant portion of the acreage is usually either forested, turf grass, vegetated open space, and/or used for agriculture.
- Rural lands are typically well-suited for minimization of impervious areas and small-scale vegetated BMPs such as bioretention, dispersion, and biofiltration swales.

Residential

- Residential development consists of medium- to high-density developments generally occurring on lot sizes of less than 1/3 acre. The land cover includes areas with a mixture of houses, paved areas, and vegetation.
- Limitations on selection and siting of BMPs are typically related to traffic safety, large storm conveyance, and lack of available space for pretreatment. Also, BMPs may need to be located close to residences, where public safety, nuisance insects, and maintenance access are common concerns.

Commercial Development

- Commercial developments can consist of a wide variety of lot sizes and land cover characteristics. They often contain a high percentage of impervious cover.
- BMP selection and siting considerations vary depending on the size and type of commercial development.

Industrial Development

- Industrial areas are often dominated by impervious or semi-impervious (gravel) surfaces. Runoff generated in these areas often has the highest and most variable concentrations of certain pollutants compared with other land uses.
- Limitations on BMPs are generally based on the potential for storm water hotspots. For instance, infiltration-based BMPs are often prohibited in certain industrial areas because of the potential for groundwater contamination. Additional discussion on storm water hotspots is provided in Section 4.3.4.

Local Roads

- Local roads are developed within linear corridors that vary in size depending on the extent of the project. Land cover generally consists of impervious areas and grass right-of-way. Roads typically generate higher storm water pollutant loads, most of which is generated from vehicles (oil, grease, brake dust, etc.) and winter sanding and/or deicing activities.
- BMPs such as biofiltration swales and bioretention areas are often suitable, given their ability to have a linear footprint and fit within the right-of-way. In some cases, it may be necessary to use a conveyance system to route flows to a larger BMP such as an extended detention basin or wet detention pond.

4.3.2 Storm Water Management Objectives

Often, multiple objectives are identified to manage storm water runoff from a new or redevelopment project. Three objectives common to storm water management in Montana's MS4 areas include meeting the Post-Construction Performance Standard, providing treatment for specific pollutants, and addressing flood control requirements. When selecting BMPs, it is important to understand the storm water management objectives specific to the project and consider whether certain BMPs will help or hinder the ability to meet those objectives. The following sections summarize the three primary objectives.

Post-Construction Performance Standard

- The ability to meet the Post-Construction Performance Standard—either through runoff reduction or runoff treatment—is a key consideration when selecting BMP(s) for a given site.
- Chapter 5 provides information on BMPs that can be designed, operated, and maintained to meet the Post-Construction Performance Standard.

Treatment of Specific Pollutants

- Areas that drain to a sensitive receiving waterbody may have requirements related to treatment of specific pollutants within storm water runoff. For instance, wet detention basins can raise the water temperature of storm water runoff prior to discharge and, therefore, should be avoided if discharging directly to waterbodies listed as impaired for temperature.
- Table 4-3 provides a brief overview of pollutant removal capabilities for the BMPs presented in this manual.

Flood Control

- Flood control is an important consideration when designing a site and selecting BMPs.
- Given space constraints or other site-related factors, it may be beneficial to combine water quality BMPs with flood control facilities.

4.3.3 Physical Site Characteristics

Physical site characteristics, such as contributing drainage area and the native soil's infiltration capabilities, are critical screening factors when determining whether a BMP will be able to meet the desired objectives. For instance, infiltration-based BMPs will have a high probability of failure if sited on soils that are not conducive to infiltration. Therefore, it is important for the designer to consider, identify, and document any physical constraints at the project site that may restrict or preclude the use of a particular BMP. Most physical site characteristics will be identified during the site analysis step discussed in Chapter 2. A brief summary of site characteristics that should be considered is discussed below; however, additional details specific to each BMP discussed in this manual are addressed in Sections 5.2 to 5.9.

Contributing Drainage Area

- Contributing area is defined as the total area, including pervious and impervious surfaces, contributing to a BMP. This screening factor reflects the recommended minimum and/or maximum drainage area that is considered optimal for a given BMP.
- The maximum allowable contributing drainage area for each BMP should be decreased when higher-than-normal pollutant loads are expected or may be increased when lower-than-normal pollutant loads are expected.
- The contributing drainage area used for final sizing and design calculations must be determined from the final grading plan.

Soil Characteristics

- The primary soil characteristic to be considered during the screening process is the infiltration rate of the soils on site.
- Determining the infiltration rate is a critical factor in determining the feasibility of runoff reduction BMPs because implementing such BMPs on soils not conducive to infiltration will most likely result in failure of the BMP.

- Obtaining the HSG information from the NRCS Web Soil Survey is typically sufficient for initial screening of BMPs; however, confirmation of infiltration rates is required prior to final design when the use of infiltration-based BMPs is proposed.

Depth to Groundwater and/or Bedrock

- Depth to groundwater or bedrock is defined as the distance measured from the bottom or floor of the BMP to the seasonal high water table or bedrock formation.
- Shallow water tables may lead to BMP failure, significant maintenance concerns, and/or contamination of groundwater. Designers must be careful not to “remove” pollution through a system with the potential to adversely affect groundwater.
- Shallow bedrock may limit the constructability of all BMPs and the effectiveness of infiltration practices.
- Depth to groundwater may be initially estimated using the NRCS Web Soil Survey, local records, Montana Bureau of Mines and Geology studies, or historic data. When limited information exists or shallow groundwater is likely, field observations should verify the depth to groundwater for final design. Consult the local jurisdiction for additional information regarding groundwater investigation requirements.

Site Topography

- Site topography refers to the land slopes within the nearby drainage area of the BMP. This screening factor reflects the potential effect of topographic influences on the functionality of a BMP.
- Steep slopes increase the potential for erosion, resulting in increased pollutants draining to the BMP. If not properly accounted for during design and construction, this can result in increased maintenance or failure of the BMP.
- The topography in the immediate vicinity of a BMP affects both the ability of water to flow through a BMP and the site’s retention capacity.
- Topographic information may be obtained using online resources such as U.S. Geological Survey topographic maps for preliminary design purposes, but should be surveyed on site for final design.

4.3.4 Special Storm Water Management Areas

Special storm water management areas are those that possess certain on- or offsite (downstream) characteristics that would limit the use of certain BMPs given their potential negative effect on the immediate or surrounding areas. This section provides a general description of four special storm water management areas and considerations for BMP selection in these areas.

Karst Geology

- Karst is a dynamic landscape formed by the dissolution of soluble bedrock such as limestone or dolomite. Karst geology is often associated with sinkholes, springs, caves, and a highly irregular soil-rock interface (11).
- BMPs that store and/or infiltrate runoff that are located within karst geology have the potential to promote sinkhole formation and to threaten the integrity of the BMP and nearby structures (11).
- Karst geology provides rapid pathways for water to travel from the surface to the groundwater, creating a risk of groundwater contamination (12).

- If the presence of Karst is suspected, a detailed site investigation, including a subsurface materials investigation, should be conducted. Specific site and BMP design considerations must be employed in areas of karst geology.

Sensitive Receiving Waterbodies

- Sensitive receiving waterbodies are particularly sensitive to certain pollutants in runoff because of the harmful effect that the pollutant(s) have on the waterbodies ability to support certain uses. Examples include impaired waterbodies, cold-water fisheries, and high-quality wetlands.
- Developments that drain to a sensitive receiving waterbody often require additional measures to protect or restore the waterbodies unique properties.
- Consulting the State's 303(d) list (impaired waterbodies) and the local jurisdiction's storm water master plan or watershed plan is often a good starting place to identify BMP design considerations and limitations for specific watersheds and/or receiving waterbodies.

Storm Water Hotspots

- Storm water hotspots are areas that produce higher concentrations of pollutants than is normally found in urban runoff. Examples include gas stations, vehicle maintenance/repair areas, and auto recyclers.
- When selecting a BMP for an area that receives runoff from a storm water hotspot, it is important to quantify the BMP's ability to provide treatment for the expected pollutants. For instance, the use of infiltration-based BMPs often poses the risk of groundwater contamination when used to provide treatment for storm water hotspots.
- Oftentimes, the entire project area may not be a hotspot; therefore, the designer may choose to isolate hotspot areas with BMPs designed to handle the expected pollutants (11).

Water Supply Areas

- Water supply areas include locations near water supply wells and within source water protection areas. Designers should be aware of any design limitations or restrictions for projects located in or near these areas.
- Setback requirements can vary based on project location and the local jurisdiction's standards; however, minimum setback requirements have been established by the State of Montana through ARM 17.36.323. Table 4-2 briefly summarizes these requirements.

Table 4-2. Minimum Setback Requirements from ARM 17.36.323

From	To	Horizontal Setback Distance (ft)[1]
Storm water ponds and ditches	Drinking water wells	25[2]
	Sealed components and other components	10
	Drain fields/soil absorption systems	25

[1] Local jurisdiction may have more stringent standards.
[2] The setback is 100 feet for public wells, unless a deviation is granted under ARM Title 17, Chapter 38, Subchapter 1.

4.3.5 Maintenance

Routine and proper maintenance is essential for long-term effectiveness of all BMPs. Even when BMPs are correctly designed and installed, they will likely become eyesores and cease to function if not properly maintained. Because maintenance requirements vary for different BMPs, maintenance must be considered during the BMP design and selection process. A brief summary of maintenance items that should be considered during the BMP selection process is discussed below; however, additional details specific to each BMP discussed in this manual are addressed in Sections 5.2 to 5.9 (10).

Compatibility with the Project Owner's Maintenance Capabilities

- Each BMP requires certain equipment and skills to conduct proper maintenance. For instance, sediment removal will be a common maintenance requirement for BMPs which have a sediment forebay.
- When selecting a BMP, it is important to consider who will conduct the long-term maintenance on the BMP and assess whether the project owner/operator has the correct maintenance equipment, necessary skills, and is in agreement with the required maintenance schedule.

Vegetated BMPs

- Vegetated BMPs such as bioretention and biofiltration swales require special care to maintain the functionality of the BMP.
- When planning to use vegetated BMPs, the maintenance frequency and need for specialized training often varies depending on the type(s) of vegetation selected for use. For example, the designer should consider whether vegetation will require supplemental irrigation throughout the growing season and verify that the project owner/operator will irrigate and maintain the vegetation.

Figure 4-2. Vegetation in Urban Bioretention Area
Source: HDR

This urban bioretention area will require considerable maintenance to sustain healthy vegetation. It is important to consider maintenance and vegetation management requirements when selecting and designing BMPs.

Accessibility

- Access must be considered because it is critical that all BMPs be accessible for inspections and maintenance.
- When selecting and siting a BMP, consider what type of equipment will be needed to conduct the required maintenance activities and the frequency at which the maintenance will be conducted. Large BMPs such as extended detention basins will require both regular access for equipment such as lawnmowers and less frequent access for large equipment to remove accumulated sediment from the main treatment cell.
- Difficult access situations, including those with safety concerns, must also be considered. These include BMPs close to buildings and high traffic areas (13).

4.3.6 Community Factors

Considering community screening factors such as safety and aesthetics helps the designer consider whether a BMP is well-suited for the general project area. This section describes two community factors that should be considered during the BMP selection process (13).

Safety

- Consideration of safety will help to determine whether certain BMPs pose a safety risk to the surrounding community.
- Safety considerations often include the potential for a drowning hazard due to the deep water associated with BMPs such as wet detention basins.
- Safety hazards can sometimes be mitigated by the addition of project features such as a fence around a pond and trash racks on outlet structures.

Aesthetics

- For some projects, aesthetics is an important screening factor, particularly if the community or project owner requests that storm water facilities blend in with the existing or proposed landscape.
- In these cases, the surrounding land use and users should be considered when selecting and designing a BMP. For example, considering whether the BMP will be visible and assessing who will see the BMP may help the designer determine which BMP(s) may be suitable.
- When designing and/or selecting a BMP to be aesthetically appealing, it is of utmost importance that functionality and maintainability are not compromised.

Figure 4-3. Urban Bioretention
Source: HDR
This bioretention facility is an example of a multifunctional facility with several functions including storm water management, plant habitat, and aesthetics.

Table 4-3. BMP Summary Table

BMP	Primary Function		Pollutant Removal Considerations						Site Applicability			
	Runoff Reduction[1]	Runoff Treatment[2]	TSS[3]	Total Phosphorus	Total Nitrogen	Temperature	Metals	Fecal Coliform	Contributing Drainage Area	Soil Characteristics	Depth to Groundwater and/or Bedrock	Maximum Site Slope
Infiltration Basin	✓		Preferred	Preferred	Preferred	Preferred	Preferred	Preferred	0 to 50 acres	HSG A or B	3-foot minimum	5%
Bioretention	✓[4]		Preferred	Avoid	Avoid	Preferred	Preferred	—	2.5 acres or less	Applicable to most soil types	*Infiltration:* 3-foot minimum *No infiltration:* 1-foot minimum	5%
Permeable Pavement Systems	✓		Preferred	Preferred	Preferred	Preferred	Preferred	Preferred	2:1 ratio	Applicable to most soil types	*Infiltration:* 3-foot minimum *No infiltration:* 1-foot minimum	6%
Dispersion	✓		Preferred	Preferred	Preferred	Preferred	Preferred	Preferred	Limit sheet flow to 150 feet	Applicable to most soil types	3-foot minimum	Low to Moderate
Biofiltration Swale		✓	Preferred	—	—	—	—	—	5 acres or less	Applicable to most soil types	1-foot minimum	Low to Moderate
Extended Detention Basin		✓	Preferred	—	—	Avoid	—	—	5 acres to 1 square mile	Applicable to most soil types	2-foot minimum	15%
Wet Detention Basin		✓	Preferred	Preferred	—	Avoid	—	—	10 acres minimum	Low infiltration rates preferred	No restrictions	25%
Proprietary Treatment Devices		✓	Varies for different units						Varies for different units			

[1] *BMP is expected to infiltrate, evapotranspire, or capture for reuse the RRV when designed, operated, and maintained as described in this manual.*
[2] *BMP is expected to remove 80 percent TSS from the RTV when designed, operated, and maintained as described in this manual.*
[3] *TSS is the only pollutant regulated in the General Permit.*
[4] *Runoff treatment may be the primary function in cases where an underdrain is required.*
[5] *Additional research is necessary in cases when pollutant removal considerations are not provided.*

4.4 Cold Climate Considerations

Storm water management facilities in Montana are subject to cold climate conditions in the winter, requiring special considerations when selecting, siting, and designing BMPs. This section discusses some of the BMP selection and design considerations associated with cold climates.

4.4.1 Design Challenges

Cold climates present multiple design challenges that, if not accounted for, can detrimentally affect the structural integrity, performance, and maintainability of BMPs. Some of the primary issues encountered when selecting, siting, and designing BMPs for cold climate conditions can include high pollutant concentrations within snowmelt runoff; operational challenges resulting from ice, cold water, and decreased biological activity; and challenges related to sand and/or deicing materials. Table 4-4 summarizes some of the additional design challenges that should be considered and mitigated when designing BMPs in cold climates.

Table 4-4. Cold Climate Design Challenges

Cold Climate Characteristics	BMP Design Challenge
Cold temperature	▪ Pipe and/or outlet structure freezing ▪ Ice formation on permanent pools ▪ Reduced biological activity ▪ Reduced oxygen levels during ice cover ▪ Reduced settling velocities
Deep frost line	▪ Pipe freezing ▪ Reduced soil infiltration ▪ Frost heaving
Short growing season	▪ Reduced time period to establish vegetation ▪ Selection of appropriate plant species for cold climates
Significant snowfall	▪ High runoff volumes during snowmelt and rain-on-snow ▪ High pollutant loads during spring melt ▪ Impacts from road salt/deicers ▪ Snow management may affect BMP storage capabilities

Source: Adapted from Caraco and Claytor (14)

4.4.2 BMP Siting, Design, and Operations Adaptations

Each of the design challenges presented in Table 4-4 will have varying solutions depending on the type of BMP being implemented, the expected amount of snowfall, the severity of cold temperatures, and the surrounding land use that will drain to the BMP. While each designer should consider these items and apply appropriate mitigating techniques, some general siting, design, and operations strategies are provided as follows:

- **Careful Site Selection**: When possible, consider placing BMPs in areas where they will not receive immediate runoff from roads that receive high concentrations of sand and/or gravel. A common method to address this is placing filter strips or dispersion areas along roadways to promote settling of sand and gravel prior to runoff entering a BMP (15).

Figure 4-4. Snow on Storm Drain Inlet
Source: Courtesy of the City of Missoula
Snow storage planning can help reduce the amount of pollutants discharged into the storm drain system.

- **Careful Plant Selection and Placement**: When vegetated BMPs will be subject to runoff from roads, salt-resistant plants should be used. Plant placement should also be considered if BMPs are located near roadways that will be plowed during the winter because piles of ice and snow can damage vegetation (15).
- **Snow Storage Planning:** If dedicated snow storage areas will be incorporated into a new or redevelopment project, consider placing such areas on pervious surfaces where a portion of the runoff will be infiltrated or directing runoff from these areas to pretreatment BMPs such as vegetated filter strips or swales prior to entering a BMP that is more difficult to clean (for example, an infiltration basin or wet detention pond).
- **Perform Timely Maintenance Activities**: Perform maintenance activities such as street sweeping as soon as the spring melt has occurred, which will help to limit the amount of debris carried into BMPs and the storm drain conveyance system (15).

4.5 Offsite Treatment Planning Guidance

Offsite treatment is a storm water management approach in which regional BMPs strategically located within a subwatershed are sized to manage runoff from multiple projects that drain to the facility (see Figure 4-5). For this manual, offsite treatment BMPs are defined as regional facilities designed to manage storm water runoff from multiple development projects located within the same subwatershed. This process is typically managed by the local jurisdiction, where individual project owners may assist in financing the regional BMP. This section discusses the General Permit's requirements regarding offsite treatment and considerations for evaluating the offsite treatment option (9).

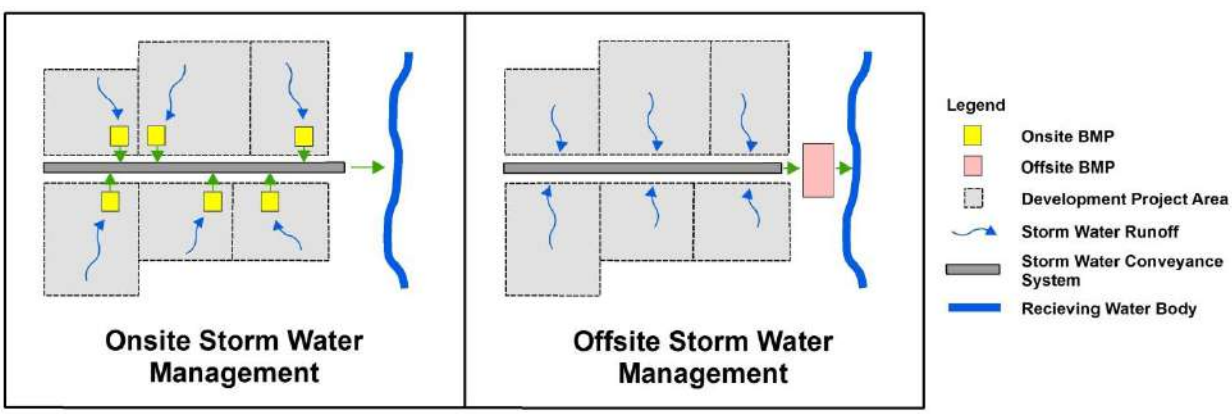


Figure 4-5. Onsite Versus Offsite Storm Water Management

4.5.1 Offsite Treatment Evaluation

As described in Section 1.3, offsite treatment is an option which may be employed to attain the Post-Construction Performance Standard only when it meets the offsite treatment eligibility criteria defined by the local jurisdiction. Subsequently, if offsite treatment is to be used, an evaluation must be conducted that documents the evaluation of both onsite and offsite storm water management options (hereby referred to as an Offsite Treatment Evaluation).

According to the General Permit, each MS4 has the latitude to develop its own criteria and evaluation process for assessing the feasibility of onsite BMPs to determine the circumstances under which offsite treatment may be allowed. The following tools are provided in this manual to assist both MS4 program managers and designers in determining the feasibility of BMPs:

- Site selection guidance is provided for each BMP in Sections 5.2 to 5.9.
- A template for an Offsite Treatment Evaluation Form is provided in Appendix E.

4.5.2 Advantages and Disadvantages of Offsite Treatment

The use of offsite treatment has both advantages and disadvantages that should be understood when considering this option for storm water management. Some of the advantages and disadvantages are discussed below (9).

Advantages of Offsite Treatment BMPs

- **Cost Effective**: Regional BMPs are often more cost-effective than onsite BMPs because it is more efficient and less expensive to build, operate, and maintain one large facility compared with several small BMPs.
- **Consolidated Maintenance**: It is typically easier to track and accomplish maintenance requirements for one large regional BMP than it is for multiple small BMPs located throughout a watershed.
- **Higher Probability of Maintenance**: Regional BMPs are often more likely to be properly maintained when compared with onsite BMPs because they are large and have a higher visibility, and are typically the responsibility of the local jurisdiction.
- **Potential Integration with Flood Control**: Pairing water quality BMPs with flood control facilities can be an effective use of space in situations where a local jurisdiction takes a regional approach to flood control through the use of large regional detention basins.
- **More Effective Treatment Capabilities**: Some sites are not conducive to onsite BMPs (because of high groundwater, geotechnical concerns, etc.). In these cases, regional BMPs are often safer and/or more effective at reducing pollutants in runoff.

Disadvantages of Offsite Treatment BMPs

- **Disruption of Natural Hydrology**: Infiltration or treatment of storm water close to its source is a way to mimic predevelopment hydrology and to attempt to maintain or restore natural conditions. The use of regional BMPs disrupts this process.
- **Potential Location and Siting Difficulties**: Regional BMPs usually require a large amount of contiguous space and, therefore, can be difficult to site, especially for large facilities or in areas with existing development.
- **High Capital Costs**: It can often be difficult to fund a regional BMP because of the large amount of capital required for initial construction. The matter is complicated by fact that the facility must be completed prior to development of the full upstream area.

- **Need for Planning**: The implementation of regional BMPs requires substantial planning, financing, and permitting; each of which must be in place ahead of future projected growth.

4.5.3 Important Considerations for the Use of Regional BMPs

The use of regional BMPs requires significant planning. Many items must be considered so that the system functions properly, treatment objectives are met, and environmental concerns are addressed. Some of the items that should be considered are discussed below (9).

- The conveyances between the individual upstream developments and the regional facility must be able to handle the design peak flows and volumes without causing adverse environmental impacts or property damage. In the event that natural waterways are used for conveyance to the facility (as opposed to facilities such as storm drains), upstream BMPs may be required to protect the natural drainage way and additional permitting requirements may apply (see Table 1-2).
- An analysis must be conducted to verify that the Post-Construction Performance Standard will be achieved for the proposed new and/or redevelopment project(s) in the BMP's drainage area. Full build-out conditions that account for the projected future land use within the BMP's drainage area are recommended for use in the design analysis; however, in cases where this is not done, a procedure should be set in place to assess the regional facility's ability to manage runoff from future development in the drainage area.
- A funding analysis should be conducted to determine how the facility will initially be paid for, how future maintenance will be paid for, and what fees will be applied to projects draining to the BMP.
- Siting and designing regional BMPs should be done within the context of storm water master planning or watershed planning.
- It is highly recommended that online regional BMPs be avoided because of environmental issues and permitting complexities.

Note: Design of offsite treatment BMPs must account for the current and future conditions of the entire drainage area—not just the project site. The BMPs presented in Chapter 5 of this manual are applicable to offsite treatment only when the current and future conditions of the entire drainage area are accounted for. This manual does not include technical guidance on partial onsite or offsite treatment or partial use of the Runoff Reduction Requirement and Runoff Treatment Requirement.

5 Design Guidance for Post-Construction BMPs

5.1 Introduction

This chapter provides guidance for design, construction, and maintenance of a number of BMPs that can be used at new and redevelopment sites to meet the Post-Construction Performance Standard. The guidance presented in this chapter is based on information from multiple storm water management manuals and resources from across the United States, while accounting for items such as Montana's MS4 General Permit requirements and cold climate considerations. This chapter includes the following BMPs:

Section 5.2 – Infiltration Basin

Section 5.3 – Bioretention

Section 5.4 – Permeable Pavement Systems

Section 5.5 – Dispersion

Section 5.6 – Biofiltration Swale

Section 5.7 – Extended Detention Basin

Section 5.8 – Wet Detention Basin

Section 5.9 – Proprietary Treatment Devices

Each BMP section contains the following information:

- **Description**: An overview of the characteristics and function of the BMP.
- **Performance**: The expected performance of the BMP with respect to meeting the Post-Construction Performance Standard (see Section 1.3 of this manual). This section describes the BMP's potential effectiveness in meeting either the Runoff Reduction Requirement or Runoff Treatment Requirement.
- **Site Selection**: Items to consider when evaluating a potential site for locating the BMP. Additional site selection guidance is also provided in Chapter 4.
- **Design and Sizing Procedure**: Guidance and procedures to be used in conjunction with the hydrology calculations in Chapter 3 to properly size and design the BMP.
- **Vegetation Considerations**: Guidelines for considering, evaluating, and selecting vegetation.
- **Construction Considerations**: Suggestions and considerations for construction.
- **Maintenance**: An outline of recommended protocols for maintaining the BMP.
- **Plan View and Typical Details**: Example plan view drawings and typical details.

> Note: The BMP functions presented in this chapter may include runoff reduction, runoff treatment, and combined water quality/flood control; however, while this manual references flood control aspects of storm water management, that is not its intended use. Some of the BMPs identified in this chapter may be designed to provide flood control benefits, but they should be used in conjunction with appropriate flood control design guidance and floodplain management measures.

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5.2 Infiltration Basin

Figure 5.2-1. Infiltration Basin
Source: HDR

Description
A constructed basin designed to collect and retain storm water runoff so that it can infiltrate into underlying soils. These facilities remain dry between runoff events and often have permanent vegetation ranging from grass to small shrubs.

Primary Components	Primary Function
▪ Inlet structure ▪ Pretreatment ▪ Infiltration cell ▪ Overflow outlet structure (optional)	☑ Runoff reduction ☐ Runoff treatment

Benefits	Limitations
▪ Effective method for achieving the Runoff Reduction Requirement within large drainage basins ▪ Provides groundwater recharge ▪ Mimics pre-development hydrology	▪ Not suitable for sites containing soils with low permeability ▪ Susceptible to clogging by sediment and organic debris if proper pretreatment measures are not employed ▪ May not be suitable for industrial sites or locations where spills could occur

Design and Site Selection Considerations	
☑ Setbacks	☐ Underdrain
☑ Depth to groundwater or bedrock	☐ Facility liners
☑ Soil permeability	☑ Landscaping/planting
☑ Soil preparation/amendments/compost	☑ Fencing
☑ Pretreatment	☑ Size of contributing drainage area
☐ Inlet and outlet spacing	☑ Area required
☑ Energy dissipater/level spreader	☑ Incorporate flood control

TMDL Considerations			Maintenance Requirements
Avoid	Preferred		
☐	☑	Total suspended solids (TSS)	☑ Access roads or pullouts
☐	☑	Total phosphorus	☑ Sediment removal
☐	☑	Total nitrogen	☑ Irrigation
☐	☑	Temperature	☑ Vegetation management
☐	☑	Metals	☑ Erosion and embankment stabilization repair
☐	☑	Fecal coliform	☐ Specialized equipment and training

5.2.1 Description

An infiltration basin is an above ground earthen impoundment that uses the natural filtering ability of soils to remove pollutants in storm water runoff. Storm water runoff is retained in the basin with the only means of emptying being through evapotranspiration and infiltration. Infiltration basins have high pollutant removal efficiencies and can help recharge groundwater.

The primary characteristics of an infiltration basin are as follows:

- An infiltration basin consists of an inlet structure, pretreatment BMP(s), an infiltration cell, and an optional outlet structure.
- The recommended maximum drawdown time for the design volume is 72 hours. Storage in excess of 72 hours may result in both water quality and mosquito breeding issues.
- An infiltration basin can be designed to provide both runoff reduction and flood control.

5.2.2 Performance

Runoff Reduction

An infiltration basin is expected to infiltrate 100 percent of the RRV when designed, operated, and maintained as described in this manual.

Runoff Treatment

An infiltration basin is designed to infiltrate the entire RRV from a contributing drainage area; therefore, runoff treatment is not applicable.

5.2.3 Site Selection

Basic guidelines are provided below to aid in evaluating whether infiltration basins are feasible for use at an individual site.

Contributing Drainage Area

- Infiltration basins are best suited for sites with a contributing drainage area of less than 50 acres.
- This guidance assumes that, in most cases, impervious surfaces will constitute more than 50 percent of the contributing drainage area and that most of this impervious area is directly connected. The recommended maximum contributing area to an infiltration basin may be increased if pervious surfaces constitute the majority of the contributing drainage area and soils are highly permeable (HSG A or B).
- It is recommended that contributing drainage areas have a maximum 5:1 ratio of impervious area to infiltration area (16).

Soil Characteristics

- Native soils should have an infiltration rate such that the facility is capable of infiltrating the design volume in a maximum of 72 hours (or in accordance with local jurisdiction requirements).
- Soil characteristics can initially be estimated from NRCS soil data, but must be field verified prior to final design using the onsite soil investigation methods discussed in Chapter 2 and Appendix C of this manual.

- A minimum of two soil profile pits are recommended within the infiltration cell area to confirm its ability to function as designed. Consult the local jurisdiction for soil assessment requirements.
- Infiltration basins should only be sited on natural, uncompacted soils.

Depth to Groundwater and/or Bedrock

- A minimum vertical distance of 3 feet is recommended between the bottom of the infiltration basin and the seasonal high water table or bedrock layer (16).
- An evaluation of the depth to groundwater should be conducted, as described in Section 4.3.3.

Site Topography

- Infiltration basins should be located on relatively flat areas, and the grade immediately adjacent to the basin (within 15 to 20 feet) should be less than 5 percent to limit erosion, but greater than 1 percent to promote flow toward the basin.
- The area of the facility intended for siting of the infiltration cell should be as level as possible to uniformly distribute runoff.
- If steep grades are present throughout a project site, the basin can be split into multiple cells with adequate conveyance between the cells to take advantage of relatively flat areas.
- Unless slope stability analyses demonstrate otherwise, basins should be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20 percent (17).

Land Use and Considerations of Surrounding Area

- Use caution when placing infiltration basins in drainage areas that produce high sediment or trash/debris loads because such loads may cause clogging (17).
- Infiltration basins located above sloped areas may result in shallow lateral flow (interflow) that can re-emerge and negatively affect down-gradient structures. For these sites, an assessment of the impact on down-gradient structures is recommended.
- Consider minimum setback requirements, as discussed in Section 4.3.4.

Community and Environmental Considerations

- Infiltration basins should be avoided at locations where storm water runoff could pose a risk of groundwater contamination (i.e., storm water hotspots) (17).
- Safety concerns may be associated with standing water as an infiltration basin drains. Section 5.2.4 provides guidance and recommendations for designing basin depths and side slopes that may help alleviate safety concerns. Consult the local jurisdiction for fencing requirements.
- Opportunities may be available for an infiltration basin to be located within or near multiuse facilities such as parks and open space.

5.2.4 Design and Sizing Procedure

The following steps outline the design procedure and criteria for an infiltration basin.

1. Infiltration Cell Volume

The infiltration cell is the primary component of the facility where storm water runoff is captured, treated, and released through infiltration. Design the infiltration cell volume to be 100 percent of the RRV. Determine the RRV using the guidance provided in Section 3.2. Additional sizing requirements are as follows:

- Calculate the maximum basin depth for the design infiltration rate using Equation 5.2-1. For highly permeable sites, the calculated maximum basin depth may be greater than the maximum depth permitted by the local jurisdiction. Coordinate with the local jurisdiction for additional details.

$$D_{max}=\frac{i}{2}*t_d \qquad \text{Equation 5.2-1}$$

Where:

D_{max} = Maximum depth of the infiltration cell (in)

i = Field-verified infiltration rate for the native soils (in/hr)

t_d = Maximum draw down time (hrs)

Note: *For design purposes, the field-tested subgrade soil infiltration rate (i) is divided by 2 within Equation 5.2-1 as a factor of safety to account for potential compaction during construction and to approximate long-term infiltration rates.*

- Calculate the infiltration bed area using Equation 5.2-2.

$$A=\frac{V}{D} \qquad \text{Equation 5.2-2}$$

Where:

A = Infiltration cell bottom area (ft^2)

V = Infiltration cell volume (ft^3)

D = Design depth of the infiltration cell (ft)

Note: *The entire RTV is assumed to be instantaneously ponded within the infiltration basin.*

Infiltration Basin Minimum Design Criteria[1]

Required Components
☑ Inlet structure ☑ Pretreatment ☑ Infiltration cell ☑ Overflow outlet structure or spillway (only if facility is designed to accommodate flood control flows)
Design and Sizing
General ☑ Infiltration cell is sized for 100% of RRV (minimum) ☑ Provide maintenance access ☑ Provide a landscaping plan ☑ Provide an operations and maintenance plan
Pretreatment forebay (if applicable) ☑ Volume is 10% of RTV (minimum) ☑ Depth between 4–6 feet ☑ Hard bottom ☑ Provide maintenance access ☑ Armored barrier or berm separating pretreatment forebay and infiltration cell
Infiltration cell ☑ 72-hour drain time for the RRV (maximum)

[1] This table presents the minimum design criteria for satisfying the Runoff Reduction Requirement as defined in Section 1.3.2 of this manual.

2. Inlet and Conveyance

Design the infiltration basin so that the inlet discharges into a pretreatment facility. The inlet locations should be designed to dissipate flow energy to limit erosion and promote particle sedimentation. Infiltration basins may be constructed as either offline or online systems; see Section 4.2.2 for additional guidance.

3. Pretreatment Forebay

Pretreatment facilities are an important component of an infiltration basin because they protect the infiltration cell from the build-up of trash, solids, and particulate matter. A pretreatment forebay is recommended at each major inlet to allow larger particles to settle out prior to discharging flows to the infiltration cell. Guidance for forebay sizing and design are as follows:

- Maximize the length of the flow path through the forebay and minimize the slope to encourage settling.
- Provide a depth between 4 and 6 feet with a volume equal to 10 percent of the RRV.
- A barrier separating the pretreatment forebay and infiltration cell should be constructed to contain the forebay opposite of the inlet. If the barrier is an earthen berm, a minimum top width of 8 feet and side slopes no steeper than 4:1 are recommended. The barrier should be armored with material such as gabions, concrete, or riprap.
- It is recommended that a level spreader be provided in the transition area between the pretreatment forebay and infiltration cell to enable even distribution.
- A concrete bottom is recommended to facilitate sediment removal during maintenance.
- Provide a way to monitor sediment accumulation. Options include a metered rod within the forebay or concrete lining that defines sediment removal limits.

4. Infiltration Cell Shape

Basin side slopes should be stable and gentle to facilitate maintenance and access. 4:1 (H:V) or flatter side slopes are preferred to allow for conventional maintenance equipment and for improved safety and aesthetics. Side slopes should be no steeper than 3:1 (H:V); however, local design standards should be consulted to confirm the maximum allowable slopes. Using walls is discouraged because of maintenance constraints.

5. Infiltration Cell Bottom

The bottom of the infiltration cell should be as flat as possible to enable even distribution and infiltration of storm water. Lateral slopes should have a 0 percent grade and longitudinal slopes should range from 0 to 1 percent. It is not recommended to use any type of filter fabric on the bottom of the basin because this could reduce infiltration rates and possibly clog the practice entirely (17).

6. Outlet Structure (Optional)

An infiltration basin may be designed as part of an online, combination system that provides both water quality and flood control for storm water runoff. In such cases, an outlet structure will be required to attenuate flood flows. General outlet structure design guidance is provided in Section 5.8.4, in the Outlet Structure subsection, and guidance specific to an infiltration basin is as follows:

- Design the outlet structure to manage flows greater than the RTF (or greater than the design infiltration capacity if infiltration capacity is larger than the RTF).

Figure 5.2-2. Infiltration Basin with Outlet Structure
Source: HDR

- The lowest weir or orifice elevation should be above the water surface elevation associated with the RRV so that the infiltration process is not bypassed.
- The structure must be designed so that outflow velocities are non-erosive.

7. Embankment and Overflow Spillway

Infiltration basins are typically constructed with an overflow spillway designed to safely convey excess flows through the facility. Design guidance for the overflow spillway and embankment is as follows:

- If the embankment falls under the jurisdiction of Montana DNRC, it must be designed to meet the applicable requirements (Table 1-2).
- Embankment soils should be compacted as determined by a licensed engineer.
- Slopes that are 4:1 (H:V) or flatter are preferred to allow for conventional maintenance equipment and for improved safety, maintenance, and aesthetics.
- Locate the overflow spillway at a point where waters can best be conveyed downstream.
- Design spillway structures and associated freeboard in accordance with applicable state or local regulations.
- In accordance with the local jurisdiction's design standards, materials such as concrete, riprap, or articulated concrete block mats may be necessary to mitigate the potential for erosion and failure of the spillway during less frequent events.

8. Maintenance Access

Consideration of maintenance access during the design phase of an infiltration basin is critical because it will facilitate long-term performance of the facility. Guidelines for the design of maintenance access are as follows:

- Provide appropriate maintenance access to the pretreatment facility, infiltration cell, basin bottom, and outlet structure if one is present. For larger basins, this typically means stabilized access designed to withstand the expected loads from maintenance vehicles.
- Stabilized access typically includes materials such as concrete, articulated concrete block, concrete grid pavement, or reinforced grass pavement.
- If stabilized access is not provided, a maintenance plan that provides detail, including recommended equipment, on how trash and debris will be removed from the basin may be required by the local jurisdiction.

9. Guidelines for Incorporating Flood Control

Infiltration basins can be designed to provide flood control by increasing the basin volume for flood detention storage and designing the outlet structure to detain and release flood flows. Appropriate flood control design guidance and local regulations should be referenced when incorporating flood control into an infiltration basin.

5.2.5 Vegetation Considerations

Vegetation is crucial because it provides erosion control and enhances site stability. Developing a landscaping plan for the infiltration basin and surrounding area is required to indicate how the infiltration basin will be stabilized and established with vegetation. Considerations when developing the vegetation and landscaping plan are as follows:

- Keep adjacent vegetation from forming an overhead canopy above the infiltration basin. This prevents litter, fruits, and other vegetative material from clogging the facility (16).

- The use of sod is not recommended over the infiltration cell bottom. For designs that call for a grass cover over the infiltration cell bottom, seeding and use of biodegradable erosion control matting are recommended (17).
- Stabilize and plant the interior of the infiltration basin as well as the surrounding embankments, spoil areas, borrow areas, and other disturbed areas using native plant species. Without healthy vegetation, the surface soil pores will quickly clog.
- Salt-resistant vegetation should be used in locations where adjacent salt application is probable, such as roadsides and parking lots.
- Schedule planting and seeding activities during optimal growing seasons.
- Determine the location and type of irrigation facilities, if necessary. Where possible, place irrigation heads outside the infiltration cell bottom because irrigation heads can become buried with sediment over time.
- The infiltration basin should not be operated until vegetation is established.

Note: Given the wide range of native vegetation across Montana, designers should consult local specialists, landscape architects, and/or agencies for recommendations on appropriate plant species and landscaping considerations for the site.

5.2.6 Construction Considerations

Basic construction considerations and guidelines are provided below.

Construction Site Management

- Acquire all applicable permits prior to construction. See Section 1.4 for more information.
- Apply appropriate erosion control measures to minimize erosion during construction.
- Siting a construction storm water BMP within the location of an infiltration basin is discouraged; however, if this approach is used, excavation for the construction storm water BMP should be at least 2 feet above the final design elevation of the infiltration cell bottom.
- Conduct the initial excavation to within 1 foot of the final elevation of the infiltration cell bottom. Defer the final excavation to the finished grade until all disturbed areas within the contributing drainage area are stabilized or protected with BMPs. The final phase of excavation should remove all accumulated sediment.
- Contributing drainage areas should be properly stabilized with the appropriate erosion and sediment controls or permanent seeding before allowing storm water runoff to drain to the infiltration basin.
- To avoid excessive compaction, prevent construction equipment and vehicles from traveling over the proposed location of the infiltration cell. Excavation and construction of the infiltration cell should be performed using equipment placed outside the limits of the infiltration cell.
- If compaction occurs during construction, consider tilling the infiltration cell to a depth of at least 18 inches below subgrade. This technique has been shown to increase infiltration and reduce compaction from construction activities (16).
- Post-construction testing may be required by the local jurisdiction to ensure that the design drain time has been achieved.

Construction Inspection

- Inspections are recommended during the following phases of construction:
  - Pre-construction meeting

  - Initial site preparation
  - Excavation/grading
  - Implementation of the vegetation and landscaping plan
  - Final inspection
- Inspectors should be familiar with project plans and specifications to ensure the contractor's interpretation of the plans are consistent with the designer's intent. The inspectors should take frequent photos and notes of construction activities and features as work progresses and at all critical points during the construction process. Check dimensions and depths of all installed materials, and all materials and products should be verified or tested for conformance with the specifications (16).

Transition to Post-Construction

- Impervious area construction should be completed and pervious areas should be established with vegetation prior to introduction of storm water into an infiltration basin.
- Coordinate with the local jurisdiction prior to terminating coverage of the Construction General Permit.

5.2.7 Maintenance

Maintenance is required on all BMPs. Recommended maintenance activities are provided in Table 5.2-1, which may be used as a guide when developing a maintenance plan. Additionally, an example inspection form is provided in Appendix F that may be adapted or adopted as part of the maintenance plan.

Table 5.2-1. Recommended Maintenance Activities for an Infiltration Basin

Activity	Frequency
▪ Remove litter/debris from all components of the infiltration basin. ▪ Repair structural components including inlets, diversion structures, and outlet structure (if applicable). ▪ Inspect the basin for signs of erosion and repair eroded areas accordingly. Perform spot-reseeding if necessary. ▪ Observe drain time following rainfall events to determine if the facility is clogged. If the observed drain time is longer than the local jurisdiction's allowable maximum drain time, corrective action must be taken to return the infiltration basin to the design drain time. ▪ Regularly manage all vegetation associated with the infiltration basin and remove all clippings. ▪ Repair maintenance access routes, if applicable.	As needed
▪ Trim vegetation for aesthetics and to prevent the establishment of woody vegetation that may drop leaf litter, fruits, and other vegetative material that may clog the facility. ▪ Remove all green waste and dispose of properly to prevent clogging.	Semiannually
▪ Inspect all components of the infiltration basin in accordance with an approved inspection form in accordance with local jurisdiction requirements. An example inspection form is provided in Appendix F. ▪ Remove sediment from inlets, pretreatment facilities, diversion structures, and overflow structures (if applicable).	Annually

5.2.8 Considerations for Use of Subsurface Infiltration Facilities

The guidance provided within the subsections above is specific to above ground infiltration basins; however, subsurface infiltration facilities may also be designed and constructed to achieve the Post-

Construction Performance Standard. A subsurface infiltration facility stores storm water runoff beneath the ground surface and slowly releases the runoff through the underlying, uncompacted soil. Examples of these facilities include a vault, large-diameter perforated pipes, and/or boulder pits.

While subsurface infiltration facilities have similar performance capabilities and site selection constraints, there are design, construction, and maintenance criteria that differ from an above ground infiltration basin. Subsurface infiltration facilities are common throughout certain areas of Montana; however, designers should consult the local jurisdiction to determine whether they are allowed. Consultation with the local jurisdiction and use of appropriate guidance materials should be adhered to for the design and implementation of underground infiltration facilities. Basic considerations for subsurface infiltration facilities are discussed as follows (18).

Pretreatment for Subsurface Infiltration Basins

- Pretreatment is recommended for all subsurface infiltration facilities to prevent clogging.
- Contact the local jurisdiction to discuss acceptable pretreatment BMPs.

Component Requirements for Subsurface Infiltration Basins

- Filter fabric is recommended along the top and sides of a subsurface infiltration facility to prevent the migration of fine particles from the surrounding soil, unless the basin is enclosed in an impermeable structural housing. Filter fabric should not be used along the bottom of the facility because it may result in a reduced infiltration rate.
- Any aggregate used in a subsurface infiltration facility must be free from debris, silt, or other material that could contribute to clogging.

Access Requirements

- Where applicable, at least one inspection access point that extends into the facility should be provided to monitor functionality. The location of the inspection point must be shown in the maintenance plan. Additionally, the maximum design volume depth should be marked on the structure and its level included in the design report and maintenance plan.
- All points of access must also be covered to prevent sediment or other material from entering the facility and to prevent the accumulation of standing water, which could lead to mosquito breeding.

5.2.9 Plan View and Typical Details

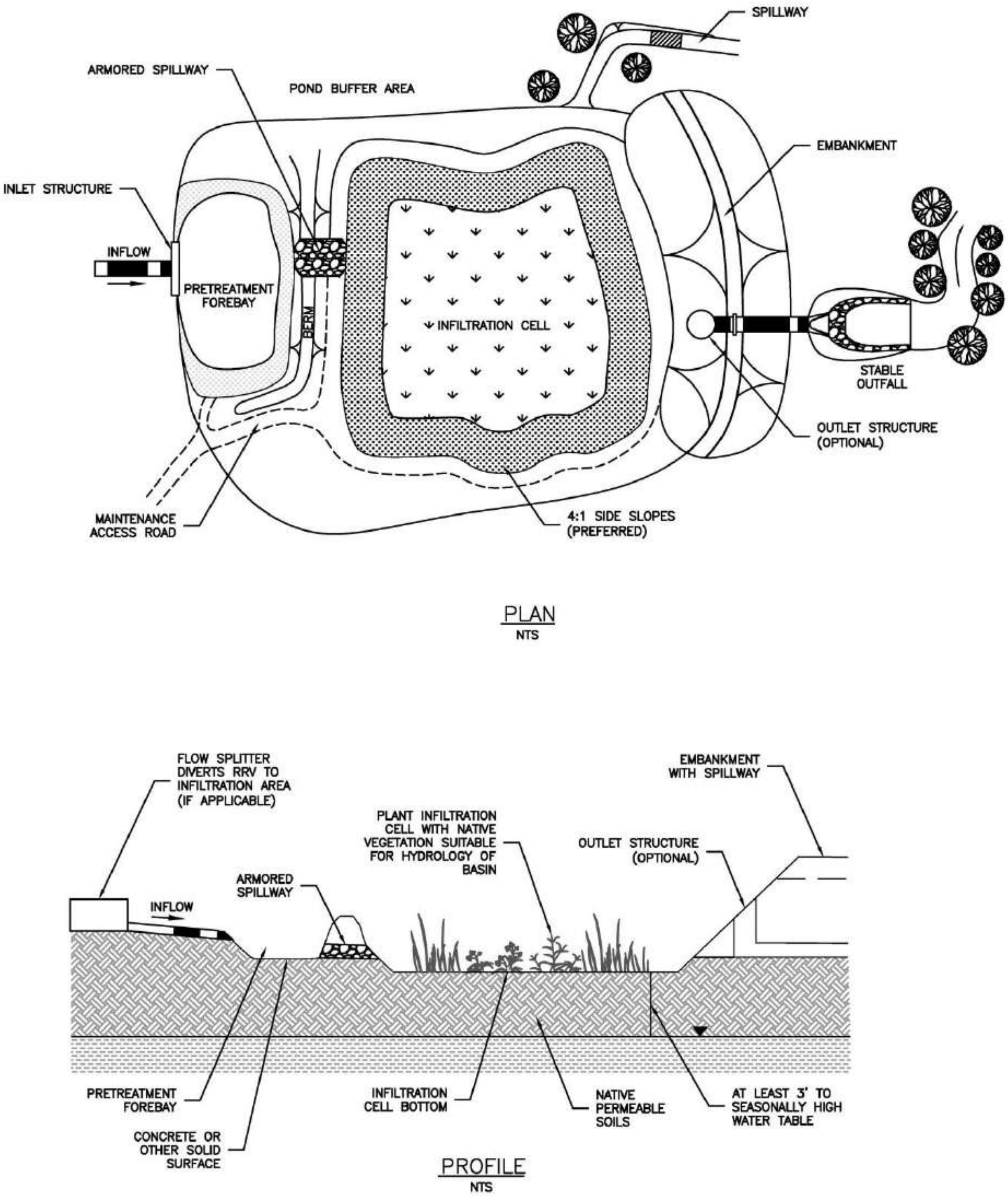

Figure 5.2-3. Infiltration Basin Plan View and Typical Section
Source: Adapted from Minnesota Stormwater Manual (19)

5.3 Bioretention

Figure 5.3-1. Bioretention Area
Source: Courtesy of the City of Bozeman

Description
Bioretention areas are shallow, landscaped depressions that capture and infiltrate or filter storm water runoff through plants, an engineered soil media, and often an underdrain.

Primary Components	Primary Function
▪ Inlet ▪ Pretreatment ▪ Surface ponding area ▪ Bioretention soil media ▪ Bioretention plants ▪ Underdrain (optional)	☑ Runoff reduction ☑ Runoff treatment

Benefits	Limitations
▪ Siting is generally not limited by native soils; design accommodations can be made for most soil types ▪ Dimensions are flexible, allowing this BMP to fit various site conditions ▪ Good retrofit capability	▪ Not recommended for contributing drainage basins greater than 2.5 acres ▪ Not recommended in developing or erosive watersheds given the potential for high sediment loads that can clog the BMP ▪ Not recommended for sites with steep slopes

Design and Site Selection Considerations	
☑ Setbacks	☑ Underdrain (optional)
☑ Depth to groundwater or bedrock	☑ Facility liners (optional)
☑ Soil permeability	☑ Landscaping/planting
☑ Soil preparation/amendments/compost	☐ Fencing
☑ Pretreatment forebay	☑ Size of contributing drainage area
☑ Inlet and outlet spacing	☐ Area required
☑ Energy dissipater/level spreader	☑ Incorporate flood control

TMDL Considerations[1]			Maintenance Requirements
Avoid	Preferred		
☐	☑	Total suspended solids (TSS)	☑ Access roads or pullouts
☑	☐	Total phosphorus	☑ Sediment removal
☑	☐	Total nitrogen	☑ Irrigation, if applicable
☐	☑	Temperature	☑ Vegetation management
☐	☑	Metals	☐ Erosion and embankment stabilization repair
☐	☑	Fecal coliform	☑ Specialized equipment and training

[1] TMDL considerations listed are for facilities with an underdrain. Bioretention is preferred for all pollutants when using a full infiltration section.

5.3.1 Description

Bioretention facilities are vegetated, shallow landscaped areas that capture and temporarily store storm water runoff. Runoff is directed into the bioretention area and then treated by the interaction of plants, engineered soil media, and microorganisms. The treated runoff is either infiltrated or returned to the down gradient conveyance system via an underdrain.

The primary characteristics of bioretention areas are as follows:

- Bioretention areas usually consist of a pretreatment facility, surface ponding area, surface cover, bioretention soil media, optional underdrain, and overflow outlet.
- The recommended maximum drawdown time for the design volume is 48 hours. Storage in excess of 48 hours may result in both maintenance and mosquito breeding issues.
- Depending on site characteristics, bioretention areas can be designed to provide runoff reduction, runoff treatment, and/or flood control.

> Note: Bioretention areas differ slightly from rain gardens in that they typically have a larger drainage area and may also have an underdrain.

5.3.2 Performance

Runoff Reduction

When located on soils that are conducive to infiltration, bioretention areas are expected to infiltrate 100 percent of the RRV when designed, operated, and maintained as described in this manual.

Runoff Treatment

Bioretention areas are expected to achieve an 80 percent or greater removal rate of TSS from the RTV when designed, operated, and maintained as described in this manual (20) (21).

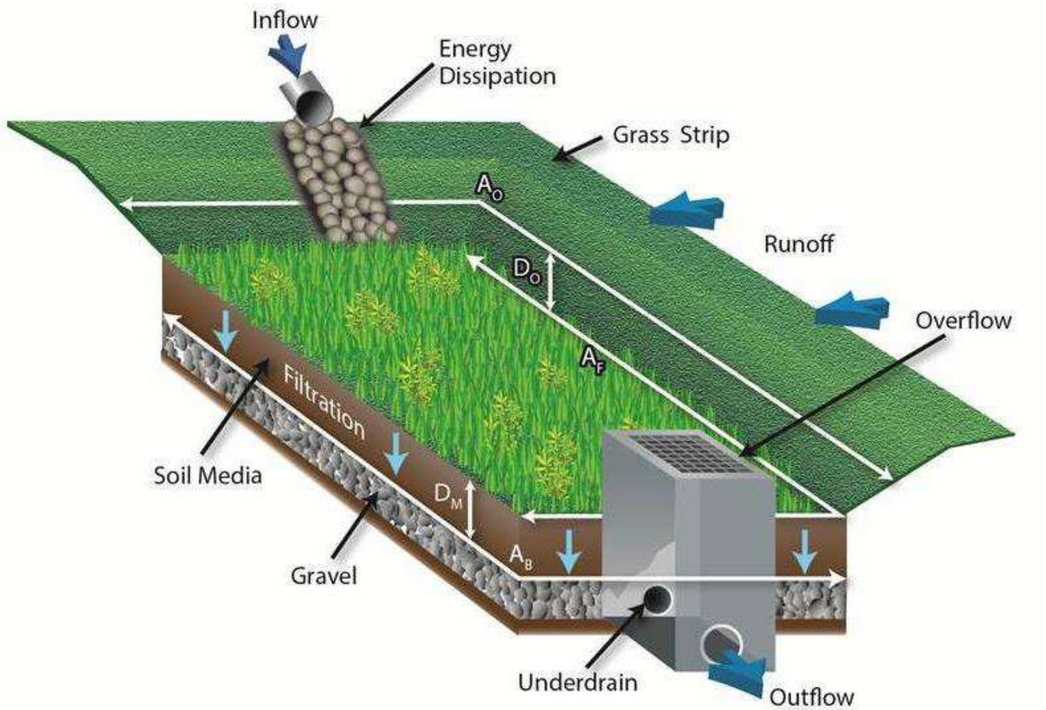

Figure 5.3-2. Example Bioretention Configuration
Source: Courtesy of Minnesota Pollution Control Agency

5.3.3 Site Selection

Basic guidelines are provided below to aid in evaluating whether bioretention areas are feasible for use at an individual site.

Contributing Drainage Area

- Bioretention areas are best suited for sites with a contributing drainage area of 2.5 acres or less. Smaller practices such as rain gardens typically have a contributing drainage area of 0.5 to 1.0 acre (22).
- Bioretention requires a stable watershed that is not subject to high levels of erosion. Pretreatment is required when the watershed includes phased construction, sparsely vegetated areas, or steep slopes in sandy soils (23).
- Bioretention areas should not receive continuous dry-weather flow, excessive irrigation water, or other non-storm water flows (22).

Soil Characteristics

- The site's soil characteristics do not typically limit the use of bioretention; however, soil characteristics must be used to determine whether an underdrain system is needed. At a minimum, underdrain systems are required when the bioretention area is used for treating runoff from storm water hotspots or located above contaminated groundwater and/or soils.
- An underdrain system is recommended if the bioretention area is located on soils that cannot infiltrate the design volume within 48 hours. When calculating drawdown time for the design volume, divide the field-tested soil infiltration rate by 2 as a factor of safety to account for potential compaction during construction and to approximate long-term infiltration rates.
- In locations where potentially expansive soils or bedrock exist, placement of a bioretention area adjacent to structures and pavement should be considered only if the BMP includes an underdrain and an impermeable liner designed to restrict infiltration (23).
- Soil characteristics can initially be estimated from NRCS soil data but must be field-verified prior to final design using the onsite soil investigation methods discussed in Chapter 2 and Appendix C of this manual.

Depth to Groundwater and/or Bedrock

- Soil acts as a filter for pollutants between the bottom of the facility and the underlying groundwater; therefore, a minimum vertical distance of 3 feet is recommended between the bottom of the facility and the seasonally high groundwater table or bedrock for full and partial infiltration sections (24).
- For systems with an impermeable liner and underdrain system, a minimum vertical distance of 1 foot is recommended between the bottom of the facility and the seasonally high groundwater table or bedrock.
- An evaluation of the depth to groundwater should be conducted as described in Section 4.3.3.

Site Topography

- Bioretention areas should be located on relatively flat terrain, and the grade immediately adjacent to the basin (within 15 to 20 feet) should be between 1 and 5 percent to promote drainage while limiting the potential for erosion (22).
- If steep grades are present, bioretention areas should be split into multiple cells throughout a project site.

- Bioretention areas with an underdrain are constrained by the invert elevation of the existing conveyance system to which the practice discharges (i.e., the bioretention area underdrain must connect to the storm drain or down-gradient natural conveyance system). In general, 4 to 5 feet of elevation change between the top of natural ground and the outlet invert is typically needed for bioretention areas with an underdrain (22).

Land Use and Characteristics of Surrounding Area

- Bioretention can be easily integrated into areas such as parking lot islands, roadway medians, and right-of-ways along roads because it is not limited to a specific shape.
- Runoff from hotspot areas should not be treated with infiltrating bioretention areas. An impermeable liner with an underdrain is required when treating runoff from hotspot areas.
- Interference with underground or overhead utilities should be avoided whenever possible. Consult applicable utility companies or agencies for site-specific requirements prior to implementing bioretention areas (25).
- When bioretention areas are located adjacent to buildings or pavement areas, protective measures should be implemented to avoid adverse impacts to these structures. Oversaturated subgrade soil underlying a structure can cause the structure to settle or result in moisture-related problems. Wetting of expansive soils or bedrock can cause swelling, resulting in structural movements. A geotechnical engineer should evaluate the BMP's potential impact on adjacent structures based on an evaluation of the subgrade soil, groundwater, and bedrock conditions at the site (23).
- Consider minimum setback requirements, as discussed in Section 4.3.4.

Community and Environmental Considerations

- Bioretention areas can be an urban aesthetic feature when installed in locations such as parking lot islands, street medians, and landscaped areas between roads and sidewalks.

Figure 5.3-3. Bioretention Area within Roadway Median
Source: HDR

Bioretention areas can be designed as an urban aesthetic feature shaped to fit the surrounding area.

5.3.4 Design and Sizing Procedure

The following discussion provides design criteria and procedures for the various components of bioretention areas. Annual precipitation across Montana can vary considerably; therefore, the character of bioretention areas will vary across the state. Some or all of the components may be used for a given application, depending on the site characteristics, restrictions, pollutant loading, and design objectives.

Bioretention Minimum Design Criteria[1]

Required Components	
☑	Inlet structure(s)
☑	Pretreatment
☑	Surface ponding area (filter area)
☑	Surface cover
☑	Bioretention soil media
☑	Overflow outlet structure (for online facilities)
Design and Sizing	
General	
☑	Basin storage volume sized for 100% of RRV or RTV (minimum)
☑	Bioretention soil media with minimum depth of 18 inches
☑	Pretreatment facility applicable to inlet configuration
☑	Provide maintenance access
☑	Provide a landscaping plan
☑	Provide an operations and maintenance plan
Full infiltration section	
☑	Native subsurface soil is capable of infiltrating the design volume within 48 hours (with safety factor of 2)
Partial infiltration section	
☑	Underdrain sized to release the design volume within 48 hours
☑	Underdrain aggregate layer
No infiltration section	
☑	Underdrain sized to release the design volume within 48 hours
☑	Underdrain aggregate layer
☑	Impermeable liner

[1] This table presents the minimum design criteria for satisfying the Post-Construction Performance Standard as defined in Section 1.3.2 of this manual.

1. Full Infiltration, Partial Infiltration, or No Infiltration Section

Bioretention areas can be classified into three different types of sections, depending on whether an underdrain is used. The section used will depend on site characteristics such as land use, proximity to adjacent structures, and soil characteristics. The three section types are described as follows:

- **Full Infiltration Section**: This section does not have an underdrain and, therefore, infiltrates all water captured by the facility into the native subsurface soils. Full infiltration sections should be used when the native subsurface soils have the ability to infiltrate the design volume and infiltration will not adversely affect the environment or adjacent structures.
- **Partial Infiltration Section**: This section uses both infiltration and an underdrain to discharge treated runoff from the BMP. A partial infiltration section does not include an impermeable liner. Any storm water that does not infiltrate into the native subsurface soils will be discharged to the downstream conveyance system via an underdrain. This type of section should be used when native subsurface soils do not have the ability to infiltrate 100 percent of the design runoff volume and when infiltration will not adversely affect the environment or adjacent structures.
- **No Infiltration Section**: This section uses an underdrain to discharge 100 percent of the runoff that has been captured and stored in the BMP. The section also includes an impermeable liner to prevent infiltration. A no infiltration section should be used when infiltration has the potential to adversely affect the environment or adjacent structures (for example, when treating runoff from a storm water hotspot).

2. Basin Storage Volume

The volume of runoff that can be stored and managed within a bioretention facility is a combination of the surface ponding volume, bioretention soil media storage volume, and underdrain aggregate layer storage volume (if applicable). Calculate the minimum required basin storage volume using the following guidance:

- **Full Infiltration Section**: Design the bioretention storage volume to be 100 percent of the RRV. Calculate the RRV using the guidance provided in Section 3.2.
- **No Infiltration Section or Partial Infiltration Section**: Design the bioretention storage volume to be 100 percent of the RTV. Calculate the RTV using the guidance provided in Section 3.2.

> Note: The design volume must be greater than or equal to the RRV or RTV if there is only one BMP in the contributing drainage area. Where multiple BMPs are used as part of a treatment train, the design volume may be only part of the overall RRV for the drainage area, with the sum of each BMP's design volume equaling or exceeding the RRV.

The following discussion provides guidance for sizing a bioretention facility by calculating the available runoff storage volume of the surface ponding area, bioretention soil media, and underdrain aggregate layer (if applicable). The sum of the available storage volume of each of these components of the facility will be equal to the total available storage volume.

Surface Ponding Area

The surface ponding area is the area where runoff is captured and stored before it begins to infiltrate into the underlying bioretention soil media. When designing the surface ponding area, provide an area and depth that offers adequate volume to store a portion of the design volume and to allow it to begin filtering through the bioretention soil media. It is recommended that the surface ponding volume account for at least 50 percent of the total basin storage volume. Calculate the surface ponding area volume using Equation 5.3-1.

$$SP_v = SA_p d_p \qquad \text{Equation 5.3-1}$$

Where:

SP_v = Surface ponding area volume (ft^3)

SA_p = Average ponding surface area, calculate using Equation 5.3-2 (ft^2)

$$= \frac{(\text{SA at top of ponding area})(\text{SA at bottom of ponding area})}{2} \qquad \text{Equation 5.3-2}$$

d_p = Design ponding depth (ft)

> Note: The minimum surface ponding volume requirement is based on the need to capture runoff from the 0.5-inch rainfall event from a full range of expected storm intensities. During high-intensity storm events, the surface ponding area may fill up faster than the collected storm water runoff is able to filter through the soil media. In addition, the infiltration rate of the bioretention soil media will vary over the maintenance life-cycle of the practice. Therefore, an adequate surface ponding volume is necessary to allow the runoff to begin to filter into the bioretention soil media before the runoff bypasses the BMP or overflows the surface ponding area (22).

Bioretention Soil Media

The bioretention soil media provides additional storage volume within the void spaces, referred to as porosity (η), to manage the design volume. Calculate the bioretention soil media storage volume using Equation 5.3-3.

$BSM_v = SA_b d_{BSM} \eta_{BSM}$ Equation 5.3-3

Where:

BSM_v = Bioretention soil media storage volume (ft^3)

SA_b = Bottom surface area of the bioretention soil media and aggregate layer (ft^2)

d_{BSM} = Depth of the bioretention soil media (ft)

η_{BSM} = Effective porosity of the bioretention soil media (typically 0.25)

Underdrain Aggregate Layer Storage

The underdrain aggregate layer is only applicable for partial infiltration and no infiltration sections. When applicable, this layer provides additional storage to manage the design volume. Calculate the underdrain aggregate layer storage volume using Equation 5.3-4.

$AL_v = SA_b d_{AL} \eta_{AL}$ Equation 5.3-4

Where:

AL_v = Aggregate layer storage volume (ft^3)

SA_b = Bottom surface area of the bioretention soil media and aggregate layer (ft^2)

d_{AL} = Depth of the aggregate layer (ft)

η_{AL} = Effective porosity of the aggregate layer (typically 0.40)

Verify Total Design Volume

Verify that the combination of the surface ponding area volume, bioretention soil media storage volume, and underdrain aggregate layer storage volume (if applicable) is greater than or equal to the total basin storage design volume. The recommended porosity values for the storage components are listed below.

- Surface ponding area (η_p) = 1.0
- Bioretention soil media (η_{BSM}) = 0.25
- Underdrain aggregate (η_{AL}) = 0.40

$D_v = SA_b\left[\left(d_{BSM} * \eta_{BSM}\right) + \left(d_{AL} * \eta_{AL}\right)\right] + \left(SA_p * d_p\right)$ Equation 5.3-5

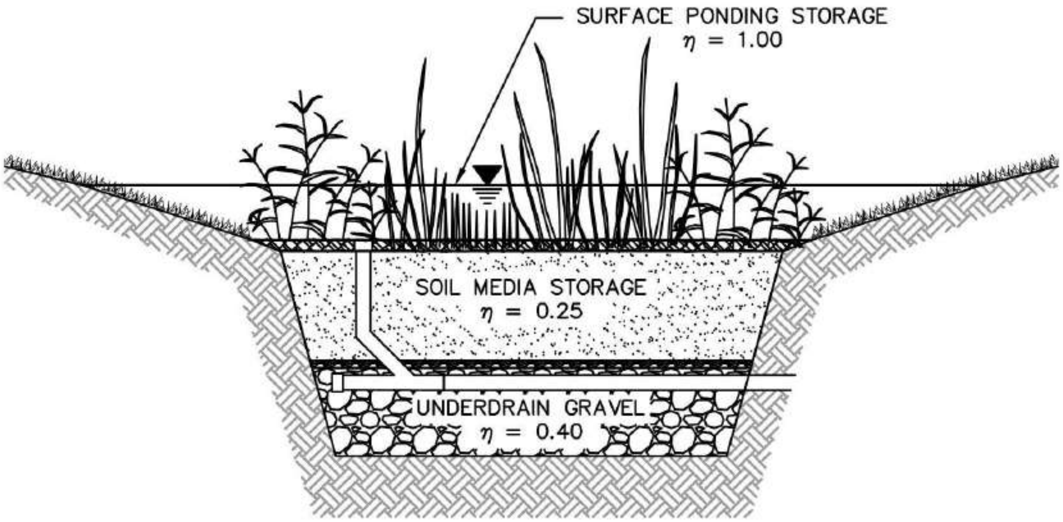

Figure 5.3-4. Bioretention Section with Typical Porosity Values

3. Surface Ponding Area Geometry

The surface ponding area, located above the bioretention soil media as shown in Figure 5.3-4, is the portion of the facility that collects and temporarily stores runoff. Guidance for the surface ponding area geometry and design is as follows:

- Select a ponding depth between 6 to 12 inches. Consider the local jurisdiction's fencing requirements associated with ponding areas for storm water management.
- The bottom of the surface ponding area (filter area) should be flat to enable even distribution and infiltration of storm water runoff.
- The recommended minimum bottom width of the surface ponding area is 2 feet.
- Provide freeboard above the top of the design ponding elevation. The recommended minimum freeboard is 6 inches or as specified by the local jurisdiction.
- The side slopes of the surface ponding area should be 3:1 (H:V) or flatter; however, in highly urbanized or space-constrained areas, concrete vertical sidewalls may be used to conserve space. When using vertical sidewalls, the vertical distance from the top of the side wall to the bottom of the ponding area should not exceed 12 inches.

4. Inlet and Conveyance

Inlet and conveyance considerations for design of bioretention areas include online vs. offline facilities, available inlet configurations, and surface overflows. Guidance for each of these considerations is discussed as follows:

- Online systems operate such that all runoff from the drainage area flows into the bioretention area. Flows that exceed the design capacity flow through the facility and exit through an overflow structure or weir without being treated.
- Offline systems operate such that flow is split or diverted so that only the design flow enters the bioretention area and larger flows bypass the facility. Offline bioretention areas are often designed by establishing a maximum ponding depth—at which point higher flows bypass the facility. Curb cuts along a roadside or parking lot area are commonly used as inlets for offline facilities (see Figure 5.3-6).
- Offline facilities are typically preferred over online facilities, especially for contributing drainage

Figure 5.3-5. Online Bioretention Area with Overflow Outlet Structure
Source: HDR

Figure 5.3-6. Offline Bioretention Area
Source: Courtesy of the City of Spokane

basins greater than 0.5 acre. Larger drainage basins can generate flows that overwhelm or damage bioretention areas for online facilities (22).

- The inlet of a facility will depend on characteristics of the bioretention area and drainage basin, such as topography, land use, flow velocities, and design volume. Suitable types of flow entrances range from sheet flow across paved or landscaped areas to curb cuts to concentrated piped flow entrances.
- Overflow conveyance systems are necessary for all bioretention facilities to safely convey flows that exceed the facility's design capacity. Surface overflow systems may include vertical catch basins or stand pipes connected to underdrain systems, horizontal drainage pipes, armored overflow channels, or curb cuts at the down-gradient end of the area to direct overflows back to the street (26).
- Bioretention areas must be designed with an internal flow path such that the treatment mechanisms are not bypassed or short-circuited. Travel time from each inlet to the outlet should be maximized by locating the inlets and outlets as far apart as possible, and incoming flow must be distributed as evenly as possible across the entire filter surface area (22).

Note: Designers must include provisions for safe conveyance of larger flows either contained within properly sized pipe or channel systems or as overland flood routing to a receiving waterbody so as to minimize public safety risks and property damage (22).

5. Pretreatment Facilities

Pretreatment facilities are recommended to reduce the maintenance cycle by reducing trash and sediment accumulation within the filter area. The type of pretreatment facility will vary depending on the drainage area characteristics and inlet configuration; however, common pretreatment facility options include a gravel diaphragm, grass filter strip, vegetated swale, pretreatment cell, and proprietary treatment devices. Guidance for pretreatment facility design options is as follows:

- **Gravel or stone diaphragm** (sheet flow): A gravel diaphragm is a 1- to 2-foot-wide strip of gravel located at the edge of a road or parking lot to provide pretreatment for sheet flow from a contributing drainage area. The gravel diaphragm should be oriented perpendicular to the sheet flow path with a 2- to 4-inch drop from the edge of pavement to the top of the stone. Size the stone to dissipate flows and prevent erosion based on the expected rate of discharge.
- **Grass filter strip** (sheet flow): A grass filter strip is a gently sloped vegetated area that provides pretreatment for sheet flow from a road or parking lot. Grass filter strips should be oriented perpendicular to the sheet flow path with a 2- to 3-inch drop from the edge of pavement to the top of the grass. The filter strip should extend from below the edge of pavement to the bottom of the surface ponding area at a 5:1 slope or flatter.
- **Vegetated swale** (concentrated flow): A vegetated swale is a broad and shallow vegetated channel which is similar to a biofiltration swale. Vegetated swales can be used to provide pretreatment for runoff from concentrated flows, such as piped or curb cut inlets.
- **Pretreatment cell** (concentrated flow): Similar to a forebay, a pretreatment cell is located at piped inlets or curb cuts leading to the bioretention area and consists of an energy dissipater sized for the design flow rates. A storage volume equivalent to at least 15 percent of the total design volume with a 2:1 length-to-width ratio is recommended. The cell may be formed by a wooden or stone check dam or an earthen or rock berm. Pretreatment cells do not need underlying engineered soil media.

- **Proprietary treatment device** (concentrated flow): If allowed by the local jurisdiction, a proprietary treatment device may be used to provide pretreatment (22).

6. Surface Cover

The surface cover for bioretention areas is variable and depends on the landscape context (for example, highly visible versus less visible, routine mowing versus managed landscape). The choice of surface cover will also influence the complexity and frequency of long-term maintenance activities. Surface cover options are provided as follows:

- **Mulch**: A 2- to 3-inch layer of mulch on the surface of the filter area enhances plant survival, suppresses weed growth, regulates soil temperatures, and provides pretreatment before runoff reaches the bioretention soil media. Shredded hardwood bark mulch, aged for at least 6 months, is recommended because it retains a significant amount of pollutants and typically will not float.
- **Alternative to Mulch Cover**: Alternative surface covers include turf grass, native groundcover, erosion control matting (coir or jute matting), river stone, or pea gravel. The surface cover selected for use must be able to support plant growth for the type of vegetation that will be used in the facility. Stone or gravel are not recommended in parking lot applications because they increase soil temperature and have low water-holding capacity (22).

Figure 5.3-7. Bioretention Mulch Surface Cover
Source: HDR

Mulch surface cover enhances plant survival, suppresses weed growth, regulates soil temperatures, and provides pretreatment.

7. Bioretention Soil Media

The bioretention soil media is an engineered soil mixture that is essential to the performance of a bioretention area. Located below the ponding area, the bioretention soil media is designed to maintain long-term permeability while also providing nutrients to support plant growth. More specifically, soil media mixes should balance the following four primary design objectives:

- Provide high enough infiltration rates to meet minimum surface water drawdown time
- Provide long-term infiltration rates that are not too high in order to optimize pollutant removal capability (typically less than 6 inches per hour)
- Support long-term plant and soil health
- Balance nutrient availability and retention to reduce or eliminate nutrient export (27)

Soil media is typically composed of a mixture of sand and organic matter, and ranges in depth from 18 to 36 inches. The mixture will vary depending on local climate characteristics, material availability, and performance objectives. Recommendations for design of soil media mixtures, also referred to as soil amendments, are provided in Appendix D.

8. Underdrain System (If Applicable)

An underdrain system is required for partial infiltration and no infiltration sections in order to drain the bioretention area after storm water runoff has been treated. An underdrain system consists of an aggregate choking layer, a slotted pipe that conveys treated runoff out of the bioretention area, and an aggregate layer that reduces clogging of the underdrain. Design guidance for the underdrain pipe and aggregate layer is as follows.

Choking Layer

A choking layer is a layer of choker stone placed between the bioretention soil media and above the underdrain aggregate layer to prevent the media from migrating into the aggregate layer. The recommended choking layer thickness is 2 inches, composed of ASTM No. 8 or No. 89 washed gravel.

Underdrain Pipe

Underdrains should be slotted plastic pipe. The openings should be smaller than the smallest aggregate gradation for the underdrain layer aggregate to prevent migration of material into the drain and clogging. This configuration also allows for pressurized water cleaning and root cutting if necessary. Additional underdrain pipe recommendations are as follows:

- Use slotted subsurface drain polyvinyl chloride (PVC) pipe in accordance with ASTM D1785-12 SCH 40. Pipe diameters may range from 4 to 8 inches, depending on the required hydraulic capacity.
- Slots should be cut perpendicular to the long axis of the pipe and be 0.04 to 0.069 inch by 1 inch long and be spaced ¼ inch apart (spaced longitudinally). Slots should be arranged in two rows spaced on 45-degree centers and cover one half of the circumference of the pipe.
- Perforated PVC or flexible slotted high-density polyethylene (HDPE) pipe are not recommended because they cannot be cleaned with pressurized water or root cutting equipment and are less durable.
- The underdrain can be installed with slots oriented on the top or bottom of the pipe.
- Underdrains should be sloped at a minimum of 0.5 percent and spaced a maximum of 20 feet on center.
- Design the underdrain system to drain the design volume within 48 hours.
- Provide at least one cleanout to enable maintenance and observation of infiltration rates over the life of the facility. For pipe lengths greater than 100 feet, two cleanouts are recommended (one on each end of the pipe).
- Wrapping the underdrain pipe in a filter fabric is not recommended because this has been shown to increase the potential for clogging (26).

Underdrain Aggregate Layer

An aggregate filter layer buffers the underdrain system from sediment input and clogging. The underdrain system should be placed within a 6-inch-thick section of washed ASTM No. 57 stone or similar aggregate filter material.

Orifice and Other Flow Control Structures

An orifice flow control structure may be used to regulate flows discharging from the underdrain system. A minimum orifice diameter of 3/8 inch is recommended to avoid clogging (23).

9. Impermeable Liner (if Applicable)

An impermeable liner is required for no infiltration sections to prevent storm water runoff from infiltrating into the underlying soils. Design guidance for impermeable liners is provided as follows:

- Install a 30 mil (minimum) PVC geomembrane liner on the bottom and sides of the basin, extending up at least to the top of the underdrain layer.
- Provide at least 9 inches (12 inches if possible) of cover over the membrane where it is attached to the wall to protect the membrane from UV deterioration (23).
- When high groundwater is anticipated, the design should consider the potential effect that buoyancy forces may have on the facility.

10. Guidelines for Incorporating Flood Control

Bioretention areas can be designed to provide flood control by increasing the basin storage volume for flood detention storage and designing the outlet structure (if applicable) to detain and release flood flows. Basin storage volume may be increased by expanding the surface ponding footprint and/or by incorporating additional subsurface storage within the underdrain aggregate layer. Appropriate flood control design guidance and local regulations should be referenced when incorporating flood control into an infiltration basin.

5.3.5 Vegetation Considerations

Vegetation is crucial because it provides treatment and enhances stability of the bioretention facility. Developing a landscaping plan for the bioretention area is required in order to indicate how the facility will be stabilized, established with vegetation, and maintained. The landscaping plan should include information such as area delineations, plant lists and quantities, handling instructions, planting sequence, and plant-specific maintenance requirements (22). Additional considerations when developing the vegetation and landscaping plan are as follows:

- Consider the level of maintenance that will be associated with the vegetation selected for the bioretention area and whether the facility's owner/operator is willing and able to conduct the required maintenance.
- For sites where less technical maintenance is desired, consider using managed turf grass for vegetation. Seeded turf grass is preferred because sod may reduce the facility's infiltration capabilities.
- In general, plants should tolerate summer drought, ponding fluctuations, and saturated soil conditions for lengths of time anticipated according to the facility's design (26).
- If the bioretention area will be used for snow storage or to treat runoff from a surface where salt is used as a deicer, the

Figure 5.3-8. Bioretention Vegetation
Source: HDR

Consider whether the project owner/operator is able to conduct the required maintenance when selecting vegetation.

area should be planted with salt-tolerant, non-woody plant species (26).

- Consider nearby infrastructure, underground utilities, and whether an impermeable liner will be used when selecting vegetation. When using an impermeable liner, select plants with diffuse (or fibrous) root systems, not taproots. Taproots can damage the liner and/or underdrain pipe (23).
- Trees should not be planted above an underdrain, but should be located closer to the perimeter of the facility (22).
- Select plants that will tolerate the expected pollutants and pollutant loadings from the contributing drainage area (26).
- Schedule planting and seeding activities during optimal growing seasons.
- Provide a plan to address weed control, especially within the first 2 to 3 years during the vegetation establishment period.
- Irrigation systems will likely be necessary to establish vegetation. These systems can be temporary or permanent depending on the type of vegetation to be used. Place irrigation heads outside the filter area because irrigation heads can become buried over time.
- When pedestrian traffic through bioretention areas is anticipated, consider incorporating elevated pathways to prevent vegetation damage. Where necessary, provide pipes through elevated berms to allow flows from one cell to another (26).

Note: Given the wide range of native vegetation across Montana, designers should consult local specialists, landscape architects, and/or agencies for recommendations on appropriate plant species and landscaping considerations for the site.

5.3.6 Construction Considerations

Basic construction considerations and guidelines are provided below.

Construction Site Management

- Acquire all applicable permits prior to construction. See Section 1.4 for more information.
- Construction on bioretention areas is not recommended until the entire contributing drainage area is stabilized. If this is not feasible, apply appropriate erosion control measures to minimize erosion during construction and protect the bioretention area from sediment loading during construction.
- Using bioretention areas for construction storm water management controls is not recommended. However, if bioretention areas are used for this purpose, notes and graphical details should specify that the maximum excavation depth at the construction stage should be at least 1 foot above the post-construction installation and that the facility must contain an underdrain (25).
- Onsite soil mixing or placement is not recommended when the bioretention

Figure 5.3-9. Inlet Protection
Source: Courtesy of the City of Missoula
Protect the bioretention area from runoff until the BMP construction is finalized and the contributing drainage area is stabilized.

soil media or subgrade soil is saturated (26).

- It is recommended that the bioretention soil media be compacted to between 80 to 85 percent of modified maximum dry density. Optimal compaction of the bioretention soil media mix can be achieved by placing the soils in 6-inch lifts and boot packing the soils between lifts.
- When using an impermeable liner, ensure enough slack in the liner to allow for backfill, compaction, and settling without tearing the liner. Provide quality assurance and quality control to ensure the liner will perform as designed (e.g., inspect for tears, inspect seams, conduct tests as specified by the manufacturer) (23).
- Care should be taken to not over compact the soils, which can reduce their permeability. To avoid excessive compaction, prevent construction equipment and vehicles from traveling over the proposed location of the filter area. Excavation and construction of the filter area should be performed using equipment placed outside of the limits of the filter area.
- If compaction of subgrade soils occurs, it may be necessary to till the bottom soils to a depth of 6 to 12 inches to promote greater infiltration rates.
- Extreme care is required during construction to ensure that the design grades and drainage patterns are implemented. This is especially important for offline facilities with inlets such as curb cuts, where incorrect final grading can result in runoff bypassing the bioretention area.
- Refer to the local jurisdiction's construction site storm water management program for additional guidance and local requirements.

Construction Inspection

- Inspections are recommended during the following phases of construction:
  - Pre-construction meeting
  - Initial site preparation
  - Excavation/grading
  - Installation of the bioretention soil media
  - Implementation of the vegetation and landscaping plan
  - Final inspection
- Inspectors should be familiar with project plans and specifications to ensure the contractor's interpretation of the plans are consistent with the designer's intent. The inspectors should take frequent photos and notes of construction activities and features as work progresses and at all critical points during the construction process (such as immediately prior to backfilling). Check dimensions and depths of all installed materials, and all materials and products should be verified or tested for conformance with the specifications (24).

Transition to Post-Construction

- Develop a plan prior to construction that will allow for an effective transition from construction storm water management BMPs to post-construction BMPs without compromising the integrity of the post-construction BMPs.
- Coordinate with the local jurisdiction prior to terminating coverage of the Construction General Permit.

5.3.7 Maintenance

Bioretention areas require consistent vegetation, soil, and surface cover maintenance to ensure optimum performance. Where applicable, maintenance of bioretention areas can be integrated into routine landscape maintenance tasks. If landscaping contractors will be expected to perform maintenance, their contracts should contain specifics on the unique bioretention landscaping needs, such as maintaining elevation differences needed for ponding, proper mulching, sediment and trash removal, and limited use of fertilizers and pesticides (22).

Frequent and well-timed maintenance (e.g., weeding prior to seed dispersal) is especially critical during the first 2 to 3 years while vegetation is being established. A portion of the plant stock may die off in the first year, so consider including a care and replacement warranty in construction contracts to ensure that vegetation is properly established and survives during the first growing season following construction.

Recommended maintenance activities are provided in Table 5.3-1, which may be used as a guide when developing a maintenance plan. Additionally, an example inspection form is provided in Appendix F that may be adapted or adopted as part of the maintenance plan.

Table 5.3-1. Recommended Maintenance Activities for Bioretention Areas

Activity	Frequency
▪ Inspect the bioretention area and contributing drainage area following rainfall events. Conduct any needed repairs or stabilization. ▪ One-time, spot fertilization may be needed for initial plantings. ▪ Follow the watering schedule provided by the designer because frequent watering is typically needed to establish vegetation. ▪ Remove and replace dead plants.	Upon establishment
▪ Perform spot weeding, trash removal, and mulch raking.	Semiannually during growing season
▪ Add reinforcement planting to maintain the desired vegetation density. ▪ Manage all vegetation associated with the bioretention area. ▪ Remove sediment from inflow points, pretreatment facilities, diversion structures, and overflow structures (if applicable). ▪ Remove any dead or diseased plants and invasive plants using recommended control methods. ▪ Stabilize the contributing drainage area to prevent erosion. ▪ Observe drain time following rainfall events to determine if the facility is clogged. If the observed drain time is longer than the local jurisdiction's allowable maximum drain time, corrective action must be taken to return the facility to the design drain time.	As needed
▪ Inspect all components of the bioretention area in accordance with an approved inspection form in accordance with local jurisdiction requirements. An example inspection form is provided in Appendix F. ▪ Supplement mulch where needed to maintain a 2- to 3-inch layer. ▪ Plants can provide nutrient uptake during the growing period. Once a year, prior to the dormant season, plants should be cut back to maintain the nutrient mass removal. If vegetation is left to decay, it will release nutrients back into the bioretention soil media (28).	Annually
▪ Remove sediment in pretreatment facility and inflow points. ▪ Remove and replace the mulch layer and the top 2 to 3 inches of the bioretention soil media. This is necessary because TSS can accumulate in the top layers of the facility and reduce infiltration rates (21). For designs that include pretreatment upstream of the bioretention area, the frequency with which the top layer is removed may be reduced. For bioretention soil media mixes with a design infiltration rate of less than 2 inches per hour, the top layer should be removed more frequently.	Once every 2 to 3 years

5.3.8 Plan View and Typical Details

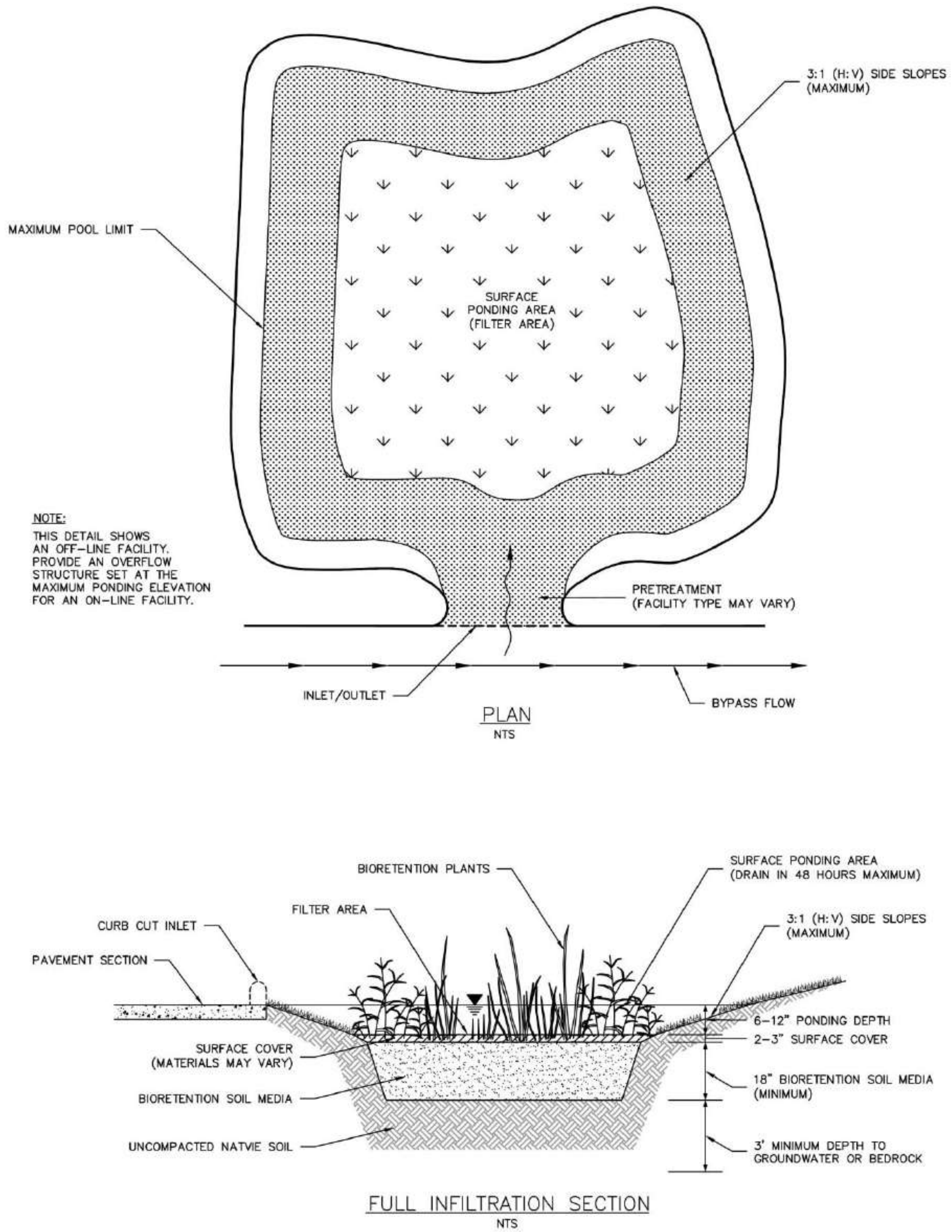

Figure 5.3-10. Bioretention Plan View and Typical Section (Offline with Full Infiltration Section)
Source: Adapted from Minnesota Stormwater Manual (29)

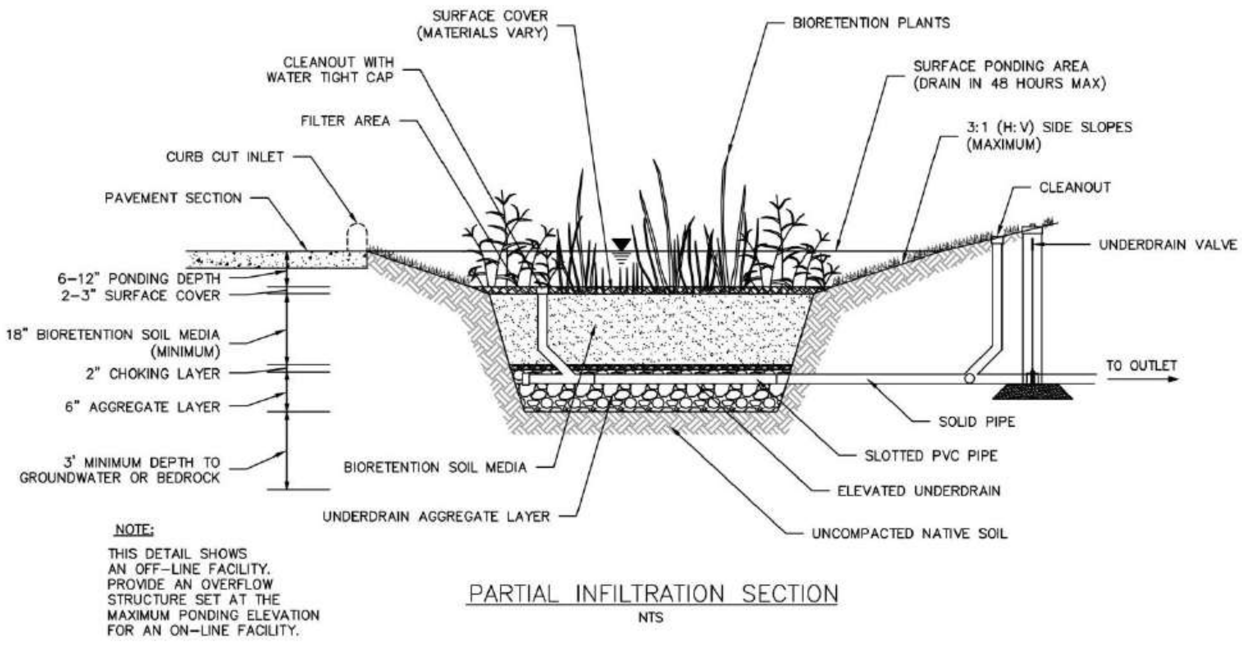

Figure 5.3-11. Bioretention Partial Infiltration Typical Section
Source: Adapted from Minnesota Stormwater Manual (29)

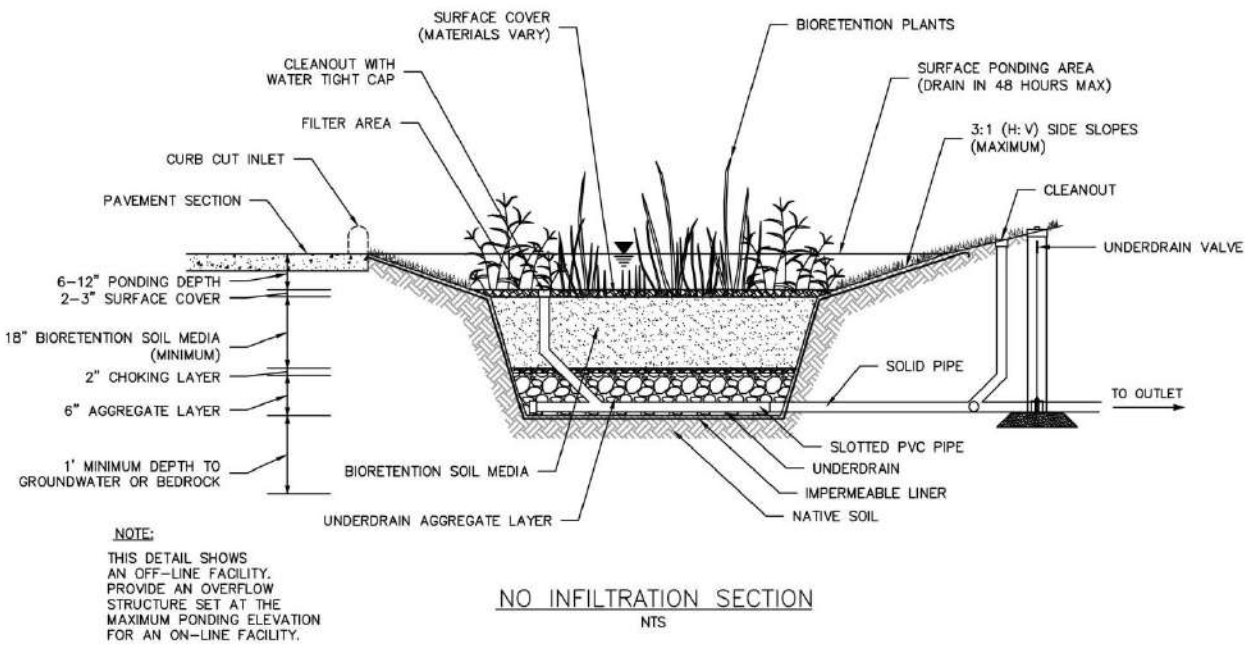

Figure 5.3-12. Bioretention No Infiltration Typical Section
Source: Adapted from Minnesota Stormwater Manual (29)

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5.4 Permeable Pavement Systems

Figure 5.4-1. Permeable Interlocking Concrete Pavers in Bozeman
Source: Courtesy of the City of Bozeman

Description
A pavement system with a permeable surface that allows storm water runoff to move through surface voids into an underlying aggregate reservoir for temporary storage and/or infiltration.

Primary Components	Primary Function
▪ Permeable pavement ▪ Bedding material ▪ Base reservoir ▪ Subbase reservoir ▪ Soil subgrade	☑ Runoff reduction ☐ Runoff treatment

Benefits	Limitations
▪ Accomplishes storm water management in areas with a different primary purpose (i.e., parking lots) ▪ Decreases effective impervious area ▪ Less likely to form ice on the surface when compared with conventional pavements ▪ Good retrofit capability	▪ Not recommended in developing or erosive watersheds due to potential for high sediment loads that can clog the facility ▪ Not recommended for sites with steep slopes ▪ Limited to pedestrian and low-speed traffic areas

Design and Site Selection Considerations	
☑ Setbacks	☑ Underdrain (optional)
☑ Depth to groundwater or bedrock	☑ Facility liners (optional)
☑ Soil permeability	☐ Landscaping/planting
☐ Soil preparation/amendments/compost	☐ Fencing
☐ Pretreatment forebay	☑ Size of contributing drainage area
☐ Inlet and outlet spacing	☑ Area required
☑ Energy dissipater/level spreader	☑ Incorporate flood control

TMDL Considerations[1]

Avoid	Preferred	
☐	☑	Total suspended solids (TSS)
☐	☑	Total phosphorus
☐	☑	Total nitrogen
☐	☑	Temperature
☐	☑	Metals
☐	☑	Fecal coliform

Maintenance Requirements

- ☑ Access roads or pullouts
- ☑ Sediment removal
- ☐ Irrigation
- ☐ Vegetation management
- ☐ Erosion and embankment stabilization repair
- ☑ Specialized equipment and training

[1]TMDL considerations listed are for facilities with a full infiltration section and do not apply to facilities with an underdrain.

5.4.1 Description

The term *permeable pavement system*, as used in this manual, describes any one of several surfaces that allow storm water runoff to filter through surface voids into an underlying aggregate reservoir for temporary storage and/or infiltration (30). Examples of these systems include permeable interlocking concrete pavers (PICPs), pervious concrete, and pervious asphalt.

Note: The guidance in this section focuses exclusively on PICPs because they are currently the more common application of permeable pavement systems in Montana. A brief introduction to additional types of permeable pavement systems is provided in Section 5.4.9. While most permeable pavement systems have similar performance capabilities and site selection constraints, the design, construction, and maintenance criteria differ from PICPs. Consult with the local jurisdiction and follow appropriate guidance for the design and implementation of other types of permeable pavement systems.

The primary characteristics of PICPs are as follows:

- PICP facilities usually consist of a subbase reservoir layer, a base reservoir layer, a bedding course layer, and concrete pavers with joint areas that are filled with small-sized aggregates to allow infiltration of runoff.
- The recommended maximum drawdown time for the design volume is 48 hours.
- PICP facilities can be designed to provide both runoff reduction and flood control. Treatment of pollutants may also be provided for systems that infiltrate into the underlying subgrade.

5.4.2 Performance

Runoff Reduction

When using a full infiltration section on soils conducive to infiltration, a PICP system is expected to infiltrate 100 percent of the RRV when designed, operated, and maintained as described in this manual.

Runoff Treatment

For the purposes of this manual, runoff treatment is applicable to BMPs that discharge treated runoff to a waterbody or downstream conveyance system. Specifically, runoff treatment BMPs must be expected to remove 80 percent TSS from storm water runoff. PICPs with an underdrain system provide some TSS reduction; however, these systems have not consistently demonstrated 80 percent removal of TSS when used as a stand-alone BMP. The Runoff Treatment Requirement can be met when PICPs are used as part of a treatment train with other BMPs; however, it is the responsibility of the designer to determine performance capabilities of BMP treatment trains.

5.4.3 Site Selection

Basic guidelines are provided below to aid in evaluating whether PICPs are feasible for use at an individual site.

Contributing Drainage Area

- PICPs are best suited for sites that receive runoff only from impervious areas. Runoff from non-impervious areas is not recommended because it may increase the potential for clogging (31).

- If runoff from non-impervious areas drains to PICPs, the drainage area should be stable with shallow slopes to limit the potential for sediment to drain onto the facility and clog the PICPs. Pretreatment is recommended for sites where runoff drains from non-impervious areas.
- The recommended ratio of contributing drainage area to PICP surface area is 2:1 or less. This ratio may be increased to no greater than 5:1 if a large portion of the runoff is generated from rooftops, where runoff tends to have low sediment contents or pretreatment BMPs are in place to reduce the sediment content within runoff prior to entering the PICP facility (32).

Soil Characteristics

- The site's soil characteristics do not typically limit the use of PICPs; however, soil characteristics must be used to determine whether an underdrain system is needed. At a minimum, underdrain systems are required when the PICP facility is used for treating runoff from storm water hotspots and located above contaminated groundwater and/or soils. Underdrain systems are recommended when the PICP facility is located on soils that cannot infiltrate the design volume within 48 hours.
- Siting of infiltrating PICPs is not recommended above fill soils because of the potential for reduced infiltration rates and slope stability issues. Infiltrating PICP installations should only be placed on fill soils if laboratory tests indicate the compacted fill will be stable when saturated and the slope stability of deep fills has been verified by a geotechnical engineer. PICPs sited above fill soils typically require an impermeable liner and underdrain system (32).
- Soil characteristics can initially be estimated from NRCS soil data, but must be field-verified prior to final design using the onsite soil investigation methods discussed in Chapter 2 and Appendix C of this manual.

Depth to Groundwater and/or Bedrock

- The bottom of the subbase reservoir should be a minimum of 3 feet above the seasonally high groundwater table or bedrock (hardpan) layer. A high groundwater table may cause seepage into the bottom of a PICP facility, and both groundwater and bedrock can prevent complete drainage. Also, soil acts as a filter for pollutants between the bottom of the subbase reservoir and the underlying groundwater. For systems with an impermeable liner and underdrain system, a minimum vertical distance of 1 foot is recommended between the bottom of the subbase reservoir and the seasonally high groundwater table (32).
- An evaluation of the depth to groundwater should be conducted, as described in Section 4.3.3.

Site Topography

- PICPs should be located on relatively flat areas that can be graded to maintain a finished surface grade of between 1 and 6 percent.
- Pavement slopes of at least 1 percent are recommended to evenly distribute flow and provide an alternative means for drainage if an area becomes clogged because of lack of maintenance (32).
- Pavement slopes of less than 6 percent are recommended because steep pavement slopes allow runoff to migrate downslope through the reservoir and pool at the lower end of the PICP facility.
- For pavement surface slopes greater than 3 percent, a terraced surface and/or terraced subgrade is recommended to provide a more even distribution of ponded runoff within the aggregate reservoir.

Land Use and Considerations of Surrounding Area

- PICPs are best suited for areas that receive pedestrian use and low-speed (less than 40 mph) vehicle traffic. Examples of such areas include parking lots, street parking lanes, residential driveways, residential streets, alleyways, recreational trails, sidewalks, and patios.
- To avoid adverse effects from seepage, care must be taken when siting infiltrating PICPs near building foundations, hardscapes, or conventional pavement areas. An impermeable liner may be necessary to prevent the PICP facility from being hydraulically connected to nearby infrastructure.
- Interference with underground utilities should be avoided whenever possible. Consult applicable utility companies or agencies for site-specific requirements prior to implementing PICP areas (31).
- Runoff from hotspot areas should not be treated with infiltrating PICPs. An impermeable liner with an underdrain is required when treating runoff from hotspot areas.
- PICPs should not be used in areas that produce high sediment loads because such loads may cause clogging.
- Consider minimum setback requirements, as discussed in Section 4.3.4.

Community and Environmental Considerations

- PICPs can be an urban aesthetic feature when installed in locations such as parking lots, sidewalks, and patio areas.

Figure 5.4-2. PICP Parking Lot Application
Source: HDR

Parking lots can be designed to use PICPs within the parking stall areas while using conventional pavements in other areas that receive more vehicle traffic.

5.4.4 Design and Sizing Procedure

This section provides a general outline of the design procedure and criteria for PICP facilities. A variety of PICP paver products are available, each of which may have unique design constraints. Manufacturers and/or suppliers should be consulted for materials and guidelines specific to each product. Additionally, the Interlocking Concrete Pavement Institute (ICPI) is recommended as a reference for more information because it provides technical information on best practices for PICP facility design, specifications, construction, and maintenance.

Design of PICP facilities is an iterative process in which the designer must balance site constraints, hydrologic design requirements, and structural design requirements. This section does not provide a step-by-step process for PICP design, but rather is separated into three general sections to aid in the design process:

- **PICP FACILITY OVERVIEW**: This subsection identifies and describes the types of facilities and typical components within a facility. The considerations provided in this section can be combined with guidance in the Facility Sizing section to size the facility.
- **FACILITY SIZING**: The sizing of a PICP facility depends on a hydrologic analysis and structural analysis because the facility's depth must be designed to retain or detain the entire design runoff volume and accommodate expected traffic loads. This section provides guidance on calculating the design volume and sizing the facility for the design volume, and provides structural analysis considerations.
- **ADDITIONAL DESIGN COMPONENTS**: After the facility has been sized, additional components such as a perimeter barrier and observation wells can be designed. In some cases, the additional components are integral to the facility sizing (i.e., underdrains); therefore, guidance in this section may need to be considered when sizing the facility.

PICP Minimum Design Criteria[1]

Required Components
☑ Soil subgrade ☑ Open-graded subbase reservoir ☑ Open-graded base reservoir ☑ Bedding course ☑ Concrete pavers
Design and Sizing
General ☑ Facility is sized for 100% of RRV or RTV (minimum) ☑ 100% of run-on flows across a pretreatment BMP ☑ Provide maintenance access ☑ Provide an operations and maintenance plan
Full infiltration section ☑ Native soil is capable of infiltrating the design volume within 48 hours (with safety factor of 2)
Partial infiltration section ☑ Underdrain system sized to release the design volume within 48 hours
No infiltration section ☑ Underdrain system sized to release the design volume within 48 hours ☑ Impermeable liner

[1] This table presents the minimum design criteria for satisfying the Runoff Reduction Requirement as defined in Section 1.3.2 of this manual.

PICP FACILITY OVERVIEW

Full Infiltration, Partial Infiltration, or No Infiltration Section

PICP facilities can be classified into three different types of sections, depending on whether an underdrain is used. The section used will depend on site characteristics such as land use, proximity to adjacent structures, and soil characteristics. The three section types are described as follows:

- **Full Infiltration Section**: This section does not have an underdrain and, therefore, infiltrates all water captured by the facility into the subgrade below. Full infiltration sections should be used when the native subgrade soils have the ability to infiltrate the design volume and infiltration will not adversely affect the environment or adjacent structures.

- **Partial Infiltration Section**: This section uses both infiltration and an underdrain to discharge treated runoff from the BMP. A partial infiltration section does not include an impermeable liner. Any storm water that does not infiltrate into the underlying soils will be discharged to the downstream conveyance system through an underdrain. This type of section should be used when native subgrade soils are not able to infiltrate 100 percent of the design runoff volume and infiltration will not adversely affect the environment or adjacent structures.
- **No Infiltration Section**: This section uses an underdrain to discharge 100 percent of the runoff that has been captured and stored in the BMP. This section also includes an impermeable liner to prevent infiltration. A no infiltration section should be used when infiltration has the potential to adversely affect the environment or adjacent structures (that is, when treating runoff from a storm water hotspot).

PICP Facility Layers

PICP facilities typically consist of concrete pavers and three aggregate layers: (1) open-graded bedding course, (2) open-graded base reservoir, and (3) open-graded subbase reservoir. Design these layers to meet runoff storage goals and support the anticipated traffic loads. Descriptions and design recommendations for the facility layers are as follows.

Concrete Pavers

Several brands of PICPs are available, most of which have design and installation specifications provided by the manufacturer. Common design information is as follows (33):

- Concrete pavers are typically a minimum of 3⅛ inches thick for vehicular areas and 2⅜ inches thick for pedestrian areas.
- The joint areas between pavers are usually filled with small-sized aggregates, such as ASTM No. 8, 89, or 9 stone in accordance with ASTM D448. These joint areas allow water to infiltrate through the pavers to the open-graded bedding course.

Open-Graded Bedding Course

The open-graded bedding course layer is a highly permeable aggregate layer that provides a level bed for the pavers. Design recommendations for this layer are as follows (33):

- Provide a 1½- to 2-inch thick layer of small-sized, open graded aggregate.
- Use an ASTM No. 8 stone or similar sized material.

Open-Graded Base Reservoir

The open-graded base layer is an aggregate layer that provides a structural transition between the bedding and subbase aggregate layers and has the ability to store runoff. Design recommendations for this layer are as follows (33):

- Design the layer to be 4 inches thick.

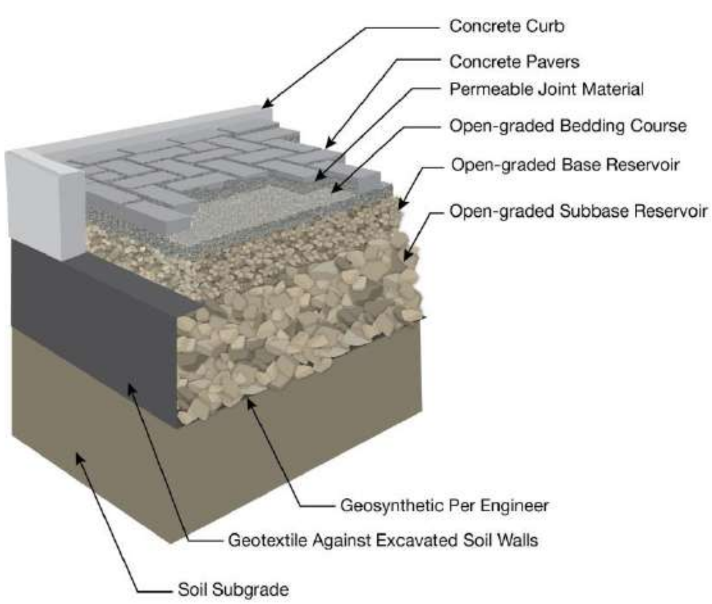


Figure 5.4-3. Full Infiltration Section Cross Section
Source: Courtesy of ICPI

- Use crushed stone from 1 inch down to ½ inch.
- Use ASTM No. 57 or similar sized material.

Figure 5.4-4. PICP and Bioretention System Treatment Train
Source: Courtesy of Altitude Training Associates, LLC

Open-Graded Subbase Reservoir

The open-graded subbase layer provides additional storage for runoff and structural support for the expected traffic loads. Design recommendations for this layer are as follows (33):

- A minimum depth of 6 inches is recommended; however, the depth of this layer will vary depending on the expected traffic loading, infiltration rate of the underlying soils, and the design volume. Ultimately, the thickness of this layer must accommodate both hydrological and structural needs, so the thicker of two sections must be selected for construction.
- Use crushed stone from 3 inches down to 2 inches.
- Use ASTM No. 2, 3, or 4 stone.
- Maintain a subbase slope of less than 1 percent for full or partial infiltration sections. Use a stepped installation on sites where this is not achievable.
- A subbase layer may not be necessary in pedestrian or residential driveway applications; however, in such instances, the base layer thickness should be increased to provide runoff storage and structural support.

Subgrade

The subgrade must balance the need for structural support and infiltration, particularly for full and partial infiltration sections. Consider the native soil characteristics, expected loading, and the design infiltration rate when specifying compaction, if any, of the subgrade.

Stepped Installation (if applicable)

Sloped and stepped installations contain flow barriers, check dams, or soil berms along the subbase to enable even distribution of ponded runoff and facilitate infiltration across the entire facility (see Figure 5.4-10 and Figure 5.4-11). A sloped or stepped installation is recommended for facilities with a surface slope of greater than 3 percent.

FACILITY SIZING

Hydrological Analysis

Aggregate Reservoir Depth

The aggregate reservoir consists of a combination of the open-graded base reservoir and open-graded subbase reservoir, where storm water runoff is stored and released through infiltration or an underdrain. Calculate the minimum depth required for management of the RRV for the aggregate reservoir using Equation 5.4-1.

$$D_{AL} = \frac{(PA_i R_{vi}) + (PA_p)}{\eta A_p}$$ Equation 5.4-1

Where:

D_{AL} = Minimum depth of aggregate reservoir (inches)

P = Water quality rainfall depth (use 0.5 inch)

A_i = Area draining to the PICP facility; this does not include the PICP area (acres)

R_{vi} = Dimensionless runoff coefficient of A_i, R_{vi} = 0.05 + 0.9(I)

I = Percent impervious cover draining to the facility converted to decimal form

A_p = PICP area (acres)

η = Porosity of aggregate layer (typically 0.40)

Equation 5.4-1 makes the following assumptions:

- The PICP area, A_p, is known. This is often the case for PICP facilities given the nature of the areas in which they are located (e.g., parking lots, sidewalks, roadways). For designs where the PICP area is not known, an area can be assumed and final design dimensions can be reached by iterating aggregate reservoir depth and area options.
- The runoff from the contributing drainage area and the rainfall that falls directly onto the PICPs are calculated separately. A portion of the runoff from the contributing drainage area drains to the aggregate reservoir, using the methods discussed in Chapter 3 to calculate the RRV. 100 percent of the rainfall that falls onto the PICP surface area drains to the aggregate reservoir.
- The surface area of the PICPs is equal to that of the aggregate reservoir.

> Note: The minimum volume to be managed by a PICP facility must be equal to the RRV or RTV (depending on how the site runoff will be managed). Most PICP facilities receive runoff from all storm events that occur within a contributing drainage area; therefore, designers typically need to account for additional runoff volumes to accommodate flood control requirements. Coordinate with the local jurisdiction to determine overall design volume requirements.

Maximum Allowable Infiltration Depth (Full and Partial Infiltration Sections Only)

It is recommended that full and partial infiltration sections be able to infiltrate the design volume within 48 hours. Use Equation 5.4-2 to calculate the maximum allowable depth of runoff to be infiltrated within the aggregate reservoir. If the maximum allowable depth is less than the design depth calculated using Equation 5.4-2, increase the PICP surface area, use an overflow system, or find ways to reduce the volume of water draining to the facility.

$$D_{AL\text{-}max} = \frac{i t_d}{2\eta} \qquad \text{Equation 5.4-2}$$

Where:

$D_{AL\text{-}max}$ = Maximum allowable infiltration-depth of the reservoir, see Figure 5.4-5 (inches)

i = Field-verified infiltration rate for the native soils (in/hr)

t_d = Maximum allowable draw down time (typically 48-hrs)

η = Porosity of aggregate layer (typically 0.40)

Note: *For design purposes, the field-tested subgrade soil infiltration rate (i) is divided by 2 within Equation 5.4-2 as a factor of safety to account for potential compaction during construction and to approximate long-term infiltration rates.*

Structural Analysis

Structural support for PICP facilities is provided by a combination of the concrete pavers and underlying aggregate layers. The structural design procedure for PICP facilities is the same as for flexible pavements because the load distribution and failure modes of PICPs are similar to those for other flexible pavement systems. Therefore, the 1993 American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures* can be used. This design process uses a structural number, given the expected axle loads, soil type, climatic, and moisture conditions (33).

The structural design considerations are often outside the realm of typical storm water BMP design. An engineer who is qualified to analyze and design pavement systems should reference applicable sources such as the 1993 AASHTO *Guide for Design of Pavement Structures* and Smith's *Permeable Interlocking Concrete Pavements* for detailed structural design guidance for PICP facilities.

ADDITIONAL DESIGN COMPONENTS

Pretreatment

Pretreatment facilities are recommended for all sites that receive run-on from non-impervious areas to reduce the potential for clogging of the PICPs. Sheet flow is the preferred flow entrance method for run-on. Place sheet flow pretreatment practices such as vegetated filter strips adjacent to non-impervious stabilized areas to trap coarse sediment particles before they reach the PICP surface (31).

Conveyance and Overflow

PICP areas typically receive all runoff from the contributing drainage area; therefore, the facility should be designed to accommodate and/or convey runoff events that are greater than the design volume. Coordinate with the local jurisdiction to determine which runoff events should be considered. The following types of conveyance designs are generally used:

- **Underdrain System**: An underdrain system consists of perforated pipes at the bottom of the aggregate storage layer that discharge to a downstream waterbody or conveyance system. PICP underdrain systems are similar to bioretention underdrain systems (see Section 5.3.4) with the exception that most bioretention underdrain systems will not be designed to accommodate traffic loading. Also, the PICP underdrain system can be designed with an orifice outlet structure so that the facility will act as an underground detention system. When designing the underdrain system, consult with the pipe manufacturer to verify that the underdrain pipe is appropriate for locations with traffic loading and verify that the cover thickness of aggregate over the underdrain pipe will accommodate the expected vehicle loads.
- **Elevated Drain**: An elevated drain, also referred to as an overflow system, consists of slotted or perforated pipes suspended within the aggregate reservoir that discharge to a downstream waterbody or conveyance system (see Figure 5.4-5). Runoff that pools beneath the elevated drains infiltrates into the underlying soils and excess runoff is able to exit the facility through the overflow system. These systems should be designed

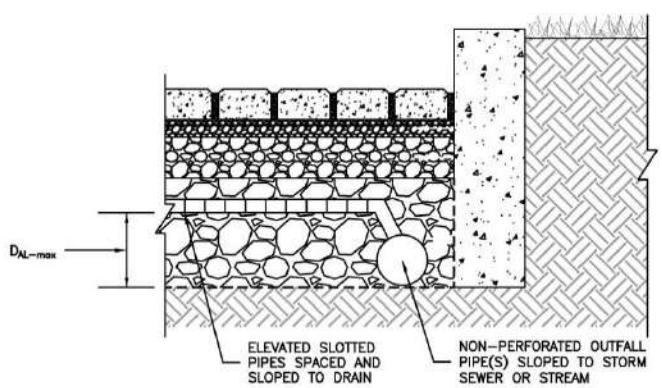


Figure 5.4-5. PICP Facility with Elevated Drain
Source: Adapted from Smith (33)

to maximize the use of infiltration while limiting the duration when ponded water is stored in the facility in order to protect the subgrade from oversaturation.

- **Oversized Subbase Reservoir Layer**: Some sites may be able to accommodate an increased depth within the subbase reservoir layer to store and infiltrate large runoff events. Sites that may be conducive to this option include soils with high infiltration rates and sites with limited contributing drainage areas. When considering this option, check the maximum allowable depth using Equation 5.4-2.

Perimeter Barrier

A structural barrier should be installed along the perimeter of the PICP facility to restrain movement of the pavers and reduce lateral flow. The type of barrier to be used depends on whether the facility is for pedestrian, residential, or a parking lot or street use. Perimeter barrier recommendations are as follows:

- For vehicular installations, use a cast-in-place curb (typically 9 inches deep) that rests on the top of the subbase or that extends the full depth of the base and sub-base (34).
- If a PICP facility is adjacent to an existing road or parking lot, provide a curb that is level with the adjacent surface. The curb should extend to the subbase of the PICP facility, or an impermeable liner should be used to protect the adjacent subgrade material from excessive moisture (33).
- For pedestrian areas and residential driveways, cast-in-place concrete curbs or dense-graded berms that provide a base to secure spiked metal or plastic edge restraints can be used (33).
- An additional option for a pedestrian and light parking application is a subsurface concrete grade beam with pavers cemented to the concrete beam to create a rigid paver border (34).

Figure 5.4-6. PICPs with Perimeter Barrier
Source: Courtesy of the City of Bozeman

Observation Wells

An observation well is recommended for PICP facilities that are subject to vehicular traffic to verify that the facility drains within the maximum allowable drain time. Provide a vertical 4- to 6-inch perforated pipe that extends 4 to 6 inches into the soil subgrade and is located a minimum of 3 feet from the edge of the facility at the lowest elevation of the subbase (33).

Geotextiles (Optional)

Geotextiles are optional for use within PICP facilities. Recommendations for use of geotextiles are as follows:

- Geotextile is optional for placement between the soil subgrade and aggregate base. The purpose of geotextile is to prevent the bottom of the aggregate base from intrusion by underlying soils, although there is some concern that using geotextiles can lead to clogging of the facility over time.
- To prevent erosion of adjacent soil into the aggregate reservoir, geotextiles are recommended on the sides of PICP facilities when a full-depth concrete curb is not used. The geotextile fabric should extend horizontally at least 1 foot onto the subgrade bottom,

resting on the soil subgrade. A minimum overlap of 1 foot is recommended for well-drained soils and 2 feet for poorly draining soils (33).

Impermeable Liner (If Applicable)

An impermeable liner is required for no infiltration sections to prevent storm water runoff from infiltrating into the underlying soils. Design considerations for impermeable liners are as follows:

- Install a 30 mil (minimum) PVC geomembrane liner on the bottom and sides of the facility, extending up at least to the top of the underdrain layer.
- Provide at least 9 inches (12 inches, if possible) of cover over the membrane where it is attached to the wall to protect the membrane from UV deterioration (23).

5.4.5 Vegetation Considerations

Vegetation considerations are not applicable to PICP facilities.

5.4.6 Construction Considerations

Installation of PICPs involves numerous steps and typically requires a variety of construction equipment that ranges from excavators to vibratory plate compactors. Basic construction considerations and guidelines are provided below. Consultation with PICP manufacturers or suppliers and the ICPI is necessary for more installation instructions and considerations specific to the PICP selected for a project.

Construction Site Management

- Acquire all applicable permits prior to construction. See Section 1.4 for more information.
- Installation of many PICP products requires special construction techniques. Some project owners and/or local jurisdictions may require the contractor to have previous PICP installation experience or certification through ICPI.
- A pre-construction meeting is recommended to review the design and installation requirements and discuss items such as plans for sediment management and construction sequencing.
- To reduce the potential for clogging of the facility, keep stockpiled aggregate material, installed base material, and installed pavers protected from construction site runoff and tracking of mud and sediment from construction equipment.
- If the excavated PICP area will be used as a construction storm water management control prior to installation of the PICPs, then excavation for the construction storm water management control should be at least 6 inches above the final design elevation of the soil subgrade. Excavation to the final bottom elevation should not occur until immediately before installing the aggregate subbase and base (33).

Figure 5.4-7. PICP Installation
Source: HDR

Pavers often need to be cut to fit along the perimeter of a facility.

- Compaction of the subgrade will reduce the infiltration rate of the native soil and should be avoided unless required in the plans and specifications.
- Store aggregate materials on a hard surface or geotextile material (as opposed to natural ground) so that sediment is not introduced to the aggregates.
- Paver installation can be by hand or with mechanical equipment. Mechanical equipment is faster and may be more cost effective, depending on the size of the installation.
- Cut pavers should be no smaller than one-third of a whole paver for facilities that will be subject to vehicle loading (33).
- When using an impermeable liner, ensure enough slack in the liner to allow for backfill, compaction, and settling without tearing the liner (23).
- Project specifications should require the contractor to revisit the site 6 months after project completion to inspect the joints and top them with aggregate if they have settled to more than ¼ inch below the paver surface (33).

Construction Inspections

- Inspections are recommended during the following phases of construction:
  - Pre-construction meeting
  - Initial site preparation
  - Excavation/grading
  - Installation of the impermeable liner (if applicable), aggregate base, bedding layer, and pavers
  - Final inspection
- Inspectors should be familiar with project plans and specifications to ensure the contractor's interpretation of the plans is consistent with the designer's intent. The inspectors should take frequent photos and notes of construction activities and features as work progresses and at all critical points during the construction process (such as immediately prior to backfilling). The photos will serve as a helpful resource when creating inspection reports. Check dimensions and depths of all installed materials, and all materials and products should be verified or tested for conformance with the specifications (16).

Transition to Post-Construction

- Develop a plan prior to construction that will allow for an effective transition from construction storm water management BMPs to post-construction BMPs without compromising the integrity of the post-construction BMPs.
- Coordinate with the local jurisdiction prior to terminating coverage of the Construction General Permit.

5.4.7 Maintenance

Maintenance is required on all BMPs. Recommended maintenance activities are provided in Table 5.4-1, which may be used as a guide when developing a maintenance plan. An example inspection form is provided in Appendix F that may be adapted or adopted as part of the maintenance plan.

Table 5.4-1. Recommended Maintenance Activities for Permeable Surfaces

Activity	Frequency
▪ Observe the system during and following rainfall events to determine if the facility is clogged. If clogging is suspected, test the surface infiltration rate using ASTM C1701. Vacuum, refill joints with clean aggregate, sweep the surface clean, and retest the infiltration rate again in accordance with ASTM C1701. The retest should result in a minimum 50 percent increase or a minimum 10 inches/hour (33). ▪ Stabilize the contributing drainage area to prevent erosion. ▪ Regularly manage all vegetation around the permeable pavers and remove all clippings. ▪ Keep the pavers free of trash, debris, and sediment.	As needed
▪ Vacuum sweep the surface with equipment such as a regenerative air vacuum sweeper. Adjust the vacuum settings to remove visible sediment without uptake of aggregate from paver openings. Additional aggregate may be needed between pavers after vacuuming (34).	Semiannually (typically spring and fall)
▪ Inspect the PICP facility. ▪ Replenish aggregate in joints if more than ½ inch of space exists between aggregate and chamfer bottoms on the paver surface (33). ▪ Inspect and repair all paver surface deformations exceeding ½ inch (33). ▪ Repair pavers offset by more than ¼ inch above/below adjacent pavers or curbs, inlets, etc. (33). ▪ Replace cracked pavers. ▪ Check underdrain system and outfalls for free flow of water and outflow from the observation well(s) after a major rainfall event. ▪ Flush the underdrain system to check for clogging (if applicable). ▪ Inspect all components of the PICP facility in accordance with an approved inspection form according to local jurisdiction requirements. An example inspection form is provided in Appendix F.	Annually

Considerations for Winter Operations and Maintenance

Winter operation and maintenance of PICPs varies from traditional pavement surfaces primarily because of the potential for clogging. Winter operations and maintenance recommendations are as follows:

- Snow can be plowed from pavers. Most pavers have chamfered edges to reduce chipping from snowplows; however, skids on the corners of the plow blades are recommended as well as raising the blade slightly above the paver surface to reduce the potential for damage to the pavers (34).
- Deicing materials and application of sand is not recommended. Deicing materials can infiltrate into the subgrade and sand may clog the facility. If traction is required, ASTM No. 8, 89, or 9 stone (or similar) may be applied (33).
- If sand is used, the PICP surface should be vacuumed in the spring to reduce the potential for clogging (33).
- Locate large snow piles in adjacent grassy areas so that sediments and pollutants in snowmelt are partially filtered before they reach the PICP facility.

Figure 5.4-8. Cold Climate PICP Application
Source: Courtesy of the City of Bozeman

5.4.8 Plan View and Typical Details

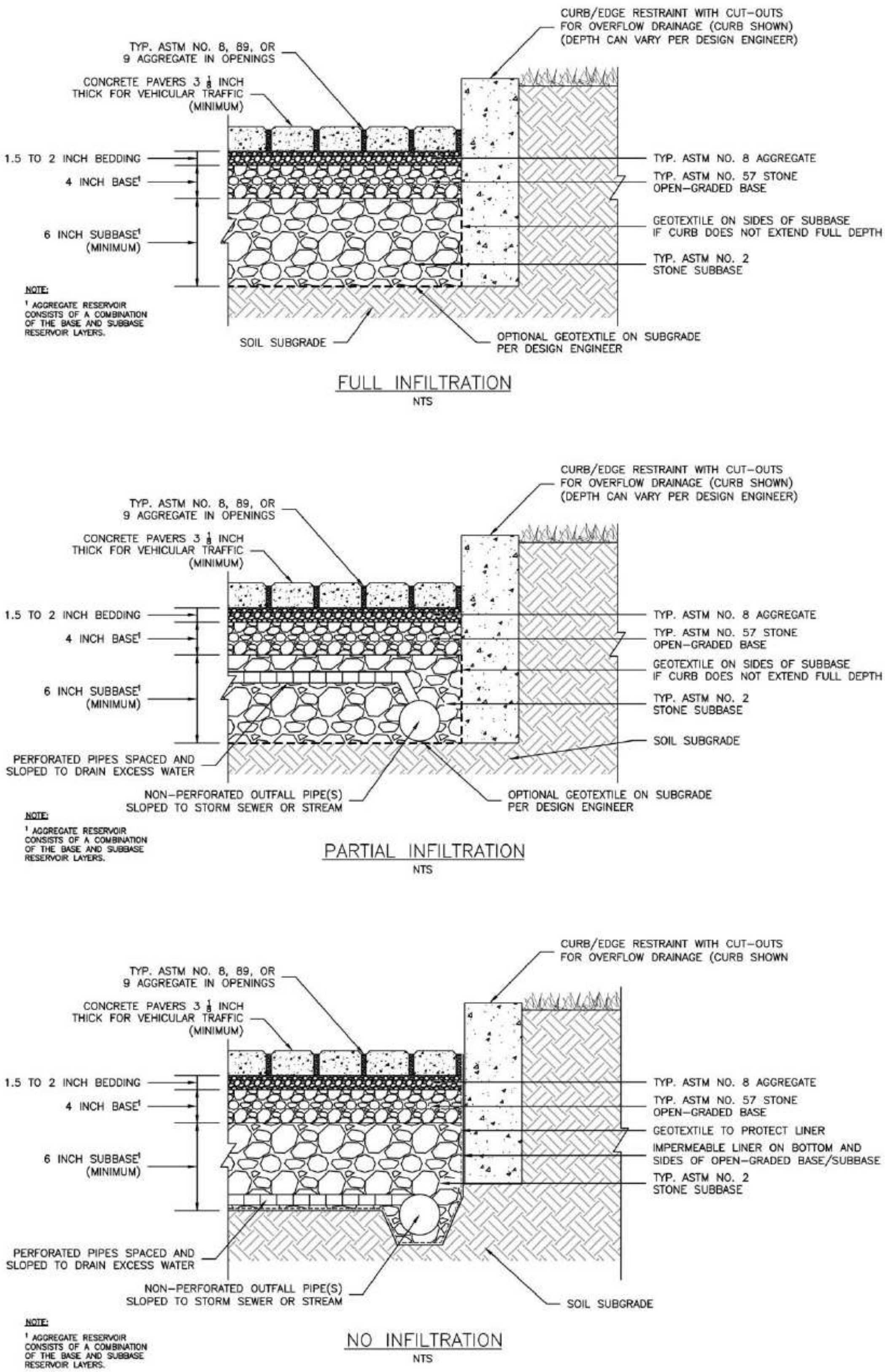


Figure 5.4-9. Full, Partial, and No Infiltration Sections
Source: Adapted from Smith (33)

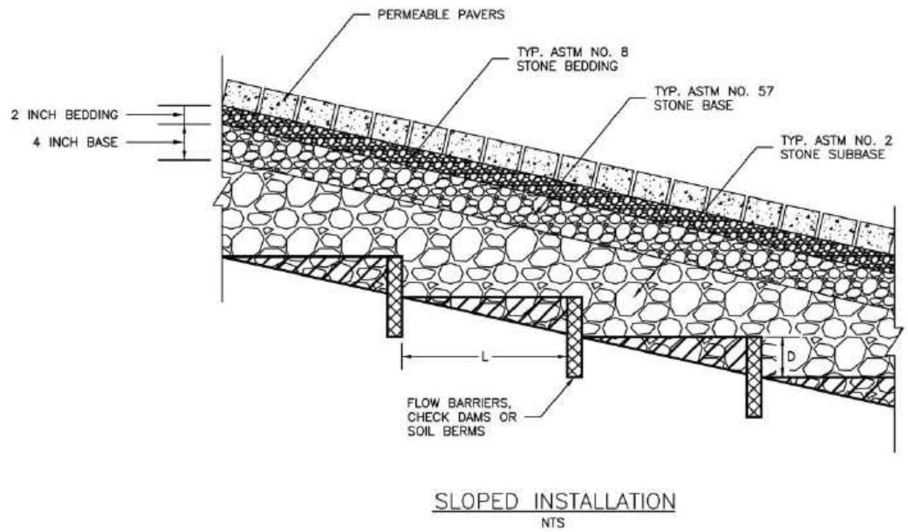


Figure 5.4-10. Sloped Installation Section
Source: Adapted from Smith (33)

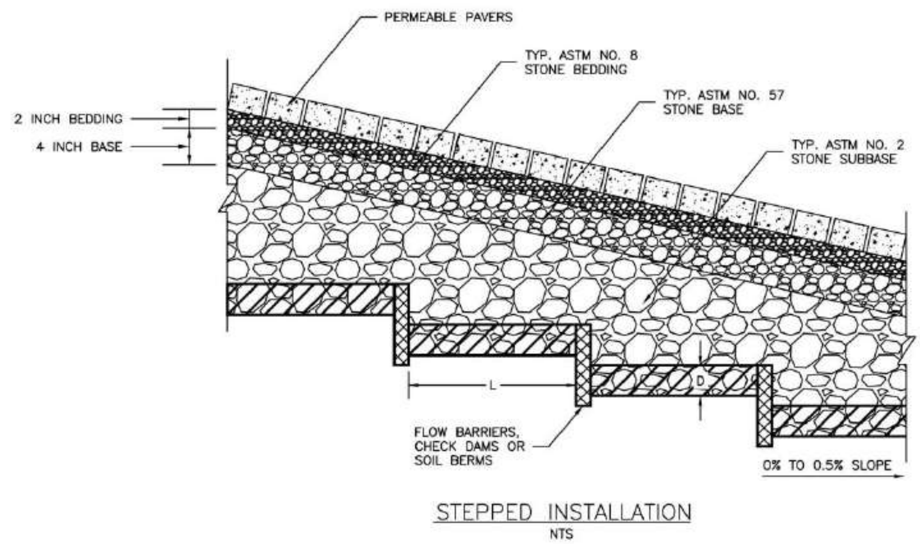


Figure 5.4-11. Stepped Installation Section
Source: Adapted from Smith (33)

5.4.9 Additional Types of Permeable Pavement Systems

Description	Example Photo
Pervious Concrete Pervious concrete is similar to conventional concrete with reduced or no fine aggregates (sand). The reduction of fine aggregates creates interconnected voids that allow runoff to filter through the concrete into the underlying aggregate base and subgrade. One way that pervious concrete differs from most other pervious pavement systems is that it is a ridged system and does not rely as heavily on the aggregate base for structural support. Pervious concrete can be used for various light to heavy duty applications supporting low to moderate speeds (34).	 *Source: HDR*
Pervious Asphalt Pervious asphalt is very similar to standard hot or warm-mix asphalt except that the aggregate fines have been removed to create interconnected void spaces. These void spaces allow runoff to filter through the asphalt into the underlying aggregate base and subgrade. Permeable asphalt applications can include facilities such as parking lots, residential access and collector roads, light arterial roads, pedestrian and bicycle paths, and utility access (34).	 *Source: HDR*
Concrete Grid Pavers Concrete grid pavers are similar to PICPs except that they have larger open areas that are filled with topsoil planted with grass or small aggregates. Like other permeable pavement systems, the open areas allow runoff to infiltrate into the underlying aggregate base and subgrade. These facilities provide a greenspace that can withstand vehicle loading without compaction and loss of infiltration capabilities. Common applications include alleys, driveways, patio areas, utility access, and overflow parking areas.	 *Source: Public Domain. By Immanuel Giel*
Plastic Grid Systems Plastic grid systems consist of flexible plastic interlocking units that allow for infiltration through large gaps filled with gravel or topsoil planted with turf grass (35). These systems provide the largest void space compared with other permeable pavement systems. Similar to concrete grid pavers, plastic grid systems provide a greenspace that can withstand vehicle loading without compaction and loss of infiltration capabilities. Common applications include parking lots, overflow parking areas, and emergency access routes.	 *Source: Courtesy of Emmons & Olivier Resources, Inc. and Minnesota Pollution Control Agency*

5.5 Dispersion

Figure 5.5-1. Dispersion Area
Source: Courtesy of WSDOT

Description
A BMP that achieves runoff reduction by using vegetation, soils, and gentle slopes located adjacent to impervious surfaces to impede the velocity of storm water runoff and encourage infiltration.

Primary Components	Primary Function
▪ Sheet flow conditions ▪ Level spreader ▪ Vegetated sloped area ▪ Infiltrative soils	☑ Runoff reduction ☐ Runoff treatment

Benefits	Limitations
▪ Maintains and preserves natural hydrologic functions ▪ Siting is generally not limited by native soils. Design accommodations can be made for most soil types. ▪ Reduces directly connected impervious areas that can result in reduced runoff volumes	▪ Storm water runoff must maintain sheet flow across a dispersion area ▪ Limited to small contributing drainage areas ▪ Not recommended for sites with steep slopes

Design and Site Selection Considerations	
☑ Setbacks	☐ Underdrain
☑ Depth to groundwater or bedrock	☐ Facility liners
☑ Soil permeability	☑ Landscaping/planting
☑ Soil preparation/amendments/compost	☐ Fencing
☐ Pretreatment forebay	☑ Size of contributing drainage area
☐ Inlet and outlet spacing	☑ Area required
☑ Energy dissipater/level spreader	☐ Incorporate flood control

TMDL Considerations			Maintenance Requirements
Avoid	Preferred		
☐	☑	Total suspended solids (TSS)	☐ Access roads or pullouts
☐	☑	Total phosphorus	☐ Sediment removal
☐	☑	Total nitrogen	☐ Irrigation
☐	☑	Temperature	☑ Vegetation management
☐	☑	Metals	☑ Erosion and embankment stabilization repair
☐	☑	Fecal coliform	☐ Specialized equipment and training

5.5.1 Description

Dispersion areas are composed of vegetated slopes that receive runoff as sheet flow from impervious or pervious areas. The vegetation and sloped dispersion area reduce the velocity of runoff, promoting infiltration and evapotranspiration. Dispersion often occurs naturally; depending on site characteristics, only minor construction activity may be required to implement this BMP.

The primary characteristics of dispersion areas are as follows:

- A dispersion area usually consists of a level spreader, vegetated sloped area, and infiltrative soils.
- Sheet flow must be maintained through dispersion areas to promote infiltration.
- Dispersion areas should be designed to provide runoff reduction.

5.5.2 Performance

Runoff Reduction

Dispersion areas are expected to infiltrate 100 percent of the RRV when designed, operated, and maintained as described in this manual (36).

Runoff Treatment

Dispersion areas are designed to manage the RRV from contributing drainage areas such that no runoff leaves the dispersion area; therefore, runoff treatment is not applicable.

5.5.3 Site Selection

Basic guidelines are provided below to aid in evaluating whether dispersion is feasible for use at an individual site.

Contributing Drainage Area

- Dispersion areas require sheet flow to operate properly; therefore, impervious contributing drainage areas that promote sheet flow are preferred (e.g., roads and parking lots). Where sheet flow cannot be maintained, a flow spreader can be used to promote sheet flow across the dispersion area. See Section 5.5.4, in the Pretreatment Diaphragms and Flow Spreaders subsection, for guidance.
- For sheet flow dispersion, the sheet flow path leading to the dispersion area should not be longer than 150 feet (not including pervious shoulders and side slopes of a road or parking area) (36).
- The resultant slope of the contributing drainage area must be less than or equal to 9.4 percent (see Figure 5.5-3). Calculate the resultant slope using Equation 5.5-1.

$$S_{CFS} \leq \left(G^2 + e^2\right)^{0.5} \qquad \text{Equation 5.5-1}$$

Where

S_{CFS} = Resultant slope of the lateral and longitudinal slopes (%)

G = Lateral slope (superelevation) (%)

e = Longitudinal slope (grade) (%)

Soil Characteristics

- Dispersion areas are suitable for most soil types; however, some sites may have native soils conditions that limit the ability to establish and maintain vegetation. This decision may be based on visual observations of the existing site or by testing the organic content of the soils. Specifically, an organic content of 8 percent is recommended. In some cases, soil amendments will be necessary.

- Soil characteristics can initially be estimated from NRCS soil data, but must be field-verified prior to final design using the onsite soil investigation methods discussed in Chapter 2 and Appendix C of this manual.

Depth to Groundwater and/or Bedrock

- A vertical distance of 3 feet is recommended between the existing ground elevation and the seasonal high water table or bedrock layer. Note that this depth recommendation applies to the entire limits of the dispersion area (36).

Site Topography

- Dispersion areas should be located on sites with low to moderate slopes (less than 33 percent).
- Infiltration of storm water runoff above steep slopes can create landslide hazards. Dispersion areas should not be located above slopes greater than 33 percent or above erosion hazard areas without evaluation by a geotechnical engineer and approval by the local jurisdiction (36).

Land Use and Considerations of Surrounding Area

- Dispersion areas typically look like a natural vegetated slope and are not always recognizable as a BMP. As such, they should be sited in areas where they are likely to receive maintenance and protection from future development. Examples of these areas include public right-of-way, designated open space, and protected conservation easements.
- Dispersion areas are best suited for areas adjacent to linear facilities such as roadside ditches and parking lots.
- Depending on soil characteristics, dispersion areas may not infiltrate runoff from larger rainfall events (e.g., 10- or 25-year event). Coordinate with the local jurisdiction to determine flood flow conveyance requirements. Ensure that the dispersion area will not increase runoff to down-gradient properties or structures.
- Consider minimum setback requirements as discussed in Section 4.3.4.

Figure 5.5-2. Dispersion Area Adjacent to a Roadway
Source: Courtesy of WSDOT
This dispersion area adjacent to a roadway provides storm water management within the existing right-of-way.

Community and Environmental Considerations

- Dispersion should be avoided at locations where storm water runoff could pose a risk of groundwater contamination (i.e., storm water hotspots).

5.5.4 Design and Sizing Procedure

The following steps outline the design procedure and criteria for dispersion. The information provided has been adopted from the Washington State Department of Transportation (WSDOT) *Highway Runoff Manual*, with minor revisions to account for local considerations. Guidance and standards from the local jurisdiction should be considered during the design process.

1. Sheet Flow or Channelized Dispersion

Dispersion areas can be classified into two different types of facilities depending on how runoff drains to the BMP:

- **Sheet Flow Dispersion**: Runoff flows across and leaves the contributing drainage area as sheet flow. The dispersion area is immediately adjacent to the contributing drainage area.
- **Channelized Dispersion**: Runoff from the contributing drainage area is conveyed to the dispersion area. A flow spreader is used to evenly distribute runoff across the dispersion area and to reestablish sheet flow.

Dispersion Minimum Design Criteria[1]

Required Components
☑ Dispersion area grading to maintain sheet flow ☑ Turf grass established throughout dispersion area
Design and Sizing
General ☑ Contributing drainage area maximum sheet flow length of 150 feet ☑ Dispersion area width greater than or equal to width of contributing drainage area ☑ Maximum lateral slope of 3:1 (H:V) ☑ Provide maintenance access ☑ Provide a landscaping plan ☑ Provide an operations and maintenance plan
Sheet flow dispersion ☑ Provide level spreader for lateral slopes greater than 6:1 (H:V) ☑ Minimum length as presented in Table 5.5-1
Channelized dispersion ☑ Provide a flow spreader sized to evenly distribute the design flow rate over the dispersion area ☑ Flow spreader and diversion structure (if applicable) design flow rate is ≥ RTF ☑ Minimum length as presented in Table 5.5-2

[1] This table presents the minimum design criteria for satisfying the Post-Construction Performance Standard as defined in Section 1.3.2 of this manual.

2. Dispersion Area Geometry

Geometry guidance for both sheet flow and channelized dispersion areas is as follows:

- Storm water runoff must enter the dispersion area as sheet flow.
- If a level spreader is not located immediately upstream of the dispersion area, the average lateral slope of the dispersion area may not exceed 15 percent or 6:1 (H:V).
- If a level spreader is located immediately upstream of the dispersion area, the average lateral slope of the dispersion area may not exceed 33 percent or 3:1 (H:V).
- The width of the dispersion area (perpendicular to the direction of sheet flow) must be greater than or equal to the width of the contributing drainage area (see Figure 5.5-3).
- Provide a uniform slope across the dispersion area to promote sheet flow. There should be no discernible flow paths through the dispersion area.
- Dispersion areas are generally considered online facilities (refer to Section 4.2.2 for discussion of online and offline facilities). The limitations on the contributing drainage area size for dispersion BMPs minimizes the need for large storm conveyance and overflow systems; however, in channelized dispersion cases where inflow comes from a pipe or channel and must be converted to sheet flow, the dispersion area can be implemented as an offline facility by using a diversion structure in conjunction with the flow spreader. The purpose is to prevent the conveyance system design discharge (e.g., 10- or 25-year peak flow) from scouring a channel or rill through the dispersion area. Figure 5.5-4 shows a diversion structure in conjunction with a level spreader (37).

3. Dispersion Sizing Guidance

Sheet Flow Dispersion Sizing Guidance

Sheet flow dispersion occurs at sites where a dispersion area is implemented immediately adjacent to the contributing drainage area. Sizing guidance and requirements that are specific to sheet flow dispersion are as follows:

- Sizing of a dispersion area is based on soil and contributing drainage area characteristics. Dispersion design length requirements are presented in Table 5.5-1.

Table 5.5-1. Sheet Flow Dispersion Sizing Guidance

Soil Characteristic	Contributing Drainage Area Characteristics	Dispersion Area Sizing Requirement
All HSG A soils and HSG B soils with saturated hydraulic conductivity (Ksat) of 4 inches/hour or greater	Impervious surfaces	▪ Provide a minimum lateral dispersion area length of 10 feet ▪ Add 0.25 feet of lateral dispersion area length for every 1 foot of contributing area sheet flow length beyond 20 feet
All HSG A soils and HSG B soils with Ksat of 4 inches/hour or greater	Pervious surfaces (bare soil and nonnative landscaping)	▪ Provide 1 foot of lateral dispersion area length for every 6 feet of contributing area sheet flow length
All HSG C and D soils and HSG B soils with Ksat of less than 4 inches/hour	All surface types	▪ Provide a minimum lateral dispersion area length of 100 feet ▪ Provide 6.5 feet of lateral dispersion area length for every 1 foot of contributing area of sheet flow length

Note: If roadway side slopes will be considered part of the dispersion area, the sizing must consider the roadway side slope soil type. In particular, the K_{sat} may be lower on the side slope because of typical compaction activities associated with construction.

Channelized Flow Dispersion Sizing Guidance

For sites where a dispersion area cannot be implemented immediately adjacent to a sheet flow area, the flows may be channelized and then redispersed over a dispersion area with a flow spreader (see Figure 5.5-4). Sizing guidance and requirements that are specific to channelized dispersion are as follows:

- Do not allow runoff from adjacent drainage areas to intersect with the channelized flow conveyance system of dispersion area.
- Locate discharge points a minimum of 100 feet upgradient of steep slopes (slopes steeper than 40 percent within a vertical elevation change of at least 10 feet), wetlands, and streams.
- Sizing is based on soil characteristics. Channelized dispersion design length requirements are presented in Table 5.5-2.

Table 5.5-2. Channelized Flow Dispersion Sizing Guidance

Soil Characteristic	Dispersion Area Sizing Requirement
All HSG A soils and HSG B soils with saturated hydraulic conductivity (K_{sat}) of 4 inches/hour or greater	▪ Provide a minimum lateral dispersion area length of 10 feet ▪ Add 0.25 feet of lateral dispersion area length for every 1 foot of contributing area sheet flow length beyond 20 feet
All HSG C and D soils and HSG B soils with K_{sat} of less than 4 inches/hour	▪ Provide a minimum lateral dispersion area length of 100 feet ▪ Provide 6.5 feet of lateral dispersion area length for every 1 foot of contributing area of sheet flow length

4. Pretreatment Diaphragms and Flow Spreaders

Level Spreader Design Guidance

- A gravel diaphragm level spreader is a 1- to 2-foot-wide strip of gravel located at the edge of a road or parking lot to provide pretreatment for sheet flow from a contributing drainage area. The gravel diaphragm should be oriented perpendicular to the sheet flow path with a 2- to 4-inch drop from the edge of pavement to the top of the stone. Size the stone to dissipate flows and prevent erosion. A design velocity of 1 foot per second or less is recommended.
- Use of a level spreader is recommended for all sheet flow dispersion areas and is required for all sheet flow dispersion areas with slopes steeper than 6:1 (H:V).
- For any existing slope that will lead to a dispersion area, if evidence of channelized flow (rills or gullies) is present, use a level spreader before those flows are allowed to enter the dispersion area.

Flow Spreader Design Guidance (Channelized Dispersion)

- Flows collected in a pipe or ditch conveyance system require energy dissipation and dispersal at the end of the conveyance system before entering the dispersion area.
- Flow spreaders should be sized to reduce the velocity from the conveyance system to less than 1 foot per second.
- Design the flow spreader to evenly distribute the design flow rate over the dispersion area. In cases where a diversion structure is used, the diversion structure must divert, at a minimum, the RTF rate to the flow spreader and dispersion area. Section 3.3 provides guidance for calculating the RTF.
- Flows discharging from a flow spreader must traverse the design length as provided in Table 5.5-2.

5. Signs

Installing signs that identify a dispersion area as a storm water management area is recommended because dispersion areas are not always recognizable as a BMP. Signs will increase the probability that the dispersion area will protected from additional landscaping, application of pesticides and fertilizers, future construction activity, or other disturbances.

5.5.5 Vegetation Considerations

Vegetation is crucial because it provides erosion control, promotes filtration of pollutants, and facilitates infiltration. Development of a landscaping plan for the dispersion area is required to indicate how the dispersion area will be stabilized and established with vegetation. Considerations when developing the vegetation and landscaping plan are as follows:

- If the site's existing soils are not conducive to establishment of healthy vegetation, topsoil should be imported from an offsite location and applied over the entire dispersion area prior to seeding.
- Durable, dense, and drought-tolerant grasses are recommended. Grass selection should consider both short-term and long-term maintenance requirements because some varieties have higher maintenance requirements than others (38).
- Salt-resistant vegetation should be used in locations where adjacent salt application is probable, such as roadsides and parking lots.
- Use of sod is not recommended for dispersion areas because seeding establishes deeper roots and sod may contain soil that is not conducive to infiltration (37).
- Trees are not recommended dispersion areas because they may affect the level spreading of flows across the surface (39).
- Schedule planting and seeding activities during optimal growing seasons.
- Irrigation systems will likely be necessary to establish vegetation. These systems can be temporary or permanent depending on the type of vegetation to be used. Irrigation scheduling must be appropriate for the selected vegetation since overwatering can decrease the permeability of the soil and under watering may hinder vegetation establishment and reduce the straining capabilities of the vegetation (38).
- If possible, divert runoff (other than necessary irrigation) during the period of vegetation establishment. Where runoff diversion is not possible, protect graded and seeded areas with suitable erosion control measures.
- The entire dispersion area should have mature vegetation coverage by the end of the establishment period because unplanted areas may decrease infiltration and promote erosion (39).

Note: Given the wide range of native vegetation across Montana, designers should consult local specialists, landscape architects, and/or agencies for recommendations on appropriate plant species and landscaping considerations for the site.

5.5.6 Construction Considerations

Basic construction considerations and guidelines are provided below.

Construction Site Management

- Acquire all applicable permits prior to construction. See Section 1.4 for more information.
- Apply appropriate erosion control measures to minimize erosion during construction.
- If possible, minimize disturbance, excavation, and clearing and grubbing in the location and vicinity of dispersion areas to maintain existing plant root systems (36).
- To the extent practicable, construction equipment should be restricted from the dispersion area to prevent compaction of the native soils. If construction equipment is used within the dispersion area, use low-ground-pressure vehicles to minimize compaction of soils.

- Contributing drainage areas should be properly stabilized with the appropriate erosion and sediment controls before allowing storm water runoff to drain to the dispersion area.
- Perform fine grading, application of topsoil, and seeding only after upgradient areas have been stabilized.

Construction Inspections

- Inspections are recommended during the following phases of construction:
  - Pre-construction meeting
  - Initial site preparation
  - Excavation/grading
  - Implementation of the vegetation and landscaping plan
  - Final inspection

Transition to Post-Construction

- Develop a plan prior to construction that will allow for an effective transition from construction storm water management BMPs to post-construction BMPs without compromising the integrity of the post-construction BMPs.
- Coordinate with the local jurisdiction prior to terminating coverage of the Construction General Permit.

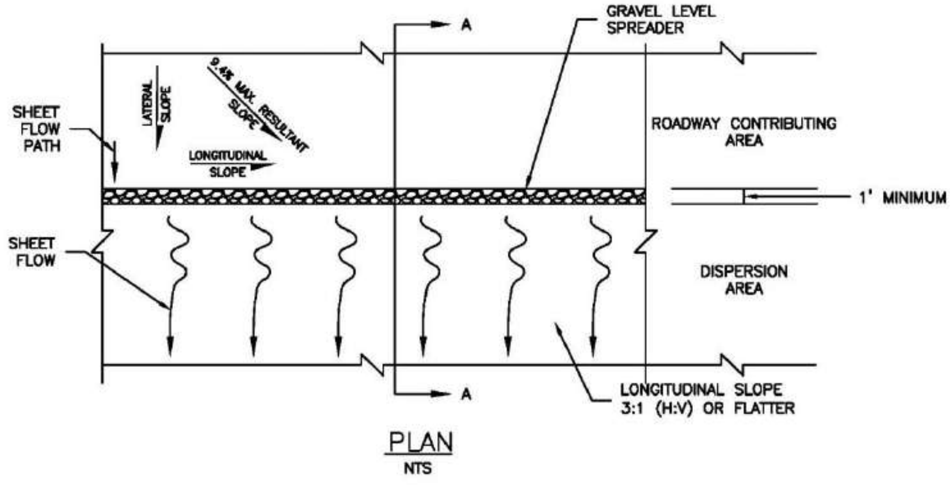
5.5.7 Maintenance

Maintenance is required on all BMPs. Recommended maintenance activities are provided in Table 5.5-3, which may be used as a guide when developing a maintenance plan. Additionally, an example inspection form is provided in Appendix F that may be adapted or adopted as part of the maintenance plan.

Table 5.5-3. Recommended Maintenance Activities for Dispersion Areas

Activity	Frequency
▪ Apply irrigation until vegetation has been established ▪ Inspect the dispersion area for signs of erosion and immediately stabilize eroded areas with grass cover	Upon establishment
▪ Remove trash and debris from the dispersion area ▪ Regularly manage all vegetation in accordance with the designer's recommendations. For locations where the grass is mowed, remove all clippings.	As needed
▪ Maintain and/or restore the level spreader so that flows are spread evenly over the entire area ▪ Remove sediment deposits and re-level so lateral slopes are even and flows pass evenly through the dispersion area ▪ Reseed as needed during fall seeding season to maintain 90% turf grass cover ▪ Inspect all components of the dispersion area in accordance with an approved inspection form according to local jurisdiction requirements. An example inspection form is provided in Appendix F.	Annually

5.5.8 Plan View and Typical Details



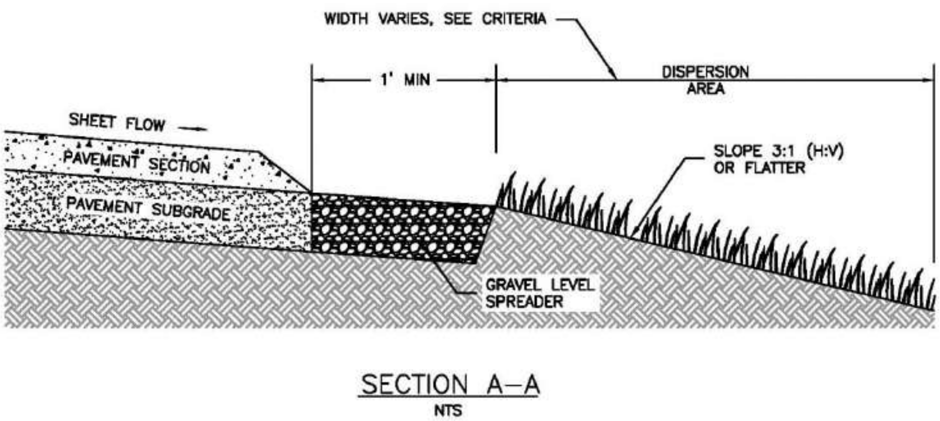


Figure 5.5-3. Dispersion Plan View and Typical Section
Source: Adapted from WSDOT (36)

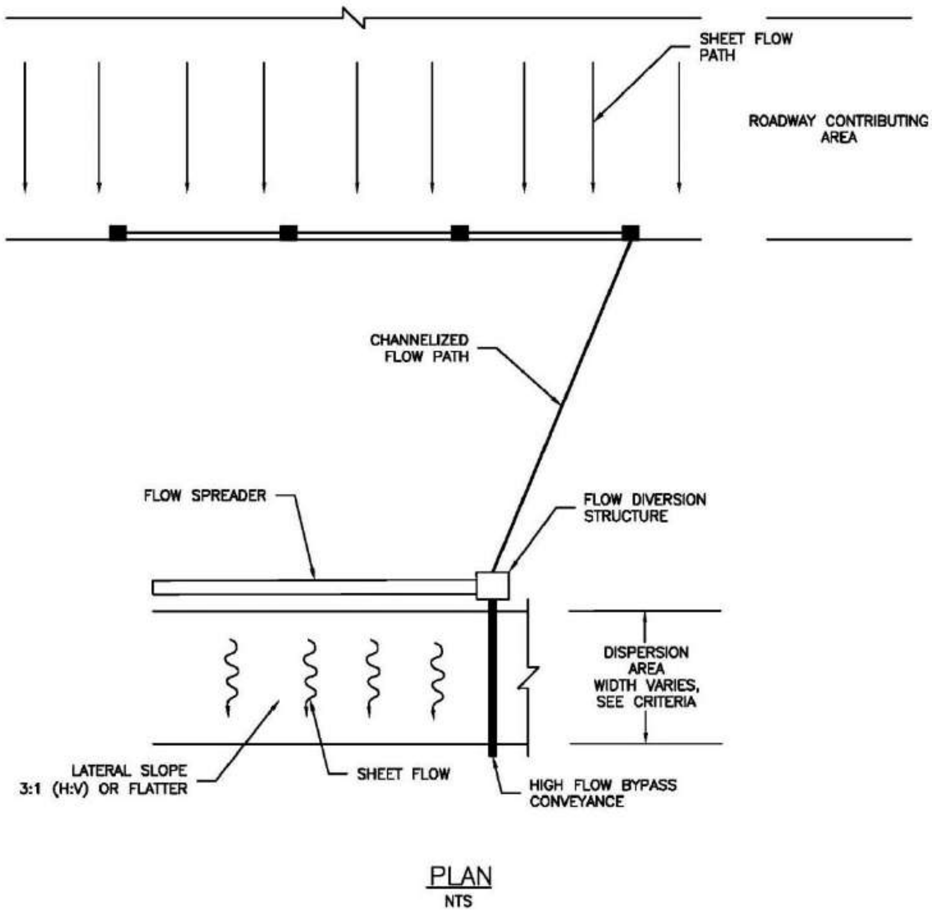


Figure 5.5-4. Channelized Dispersion Plan View
Source: Adapted from WSDOT (36)

5.6 Biofiltration Swale

Figure 5.6-1. Biofiltration Swale
Source: Courtesy of the City of Kalispell

Description
A vegetated channel designed to remove suspended solids from storm water runoff. Biofiltration swales have a trapezoidal cross-section and low longitudinal slopes to promote shallow concentrated flow that allows for filtration of storm water by plants.

Primary Components	Primary Function
▪ Inlet structure ▪ Level spreader ▪ Check dams (optional) ▪ Outlet structure	☐ Runoff reduction ☑ Runoff treatment

Benefits	Limitations
▪ Typically provides a less expensive and more attractive storm drainage conveyance feature when compared with curb and gutter systems ▪ Reduces directly connected impervious areas that can result in reduced runoff volumes	▪ Not recommended for basins greater than 5 acres ▪ Requires more land area than storm sewers ▪ Poor design and/or construction can create erosion, standing water, and mosquito problems

Design and Site Selection Considerations	
☑ Setbacks	☐ Underdrain
☑ Depth to groundwater or bedrock	☐ Facility liners
☐ Soil permeability	☑ Landscaping/planting
☑ Soil preparation/amendments/compost	☐ Fencing
☐ Pretreatment forebay	☑ Size of contributing drainage area
☑ Inlet and outlet spacing	☑ Area required
☑ Energy dissipater/level spreader	☐ Incorporate flood control

TMDL Considerations			Maintenance Requirements
Avoid	Preferred		
☐	☑	Total suspended solids (TSS)	☑ Access roads or pullouts
☐	☐	Total phosphorus[1]	☑ Sediment removal
☐	☐	Total nitrogen[1]	☑ Irrigation
☐	☐	Temperature	☑ Vegetation management
☐	☐	Metals	☑ Erosion repairs
☐	☐	Fecal coliform	☐ Specialized equipment and training

[1] Biofiltration swales that use compost amendments have been shown to release phosphorus and nitrogen. Avoidance of biofiltration swales with compost-amended topsoil is recommended in areas that drain to waterbodies listed as impaired for phosphorus and nitrogen.

5.6.1 Description

Biofiltration swales are densely vegetated channels designed to provide runoff treatment while slowly conveying storm water runoff. A trapezoidal cross-section paired with low longitudinal slopes facilitates decreased velocities and shallow concentrated flows, allowing for filtration of pollutants by plant stems and leaves.

The primary characteristics of a biofiltration swale are as follows:

- Biofiltration swales consist of an inlet structure, level spreader, main treatment channel, and an outlet structure. Some swales will also use check dams to reduce velocities and increase the hydraulic residence time (the time for runoff to travel the full length of the channel).
- A minimum hydraulic residence time of 9 minutes for the RTF rate facilitates the removal of TSS.

5.6.2 Performance

Runoff Reduction

Runoff reduction is not considered to be a primary function of biofiltration swales because they generally discharge a volume equivalent to the entire inflow runoff volume.

Runoff Treatment

Biofiltration swales are expected to achieve an 80 percent or greater removal rate of TSS from the RTF rate when designed, operated, and maintained as described in this manual (40).

5.6.3 Site Selection

Basic guidelines are provided below to aid in evaluating whether biofiltration swales are feasible for use at an individual site.

Contributing Drainage Area

- Biofiltration swales are generally suited for sites with a contributing drainage area of 5 acres or less. Contributing drainage area limitations are related to the design flows and maximum allowable velocity within the swale, because the swale's required bottom width may become impractical for larger contributing drainage areas (37). Design flow and velocity requirements are further discussed in Section 5.6.4.
- Some local jurisdictions may have smaller contributing drainage area limitations.
- Biofiltration swales should be located to avoid flows from springs or other dry weather flows.

Soil Characteristics

- Biofiltration swales are suitable for most soil types; however, some sites may have native soil conditions that limit the ability to establish thick and healthy vegetation. This decision may be based on visual observations of the existing site or by testing the organic content of the soils. Specifically, an organic content of 8 percent is recommended. In some cases, soil amendments and/or importing topsoil will be necessary.
- An impermeable liner may be appropriate for groundwater protection considerations at sites where there is a sensitive underlying aquifer and the underlying soils allow for infiltration (40).

Depth to Groundwater and/or Bedrock

- A minimum vertical distance of 1 foot is recommended between the bottom of the swale and the seasonal high water table (37).
- An evaluation of the depth to groundwater should be conducted, as described in Section 4.3.3.

Site Topography

- Biofiltration swales should be located on sites with low to moderate slopes.
- The longitudinal slope along the length of the swale should be less than 5 percent. Swales with longitudinal slopes greater than 5 percent may have erosion problems and will have difficulty meeting the velocity constraints discussed in Section 5.6.4.
- Swales with longitudinal slopes of less than 1 percent must be carefully monitored during construction to avoid flat areas that may hold pockets of standing water (41).
- For slopes greater than 2.5 percent, check dams are recommended to reduce the effective slope and increase hydraulic residence time.

Land Use and Characteristics of Surrounding Area

- Biofiltration swales are well-suited for areas adjacent to linear facilities such as roadside ditches, alongside parking lots, and along property boundaries (42).
- Biofiltration swales can sometimes be used to replace traditional curb and gutter systems.
- Consider minimum setback requirements, as discussed in Section 4.3.4.

Community and Environmental Considerations

- Biofiltration swales should be placed in a drainage or maintenance easement to increase the probability of regular maintenance.

Figure 5.6-2. Meandering Biofiltration Swale
Source: HDR

Swales can often be designed to meander through a site to reduce the longitudinal slope and velocity of runoff.

5.6.4 Design and Sizing Procedure

The following steps outline the design procedure and criteria for a biofiltration swale. The information provided has been adopted from the WSDOT *Highway Runoff Manual*, with minor revisions that account for local considerations. Determining swale dimensions is typically an iterative process to develop a geometry that balances slope, flow depth, and velocity criteria. Guidance and standards from the local jurisdiction should be considered during the design process.

1. Runoff Treatment Design Flow Rate

Calculate the RTF rate to determine the runoff treatment design flow rate. See Section 3.3 for guidance.

2. Biofiltration Swale Geometry

Swale geometry depends on site constraints such as natural topography, available area, and elevations of adjacent drainage structures, and design requirements such as peak velocity and minimum hydraulic residence time. Guidance and constraints related to swale geometry are as follows:

- The recommended longitudinal slope is between 1.5 and 5 percent. For longitudinal slopes above 2.5 percent, consider using drop structures, such as check dams, to accommodate velocity constraints. Energy dissipation techniques should be used downstream of each drop structure to prevent erosion.
- A trapezoidal cross section is required to increase pollutant contact area and maximize pollutant removal capabilities.
- Provide a bottom width between 2 and 10 feet. When the calculated bottom width exceeds 10 feet, two parallel swales can be constructed and divided in half using a non-erodible weather-resistant material such as plastic lumber. The maximum allowable total width for parallel swales is 16 feet.
- Side slopes should be stable and gentle to facilitate maintenance and access. 4:1 (H:V) or flatter side slopes are preferred to allow for conventional maintenance equipment and for improved aesthetics. Side slopes should be no steeper than 3:1 (H:V); however, local design standards should be consulted to confirm the maximum allowable slopes.

Biofiltration Swale Minimum Design Criteria[1]

Required Components
☑ Inlet
☑ Level spreader (at inlet)
☑ Trapezoidal cross section with healthy vegetation
☑ Outlet
Design and Sizing
General
☑ Runoff treatment design flow rate is 100% of RTF
☑ Longitudinal slope less than 5%
☑ Bottom width between 2 and 10 feet (or up to 16 feet if using a swale divider)
☑ Design flow depth between 2 and 4 inches (for RTF)
☑ Design flow velocity is ≤1 foot/second (for RTF)
☑ Hydraulic residence time is ≥9 minutes (for RTF)
☑ Swale length is ≥100 feet
☑ Provide maintenance access
☑ Provide a landscaping plan
☑ Provide an operations and maintenance plan

[1] This table presents the minimum design criteria for satisfying the Runoff Treatment Requirement as defined in Section 1.3.2 of this manual.

3. Select Soil and Vegetation Cover

The type of vegetation and condition of the underlying soil influence the swale's flow capacity. Use Table 5.6-1 to determine the Manning's n coefficient associated with the type of vegetation and expected soil condition for the biofiltration swale.

Table 5.6-1. Flow Resistance Coefficient in Biofiltration Swales

Vegetation and Soil Condition	Manning's n Coefficient[1]
Grass-legume mix on compacted native soil	0.20
Grass-legume mix on lightly compacted topsoil	0.22
Grass-legume mix on lightly compacted topsoil with 3-inch medium compost blanket	0.35

[1] The Manning's n coefficients presented in this table should be used only in conjunction with the RTF because they represent expected resistance for shallow flows. Separate Manning's n values should be used when calculating the swale's capacity for larger flows (i.e., the 10- or 25-year event).

4. Design Flow Depth

The flow depth associated with the RTF rate must be between 2 and 4 inches so that the vegetation is able to filter pollutants within runoff. Select a design flow depth based on the condition and type of vegetation that will be used in the swale. Recommendations are as follows:

- 2 inches if swale is mowed frequently
- 3 inches if swale consists of dryland grasses
- 4 inches if swale is mowed infrequently or inconsistently

5. Bottom Width

Calculate the bottom width of the biofiltration swale using Manning's equation (Equation 5.6-1).

$$RTF=\frac{1.49}{n}AR^{2/3}s^{1/2}$$ Equation 5.6-1

Where:

RTF = Runoff treatment design flow rate (cfs)
A = Wetted area (ft^2)
R = Hydraulic radius (ft)
s = Longitudinal slope of swale (ft/ft)
n = Manning's coefficient (see Table 5.6-1)

Equation 5.6-1 cannot be directly solved for the bottom width of a trapezoid; however, for trapezoidal channels that are flowing very shallow (4 inches or less), the hydraulic radius is approximately equal to the depth of flow. Using this assumption, Manning's equation can be rewritten as follows:

$$b=\frac{\left(\frac{n*RTF}{1.49}\right)}{\left[\left(y^{5/3}\right)\left(s^{1/2}\right)\right]}-zy$$ Equation 5.6-2

Where:

RTF = Runoff treatment design flow rate (cfs)
s = Longitudinal slope of swale (ft/ft)
n = Manning's coefficient (see Table 5.6-1)
b = Bottom width of the swale (ft)
z = Side slope of the swale in the form of z:1 (H:V)
y = Design flow depth for RTF (ft)

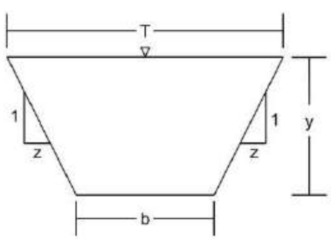


Figure 5.6-3. Trapezoid Dimensions

Calculate the bottom width of the swale using Equation 5.6-2. If the calculated value for b is less than 2 feet, then set the bottom swale width to 2 feet. Biofiltration swales are limited to a maximum width of 10 feet. If the required bottom width is greater than 10 feet, use two parallel swales with a combined width of up to 16 feet in conjunction with a device that splits the flow evenly between swales.

6. Design Velocity

The maximum allowable runoff treatment design flow velocity is 1 ft/sec because a velocity greater than 1 ft/sec can flatten grasses and reduce filtration capabilities. Compute the design flow velocity using Equation 5.6-3. If the velocity is greater than 1 ft/sec, increase the bottom width, reduce the slope, or provide check dams to reduce the design velocity and then repeat the calculation process described above until the velocity is less than or equal to 1 ft/sec.

$$V=\frac{RTF}{A} \qquad \text{Equation 5.6-3}$$

Where:

V = flow velocity at RTF (ft/sec)

RTF = Runoff treatment design flow rate (cfs)

A = Wetted area for RTF (ft^2)

7. Swale Length and Hydraulic Residence Time

The hydraulic residence time, t, must be a minimum of 9 minutes, and the swale must have a minimum length of 100 feet. Compute the swale length using Equation 5.6-4 with an assumed hydraulic residence time of 9 minutes.

$$L = Vt\left(60\frac{sec}{min}\right) \qquad \text{Equation 5.6-4}$$

Where:

L = swale length (ft)

V = flow velocity at RTF (ft/sec)

t = hydraulic residence time (set at 9 minutes)

8. Maintenance Access

Provide access to the swale for mowing or other vegetation management equipment and design the side slopes to safely operate the expected maintenance equipment.

9. Additional Considerations

Insufficient Space

If there is not sufficient space for the biofiltration swale, consider the following solutions:

- Divide the site drainage to flow to multiple BMPs.
- Use small infiltrating BMPs upstream of the biofiltration swale to provide a lower design flow rate.
- Alter the design depth of flow, if possible.
- Reduce the developed surface area to gain space for the biofiltration swale.
- Reduce the longitudinal slope by meandering the biofiltration swale.

Conveyance for Larger Flow Rates

If the biofiltration swale is designed as an online BMP, then it will need to also provide conveyance for flows greater than the RTF (as determined by the local jurisdiction). If applicable, provide a total swale depth that is designed to accommodate larger runoff events and meet local jurisdiction conveyance and freeboard requirements. In these situations, it is important to verify that the swale is designed to provide both runoff treatment for the RTF (with a maximum RTF flow depth of 4 inches) and adequate conveyance for larger rainfall events. It is also important to verify that drainage is being handled without flooding critical areas, structures, or adjacent streets.

Note: Consider the expected depth of flow when selecting the Manning's n coefficient during the design process. The design Manning's n coefficient to be used for checking conveyance of larger runoff events will likely be lower than the value used in conjunction with the RTF.

Level Spreaders

Level spreaders are objects that are aligned perpendicular to the direction of flow to evenly distribute and maintain level flow in the swale. They should be installed at the head of the biofiltration swale and every 50 feet of swale length if the swale is 6 feet or greater in bottom width. Level spreaders and swale dividers may be constructed using plastic boards, concrete, or other materials that will not leach pollutants. Constructed level spreaders should be staked into the bottom of the swale with nongalvanzed metal pins at 4 feet on center minimum. Also consider installing sediment cleanouts at the head of the swale if high sediment loads are expected.

Figure 5.6-4. Level Spreader
Source: Courtesy of the City of Kalispell
Level spreaders at concentrated flow inlets help to evenly distribute flow within the swale.

Check Dams

Check dams are 6- to 12-inch-tall obstructions that are aligned perpendicular to the direction of flow to reduce the swale's effective slope, thereby increasing the hydraulic residence time. Check dams are recommended for swales on longitudinal slopes exceeding 2.5 percent. Design recommendations for check dams are as follows:

- Design of check dams should consider the full range of design flows.
- The swale should have a continuous grade between check dams.
- Firmly anchor check dams into the bottom and side slopes of the swale.
- Provide a weep hole or similar drainage feature within the check dam to allow ponded water to drain following runoff events.
- Armoring with quarry spalls may be needed at the downstream toe of the check dam to prevent erosion.
- Construct check dams using wood, concrete, stone, or other non-erodible material.
- Check dams may take the place of level spreaders if they are designed and installed to maintain level flow in the swale.
- Use Equation 5.6-5 to calculate the effective slope of a swale when using check dams. Use the effective slope to verify a design velocity of less than 1 ft/sec and hydraulic residence time of at least 9 minutes for the RTF.

$$S_e = S_t - \frac{h}{L}$$ Equation 5.6-5

Where

S_e = effective slope (%)

S_t = longitudinal slope of the swale (%)

h = height of check dam (ft)

L = distance between check dams (ft/ft)

5.6.5 Vegetation Considerations

Vegetation is an essential component of biofiltration swales because it provides erosion control, enhances site stability, and filters pollutants. Developing a landscaping plan for a biofiltration swale and surrounding area is required to indicate how the swale will be stabilized and established with vegetation. Considerations when developing the vegetation and landscaping plan are as follows:

- Durable, dense, and drought-tolerant grasses are recommended. Grass selection should consider both short- and long-term maintenance requirements because some varieties have higher maintenance requirements than others.
- Biofiltration swales should be planted with salt-tolerant plant species if roadway salt will be applied to the contributing drainage area.
- Topsoil should be imported from an offsite location if the site's existing soils are not conducive to establishing healthy vegetation.
- Irrigation systems will likely be necessary to establish vegetation. These systems can be temporary or permanent, depending on the type of vegetation to be used in the swale. Irrigation scheduling must be appropriate for the selected vegetation because overwatering can decrease the permeability of the soil and under watering may hinder vegetation establishment and reduce the straining capabilities of the vegetation (38).
- If possible, divert runoff (other than necessary irrigation) during the period of vegetation establishment. Where runoff diversion is not possible, protect graded and seeded areas with suitable erosion control measures.
- Use of sod is not recommended for biofiltration swales because seeding establishes deeper roots and sod may contain soil that is not conducive to infiltration (37).

Figure 5.6-5. Biofiltration Swale Sign

Source: HDR

Signs can discourage activities that would cause compaction and disturbance of vegetation.

Note: Given the wide range of native vegetation across Montana, designers should consult local specialists, landscape architects, and/or agencies for recommendations on appropriate plant species and landscaping considerations for the site.

5.6.6 Construction Considerations

Basic construction considerations and recommendations are provided below.

Construction Site Management

- Acquire all applicable permits prior to construction. See Section 1.4 for more information.
- Apply appropriate erosion control measures to minimize erosion during construction.
- Topsoil should be stripped, stockpiled, and reapplied just prior to seeding of the biofiltration swale.
- To the extent practicable, construction equipment should be restricted from the swale area to prevent compaction of the native soils.
- Perform fine grading, application of topsoil, and seeding only after upgradient areas have been stabilized and all work crossing the swale has been completed (43).
- Contributing drainage areas should be properly stabilized with the appropriate erosion and sediment controls or permanent seeding before allowing storm water runoff to drain to the swale.

Figure 5.6-6. Degrading Concentrated Flow Inlet
Source: HDR

To prevent erosion, inlet areas must be designed to dissipate flows and be stabilized prior to allowing runoff to enter the facility.

Construction Inspections

- Inspections are recommended during the following phases of construction:
  - Pre-construction meeting
  - Initial site preparation
  - Excavation/grading
  - Implementation of the vegetation and landscaping plan
  - Final inspection
- Inspect level spreaders and check dams (if applicable) to verify they are at correct elevations and are properly installed.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable (37).

Figure 5.6-7. Swale Vegetation Establishment
Source: HDR

Post-construction inspections should be conducted to verify that thick and healthy vegetation is being established.

- Inspectors should be familiar with project plans and specifications to ensure the contractor's interpretation of the plans is consistent with the designer's intent. The inspectors should take frequent photos and notes of construction activities and features as work progresses and at all critical points during the construction process. The photos will serve as a helpful resource when creating inspection reports (16).

Transition to Post-Construction

- Develop a plan prior to construction that will allow for an effective transition from construction storm water management BMPs to post-construction BMPs without compromising the integrity of the post-construction BMPs.
- Coordinate with the local jurisdiction prior to terminating coverage of the Construction General Permit.

5.6.7 Maintenance

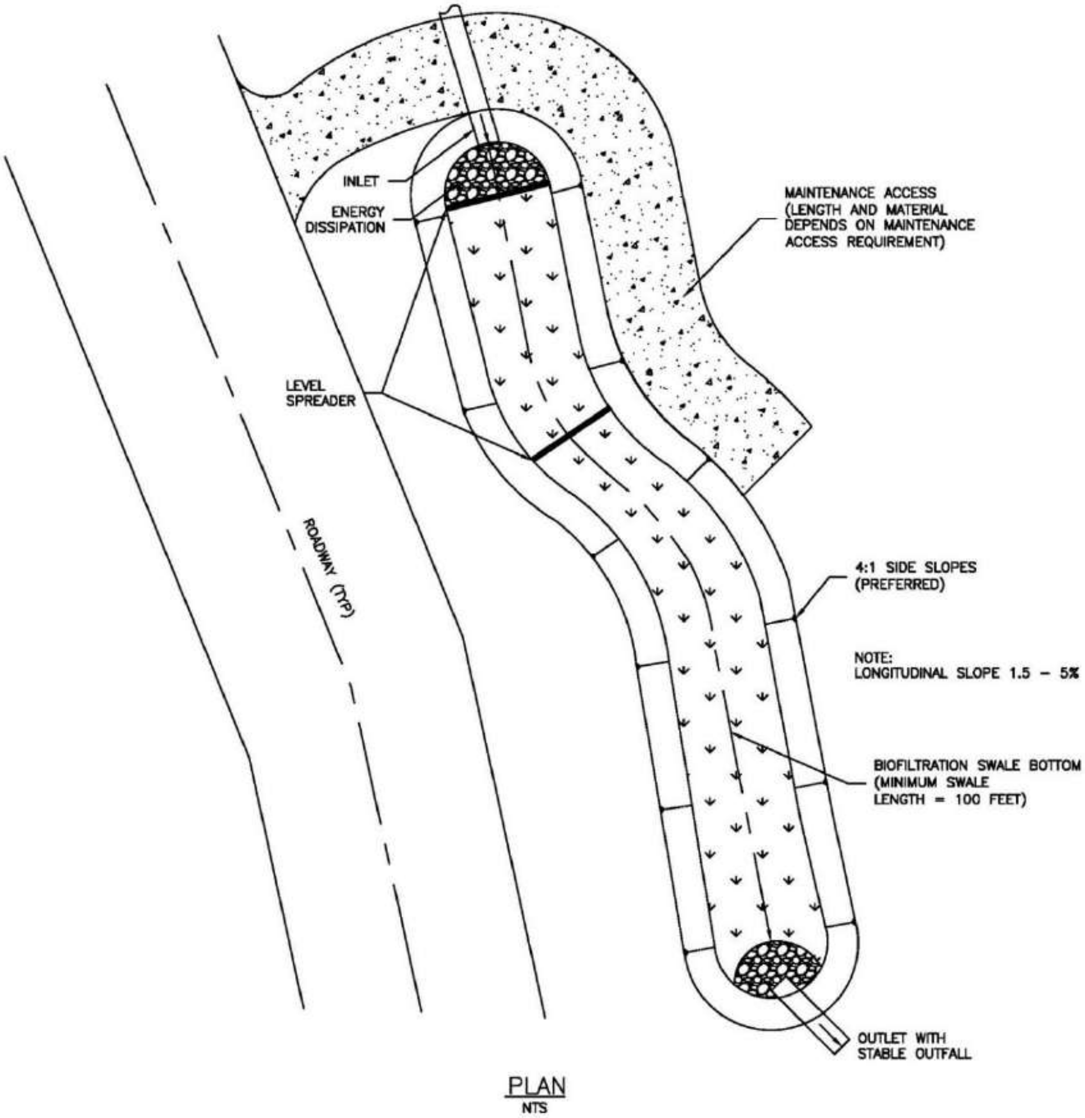
Maintenance is required on all BMPs. Recommended maintenance activities are provided in Table 5.6-2, which may be used as a guide when developing a maintenance plan. Additionally, an example inspection form is provided in Appendix F that may be adapted or adopted as part of the maintenance plan.

Table 5.6-2. Recommended Maintenance Activities for a Biofiltration Swale

Activity	Frequency
▪ Make sure full coverage of turf grass or erosion control fabric has been achieved following construction, both on the channel bed and side slopes ▪ Inspect the swale during and after runoff events to ensure that the swale is operating as designed and inspect for erosion	Upon establishment
▪ Remove litter/debris from all components of the biofiltration swale ▪ Manage all vegetation during the growing season and maintain grass heights as specified during the design documents. Remove all clippings.	As needed
▪ Ensure that the contributing drainage area is clear of debris ▪ Ensure that the contributing drainage area is stabilized and perform spot-reseeding if or where necessary ▪ Repair undercut and eroded areas as needed at swale inflow and outflow structures ▪ If applicable, inspect upstream and downstream of check dams for evidence of undercutting or erosion, and remove trash or blockages at weepholes	Quarterly
▪ Reseed as needed during fall seeding season to maintain 90% turf grass cover ▪ Remove any accumulated sand or sediment deposits behind check dams ▪ Examine channel bottom for evidence of erosion, braiding, excessive ponding or dead grass ▪ Check inflow points for clogging and remove any sediment ▪ Inspect side slopes and filter strips for evidence of erosion ▪ Inspect all components of the biofiltration swale in accordance with an approved inspection form according to local jurisdiction requirements. An example inspection form is provided in Appendix F.	Annually

Source: West Virginia Department of Environmental Protection (37)

5.6.8 Plan View and Typical Details



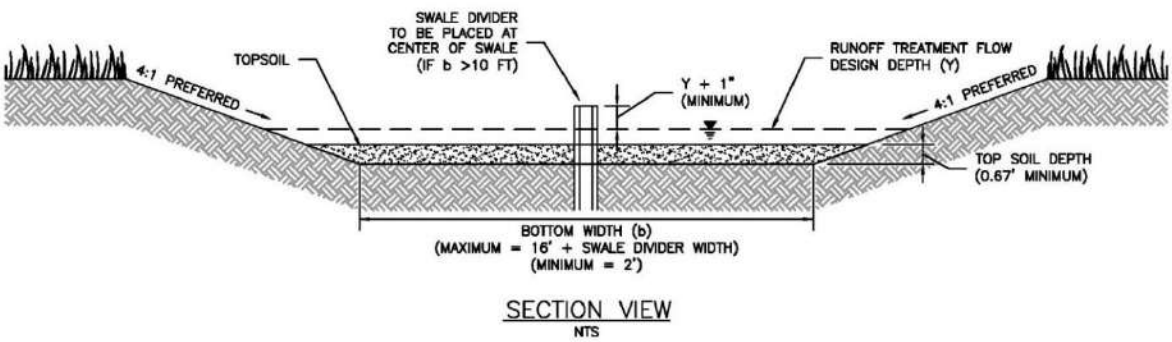


Figure 5.6-8. Biofiltration Swale Plan and Section View
Source: Adapted from WSDOT (40)

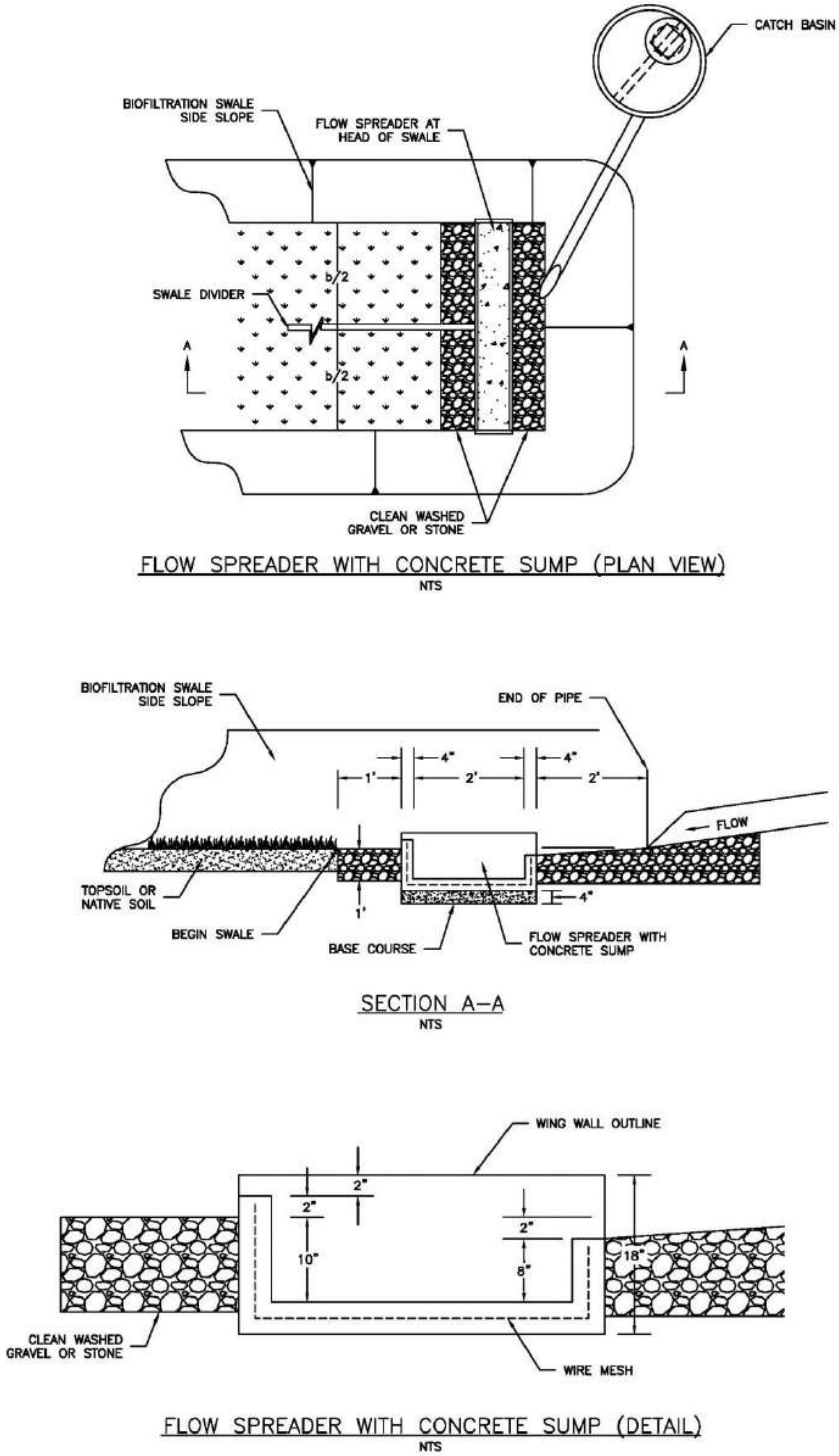


Figure 5.6-9. Biofiltration Swale Typical Details
Source: Adapted from WSDOT (40)

5.7 Extended Detention Basin

Figure 5.7-1. Extended Detention Basin
Source: Courtesy of UDFCD

Description
A constructed basin designed to capture and treat storm water runoff. Runoff is detained for a minimum of 48 hours, providing time for pollutants to settle out prior to discharge. These facilities are sometimes referred to as a "dry ponds" because they are designed to remain empty between runoff events.

Primary Components	Primary Function
▪ Inlet structure ▪ Pretreatment forebay ▪ Main treatment cell ▪ Micropool ▪ Outlet structure	☐ Runoff reduction ☑ Runoff treatment

Benefits	Limitations
▪ Siting is generally not limited by native soils; design accommodations can be made for most soil types ▪ Maintenance can be achieved using equipment and skills common to most MS4s ▪ The facility can be designed for multiple uses such as runoff treatment, flood control, and open space	▪ Not recommended for contributing drainage basins of less than 5 impervious acres ▪ Typically require a relatively large continuous area ▪ Relatively ineffective at removing dissolved pollutants ▪ Ponding time and depths may generate safety concerns and vector issues

Design and Site Selection Considerations	
☑ Setbacks	☐ Underdrain
☑ Depth to groundwater or bedrock	☑ Facility liners
☑ Soil permeability	☑ Landscaping/planting
☐ Soil preparation/amendments/compost	☑ Fencing
☑ Pretreatment forebay	☑ Size of contributing drainage area
☑ Inlet and outlet spacing	☑ Area required
☐ Energy dissipater/level spreader	☑ Incorporate flood control

TMDL Considerations			Maintenance Requirements
Avoid	Preferred		
☐	☑	Total suspended solids (TSS)	☑ Access roads or pullouts
☐	☐	Total phosphorus	☑ Sediment removal
☐	☐	Total nitrogen	☑ Irrigation
☑	☐	Temperature	☑ Vegetation management
☐	☐	Metals	☑ Erosion and embankment stabilization repair
☐	☐	Fecal coliform	☐ Specialized equipment and training

5.7.1 General Description

An extended detention basin (EDB) is a sedimentation basin designed to detain and slowly release storm water over an extended period of time following a rainfall event. This BMP is similar to a detention basin used for flood control except it uses a smaller outlet that extends the emptying time of the more frequently occurring runoff events to improve pollutant removal.

The primary characteristics of an EDB are as follows:

- EDBs consist of an inlet, a pretreatment forebay, and a main treatment cell that includes a trickle channel, a micropool, and an outlet structure.
- An EDB has a minimum 48-hour drain time for the RTV, facilitating the removal of TSS (44).
- EDBs can be designed to provide both runoff treatment and flood control.

5.7.2 Performance

Runoff Reduction

Runoff reduction is not considered to be a function of EDBs because they generally discharge a volume equivalent to the entire inflow runoff volume.

Runoff Treatment

An EDB is expected to achieve an 80 percent removal rate of TSS from the RTV when designed, operated, and maintained as described in this manual (45).

5.7.3 Site Selection

The basic guidelines are provided below to aid in evaluating whether EDBs are feasible for use at an individual site.

Contributing Drainage Area

- EDBs are best suited for sites with contributing basins ranging from 5 impervious acres to 1 square mile. EDBs located at sites with drainage areas of less than 5 impervious acres can result in small orifice sizes that are prone to clogging (44).

Soil Characteristics

- EDBs are suitable for almost all soil types; however, special consideration should be taken for sites located within karst regions, as discussed in Chapter 4.
- Sites containing soils with high infiltration rates may have the potential for seepage through the embankment. An impermeable liner may be appropriate in these situations.
- Soil characteristics can initially be estimated from NRCS soil data, but should be field-verified prior to final design using the onsite soil investigation methods discussed in Chapter 2 and Appendix C of this manual.

Depth to Groundwater and/or Bedrock

- The seasonal high water table and/or bedrock should be 2 or more feet below the bottom of the basin unless a licensed engineer with geotechnical expertise (PE), or other licensed professional acceptable to the local jurisdiction, judges that conditions are acceptable for keeping the basin dry and maintainable based on site-specific test data or analysis and the potential for groundwater contamination has been evaluated (44).
- An evaluation of the depth to groundwater should be conducted, as described in Section 4.3.3.

Site Topography

- The site should be able to accommodate a slope within the EDB that is steep enough to ensure that flows are able move through the system.
- It is recommended that the overall slope of the site should be less than 15 percent (46).

Land Use and Characteristics of Surrounding Area

- Locating EDBs in densely developed areas (i.e., downtown areas) is difficult and often cost-prohibitive because of the amount of land needed to properly size the facility.
- EDBs located on soils with high infiltration rates or near steep slopes may result in shallow lateral flow (interflow) that can reemerge and negatively affect down-gradient structures. For these sites, an assessment of the impact on down-gradient structures is recommended.

Community and Environmental Considerations

- Water temperatures may increase between the inlet and outlet of an EDB during summer months.
- EDBs have the potential to affect naturally sensitive features such as wetlands and trees located within or directly adjacent to the site. For example, changes in inundation frequency can affect established trees or other vegetation (47).
- Shallow wet areas have the potential to create conditions that lead to mosquito breeding. Constructing EDBs with consistent slopes can facilitate proper draining between events and help reduce the potential for shallow wet areas to develop.
- Opportunities may be available for an EDB to be located within or near multiuse facilities such as parks and open space.

Figure 5.7-2. Detention Basin in Billings, Montana
Source: HDR

EDBs can be sized to incorporated both runoff treatment and flood control

5.7.4 Design and Sizing Procedure

The following steps outline the design procedure and criteria for an EDB in a contributing basin greater than or equal to 5 impervious acres. The information provided has been adopted from the Urban Drainage and Flood Control District (UDFCD) *Urban Storm Drainage Criteria Manual, Volume 3*, with minor revisions that account for local considerations. EDBs contain certain features for which local standards and preferences may affect the design process (e.g., outlet structures, trash racks, and embankments). Guidance and standards from the local jurisdiction should be considered during the design process.

1. Basin Storage Volume

Design the basin storage volume to be at least 100 percent of the RTV. This volume begins at the invert of the lowest orifice in the outlet structure, as shown in Figure 5.7-7. Calculate the RTV using Equation 3-2 in Section 3.2. If the EDB is designed for flood control, the flood volume would be stacked on top of the RTV volume in the basin.

Extended Detention Basin Minimum Design Criteria[1]

Required Components
☑ Inlet structure
☑ Pretreatment forebay
☑ Main treatment cell
☑ Trickle channel
☑ Micropool
☑ Outlet structure
Design and Sizing
General
☑ Basin storage is 100% of RTV (minimum)
☑ Basin shape of 2:1 (L:W) (minimum)
☑ Main treatment cell depth of 2 feet (minimum)
☑ Provide maintenance access
☑ Provide a landscaping plan
☑ Provide an operations and maintenance plan
Pretreatment forebay
☑ Volume is 10% of RTV (minimum)
☑ Depth between 4 and 6 feet
☑ Hard bottom
☑ Provide maintenance access
Trickle channel
☑ Flow capacity equal to forebay outlet structure discharge capacity
Micropool
☑ Depth of at least 2.5 feet
☑ Surface area of 10 square feet (minimum)
☑ Hard bottom
Outlet structure
☑ 48-hour minimum drain time for RTV
☑ Provide trash rack

[1] *This table presents the minimum design criteria for satisfying the Runoff Treatment Requirement as defined in Section 1.3.2 of this manual.*

2. Basin Shape

Maximize the distance between the inlet and the outlet by providing a basin length-to-width ratio of at least 2:1 to minimize short circuiting and improve sediment removal. The flow path length is defined as the distance from the inlet to the outlet as measured at the surface. The width is defined as the mean width of the basin (see Figure 5.7-7).

Design the main treatment cell with a depth between 2 and 5 feet, depending on local standards (note that this depth includes the initial surcharge volume discussed below). The design depths for the forebay, trickle channel, and micropool are discussed in their respective sections below.

3. Basin Side Slopes

Basin side slopes should be stable and gentle to facilitate maintenance and access. 4:1 (H:V) or flatter side slopes are preferred to allow for conventional maintenance equipment and for improved safety and aesthetics. Side slopes should be no steeper than 3:1 (H:V); however, local design standards should be consulted to confirm the maximum allowable slopes. Using walls is discouraged because of maintenance constraints.

4. Inlet

Inlet locations should be designed to dissipate flow energy using materials such as riprap or concrete to limit erosion and promote particle sedimentation.

5. Pretreatment Forebay

Figure 5.7-3. Pretreatment Forebay and Trickle Channel
Source: Courtesy of UDFCD

A pretreatment forebay, located at each major inlet, provides an opportunity for larger particles to settle out prior to discharging flows to the main treatment cell. This feature helps to preserve the capacity of the main treatment cell. Guidance for forebay sizing and design are as follows:

- Maximize the length of the flow path through the forebay and minimize the slope to encourage settling.
- Provide a depth between 4 and 6 feet with a volume equal to 10 percent of the RTV.
- Size the forebay outlet structure to discharge the RTV at a flow rate equal to 2 percent of the 100-year undetained peak discharge. This structure can be created as an armored earthen berm with 3:1 (H:V) side slopes (or flatter) using gabion, concrete, or riprap along the separation embankment preceding the main treatment cell. Protecting the berm from erosion is important because it will overtop frequently.
- A concrete bottom is recommended to facilitate sediment removal during maintenance.
- Provide a way to monitor sediment accumulation. Options include a metered rod in the forebay or concrete lining that defines sediment removal limits.

6. Trickle Channel

Convey low flows from the forebay to the micropool using a trickle channel. The trickle channel may be either concrete or soft-bottomed, with a flow capacity equal to the maximum discharge from the forebay outlet (2 percent of the 100-year undetained peak discharge).

- **Concrete Trickle Channels**: A concrete trickle channel will help establish the bottom of the basin in the long term and may also facilitate regular sediment removal. It can be a “V”-shaped concrete drain pan or a concrete channel with curbs. A flat-bottom channel facilitates maintenance. A slope between 0.4 and 1 percent is recommended to encourage settling while reducing the potential for low points in the pan.
- **Soft-bottom Trickle Channels**: Soft-bottom trickle channels offer an attractive alternative to concrete and can improve water quality. However, they are not appropriate for all sites because maintenance requires mechanical removal of sediment and vegetation, and this option can increase the likelihood of creating a mosquito habitat. Therefore, they should be considered on a case-by-case basis with the approval of the local jurisdiction. Soft-bottom trickle channels should be designed with a consistent longitudinal slope from the forebay to the micropool, and they should not meander. This geometry will allow for reconstruction of the original design when sediment removal in the trickle channel is necessary. The trickle channel may also be located along the toe of the slope if a straight channel is not desired. The recommended minimum depth of a soft-bottom trickle channel is 1.5 feet, which will help limit potential wetland growth to the trickle channel, preserving the bottom of the basin.

Riprap and soil riprap lined trickle channels are not recommended because of increased maintenance requirements. Specifically, when sediment is removed during routine maintenance, riprap may be inadvertently removed and need to be replaced.

7. Micropool

A micropool is a small pool located in front of the outlet structure, designed to prevent sediment resuspension, protect the low flow outlet riser orifices or perforated plate from clogging, and reduce mosquito breeding areas (44). Design guidance for the micropool is as follows:

- The side slopes may be stabilized vertical walls or stabilized slopes of up to 3:1 (H:V).
- Provide a depth of at least 2.5 feet with a minimum surface area of 10 square feet.
- A concrete bottom is recommended.

Figure 5.7-4. Micropool and Outlet Structure
Source: Courtesy of UDFCD

8. Outlet Structure

The purpose of the outlet structure is to detain and slowly release runoff, allowing pollutants to settle out prior to release and to safely discharge runoff volumes accumulated from larger storm events. An EDB will typically have a multistage outlet control structure that includes a low-flow water quality outlet (typically an orifice), a 10- or 25-year design storm outlet depending on local jurisdiction requirements (typically a drop inlet, pipe, or weir), and may also include an auxiliary or emergency spillway designed to pass the 100-year runoff event (weir or armored spillway built into the embankment).

This manual provides guidance for sizing an orifice plate outlet structure (see Figure 5.7-5); however, a variety of outlet structure configurations could be used to meet the project's storm water management objectives. Consult the local jurisdiction prior to selecting an outlet structure configuration because preferences may vary throughout the state.

General outlet structure design guidance is as follows:

- Locate the outlet structure in the embankment of the EDB and provide a permanent micropool directly in front of the structure.
- The outlet may be sized for the RTV only or it may have a multistage control structure, depending on whether the facility is designed for water quality only or includes flood control. Outlet structure orifice sizing guidance is provided in Section 5.8.4, in the Outlet Structure subsection.
- A minimum drawdown time for the RTV of 48 hours is required, and 72 hours is the maximum drawdown time recommended. Refer to local standards because some jurisdictions have different maximum drawdown time recommendations.
- For orifice plate outlets, the trash rack may be submerged to the bottom of the micropool. This will reduce potential for clogging of the trash rack because it allows water to flow through the trash rack below the elevation of the lowest orifice even when the area above the water surface is plugged. This will prevent shallow ponding in front of the structure, which

provides a breeding ground for mosquitoes (large, shallow puddles tend to produce more mosquitoes than a smaller, deeper permanent pond).

- The low-flow orifice should be adequately protected from clogging by either an acceptable external trash rack (recommended minimum orifice of 3 inches) or by internal orifice protection that may allow for smaller diameters (recommended minimum orifice size of 1 inch). Orifices less than 3 inches in diameter may require extra maintenance because of the increased potential for clogging.
- Perforated riser pipes should be used with caution in cold climates because ice cover can cause clogging of the orifices.
- Ensure that the outlet structure is designed to accommodate the peak flows generated from each design event. For instance, if the EDB is designed to incorporate flood control, the outlet structure must be sized to safely pass the design flood flow while the basin maintains freeboard requirements specified by the local jurisdiction. An overflow outlet and/or weir may be required by the local jurisdiction to safely pass volumes greater than the RTV.

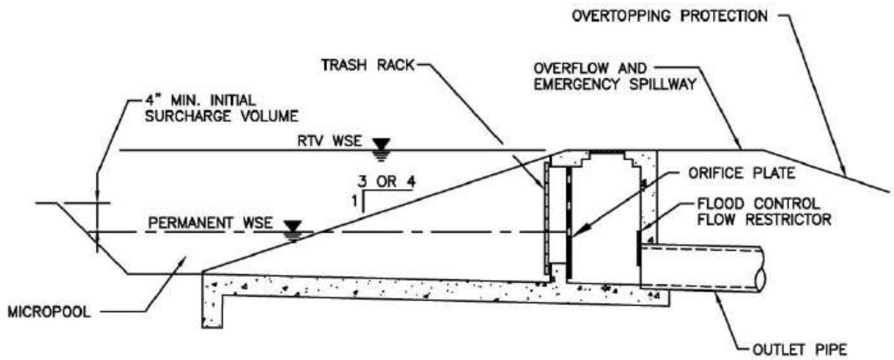


Figure 5.7-5. Example Orifice Plate Outlet Structure (Runoff Treatment Volume Only)
Source: Adapted from UDFCD (48)[1]

9. Initial Surcharge Volume

Providing a surcharge volume above the micropool for frequently occurring runoff events minimizes standing water and sediment deposition in the remainder of the basin. The initial surcharge volume is not part of the micropool nor does it include the micropool volume; rather, it is the available storage volume that begins at the water surface elevation of the micropool and extends upward to a grade break in the basin (typically the trickle channel's invert). Design guidance for incorporating the initial surcharge volume is as follows:

- The surface area of the initial surcharge volume, when full, is typically the same as or slightly larger than that of the micropool.
- The recommended initial surcharge volume is at least 0.3 percent of the RTV at a depth of at least 4 inches.

10. Trash Rack

Most basins will collect a certain amount of trash and debris from incoming flows. Floating debris such as grass clippings, tree limbs, leaves, trash, construction debris, and sediment bed load from upstream watersheds are common. A trash rack located at the outlet control structure of the facility can help reduce the potential for clogging. General trash rack design guidance is as follows:

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[1] Additional guidance pertaining to the analysis and design of orifice plate outlet structures is available in Fact Sheet T-12: Outlet Structures, in UDFCD's *Urban Storm Drainage Criteria Manual, Volume 3* (available at http://udfcd.org/).

- The trash rack's size should provide the necessary hydraulic capacity while the rack is partially clogged.
- Openings should be small enough to limit clogging of the individual orifices.
- Where applicable, it is recommended that trash racks be installed at a shallow (~15°) angle to prevent ice formation (49).
- All drop inlet spillways designed for pressure flow should have adequate anti-vortex devices. An anti-vortex device is not required if weir control is maintained in the riser through all flow stages, including the maximum design storm. Examples of anti-vortex devices include a baffle or plate installed on top of the riser, or a headwall set on one side of the riser (50).

11. Embankment and Overflow Spillway

EDBs are typically constructed with an overflow spillway designed to safely convey excess flows through the facility. Design guidance for the overflow spillway and embankment is as follows:

- If the embankment falls under the jurisdiction of Montana DNRC, it must be designed to meet the applicable requirements.
- Embankment soils should be compacted as determined by a licensed engineer.
- Slopes that are 4:1 (H:V) or flatter are preferred to allow for conventional maintenance equipment and for improved safety, maintenance, and aesthetics.
- Locate the overflow spillway at a point where waters can best be conveyed downstream.
- It is recommended that the overflow spillway be designed to safely convey runoff from the 100-year storm, at a minimum.
- Design spillway structures and associated freeboard in accordance with applicable state or local regulations.
- Materials such as concrete, riprap, or articulated concrete block mats may be necessary to mitigate the potential for erosion and failure of the spillway during less frequent events.

12. Maintenance Access

Considering maintenance access during the design phase of an EDB is critical because it will help to facilitate the facility's long-term performance. Guidelines for the design of maintenance access are as follows:

- Provide appropriate maintenance access to the forebay and micropool/outlet works. For larger basins, this typically means stabilized access designed to withstand the expected loads from maintenance vehicles.
- Stabilized access typically includes materials such as concrete, articulated concrete block, concrete grid pavement, or reinforced grass pavement.
- Grades of less than 10 percent for haul road surfaces and 20 percent for skid-loader and backhoe access are preferred. A cross slope of 2 percent is recommended for drainage.
- If stabilized access is not provided, a maintenance plan that provides details including recommended equipment and a plan for sediment and trash removal from the outlet structure and micropool may be required by the local jurisdiction.

13. Guidelines for Incorporating Flood Control

EDBs can be designed to provide flood control by increasing the surcharge volume for flood detention storage and designing the outlet structure to detain and release flood flows. Reservoir routing calculations may be used to assist in the outlet structure design for larger runoff events. Appropriate flood control design guidance and local regulations should be referenced when incorporating flood control into an EDB.

5.7.5 Vegetation Considerations

Vegetation is an essential component of an EDB because it provides erosion control and enhances site stability. Developing a landscaping plan for the EDB and surrounding area is required to indicate how the EDB will be stabilized and established with vegetation. Considerations when developing the vegetation and landscaping plan are as follows:

- Delineate landscaping zones within and surrounding the EDB.
- Select suitable plant species, including drought-tolerant plants, where applicable.
- Include sources of native plant material in a planting plan.
- Determine the location and type of irrigation facilities, if necessary. Where possible, place irrigation heads outside the basin bottom because irrigation heads in an EDB can be buried with sediment over time.
- Delineate areas that should be avoided during construction to avoid compacting native soils.
- Omit woody vegetation within 15 feet of the toe of the embankment or within 25 feet of the principal spillway structure because of potential impacts of root systems (47).

> Note: Given the wide range of native vegetation across Montana, designers should consult local specialists, landscape architects, and/or agencies for recommendations on appropriate plant species and landscaping considerations for the site.

5.7.6 Construction Considerations

Basic construction considerations and recommendations are provided below.

Construction Site Management

- Acquire all applicable permits prior to construction. See Section 1.4 for more information.
- Apply appropriate erosion control measures to minimize erosion during construction. Refer to the local jurisdiction's construction site storm water management program for additional guidance and local requirements.
- If used as a construction storm water management BMP, an EDB should be dewatered, dredged, and re-graded prior to post-construction implementation.

Construction Inspection

- Inspections are recommended during the following phases of construction:
  - Pre-construction meeting
  - Initial site preparation
  - Excavation/grading
  - Installation of the embankment, spillway(s), and outlet structure
  - Implementation of the vegetation and landscaping plan
  - Final inspection

Transition to Post-Construction

- Develop a plan prior to construction that will allow for an effective transition from construction storm water management BMPs to post-construction BMPs without compromising the integrity of the post-construction BMPs.
- Coordinate with the local jurisdiction prior to terminating coverage of the Construction General Permit.

5.7.7 Maintenance

Maintenance is required on all BMPs. Recommended maintenance activities are provided in Table 5.7-1, which may be used as a guide when developing a maintenance plan. Additionally, an example inspection form is provided in Appendix F that may be adapted or adopted as part of the maintenance plan.

Table 5.7-1. Recommended Maintenance Activities for an EDB

Activity	Frequency
▪ Remove litter/debris from all components of the EDB. ▪ Repair inlet, outlet, trickle channel, and all other structural components required for the basin to operate as intended. ▪ Repair and revegetate eroded areas. If turf grass requires replacement, use a species with similar growth requirements. ▪ Regularly manage all vegetation and remove all clippings. ▪ Where applicable, irrigate during dry weather and replace broken sprinkler heads. Completely drain the irrigation system before the first winter freeze and check for damaged components upon reactivation in the spring. ▪ Repair maintenance access routes, if applicable. ▪ Inspect the EDB for signs of mosquito larvae during summer months and provide treatment when breeding is found. If available, a local mosquito control service could be used to carry out these inspections.	As needed
▪ Trim vegetation for aesthetics and mosquito control. Prevent establishment of woody vegetation on or near berms or embankments. ▪ Evaluate the health of vegetation and remove and replace any dead or dying plants. ▪ Remove all green waste and dispose of properly.	Semiannually
▪ Inspect all components of the EDB in accordance with an approved inspection form according to local jurisdiction requirements. An example inspection form is provided in Appendix F.	Annually
▪ Remove sediment from the micropool when the depth has been reduced to approximately 18 inches. ▪ Remove sediment from the forebay before it becomes a significant source of pollutants for the remainder of the EDB.	Typically 1 to 4 years
▪ Remove accumulated sediment and re-grade when the accumulated sediment volume exceeds 10 percent of the main treatment cell design volume. Dispose of sediment properly.	Typically 10 to 20 years (or as needed)

Figure 5.7-6. Detention Basin Deferred Maintenance

Source: Courtesy of the City of Bozeman

Conducting routine maintenance is a critical component to the performance of all BMPs. Deferred maintenance allowed this BMP to be overrun with vegetation.

5.7.8 Plan View and Typical Details

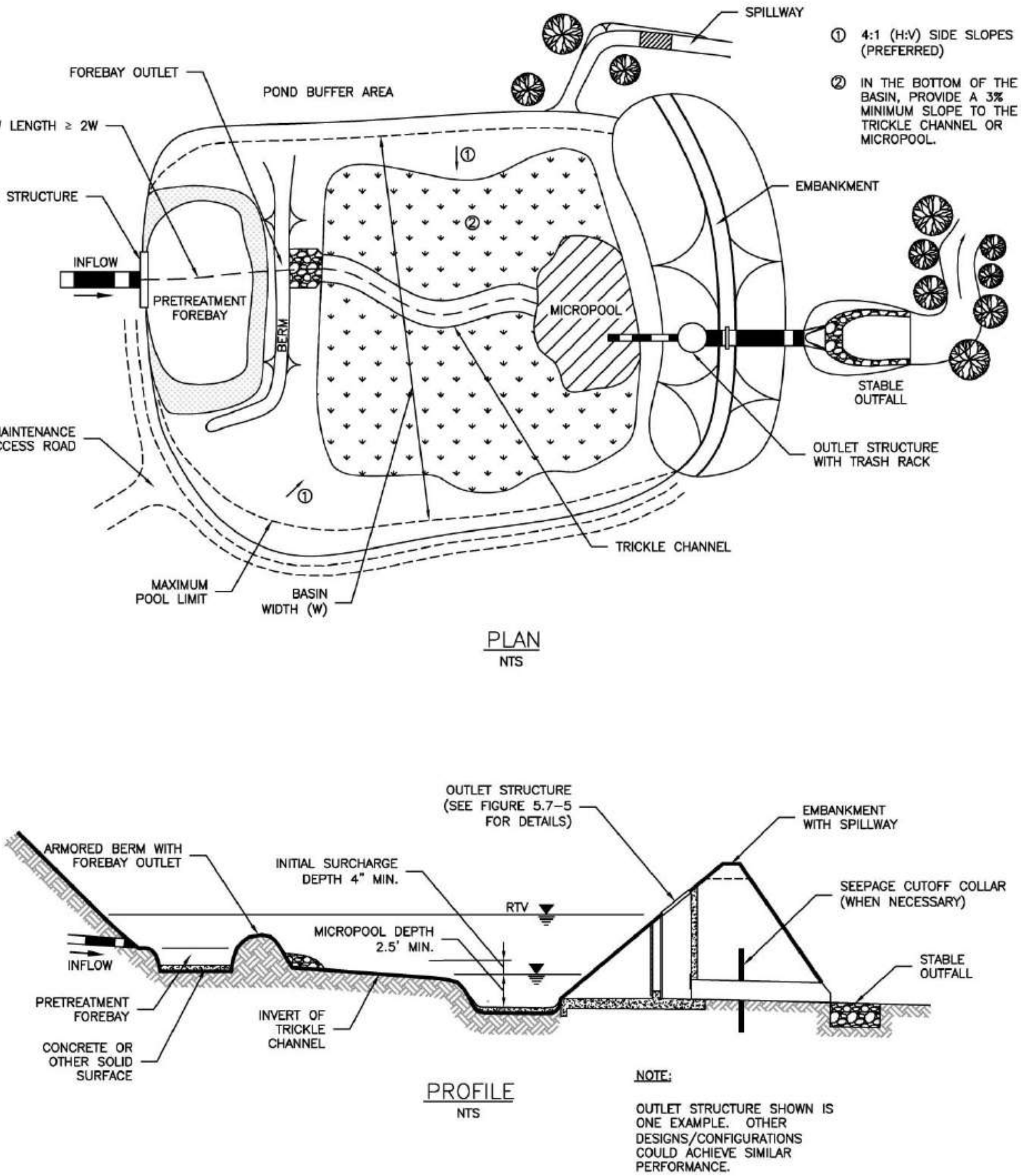

Figure 5.7-7. Extended Detention Basin Plan View and Typical Section
Source: Adapted from UDFCD (44)

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5.8 Wet Detention Basin

Figure 5.8-1. Wet Detention Basin
Source: HDR

Description

A constructed basin that maintains a permanent pool of water and is designed to manage storm water runoff. Runoff is detained for a minimum of 48 hours, providing time for pollutants to settle out prior to discharge.

Primary Components	Primary Function
▪ Inlet structure ▪ Pretreatment forebay ▪ Permanent pool ▪ Outlet structure	☐ Runoff reduction ☑ Runoff treatment

Benefits	Limitations
▪ Siting is generally not limited by native soils. Design accommodations can be made for most soil types. ▪ Maintenance can be achieved using equipment and skills common to most MS4s ▪ The facility can be designed for multiple uses such as runoff treatment, flood control, and open space	▪ Not recommended for basins less than 10 acres ▪ Typically require a relatively large continuous area ▪ There is a potential for safety concerns associated with open waters ▪ Attraction of water fowl can increase nutrients and bacteria leaving the pond ▪ The facility must be able to maintain a permanent pool of water

Design and Site Selection Considerations

☑ Setbacks	☐ Underdrain
☐ Depth to groundwater or bedrock	☑ Facility liners
☑ Soil permeability	☑ Landscaping/planting
☐ Soil preparation/amendments/compost	☑ Fencing
☑ Pretreatment forebay	☑ Size of contributing drainage area
☑ Inlet and outlet spacing	☑ Area required
☐ Energy dissipater/level spreader	☑ Incorporate flood control

TMDL Considerations

Avoid	Preferred	
☐	☑	Total suspended solids
☐	☑	Total phosphorus
☐	☐	Total nitrogen
☑	☐	Temperature
☐	☐	Metals
☑	☐	Fecal coliform

Maintenance Requirements

- ☑ Access roads or pullouts
- ☑ Sediment removal
- ☐ Irrigation
- ☑ Vegetation management
- ☑ Erosion and embankment stabilization repair
- ☐ Specialized equipment and training

5.8.1 Description

A wet detention basin (WDB) is a constructed storm water basin designed to capture, detain, and slowly release runoff to promote pollutant removal through sedimentation and biological uptake. This BMP maintains a permanent pool of water throughout most of the year. Water in the permanent pool is partially displaced during each runoff event, allowing storm water runoff to mix with permanent pool water prior to discharge. An additional function of the permanent pool is to minimize resuspension of sediments and other pollutants deposited during prior runoff events.

The primary characteristics of a WDB are as follows:

- A two-cell pond that is separated by a baffle or berm. An inlet structure conveys runoff into the first cell, which is referred to as the pretreatment forebay. The second larger cell is referred to as the wetpool cell, which contains an outlet structure at its downstream end.
- A minimum 48-hour drain time for the RTV facilitates the removal of TSS.
- WDBs can be designed to provide both runoff treatment and flood control.

5.8.2 Performance

Runoff Reduction

Runoff reduction is not considered to be a function of WDBs because they generally discharge a volume equivalent to the entire inflow runoff volume.

Runoff Treatment

A WDB is expected to achieve an 80 percent or greater removal rate of TSS from the RTV when designed, operated, and maintained as described in this manual (51).

5.8.3 Site Selection

Basic guidelines are provided below to aid in evaluating whether WDBs are feasible for use at an individual site.

Contributing Drainage Area

- A site with a consistent inflow (typically via groundwater) is desirable to help maintain a permanent pool.
- WBDs are best suited for sites with contributing basins greater than 10 acres. WDBs with drainage areas of less 10 acres can result in outlet structures that have small orifice sizes that are prone to clogging and may have difficulty maintaining a permanent pool.
- Contributing basins of less than 10 acres may be acceptable, particularly if the groundwater table provides a base flow to the pond and a water balance indicates that a permanent pool can be sustained.

Soil Characteristics

- Soils with low infiltration rates are preferred to maintain a permanent pool; however, sites containing soils with high infiltration rates may be acceptable if an impermeable liner is provided and a water balance demonstrates that a permanent pool will be maintained.
- WDBs are not recommended for Karst terrain.
- Soil characteristics can initially be estimated from NRCS soil data, but should be field-verified prior to final design using the onsite soil investigation methods discussed in Chapter 2 and Appendix C of this manual.

Depth to Groundwater and/or Bedrock

- In general, no minimum separation distance is required for WDBs because intercepting the groundwater table can help to maintain a permanent pool. However, a separation distance or impermeable liner may be appropriate for groundwater protection considerations at sites where there is a sensitive underlying aquifer and the bottom material of the pond allows for infiltration.
- An evaluation of depth to groundwater should be conducted, as described in Section 4.3.3.

Site Topography

- The site should be able to accommodate an elevation difference between the inlet and outlet that is large enough to ensure that flows are able move through the system.
- It is recommended that slopes immediately adjacent to the WDB be less than 25 percent to limit erosion, but greater than 0.5 percent to promote flow toward the pond.

Land Use and Characteristics of Surrounding Area

- Large open areas are typically required to site a WDB, which may not be cost-effective in dense urban areas.
- Use caution when placing a WDB in a drainage area where development will not be completed for an extended period or where the potential for a chemical spill is higher than typical. When these conditions exist, it is critical to provide adequate containment and/or pretreatment (44).
- WDBs located on soils that facilitate infiltration or near steep slopes may result in shallow lateral flow (interflow) that can reemerge and negatively affect down-gradient structures. For these sites, an assessment of the impact on down-gradient structures is recommended.

Community and Environmental Considerations

- Water temperatures may increase between the inlet and outlet of a WDB during summer months (52).
- WBDs can be an attractive landscape and promote habitat for fish and upland wildlife; however, attraction of geese and waterfowl is typically not desirable because their droppings add to nutrients and bacterial loading in the WDB and downstream waterways. Strategies for discouraging waterfowl use are discussed in Section 5.8.5.
- Safety concerns are often associated with open waters. Consult the local jurisdiction for fencing or sign requirements around ponds.

Figure 5.8-2. WDB with Permanent Pool
Source: HDR

A WDB should maintain a permanent pool throughout the growing season.

5.8 Wet Detention Basin

5.8.4 Design and Sizing Procedure

The following steps outline the design procedure and criteria for a WDB. The information provided has been adapted from the UDFCD *Urban Storm Drainage Criteria Manual, Volume 3*, with minor revisions that account for local considerations. WDBs contain certain features for which local standards and preferences may affect the design process (e.g., outlet structures, trash racks, and embankments). Guidance and standards from the local jurisdiction should be considered during the design process.

1. Permanent Pool Volume

The permanent pool provides storm water quality treatment between runoff events, primarily through sedimentation. Design the permanent pool volume to be 100 percent of the RTV. Determine the RTV using the guidance provided in Section 3.2.

2. Surcharge Volume

The surcharge volume is the volume located directly above the permanent pool water surface elevation (WSE) and encompasses both the wetpool cell and pretreatment forebay (see Figure 5.8-7). Design the WDB to accommodate a minimum surcharge volume equal to 100 percent of the RTV. The surcharge volume may be increased if additional storage capacity is desired for flood control considerations.

3. Base Flow and Water Budget

Maintaining a permanent pool is critical to the performance of a WDB. Climatic conditions vary throughout the state, but overall most areas are relatively arid, which makes maintaining a permanent pool challenging if base flow is not provided to the facility. For this reason, a groundwater base flow is strongly recommended.

To ensure a permanent pool is maintained, develop an overall water budget to confirm inflows will exceed losses attributable to infiltration and evaporation. Some considerations when performing a water budget are as follows:

- Potential inflows include runoff, base flow, and rainfall.
- Net inflow calculations should be conservative to account for annual variations in hydrologic conditions.
- Potential outflows include infiltration, surface overflow, and evapotranspiration.
- Evaporation can be estimated from existing local studies or from the National Weather Service Climate Prediction website.

Wet Detention Basin Minimum Design Criteria[1]

Required Components
☑ Inlet structure ☑ Pretreatment forebay ☑ Wet pool cell ☑ Outlet structure
Design and Sizing
General ☑ Permanent pool is 100% of RTV (minimum) ☑ Basin shape of 2:1 (L:W) (minimum) ☑ Surcharge volume is 100% of RTV (minimum) ☑ Ability to maintain a permanent pool ☑ Provide maintenance access ☑ Provide a landscaping plan ☑ Provide an operations and maintenance plan
Pretreatment forebay ☑ Volume is 10% of RTV (minimum) ☑ Depth between 4 and 6 feet ☑ Hard bottom ☑ Provide maintenance access ☑ Armored barrier or berm separating pretreatment forebay and wet pool cell
Wet pool cell ☑ Depth between 4 and 12 feet ☑ Safety-wetland bench (4 feet wide, 6 to 12 inches deep)
Outlet structure ☑ 48-hour minimum drain time for RTV ☑ Provide trash rack ☑ Provide pond drain (or other method to drain wet pool cell)

[1] *This table presents the minimum design criteria for satisfying the Runoff Treatment Requirement as defined in Section 1.3.2 of this manual.*

4. Basin Shape

Maximize the distance between the inlet and outlet by providing a basin length-to-width ratio of at least 2:1, which will minimize short circuiting and improve sediment removal. The flow path length is defined as the distance from the inlet to the outlet as measured at the surface. The width is defined as the mean width of the basin.

The wetpool cell should have two depth zones:

- **Safety-Wetland Bench**: The safety-wetland bench is a gently sloped bench located along the perimeter of the wetpool cell that provides a shallow area allowing people or animals that inadvertently enter the open water to gain footing to get out of the pond. Additionally, the bench facilitates aquatic plant growth along the perimeter of the permanent pool, which can help strain surface flow into the pond, protect the banks from erosion by stabilizing the soil at the edge of the pond, and provide biological uptake. Design the bench to be 6 to 12 inches deep and a minimum of 4 feet wide.
- **Open Water Zone**: The remaining pond area should be open, providing a volume to promote sedimentation and nutrient uptake by phytoplankton. Design the permanent pool with a depth between 4 and 12 feet, depending on local standards. The minimum depth helps to prevent resuspension of settled pollutants and encourages proper mixing, and the maximum depth helps to minimize stratification and an imbalance between pool volume and surface area (53) (54). For safety considerations associated with open waters, a fence or signs may be required by the local jurisdiction.

5. Inlet

Design the WDB so that inlets discharge into a pretreatment forebay. The inlet locations should be designed to dissipate flow energy to limit erosion and promote particle sedimentation.

6. Pretreatment Forebay

A pretreatment forebay, located at each major inlet, provides an opportunity for larger particles to settle out prior to discharging flows to the wetpool cell, helping preserve the capacity of the wetpool cell. Guidance for forebay sizing and design are as follows:

- Maximize the length of the flow path through the forebay and minimize the slope to encourage settling.
- Provide a depth between 4 and 6 feet with a volume equal to 10 percent of the RTV.
- A barrier separating the pretreatment forebay and wetpool cell should be constructed to contain the forebay opposite of the inlet. If the barrier is an earthen berm, a minimum top width of 8 feet and side slopes no steeper than 4:1 are recommended. The barrier should be armored with using material such as gabions, concrete, or riprap to minimize erosion because the berm may overtop frequently.
- A concrete bottom is recommended to facilitate sediment removal during maintenance.

Figure 5.8-3. WDB Pretreatment Forebay
Source: HDR

- Provide a way to monitor sediment accumulation. Options include a metered rod in the forebay or concrete lining that defines sediment removal limits.

7. Side Slopes

Basin side slopes should be stable to facilitate maintenance and access. Side slopes above the safety-wetland bench should be no steeper than 4:1 (H:V), preferably flatter to allow for conventional maintenance equipment and for improved safety. The side slope below the safety-wetland bench should be 3:1 (or flatter when access is required or when the surface could be slippery). The steeper 3:1 slope below the safety wetland bench can deter algae growth because it will reduce the shallow area of the pond, thus reducing the amount of sunlight that penetrates the pond bottom. Local design standards should be consulted to confirm the maximum allowable slopes.

8. Outlet Structure

The outlet structure detains and slowly releases runoff, allowing pollutants to settle out prior to release and to safely discharge runoff volumes accumulated from larger storm events. A WDB will typically have a multistage outlet control structure that includes a low-flow water quality outlet (typically an orifice), a 10- or 25-year design storm outlet depending on local jurisdiction requirements (typically a drop inlet, pipe, or weir), and may also include an auxiliary or emergency spillway designed to pass the 100-year runoff event (weir or armored spillway built into the embankment).

This manual provides guidance for sizing an orifice plate outlet structure (see Figure 5.8-4); however, a variety of outlet structure configurations could be used to meet the project's storm water management objectives. Consult the local jurisdiction prior to selecting an outlet structure configuration because preferences may vary throughout the state.

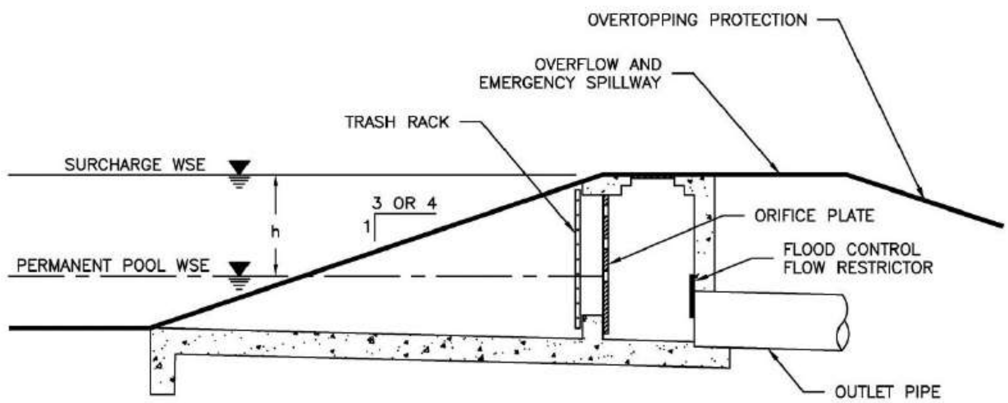


Figure 5.8-4. Typical Orifice Plate Outlet Structure
Source: Adapted from UDFCD (55)[2]

General outlet structure design guidance is as follows:

- Locate the outlet structure in the embankment of the WDB. This allows access for maintenance.
- A minimum drawdown time for the RTV of 48 hours is required, and 72 hours maximum is recommended. Refer to local standards because some jurisdictions have different maximum drawdown time recommendations.

[2] Additional guidance pertaining to the analysis and design of orifice plate outlet structures is available in Fact Sheet T-12: Outlet Structures, in UDFCD's *Urban Storm Drainage Criteria Manual, Volume 3* (available at http://udfcd.org/).

- It is recommended that the low-flow orifice be adequately protected from clogging by either an acceptable external trash rack (recommended minimum orifice of 3 inches) or by internal orifice protection that may allow for smaller diameters (recommended minimum orifice size of 1 inch).
- Orifices less than 3 inches in diameter may require extra maintenance because of the increased potential for clogging.
- An overflow outlet and/or weir may be required by the local jurisdiction to safely pass volumes greater than the RTV.
- Perforated riser pipes should be used with caution in cold climates because ice cover can cause clogging of the orifices.
- Ensure that the outlet structure is designed to accommodate the peak flows generated from each design event for the WDB. For instance, if the WDB is designed to incorporate flood control, the outlet structure must be sized to safely pass the design flood flow while the basin maintains freeboard requirements specified by the local jurisdiction.

Orifice Sizing for the RTV (Average Hydraulic Head and Average Discharge Method)

Multiple methods could be used for designing the outlet structure configuration and orifice sizing. This manual proposes using a simplified method whereby the full RTV is assumed to fill the basin instantaneously, and the drawdown time is the time it takes to drain the RTV. Guidance for the low-flow orifice sizing is as follows:

- Calculate average release rate for the RTV using Equation 5.8-1.

$$Q_{RTV}=\frac{RTV}{t} \qquad \text{Equation 5.8-1}$$

Where:

Q_{RTV}	= Average orifice discharge for the RTV (cfs)
RTV	= Runoff treatment volume (ft^3)
t	= Drawdown time, converted to seconds (48-hrs*3600 sec/hr)

- Find the elevation associated with the RTV using the WDB's stage-storage table and calculate the approximate average head on the orifice using Equation 5.8-2.

$$h=\frac{\left(WSE_{RTV}-WSE_{Perm\ Pool}\right)}{2} \qquad \text{Equation 5.8-2}$$

Where:

h	= Average head on orifice (ft)
WSE_{RTV}	= Surcharge WSE, see Figure 5.8-4 (ft)
$WSE_{Perm\ Pool}$	= Permanent pool WSE, see Figure 5.8-4 (ft)

- The orifice equation (Equation 5.8-3) can be reconfigured to calculate the diameter of the orifice using Equation 5.8-4.

$$Q_{RTV}=CA_o\sqrt{2gh} \qquad \text{Equation 5.8-3}$$

$$d_{RTV}=\left[\frac{4*Q_{RTV}}{\pi C\sqrt{2gh}}\right]^{0.5} \qquad \text{Equation 5.8-4}$$

Where:

Q_{RTV}	= Average orifice discharge for the RTV (cfs)

C	= Coefficient of discharge (typically 0.6 or as specified by vendor)
A_o	= Cross sectional area of orifice (ft^2)
g	= Gravitational acceleration (32.2 ft/sec^2)
h	= Average head on orifice (ft)
d_{RTV}	= Diameter of low-flow orifice (ft)

9. Pond Drain

WDBs should be equipped with a method to drain the permanent pool when sediment removal is required. A gravity drain pipe that can completely or partially drain the permanent pool within 24 hours is preferred; however, in cases where a low-level gravity drain is not feasible (such as in an excavated pond), pumping may be necessary. The pond drain should be equipped with a valve that will be opened only for maintenance.

10. Trash Rack

Most basins will collect a certain amount of trash and debris from incoming flows. Floating debris such as grass clippings, tree limbs, leaves, trash, construction debris, and sediment bed load from upstream watersheds are common. A trash rack located at the outlet control structure of the facility can reduce the potential for clogging. General trash rack design guidance is as follows:

Figure 5.8-5. Outlet Structure Trash Rack
Source: HDR
A trash rack can reduce the potential for clogging of the outlet structure.

- Size the trash rack to provide the necessary hydraulic capacity while the rack is partially clogged.
- Openings should be small enough to limit clogging of the individual orifices.
- Where applicable, trash racks should be installed at a shallow (~15°) angle to prevent ice formation (49).
- All drop inlet spillways designed for pressure flow should have adequate anti-vortex devices. An anti-vortex device is not required if weir control is maintained in the riser through all flow stages, including the maximum design storm. Examples of anti-vortex devices include a baffle or plate installed on top of the riser, or a headwall set on one side of the riser (50).

11. Embankment and Overflow Spillway

WDBs are typically constructed with an overflow spillway designed to safely convey excess flows through the facility. Design guidance for the embankment and overflow spillway is as follows:

- If the embankment falls under the jurisdiction of Montana DNRC, it must be designed to meet the applicable requirements (see Table 1-2).
- Embankment soils should be compacted as determined by a licensed engineer.
- Slopes that are 4:1 (H:V) or flatter are preferred to allow for conventional maintenance equipment and for improved safety, maintenance, and aesthetics.
- Locate the overflow spillway at a point where waters can best be conveyed downstream.

- The overflow spillway should be designed to safely convey runoff from the 100-year storm, at a minimum.
- Design spillway structures and associated freeboard in accordance with applicable state or local regulations.
- In accordance with the local jurisdiction's design standards, materials such as concrete, riprap, or articulated concrete block mats may be necessary to mitigate the potential for erosion and failure of the spillway during less frequent events.

12. Maintenance Access

Consideration of maintenance access during the design phase of a WDB is critical because it will facilitate the WDB's long-term performance. Guidelines for the design of maintenance access are as follows:

- Provide appropriate maintenance access to the pretreatment forebay, wetpool cell bottom, and outlet structure. For larger basins, this typically means stabilized access designed to withstand the expected loads from maintenance vehicles.
- Stabilized access typically includes materials such as concrete, articulated concrete block, concrete grid pavement, or reinforced grass pavement.
- Grades of less than 10 percent for maintenance road surfaces and 20 percent for skid-steer and backhoe access are preferred. A cross slope of 2 percent is recommended.
- If stabilized access is not provided, a maintenance plan that provides details including recommended equipment and a plan for sediment and trash removal from the outlet structure may be required by the local jurisdiction.

13. Guidelines for Incorporating Flood Control

WDBs can be designed to provide flood control by increasing the surcharge volume for flood detention storage and designing the outlet structure to detain and release flood flows. Reservoir routing calculations may be used to assist in the outlet structure design for larger runoff events. Appropriate flood control design guidance and local regulations should be referenced when incorporating flood control into a WDB.

Figure 5.8-6. WDB Maintenance Access
Source: HDR
Provide stable maintenance access designed to withstand the expected loads from maintenance vehicles.

5.8.5 Vegetation Considerations

Vegetation is an essential component of a WDB because it provides erosion control and enhances site stability. Developing a landscaping plan for the WDB and surrounding area is recommended to indicate how the WDB will be stabilized and established with vegetation. Considerations when developing the vegetation and landscaping plan are as follows.

- Berms and side-sloping areas should be planted with native grasses or irrigated turf, depending on the local setting and proposed uses for the pond area.
- The safety wetland bench should be vegetated with wetland plants that can tolerate a saturated root zone. This vegetation around the perimeter of an open water body can discourage frequent use of the pond by geese.
- Woody vegetation is not recommended within 15 feet of the toe of the embankment or within 25 feet of the principal spillway, inlet, and outlet structures because of the potential impacts of root systems.
- The soils of the area immediately surrounding a WDB are often severely compacted during the construction process to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration. Therefore, it is recommended to excavate large and deep holes around proposed planting sites and backfill them with uncompacted topsoil or other organic material.

> Note: Given the wide range of native vegetation across Montana, designers should consult local specialists, landscape architects, and/or agencies for recommendations on appropriate plant species and landscaping considerations for the site.

5.8.6 Construction Considerations

Basic construction considerations and recommendations are provided below.

Construction Site Management

- Acquire all applicable permits prior to construction. See Section 1.4 for more information.
- Apply appropriate erosion control measures to minimize erosion during construction.
- If used as a construction storm water management BMP, a WDB must be dewatered, dredged, and regraded prior to post-construction implementation.
- Consider preserving existing trees in the area surrounding the WDB during construction because it is often desirable to locate forest conservation areas adjacent to ponds.
- To the extent practicable, construction equipment should be restricted from the WDB area to prevent compaction of the native soils.
- Contributing drainage areas should be properly stabilized with the appropriate erosion and sediment controls or permanent seeding before allowing storm water runoff to drain to the storm water pond.

Construction Inspections

- Inspections are recommended during the following phases of construction
  - Pre-construction meeting
  - Initial site preparation
  - Excavation/grading
  - Installation of the embankment, spillway(s), and outlet structure
  - Implementation of the vegetation and landscaping plan

- Final inspection

Transition to Post-Construction

- Develop a plan prior to construction that will allow for an effective transition from construction storm water management BMPs to post-construction BMPs without compromising the integrity of the post-construction BMPs.
- Coordinate with the local jurisdiction prior to terminating coverage of the Construction General Permit.

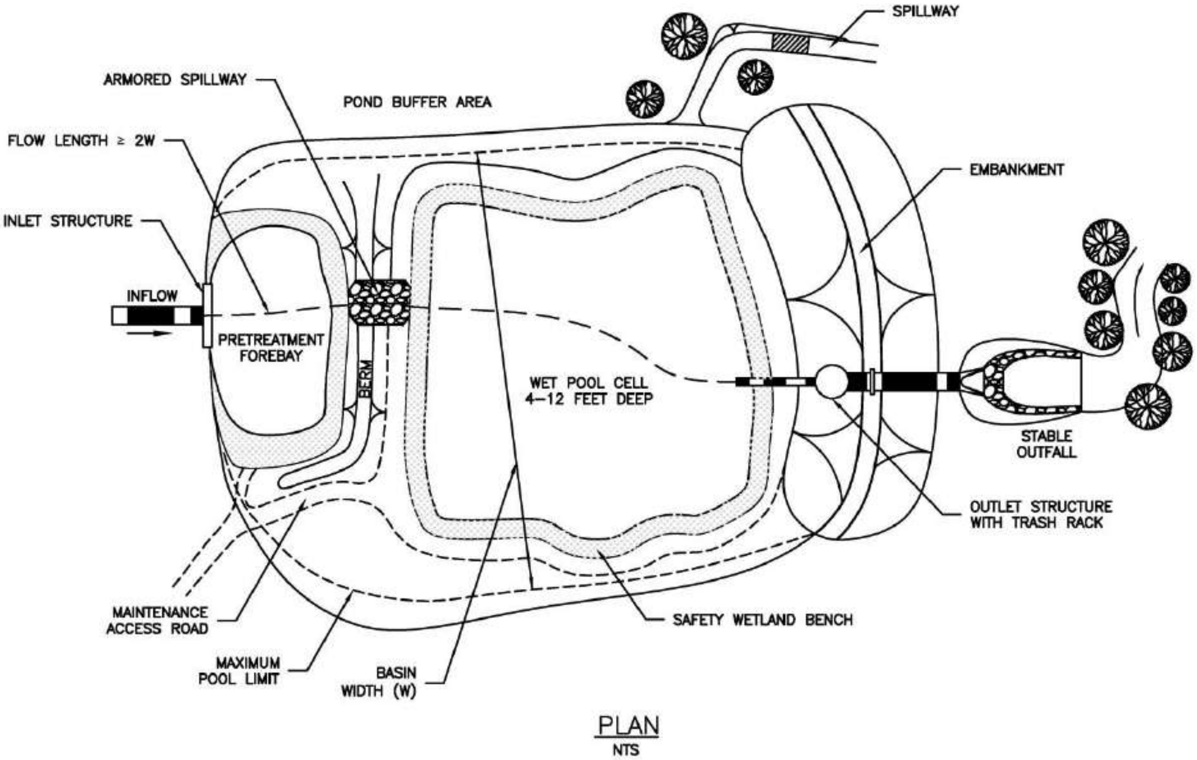
5.8.7 Maintenance

Maintenance is required on all BMPs. Recommended maintenance activities are provided in Table 5.8-1, which may be used as a guide when developing a maintenance plan. Additionally, an example inspection form is provided in Appendix F that may be adapted or adopted as part of the maintenance plan. It is recommended that maintenance responsibilities are clearly defined and/or maintenance agreements are executed prior to construction.

Table 5.8-1. Recommended Maintenance Activities for a WDB

Activity	Frequency
▪ Remove litter/debris from all components of the WDB. ▪ Repair basin inlets, outlets, and all other structural components required for the basin to operate as intended. ▪ Repair and revegetate eroded areas. ▪ Regularly manage all vegetation along maintenance right-of-ways and the embankment. Remove all clippings. ▪ Repair maintenance access routes, if applicable. ▪ Inspect the WDB for signs of mosquito larvae during summer months and provide treatment when breeding is found. If available, a local mosquito control service could be used to carry out these inspections. ▪ When necessary, drain the WDB during dry periods to prevent the release of untreated water. ▪ Inspect the WDB for damage and excessive sediment deposition following large storm events.	As needed
▪ Trim vegetation for aesthetics and mosquito control. Prevent excessive growth of woody vegetation on or near berms or embankments. ▪ Evaluate the health of vegetation and remove and replace any dead or dying plants.	Semiannually
▪ Inspect all components of the WDB in accordance with an approved inspection form according to local jurisdiction requirements. An example inspection form is provided in Appendix F. ▪ Open the riser to access and test the valves (if applicable).	Annually
▪ Remove sediment from the forebay before it becomes a significant source of pollutants for the remainder of the WDB.	Typically 1 to 4 years
▪ Remove accumulated sediment from the bottom of the wetpool cell to maintain volume and deter algae growth. This typically requires heavy equipment, designated corridors, and considerable expense. Harvesting of vegetation may also be desirable for nutrient removal. When removing vegetation from the pond, take care not to create or leave areas of disturbed soil susceptible to erosion. If removal of vegetation results in disturbed soils, implement proper erosion and sediment control BMPs until vegetative cover is reestablished. Dispose of sediment properly (56).	Typically 10 to 20 years (or as needed)

5.8.8 Plan View and Typical Details



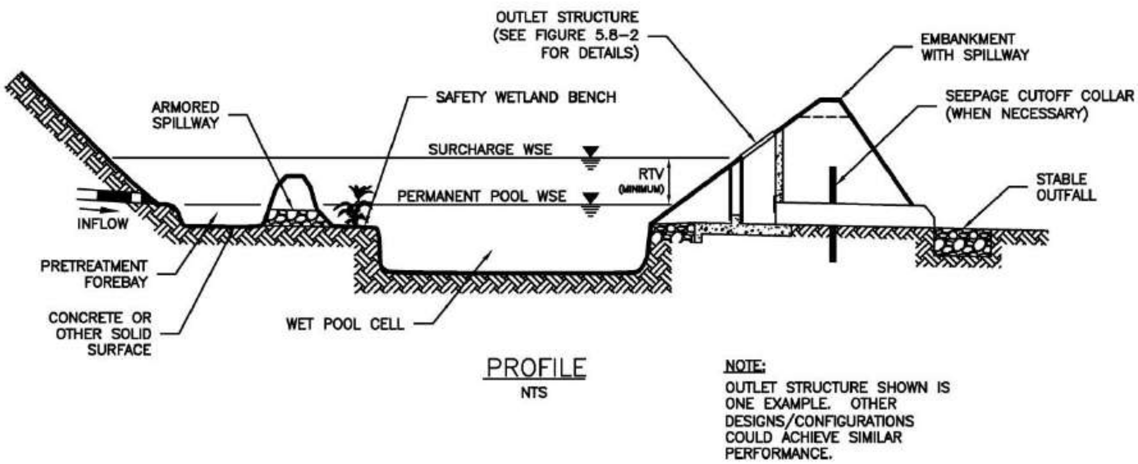


Figure 5.8-7. Wet Detention Basin Plan View and Typical Section
Source: Adapted from Minnesota Stormwater Manual (57)

5.9 Proprietary Treatment Devices

Figure 5.9-1. Proprietary Treatment Device Installation
Source: City of Kalispell
Photo is used as example only—not an endorsement.

Description
Manufactured devices used to treat storm water runoff through various processes that may include sedimentation, filtration, and sorption. These devices can provide treatment for a variety of different pollutants.

Primary Components	Primary Function
▪ Variable depending on treatment device ▪ See manufacturer's technical specifications	☐ Runoff reduction ☑ Runoff treatment

Benefits	Limitations
▪ Can often be easily incorporated into urban sites or space-constrained areas ▪ Devices are typically underground and do not consume a large amount of site space ▪ Good retrofit capability	▪ May require frequent maintenance for sites that discharge a large amount of sediment ▪ Certain devices may have cold-climate limitations, depending on installation depth ▪ Each type of device has specific design constraints and limitations for use

Design and Site Selection Considerations	
☑ Setbacks	☐ Underdrain
☑ Depth to groundwater or bedrock	☐ Facility liners
☐ Soil permeability	☐ Landscaping/planting
☐ Soil preparation/amendments/compost	☐ Fencing
☐ Pretreatment forebay	☑ Size of contributing drainage area
☐ Inlet and outlet spacing	☐ Area required
☐ Energy dissipater/level spreader	☐ Incorporate flood control

TMDL Considerations[1]

Avoid	Preferred	
☐	☐	Total suspended solids (TSS)
☐	☐	Total phosphorus
☐	☐	Total nitrogen
☐	☐	Temperature
☐	☐	Metals
☐	☐	Fecal coliform

Maintenance Requirements[2]
☑ Access roads or pullouts
☑ Sediment removal
☐ Irrigation
☐ Vegetation management
☐ Erosion and embankment stabilization repair
☑ Specialized equipment and training

[1] Pollutant removal efficiencies vary for different units.

[2] Maintenance requirements vary for different devices. See manufacturer's recommendations for maintenance requirements specific to each device.

5.9.1 Description

Proprietary treatment devices are storm water BMPs that are commercially designed and manufactured by vendors. They may be used individually or with other BMPs as part of a treatment train, depending on the site constraints and storm water management objectives. Numerous devices are available, each with different benefits, limitations, performance capabilities, and maintenance requirements. Most devices can be categorized as either a hydrodynamic separator or filtering system, as discussed below.

Hydrodynamic Separators

Hydrodynamic separators are manufactured chambers that use sedimentation to remove pollutants such as sediment from storm water runoff. They are usually round, flow-through devices that induce a circular motion to promote sedimentation as runoff flows through the chamber. They may also be designed to remove oil, grease, and other floatables from runoff through the use of baffles. Maintenance of these devices requires regular removal of accumulated sediment and floatables (58).

Filtering Systems

Filtering systems are manufactured units that typically consist of an underground chamber or catch basin that includes a filter media insert. The system is designed to pass storm water runoff through filter media to remove pollutants. The pollutants to be treated depend on the type of filter media selected, which may include a screen, fabric, activated carbon, perlite, zeolite, or other materials. These systems may be designed to provide treatment for nutrients, sediments, floatables, metals, oils, and/or organic compounds. Maintenance of these devices typically requires replacing the filter media (59).

> Note: This manual does not recommend or endorse any specific proprietary treatment devices. This section is included to provide general recommendations and considerations to assist with the selection and implementation of proprietary treatment devices.

5.9.2 Performance

Runoff Reduction

Runoff reduction is not considered to be a function of proprietary treatment devices because they generally discharge a volume equivalent to the entire inflow runoff volume.

Runoff Treatment

Certain proprietary treatment devices have been shown to achieve an 80 percent or greater removal rate of TSS from the RTV or RTF. It is the responsibility of the designer and/or project owner to document that the proposed device has demonstrated 80 percent TSS reduction for the given site conditions.

5.9.3 Site Selection

Basic guidelines are provided below to aid in evaluating whether proprietary treatment is feasible for use at an individual site.

Contributing Drainage Area

- Many proprietary treatment devices are flow-through systems sized for a design flow rate (typically the RTF). Contributing drainage area characteristics (e.g., size, percent impervious) will determine the design flow rate.
- Most devices are available in various sizes to accommodate multiple design flow rates or volumes.
- Consult manufacturer recommendations for guidance and limitations regarding contributing drainage areas and design flow rates or volumes.

Soil Characteristics

- Soil characteristics may necessitate design modifications to or limitations on the type of structural material that can be used on a given site. For example, corrosive soils may require modifications to treatment devices manufactured with steel.

Depth to Groundwater and/or Bedrock

- High groundwater can result in buoyancy and seepage of groundwater into a device. These considerations should be evaluated and mitigated in areas with consistently or seasonally high groundwater tables.

Site Topography

- Site topography considerations vary for individual devices.
- Sites with steep slopes may require the use of energy dissipation features upstream of a device to reduce runoff velocities that could damage the BMP.

Land Use and Considerations of Surrounding Area

- Proprietary treatment devices are typically small—as such, they are best suited for areas where opportunities to use larger BMPs are limited by the lack of available space. Examples of these areas include redevelopment sites, downtown areas, and space-constrained transportation corridors.

5.9.4 Guidelines for Using Proprietary Treatment Devices

This section provides general guidelines to be used when considering implementation of a proprietary treatment device. Specific design and implementation guidelines vary for different devices; therefore, manufacturers and/or suppliers should be consulted for guidance and design specifications specific to a given device.

Performance Verification

The manufacturer and/or project engineer should provide an independent third-party scientific verification showing that the proprietary device is able to meet storm water management objectives for a given project. One primary objective will likely be the ability to meet the Runoff Treatment Requirement, which states that the BMP must be expected to remove 80 percent TSS from the RTV. Consult with the local jurisdiction to determine whether they have specific product verification requirements.

Record of Longevity

The manufacturer and/or project engineer should provide data that indicate when maintenance is required (maintenance cycle). Furthermore, the data should demonstrate that when maintained correctly, the device is expected to meet storm water management objectives throughout its entire life cycle.

Ability to Function in Local Conditions

The device must be able to function in and withstand project site conditions such as climate, rainfall patterns, and soil types. Certain conditions may preclude the use of certain devices, while other conditions may simply require design adaptations. For instance, depending on site conditions, design adaptation may or may not be feasible for devices subject to freezing in cold climates. The manufacturer should provide data that indicate any limitations in function or performance of the device because of weather. The data should indicate that the device can meet the project’s storm water management objectives at the proposed site.

Flow Control Considerations

The site must be designed to handle the full range of expected flows. Some devices have flow bypass systems built into the design, while other systems may require a flow diversion upstream of the structure to divert high flows around the device.

Maintainability

There must be documented procedures for required maintenance, including collection and removal of pollutants or debris. As with all BMPs, the designer should also consider who will conduct the maintenance and whether they have access to the proper equipment and have the capability to perform the required maintenance tasks. Additionally, the designer must ensure there is adequate maintenance access capable of handling the equipment necessary to conduct maintenance activities.

> Note: The list of considerations provided in this section is not comprehensive. Designers must consider all of the project’s storm water management objectives and site constraints when selecting and specifying a device.

5.9.5 Maintenance

Maintenance is required on all BMPs because clogging of devices can hinder pollutant removal capabilities and create drainage problems. Specific maintenance tasks and schedules vary for different devices. A maintenance schedule should be provided that considers all of the manufacturer’s recommended maintenance activities. The volume of pollutants draining to a device dictates the rate at which it reaches its capacity; therefore, the characteristics of the contributing drainage area are often a primary factor in establishing the frequency of maintenance activities. Frequent inspections throughout the first year of installation are recommended to understand how often maintenance is needed.

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Appendix A. Glossary

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Appendix A: Glossary

Note: The definitions provided within this glossary are for the purposes of this manual, and are focused on post-construction BMPs in accordance with Montana's General Permit for Storm Water Discharges Associated with Small Municipal Separate Storm Sewer Systems (General Permit). Consult the local jurisdiction, General Permit, and/or Montana DEQ for regulatory definitions related to storm water management.

Best Management Practice (BMP): In the context of this manual, BMP refers to a permanent storm water management facility used to prevent or reduce the discharge or pollutants to state waters.

Biofiltration Swale: A densely vegetated channel with a trapezoidal cross-section and low longitudinal slopes which conveys runoff. The trapezoidal cross-section and low longitudinal slope promotes shallow concentrated flow which allows for filtration of storm water by plants.

Bioretention Area: A shallow landscaped depression that captures and infiltrates or filters storm water runoff through plants, engineered soil media, and often an underdrain system.

Cation Exchange Capacity (CEC): The total amount of positively charged elements that a soil can hold. This value is typically expressed in milliequivalents per 100 grams (meq/100g) of soil.

Dispersion: A BMP that achieves runoff reduction by utilizing vegetation, soil, and gentle slopes located adjacent to impervious surfaces to impede the velocity of storm water runoff and encourage infiltration.

Extended Detention Basin (EDB): A sedimentation basin designed to detain and slowly release storm water over an extended period of time following a rainfall event. These facilities are sometimes referred to as "dry ponds" because they are designed to remain empty between runoff events.

Flood Control: Management of storm water runoff to reduce peak flows from a developed area. This is often achieved using storm water management facilities which detain and slowly release runoff.

Impaired Water Body: A water body or stream segment for which sufficient credible data shows that the water body or stream segment is failing to achieve compliance with applicable water quality standards (MCA 75-5-103).

Impervious Surface: A hard surface area (e.g., parking lot, roadway, rooftop, etc.) that prevents or retards the infiltration of storm water, thus causing storm water to run off the surface in greater quantities and at an increased rate of flow when compared to pervious areas.

Infiltration Basin: A constructed basin designed to collect and retain storm water runoff so that it can infiltrate into underlying soils. These facilities remain dry between runoff events and often have permanent vegetation ranging from grass to small shrubs.

Low Impact Development (LID): A multistep storm water management approach which utilizes thoughtful site planning and manages rainfall at its source by using integrated and distributed small-scale BMPs.

Micropool: A small permanent pool located in front of an outlet structure within an EDB. A micropool is designed to prevent sediment resuspension, protect the low flow outlet riser orifices or perforated plate from clogging, and reduce mosquito breeding areas.

Municipal Separate Storm Sewer System (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains) that discharges to surface waters and is owned or operated by the state of Montana, a governmental subdivision of the state, a district, association, or other public body created by or pursuant to Montana law, including special districts such as sewer districts, flood control districts, drainage districts and similar entities, and designated and approved management agencies under section 208 of the federal Clean Water Act, which has jurisdiction over disposal of sewage, industrial wastes, storm water, or other wastes, and is:

a. Designed or used for collecting or conveying storm water;
b. Not a combined sewer; and
c. Not part of a publicly owned treatment works as defined in ARM Title 17, chapter 30, subchapter 13.

Multi-use Facility: A facility that serves more than one purpose.

Offsite: A location not within the boundaries of the development or redevelopment area.

Offsite treatment: An approach that uses a regional facility to manage storm water runoff from multiple development projects located within the same subwatershed.

Onsite: A location within the boundaries of the development or redevelopment area.

Onsite BMP: A BMP located within the boundary of a development or redevelopment area.

Permeable Pavement System: A general term to describe any one of several surfaces that allow storm water runoff to filter through surface voids into an underlying aggregate reservoir for temporary storage and/or infiltration.

Post-Construction Performance Standard: The BMP design requirement presented in Part II.A.5.b.iii of the General Permit.

Pretreatment Forebay: A small hard-bottomed basin located immediately downstream of an inlet within certain BMPs. These facilities are designed to trap incoming coarse sediments and other gross solids so that they do not accumulate within the main treatment area of the BMP.

Proprietary Treatment Devices: Manufactured devices used to treat storm water runoff through various processes which may include sedimentation, filtration, and sorption. These devices can provide treatment for a variety of different pollutants.

Regulated New and/or Redevelopment Project: New development and redevelopment projects that disturb greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale, that discharge into a permitted small MS4.

Runoff Reduction: Implementation of a BMP (or series of BMPs) designed to infiltrate, evapotranspire, or capture for reuse the RRV.

Runoff Reduction Requirement: The portion of the Post-Construction Performance Standard which requires that all regulated projects implement BMPs that are designed to infiltrate, evapotranspire, and/or capture for reuse the post-construction runoff generated from the first 0.5 inches of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation.

Runoff Reduction Volume (RRV): The volume of storm water runoff generated from the first 0.5 inches of rainfall from a 24-hour storm preceded by 48-hours of no measurable precipitation.

Runoff Treatment: Implementation of a BMP (or series of BMPs) expected to remove 80 percent TSS from the RTV.

Runoff Treatment Requirement: The portion of the Post-Construction Performance Standard which requires that for projects that cannot meet 100% of the Runoff Reduction Requirement, the remainder of the runoff from the first 0.5 inches of rainfall must be treated using BMPs expected to remove 80 percent total suspended solids.

Runoff Treatment Flow Rate (RTF): The peak flow rate associated with the RRV or RTV which is used to size flow-based systems such as biofiltration swales and flow diversion structures for off-line storm water management practices.

Runoff Treatment Volume (RTV): The remainder of the RRV which was not infiltrated, evapotranspired, or captured for reuse onsite. This volume must be treated onsite or managed offsite.

Storm Water Hotspot: An area which produces higher concentrations of pollutants than is normally found in urban runoff. Examples include gas stations, vehicle maintenance/repair areas, and auto recyclers.

Storm Water Management: The practice of managing storm water runoff to meet certain objectives which may include runoff reduction, treatment, and flood control.

Treatment: The removal of pollutants from storm water runoff.

Treatment Train: A combination of two or more treatment BMPS connected in series.

Total Maximum Daily Load (TMDL): The sum of the individual waste load allocations for point sources and load allocations for both nonpoint sources and natural background sources established at a level necessary to achieve compliance with applicable surface water quality standards (MCA 75-5-103).

Total Suspended Solids (TSS): TSS refers to all particles suspended in storm water runoff which typically have settling times that typically exceed one hour.

Turf Grass: Grasses which form a dense even turf which can be mowed and maintained.

Wet Detention Basin (WDB): A constructed basin designed to capture, detain, and slowly release storm water runoff while maintaining a permanent pool of water in order to promote pollutant removal through sedimentation and biological uptake.

Waste Load Allocation (WLA): The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources (MCA 75-5-103).

Appendix B. Additional Hydrology Information

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Appendix B: Additional Hydrology Information

Table B-1. Roughness Coefficients for Sheet Flow

Surface Description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated Soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods[3]:	
Light underbrush	0.40
Dense underbrush	0.80

[1]The n values are a composite of information compiled by Engman (1986).
[2]Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3]When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.
Source: NRCS TR-55, Table 3-1

Table B-2. Roughness Coefficients for Open Channel Flow and Pipe Flow

Conduit Material	n[1]
Closed Conduits:	
Concrete Pipe	0.011 –0.013
Corrugated Metal Pipe	0.022 – 0.024
Plastic Pipe (smooth)	0.009 – 0.011
Plastic Pipe (corrugated)	0.018 – 0.025
Pavement/gutter sections	0.012 – 0.016
Small Open Channels:	
Concrete	0.011 – 0.013
Rubble or riprap	0.020 – 0.035
Vegetation	0.020 – 0.150
Bare Soil	0.016 – 0.025
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermuda grass	0.41
Natural Channels	
Fairly regular section	0.025 – 0.050
Irregular section with pools	0.040 – 0.150

[1] Lower values are usually for well-constructed and maintained (smoother) pipes and channels.
Source: Adapted from FHWA HEC-22, Table 3-4

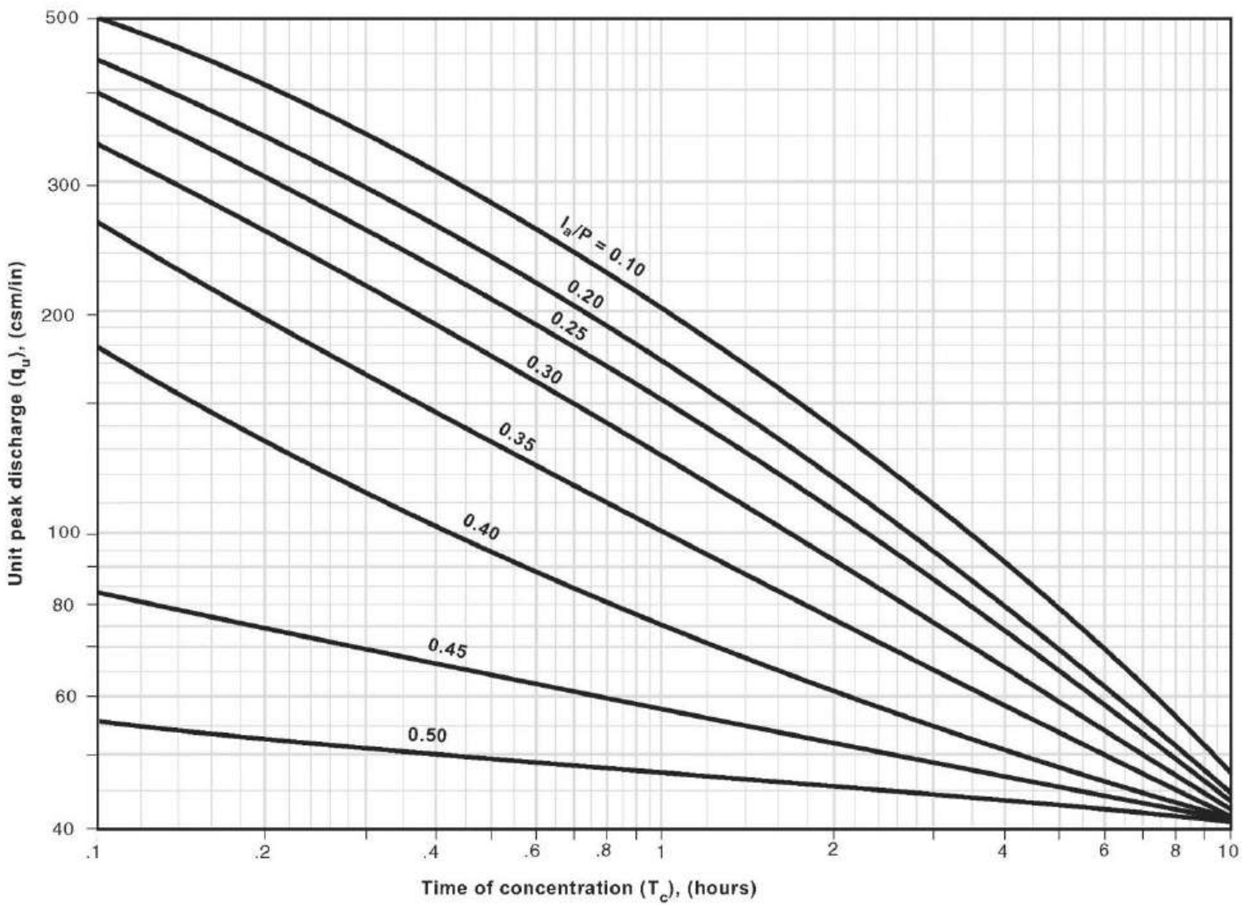

Figure B-1: Unit Peak Discharge (q_u) for NRCS (SCS) Type I Distribution

Source: NRCS TR-55, Exhibit 4-I

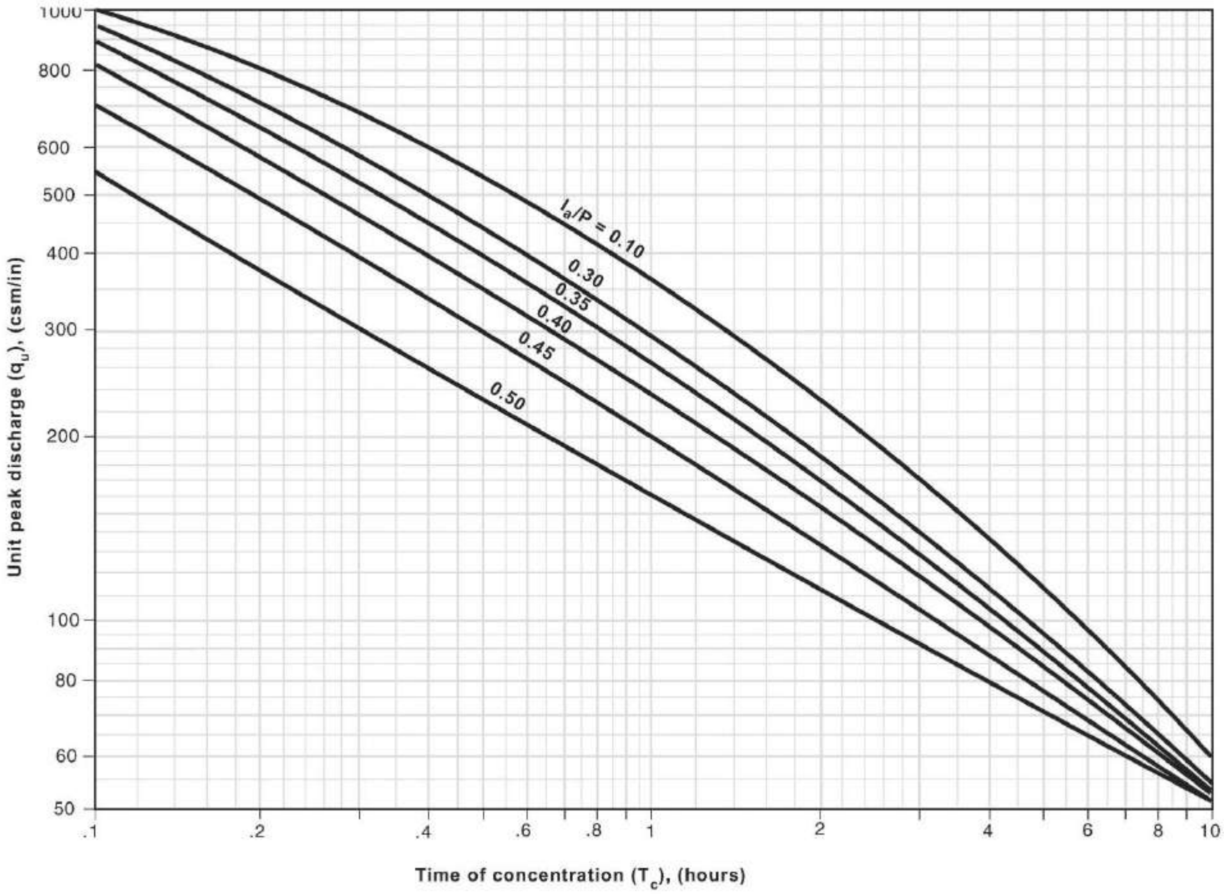

Figure B-2: Unit Peak Discharge (q_u) for NRCS (SCS) Type II Distribution

Source: NRCS TR-55, Exhibit 4-II

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Appendix C. Evaluating Soil Infiltration Rates

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Appendix C: Evaluating Soil Infiltration Rates

Introduction

Infiltration is the process of moving water (or storm water runoff) from the ground surface into the underlying soils. Infiltration of water into the underlying soils typically begins quickly (while the underlying soils are becoming saturated) and then declines until a steady-state infiltration rate is reached when the soils are saturated. Determining the steady-state infiltration rate is an essential part of BMP design because this infiltration rate is a key factor in assessing the feasibility and sizing of infiltration BMPs. Incorrect assumptions about the soils ability to infiltrate runoff can lead to failure of BMPs.

A variety of on-site tests exist for determining the infiltration rate of native soil. Three test methods are described within this appendix, each of which require excavation of a soil test pit, which is made for the purpose of exposing and evaluating the soil profile and conducting a soil infiltration test at the appropriate depth in the location of a proposed BMP. Tests should not be conducted during rainfall events, within 24 hours following significant rainfall events (greater than 0.5 inches), or when the temperature is below freezing. Laboratory tests for determining the infiltration rate of native soils are strongly discouraged because the soils are disrupted during sample collection which may not represent field conditions.

Note: When using BMPs which rely on infiltration, the field measured steady-state infiltration rate typically declines due to factors such as compaction and clogging. In order to account for this and mitigate failure of BMPs, this manual recommends dividing the field measured steady-state infiltration rate by a factor of 2.0 in order to obtain the design infiltration rate.

Large Scale Pilot Infiltration Test

A PIT is a relatively large-scale soil test used to approximate infiltration rates for design of infiltration BMPs. A PIT is recommended for use whenever adequate space and the necessary equipment are available. Guidance for conducting both a large and small scale PIT is provided in this appendix. (Guidance for when a small scale test maybe more appropriate is provided in the small scale PIT procedures section below.) The PIT procedures have been adopted from the State of Washington Department of Ecology's *Stormwater Management Manual for Western Washington*, with minor revisions which account for local considerations.

Both a large and small scale PIT involves digging a soil test pit near the proposed infiltrative surface (e.g., bottom of infiltration basin or top of the native soil for a bioretention or permeable pavement facility). Water is ponded to between 6 and 12 inches in depth and flow to the pit is maintained until the infiltration rate has stabilized (a minimum of 6 hours). Then the water source is removed from the pit and the rate of infiltration (the drop rate of the standing water) is measured and recorded.

Large Scale PIT Equipment

- Excavating equipment
- Water supply (with rigid pipe and splash plate)
- Rota- or magnetic meters to measure flow rate into the pit
- Stopwatch or timer
- Measuring rod

- Log sheets for recording data

Large Scale PIT Procedure

- Excavate the test pit to the estimated surface elevation of the proposed infiltration facility. Lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.
- The horizontal surface area of the bottom of the test pit should be approximately 100 square feet. Accurately document the size and geometry of the test pit.
- Install a vertical measuring rod (minimum 5-ft. long) marked in half-inch increments in the center of the pit bottom.
- Use a rigid 6-inch diameter pipe with a splash plate on the bottom to convey water to the pit and reduce side-wall erosion or excessive disturbance of the pond bottom. Excessive erosion and bottom disturbance will result in clogging of the infiltration receptor and yield lower than actual infiltration rates.
- Add water to the pit at a rate that will maintain a water level between 6 and 12 inches above the bottom of the pit. A rotameter can be used to measure the flow rate into the pit.

  Note: The depth should not exceed the proposed maximum depth of water expected in the completed facility. For infiltration facilities serving large drainage areas, designs with multiple feet of standing water can have infiltration tests with greater than 1 foot of standing water.
- Every 15-30 min, record the cumulative volume and instantaneous flow rate in gallons per minute necessary to maintain the water level at the same point on the measuring rod.
- Keep adding water to the pit until one hour after the flow rate into the pit has stabilized (constant flow rate; a goal of 5% variation or less variation in the total flow) while maintaining the same pond water level. The total of the pre-soak time plus one hour after the flow rate has stabilized should be no less than 6 hours.
- After the flow rate has stabilized for at least one hour, turn off the water and record the rate of infiltration (the drop rate of the standing water) in inches per hour from the measuring rod data, until the pit is empty. Consider running this falling head phase of the test several times to estimate the dependency of infiltration rate with head.
- At the conclusion of testing, over-excavate the pit to see if the test water is mounded on shallow restrictive layers or if it has continued to flow deep into the subsurface. The depth of excavation varies depending on soil type and depth to hydraulic restricting layer, and is determined by the engineer or certified soils professional. Mounding is an indication that a mounding analysis may be necessary.

Large Scale PIT Data Analysis

- Calculate and record the saturated hydraulic conductivity rate in inches per hour in 30 minutes or one hour increments until one hour after the flow has stabilized.

  Note: Use statistical/trend analysis to obtain the hourly flow rate when the flow stabilizes. This would be the lowest hourly flow rate.
- Divide the saturated hydraulic conductivity by the recommended safety factor of 2.0 (or as required by the local jurisdiction) to determine the site-specific design infiltration rate.

Small Scale Pilot Infiltration Test

A smaller-scale PIT is recommended in place of large-scale PIT in any of the following instances.

- The drainage area to the infiltration site is less than 1 acre.

- The testing is for bioretention or permeable pavement BMPs that either serve small drainage areas and /or are widely dispersed throughout a project site.
- The site has a high infiltration rate, making a full-scale PIT difficult, and the site geotechnical investigation suggests uniform subsurface characteristics.

Small Scale PIT Equipment

- See the guidance for large scale PIT equipment above.

Small Scale PIT Procedure

- Excavate the test pit to the estimated surface elevation of the proposed infiltration facility. In the case of bioretention, excavate to the estimated elevation at which the bioretention soil media will lie on top of the underlying native soil. For permeable pavements, excavate to the elevation at which the imported subgrade materials will contact the underlying native soil. If the native soils (road subgrade) will have to meet a minimum subgrade compaction requirement, compact the native soil to that requirement prior to testing. Note that permeable pavement design guidance typically recommends compaction not exceed 90% - 92%. Finally, lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.
- The horizontal surface area of the bottom of the test pit should be 12 to 32 square feet. It may be circular or rectangular, but accurately document the size and geometry of the test pit.
- Install a vertical measuring rod adequate to measure the ponded water depth and that is marked in half-inch increments in the center of the pit bottom.
- Use a rigid pipe with a splash plate on the bottom to convey water to the pit and reduce side-wall erosion or excessive disturbance of the pond bottom. Excessive erosion and bottom disturbance will result in clogging of the infiltration receptor and yield lower than actual infiltration rates. Use a 3-inch diameter pipe for pits on the smaller end of the recommended surface area, and a 4-inch pipe for pits on the larger end of the recommended surface area.
- Pre-soak period: Add water to the pit so that there is standing water for at least 6 hours. Maintain the pre-soak water level at least 12 inches above the bottom of the pit.
- At the end of the pre-soak period, add water to the pit at a rate that will maintain a 6-12 inch water level above the bottom of the pit over a full hour. The depth should not exceed the proposed maximum depth of water expected in the completed facility.
- Every 15 minutes, record the cumulative volume and instantaneous flow rate in gallons per minute necessary to maintain the water level at the same point (between 6 inches and 1 foot) on the measuring rod. The specific depth should be the same as the maximum designed ponding depth.
- After one hour, turn off the water and record the rate of infiltration (the drop rate of the standing water) in inches per hour from the measuring rod data, until the pit is empty.
- A self-logging pressure sensor may also be used to determine water depth and drain-down.
- At the conclusion of testing, over-excavate the pit to see if the test water is mounded on shallow restrictive layers or if it has continued to flow deep into the subsurface. The depth of excavation varies depending on soil type and depth to hydraulic restricting layer, and is determined by the engineer or certified soils professional. A soils professional should judge whether a mounding analysis is necessary.

Pilot Infiltration Test Data Analysis

- See the explanation under the guidance for large scale PITs.

Double Ring Infiltrometer

A double ring infiltrometer test is recommended when lack of space and/or equipment preclude the use of a large or small scale PIT. A double ring infiltrometer test (ASTM D 3385) consists of two concentric metal rings which are driven into the ground and filled with water which infiltrates into the underlying soil. The inner ring (12 inches in diameter) is used to measure the infiltration rate and the outer ring (24 inches in diameter) helps to prevent divergent flow. There are two operational techniques which can be used with this test, the constant head method and the falling head method. ASTM D 3385 mandates the use of the constant head method. Reference ASTM D 3385 for a detailed description of the testing procedure.

> Note: This appendix provides recommended soil infiltration evaluation methods; however, the local jurisdiction may have different recommendations or requirements. Coordinate with the local jurisdiction for more information on soil testing requirements.

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Appendix D. Soil Amendments

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Appendix D: Soil Amendments

Soil Suitability Criteria: Composition, Characteristics, and Configuration

Bioretention soil media mixes, often referred to as soil amendments, are composed of a mixture of sand (including top soil) and organic matter. The exact composition, characteristics, and configuration of bioretention soil media mixes may vary depending on local climate characteristics, availability of material, and performance objectives (i.e., target pollutants). This Appendix provides guidance for the design of bioretention soil media mixes. Selection of a mixture should be made considering its primary function as part of the bioretention area which includes: provide adequate drainage, reduce pollutant levels, and support plant growth. TSS removal rates of 80% or higher have been documented from bioretention soil media mixes with the characteristics described in this Appendix.

Mix Composition

The bioretention soil media mix composition is defined by either weight or volume. Recommended compositions include:

- Characterized by weight:
  - 3 to 8% organic matter
  - 95 to 97% sand (1)
- Characterized by volume:
  - 20 to 40% organic matter
  - 80 to 60% sand (1) (2)

Sand

The sand portion of a bioretention soil media mix typically includes both sand and top soil. The gradation of sands is important to achieve the primary bioretention functions described above. Recommended characteristics of the sand portion of a bioretention soil media mix include:

- Soils that are classified as sandy loam and loamy sand on the USDA Textural Triangle (1)
- Soils with less than 8-12% fines (silt and clays) (3)
- A gradation that aligns with washed medium sand or ASTM C-33 Standard Specification for Concrete Aggregates (4)
- A coefficient of uniformity, Cu, of less than 4

  $$Cu=\frac{D_{60}}{D_{10}}$$

- A coefficient of curvature, Cc, greater than or equal to 1 and less than or equal to 3 (2)

  $$Cc=\frac{(D_{30})^2}{D_{10}D_{60}}$$

Organic Matter

Organic matter consists of materials such as compost and peat moss. The purpose of organic matter is to support plant growth. Organic matter has several characteristics which are important considerations when developing a bioretention soil media mixture.

Cation Exchange Capacity (CEC)

The CEC of a soil refers to the total amount of positively charged elements that a soil can hold, which means the higher the CEC of the soils the higher the capacity of the soils to retain storm water pollutants. In addition, the CEC is known to remove dissolved metals from storm water runoff. CEC is commonly expressed in milliequivalents per 100 grams (meq/100g) of soil. The CEC of the soil is a function of the amount of clay, humus, and/or organic matter present. A minimum CEC of 5 meq/100g is recommended (5).

Phosphorus and Nitrogen Management

Bioretention researchers have reported that the phosphorus and nitrogen content in organic materials can leach into storm water runoff as it flows through the BSM mix (6). Recommendations for reducing nutrient leaching include:

- Only locate organic materials in the root zone of the plants which is typically the top 6-inches of the bioretention soil media mix
- Use organic materials with a lower nutrient content: 1000 mg/kg of nitrogen and a phosphorus index (P-index) between 10 and 30 (7) (8)
- For locations where bioretention areas will discharge to a receiving water body, use organic materials with a available phosphorus content of less than 100 mg/kg (7)

Additional Organic Matter Recommendations

- Select organic matter with a relatively neutral pH (4)
- Compost feedstocks should be limited to organic materials such as yard debris and crop residues
- The toxicity equivalent of the compost should not exceed 9.0 ng/Kg-dry (9)

Depth and Configuration

Bioretention soil media mixture depths range from 18 to 36-inches. Considerations when designing the depth are as follows:

- An 18-inch depth is recommended when TSS and dissolved metals are the target pollutants since pollutant removal typically occurs within the top 6-inches
- For locations where phosphorus and nitrogen are also a targeted for removal, depths of 24-inches and 36-inches respectively are recommended (3)
- The potential leaching of nutrients from organic matter can be reduced by locating organic matter only in the top 6-inches and placing only sand in the Bottom 12" (8) (see Figure D-1)

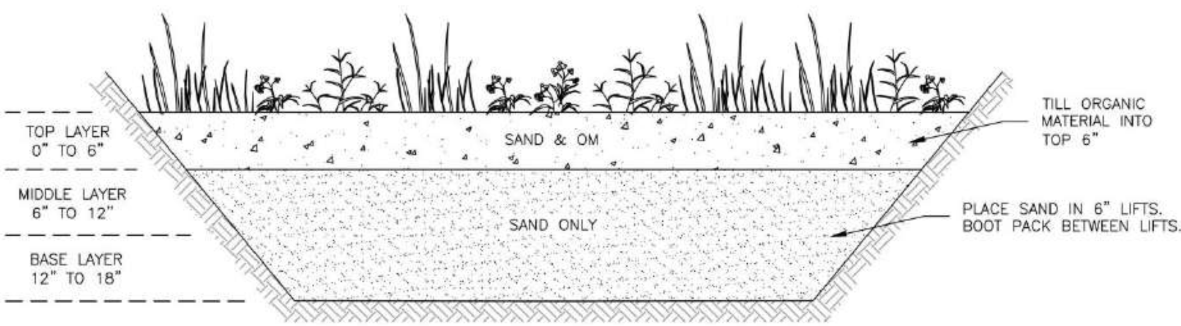

Figure D-1. Recommended Bioretention Cell Configuration (Full Infiltration Section)

Infiltration Rates

The infiltration rate defines the rate at which ponded water will infiltrate into the bioretention soil media mix. The infiltration rate must be balanced between being too low, which results in reduced capacity, and too high, which reduces treatment capabilities. Recommended infiltration characteristics are as follows:

- The long-term infiltration rate ranges from 1 to 6-inches per hour (2) (7)
  - Higher rates can allow for management of more runoff
  - Lower rates facilitate better pollutant removal and support plant growth
- For BSM mixes with lower infiltration rates, more frequent maintenance is recommended to maintain proper function (specifically remove and replace the top 2-3-inches of the mix)

Works Cited

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4. **AHBL, Inc. and HDR, Inc.** Chapter 4.4: Bioretention. *Eastern Washington Low Impact Development Guidance Manual.* s.l. : State of Washington Department of Ecology, June 2013.
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7. *Adoption Guidelines for Stormwater Biofiltration Systems.* **Facility for Advance Water Biofiltration.** s.l. : Monash University, 2009.
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Appendix E. Standard Forms

Note: This appendix contains an offsite treatment evaluation form template and a plan review checklist template. These templates may be adapted and/or adopted by a local jurisdiction to assist with the implementation of their storm water management program.

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CITY OF [*NAME*]
[*NAME OF DEPARTMENT, IF APPLICABLE*]
OFFSITE TREATMENT EVALUATION FORM

Template Instructions: In accordance with the MS4 General Permit, each MS4 must develop criteria to be considered before allowing offsite storm water treatment for new and redevelopment projects which are subject to Part II.A.5.b.iii of the Permit. The following template contains example criteria which may be used to evaluate projects for eligibility to utilize offsite treatment. The process, criteria, and other considerations provided within the template are provided as examples and should be modified and/or expanded upon to meet the local jurisdictions specific needs and goals.

Project Information

Project name:

Description of work:

Subdivision name (if applicable):

Site area (acres): Impervious surface created or altered (acres):

Runoff reduction volume (acre feet): Runoff reduction flow (cfs):

Project classification (check all that apply):
❑ New Development ❑ Redevelopment ❑ Residential ❑ Commercial

Regional Facility Considerations

Basin name:

Regional treatment facility to be utilized:

Design capacity of regional treatment facility:

Does the regional treatment facility have adequate capacity? ❑Yes ❑No

Technical Considerations

(Are following criteria considered within the technical report to provide reasoning for use of offsite treatment)

Topography (Steep Slopes)	❑Yes	❑No	Space available	❑Yes	❑No
Soil infiltration rate	❑Yes	❑No	Shallow bedrock	❑Yes	❑No
Contaminated soils	❑Yes	❑No	Prohibitive costs	❑Yes	❑No
High groundwater	❑Yes	❑No	Down-gradient structures	❑Yes	❑No
City code/ordinance	❑Yes	❑No	Community development rules	❑Yes	❑No
Water quality benefits	❑Yes	❑No	[*Insert Other*]	❑Yes	❑No

Additional Information

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DATE RECEIVED

CITY OF [*NAME*]
[*NAME OF DEPARTMENT, IF APPLICABLE*]
POST-CONSTRUCTION STORMWATER MANAGEMENT PLAN REVIEW CHECKLIST

NAME OF PROJECT	PROJECT FILE NO.	ADDRESS
TOTAL PROJECT ACRES		TOTAL DISTURBED ACRES
Latitude:	Longitude:	
GPS LOCATION OF CONSTRUCTION SITE		
APPLICANT	ADDRESS	PHONE NUMBER
OWNER *(If different from Applicant)*	ADDRESS	PHONE NUMBER

Review History

First Review

Plan Received on: ______________ Approved/Denied: ______________

Review Completed on: ______________ Comments: ______________

Reviewed by: ______________ ______________

Second Review

Plan Received on: ______________ Approved/Denied: ______________

Review Completed on: ______________ Comments: ______________

Reviewed by: ______________ ______________

Third Review

Plan Received on: ______________ Approved/Denied: ______________

Review Completed on: ______________ Comments: ______________

Reviewed by: ______________ ______________

REPORT OF TECHNICAL REVIEW

____ The Stormwater Management Plan for the above named project or activity **includes** the necessary post-construction controls in order to comply with the State and local post-construction stormwater requirements (as identified within the attached checklist).

____ The Stormwater Management Plan for the above named project or activity **does not include** the necessary post-construction controls in order to comply with the State and local post-construction stormwater requirements (as identified within the attached checklist) through failure to include the following:

____

____

____

Review by: ______________________________

Signature: ______________________________ **Date:** ______________

Project Name: ________________________ Applicant: ______________________

General Information	Complete	Incomplete	N/A
1. Location			
a. Address, subdivision name, legal description, etc…			
2. Type of development (residential, commercial, etc...)			
3. Areas (ac)			
a. Total disturbed area			
b. Existing impervious area			
c. Post-development impervious area			
4. Drainage basin maps are provided which clearly label the following:			
a. Existing basin boundaries			
b. Existing time of concentration flowpaths for each basin			
c. Post-development basin boundaries			
d. Post-development time of concentration flowpaths for each basin			
e. Discharge location(s)			
f. Receiving waters within 200 feet of project are identified			
5. Montana Licensed Engineer Stamp			
Drainage Plan Content			
1. Topographic map of existing and finished grade contours at 2-foot max intervals			
2. Location of each permanent stormwater control			
3. Plan and profile of each permanent stormwater control			
4. Invert elevations, slopes, and lengths of storm drain facilities			
5. Size, types, invert elevations and lengths of all culverts and pipe systems			
6. Discharge points clearly labeled			
7. Receiving surface waters identified			
8. Existing on-site natural resources identified and protected			
9. FEMA floodplains identified			
Calculations and Design Documentation			
1. Hydrology calculations			
a. State runoff method used (rational, SCS, etc…)			
b. State modeling constants and assumptions			
c. Description of design storms (frequency, depth, duration)			
d. Existing and post-development land uses			

Project Name: _________________________ Applicant: _______________________

Calculations and Design Documentation (Continued)		**Complete**	**Incomplete**	**N/A**
	e. Existing and post-development peak runoff rate for each design storm			
	f. Existing and post-development runoff volume for each design storm			
2.	Post-construction BMP sizing calculations			
	a. State design requirements (0.5-inch requirement, TSS removal, or other)			
	b. Required permanent controls capacities, flow rates, and operating levels			
	c. Sizing calculations with results			
	d. A statement documenting compliance with design requirements			
	e. If 0.5-inch or TSS removal requirements are not met, provide documentation showing the impracticability of infiltration, evapotranspiration, capture for reuse, and treatment.			
3.	Culvert and pipe system capacities and outlet velocities			
4.	Ditch capacities and velocities			
Additional Information				
1.	Permits, easements, setbacks, and discharge agreements			
2.	Floodplain maps			
3.	Operations and Maintenance Manual for each permanent stormwater control			
	a. Identify the owner			
	b. Identify the party responsible for long-term O&M			
	c. A schedule of inspection and maintenance for routine and non-routine maintenance tasks to be conducted			
	d. System failure and replacement criteria to define the structure's performance requirements			
4.	Geotechnical Report			

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Appendix F. Example Inspection Forms

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Example Inspection Form – Infiltration Basin

General Information

Site Name (if Applicable):	Type of BMP:
Location (Physical Address):	
Site Owner:	Phone Number:
Responsible Party:	Phone Number:
Date of Inspection:	Start/End Time:
Inspector's Name:	Inspector's Title:
Inspector's Contact Information (phone):	

Type of Inspection:
❑ Routine, Dry Weather ❑ Routine, Wet Weather ❑ Complaint Response
❑ Other: ________________

Weather Information

Weather at time of this inspection:
❑ Clear ❑ Cloudy ❑ Raining ❑ Sleet ❑ Fog ❑ Snowing ❑ High Winds
❑ Other: ________________ Temperature: ________________

Do you suspect that any physical changes or damages to the BMP may have occurred since the last inspection? ❑Yes ❑No

If yes, provide description of physical changes or damages:

Are there any storm water discharges at the time of inspection (i.e., discharge from an outlet)? ❑Yes ❑No

If yes, provide location(s) and a description of storm water discharged from the site (presence of suspended sediment, turbid water, discoloration and/or oil sheen, odor, etc…).

Prohibited Discharges

Are there any prohibited discharges at the time of inspection and/or any signs of prohibited discharges since the last inspection (i.e., chemicals, oils, or other illicit discharges flowing into the BMP)? ❑Yes ❑No

If yes, provide location(s) and a description:

Inspector's Signature: ________________________________ Date: ________________

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
General	Accessibility	Maintenance access to the basin is not obstructed in any way.	❑Yes ❑No	
	Contaminants & Pollution	Trash and debris is not accumulated within or around the basin and there is no evidence of oil, gasoline, contaminants, or other pollutants.	❑Yes ❑No	
	Sedimentation	The contributing drainage area is stabilized and not contributing excessive amounts of sediment.	❑Yes ❑No	
	Structural Damage	There is no damage to the fence or gate that permits entry to the facility.	❑Yes ❑No	
Storm Water Inlets & Conveyance	Diversion Structures	If applicable, diversion structures are operating as intended and adequately conveying storm water runoff.	❑Yes ❑No	
	Erosion Control	The inlet structure and energy dissipation area show no signs of erosion.	❑Yes ❑No	
	Structural Damage	The inlet structure is not damaged, clogged, or defective.	❑Yes ❑No	
Pretreatment Facility	Clogging	The outlet structure of the pretreatment facility is not damaged, clogged, or defective.	❑Yes ❑No	
	Drainage	There is no standing water in the pretreatment facility.	❑Yes ❑No	
	Sedimentation	There is no evidence of excessive sediment deposition in the pretreatment facility.	❑Yes ❑No	
	Structural Damage	There is no damage that impacts the performance of the pretreatment facility.	❑Yes ❑No	

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
Embankment & Side Slopes	Erosion Control	Embankments and side slopes are stabilized and not contributing sediment to the basin.	❑Yes ❑No	
	Structural Damage	There is no evidence of rodent holes or water piping through dam or berm.	❑Yes ❑No	
Infiltration Cell	Drainage	There is no standing water in the basin.	❑Yes ❑No	
	Sediment	There is no evidence of excessive sediment deposition on the bottom of the basin.	❑Yes ❑No	
	Vegetation	Vegetation is healthy and basin is not overrun by weeds.	❑Yes ❑No	
	Vegetation	Excessive vegetation is not present within the vicinity of the basin that could drop leaf litter, fruits, and other vegetative materials.	❑Yes ❑No	
Spillway	Erosion Control	The spillway does not show signs of damage or erosion.	❑Yes ❑No	
	Structural Damage	Structural components such as concrete, riprap, or concrete block mats are not damaged or defective.	❑Yes ❑No	
Outlet Structure (If applicable)	Clogging	The trash rack, orifice plate, outlet pipe, and/or riser are free of sediment, debris and/or dead vegetation.	❑Yes ❑No	
	Structural Damage	The outlet structure is not damaged, leaking, or showing signs of erosion or undercutting.	❑Yes ❑No	
	Erosion Control	Permanent erosion control measures at the outfall of the structure are not damaged or contributing excess sediment to the downstream channel.	❑Yes ❑No	

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Example Inspection Form – Bioretention

General Information

Site Name (if Applicable):	Type of BMP:
Location (Physical Address):	
Site Owner:	Phone Number:
Responsible Party:	Phone Number:
Date of Inspection:	Start/End Time:
Inspector's Name:	Inspector's Title:
Inspector's Contact Information (phone):	

Type of Inspection:
❑ Routine, Dry Weather ❑ Routine, Wet Weather ❑ Complaint Response
❑ Other: ________________

Weather Information

Weather at time of this inspection:
❑ Clear ❑ Cloudy ❑ Raining ❑ Sleet ❑ Fog ❑ Snowing ❑ High Winds
❑ Other: ________________ Temperature: ________________

Do you suspect that any physical changes or damages to the BMP may have occurred since the last inspection? ❑Yes ❑No
If yes, provide description of physical changes or damages:

Are there any storm water discharges at the time of inspection (i.e., discharge from an outlet)? ❑Yes ❑No
If yes, provide location(s) and a description of storm water discharged from the site (presence of suspended sediment, turbid water, discoloration and/or oil sheen, odor, etc…).

Prohibited Discharges

Are there any prohibited discharges at the time of inspection and/or any signs of prohibited discharges since the last inspection (i.e., chemicals, oils, or other illicit discharges flowing into the BMP)? ❑Yes ❑No
If yes, provide location(s) and a description:

Inspector's Signature: ________________________________ Date: _________________

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
General	Accessibility	Maintenance access to the bioretention area is not obstructed in any way.	❑Yes ❑No	
	Contaminants & Pollution	Trash and debris are not accumulated within or around the basin and there is no evidence of oil, gasoline, contaminants, or other pollutants.	❑Yes ❑No	
	Sedimentation	The contributing drainage area is stabilized and not contributing excessive amounts of sediment.	❑Yes ❑No	
	Structural Damage	The bioretention area's structural components are not damaged.	❑Yes ❑No	
Storm Water Inlets & Conveyance	Diversion Structures	If applicable, diversion structures are operating as intended.	❑Yes ❑No	
	Erosion Control	The inlet structure and energy dissipation area show no signs of erosion.	❑Yes ❑No	
	Structural Damage	The inlet structure is not damaged, clogged, or defective.	❑Yes ❑No	
Pretreatment Facilities	Drainage	There is no standing water in the pretreatment facility.	❑Yes ❑No	
	Sedimentation	There is no evidence of excessive sediment deposition.	❑Yes ❑No	
	Structural Damage	There is no damage that impacts the performance of the pretreatment facility.	❑Yes ❑No	
Side Slopes	Erosion Control	Side slopes are stabilized and not contributing sediment to the surface ponding area.	❑Yes ❑No	
	Structural Damage	There is no evidence of rodent holes, sinkholes, or instability.	❑Yes ❑No	

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
Surface Ponding Area (Filter Area)	Drainage	There is no standing water in the surface ponding area.	❑Yes ❑No	
	Irrigation	If applicable, the irrigation system is intact and functioning as designed.	❑Yes ❑No	
	Sediment	There is no evidence of excessive sediment deposition within or around the surface ponding area.	❑Yes ❑No	
	Surface Cover	The mulch layer is fully intact (2- to 3-inches thick) with no bare areas.	❑Yes ❑No	
	Vegetation	Vegetation is healthy and matches the original design.	❑Yes ❑No	
	Vegetation	Weeds are not growing within the surface ponding area.	❑Yes ❑No	
Underdrain (If Applicable)	Clogging	Underdrains and cleanouts are free of sediment and debris.	❑Yes ❑No	
	Structural Damage	There is no damage that impacts the performance of the underdrain system.	❑Yes ❑No	
Surface Overflow Structures (If applicable)	Clogging	Overflow structures are free of sediment, debris and/or dead vegetation.	❑Yes ❑No	
	Erosion Control	Permanent erosion control measures at the overflow structure are not damaged or contributing excess sediment to the downstream channel.	❑Yes ❑No	
	Structural Damage	The structure is not damaged or showing signs of erosion.	❑Yes ❑No	

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Example Inspection Form
Permeable Interlocking Concrete Pavers

General Information	
Site Name (if Applicable):	Type of BMP:
Location (Physical Address):	
Site Owner:	Phone Number:
Responsible Party:	Phone Number:
Date of Inspection:	Start/End Time:
Inspector's Name:	Inspector's Title:
Inspector's Contact Information (phone):	
Type of Inspection: ❑ Routine, Dry Weather ❑ Routine, Wet Weather ❑ Complaint Response ❑ Other: ________________	
Weather Information	
Weather at time of this inspection: ❑ Clear ❑ Cloudy ❑ Raining ❑ Sleet ❑ Fog ❑ Snowing ❑ High Winds ❑ Other: ________________ Temperature: ________________	
Do you suspect that any physical changes or damages to the BMP may have occurred since the last inspection? ❑Yes ❑No If yes, provide description of physical changes or damages:	
Are there any storm water discharges at the time of inspection (i.e., discharge from an outlet)? ❑Yes ❑No If yes, provide location(s) and a description of storm water discharged from the site (presence of suspended sediment, turbid water, discoloration and/or oil sheen, odor, etc…).	
Prohibited Discharges	
Are there any prohibited discharges at the time of inspection and/or any signs of prohibited discharges since the last inspection (i.e., chemicals, oils, or other illicit discharges flowing onto the BMP)? ❑Yes ❑No If yes, provide location(s) and a description:	
Inspector's Signature: ________________________________ Date: ________________	

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
General	Accessibility	Maintenance access to the permeable surface is not obstructed in any way.	❑Yes ❑No	
	Contaminants & Pollution	Trash and debris are not accumulated within or around the basin and there is no evidence of oil, gasoline, contaminants, or other pollutants.	❑Yes ❑No	
	Sedimentation	The contributing drainage area is stabilized and not contributing excessive amounts of sediment.	❑Yes ❑No	
	Structural Damage	Structural components within and around the area are not damaged or defective.	❑Yes ❑No	
	Vegetation	Vegetation around the perimeter of the permeable surface area is healthy and not overrun by excessive vegetation or weeds.	❑Yes ❑No	
Perimeter Barrier (If applicable)	Drainage	Perimeter barriers are not leaking or negatively impacting the adjacent areas.	❑Yes ❑No	
	Structural Damage	There is no evidence of cracking, settling, or deterioration.	❑Yes ❑No	
Pavers	Drainage	There is no standing water on the surface of the PICP area.	❑Yes ❑No	
	Sediment	There is no evidence of excessive sediment deposition within the PICP area or within the PICP joints.	❑Yes ❑No	
	Structural Damage	The pavers are not deteriorating, cracked, settling, or misaligned. Paver joint material is not missing.	❑Yes ❑No	
	Vegetation	Vegetation is not growing in between pavers.	❑Yes ❑No	

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
Underdrain & Overflow System (If applicable)	Clogging	Underdrains and overflow structures are free of sediment, debris and/or dead vegetation.	❑Yes ❑No	
	Erosion Control	Permanent erosion control measures at the overflow structure are not damaged or contributing excess sediment to the downstream channel.	❑Yes ❑No	
	Structural Damage	The structure is not damaged and is operating as intended.	❑Yes ❑No	

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Example Inspection Form – Dispersion

General Information

Site Name (if Applicable):	Type of BMP:
Location (Physical Address):	
Site Owner:	Phone Number:
Responsible Party:	Phone Number:
Date of Inspection:	Start/End Time:
Inspector's Name:	Inspector's Title:
Inspector's Contact Information (phone):	

Type of Inspection:

❑ Routine, Dry Weather ❑ Routine, Wet Weather ❑ Complaint Response

❑ Other: ________________

Weather Information

Weather at time of this inspection:

❑ Clear ❑ Cloudy ❑ Raining ❑ Sleet ❑ Fog ❑ Snowing ❑ High Winds

❑ Other: ________________ Temperature: ________________

Do you suspect that any physical changes or damages to the BMP may have occurred since the last inspection? ❑Yes ❑No

If yes, provide description of physical changes or damages:

Are there any storm water discharges at the time of inspection? ❑Yes ❑No

If yes, provide location(s) and a description of storm water discharged from the site (presence of suspended sediment, turbid water, discoloration and/or oil sheen, odor, etc…).

Prohibited Discharges

Are there any prohibited discharges at the time of inspection and/or any signs of prohibited discharges since the last inspection (i.e., chemicals, oils, or other illicit discharges flowing into the BMP)? ❑Yes ❑No

If yes, provide location(s) and a description:

Inspector's Signature: ________________________________ Date: _________________

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
General	Accessibility	Maintenance access to the dispersion area is not obstructed in any way.	❑Yes ❑No	
	Contaminants & Pollution	Trash and debris are not accumulated within or around the dispersion area and there is no evidence of oil, gasoline, contaminants, or other pollutants.	❑Yes ❑No	
	Sedimentation	The contributing drainage area is stabilized and not contributing excessive amounts of sediment.	❑Yes ❑No	
	Structural Damage	Structural components within and around the dispersion area are not damaged or defective.	❑Yes ❑No	
Level Spreader (If applicable)	Sedimentation	The level spreader is not filled with sediment or other debris.	❑Yes ❑No	
	Structural Damage	Gravel within the level spreader is intact and not displaced due to traffic or erosion.	❑Yes ❑No	
Flow Spreader (If applicable)	Diversion Structure	If applicable, the diversion structure is operating as intended and adequately conveying storm water runoff.	❑Yes ❑No	
	Erosion Control	Erosion is not occurring along the boundary of the flow spreader.	❑Yes ❑No	
	Structural Damage	The flow spreader is not damaged, clogged, or defective.	❑Yes ❑No	
Dispersion Area	Drainage	The dispersion area is maintaining a uniform slope to promote sheet flow.	❑Yes ❑No	
	Erosion	There is no evidence of erosion such as rills, gullies, or channels.	❑Yes ❑No	
	Vegetation	Vegetation is healthy and the area does not have excessive weeds.	❑Yes ❑No	
	Vegetation	Trees are not growing within the vegetation dispersion area.	❑Yes ❑No	

Example Inspection Form – Biofiltration Swale

General Information	
Site Name (if Applicable):	Type of BMP:
Location (Physical Address):	
Site Owner:	Phone Number:
Responsible Party:	Phone Number:
Date of Inspection:	Start/End Time:
Inspector's Name:	Inspector's Title:
Inspector's Contact Information (phone):	
Type of Inspection: ❑ Routine, Dry Weather ❑ Routine, Wet Weather ❑ Complaint Response ❑ Other: ________________	
Weather Information	
Weather at time of this inspection: ❑ Clear ❑ Cloudy ❑ Raining ❑ Sleet ❑ Fog ❑ Snowing ❑ High Winds ❑ Other: ________________ Temperature: ________________	
Do you suspect that any physical changes or damages to the BMP may have occurred since the last inspection? ❑Yes ❑No If yes, provide description of physical changes or damages:	
Are there any storm water discharges at the time of inspection (i.e., discharge from an outlet)? ❑Yes ❑No If yes, provide location(s) and a description of storm water discharged from the site (presence of suspended sediment, turbid water, discoloration and/or oil sheen, odor, etc…)	
Prohibited Discharges	
Are there any prohibited discharges at the time of inspection and/or any signs of prohibited discharges since the last inspection (i.e., chemicals, oils, or other illicit discharges flowing into the BMP)? ❑Yes ❑No If yes, provide location(s) and a description:	
Inspector's Signature: ________________________________ Date: _________________	

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
General	Accessibility	Maintenance access to the swale is not obstructed in any way.	❑Yes ❑No	
	Contaminants & Pollution	Trash and debris are not accumulated within or around the swale. There is no evidence of oil, gasoline, contaminants, or other pollutants.	❑Yes ❑No	
	Erosion Control	There is no evidence of erosion such as sloughing, rills, or gullies.	❑Yes ❑No	
	Sedimentation	The contributing drainage area is stabilized and not contributing excessive amounts of sediment.	❑Yes ❑No	
	Structural Damage	Structural components within and around the swale are not damaged or defective.	❑Yes ❑No	
Storm Water Inlets & Conveyance	Diversion Structures	If applicable, diversion structures are operating as intended and adequately conveying storm water runoff.	❑Yes ❑No	
	Erosion Control	The inlet structure and energy dissipation area show no signs of erosion.	❑Yes ❑No	
	Structural Damage	The inlet structure is not damaged, clogged, or defective.	❑Yes ❑No	
Pretreatment Facilities	Clogging	The outlet structure is not damaged, clogged, or defective.	❑Yes ❑No	
	Drainage	There is no standing water in the pretreatment facility.	❑Yes ❑No	
	Sedimentation	There is no evidence of excessive sediment deposition.	❑Yes ❑No	
	Structural Damage	There is no damage that impacts the performance of the pretreatment facility.	❑Yes ❑No	

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
Side Slopes	Erosion Control	Side slopes are stabilized and not contributing sediment to the swale.	❑Yes ❑No	
	Structural Damage	There is no evidence of rodent holes, sinkholes, or instability.	❑Yes ❑No	
Swale Area	Drainage	There is no standing water in the swale.	❑Yes ❑No	
	Sediment	There is no evidence of excessive sediment deposition within the bottom of the swale.	❑Yes ❑No	
	Structural Damage	Level spreaders, check dams, and/or energy dissipaters are not damaged and are operating as intended.	❑Yes ❑No	
	Vegetation	Vegetation is thick, healthy, and matches to original design.	❑Yes ❑No	
	Vegetation	Swale area is not overrun by weeds.	❑Yes ❑No	
Outlet Structure (If applicable)	Clogging	The outlet structure is free of sediment, debris and/or dead vegetation.	❑Yes ❑No	
	Erosion Control	Permanent erosion control measures at the outlet structure are not damaged or contributing excess sediment to the downstream channel.	❑Yes ❑No	
	Structural Damage	The structure is not damaged and operating as intended.	❑Yes ❑No	

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Example Inspection Form – Extended Detention Basin

General Information	
Site Name (if Applicable):	Type of BMP:
Location (Physical Address):	
Site Owner:	Phone Number:
Responsible Party:	Phone Number:
Date of Inspection:	Start/End Time:
Inspector's Name:	Inspector's Title:
Inspector's Contact Information (phone):	
Type of Inspection: ❑ Routine, Dry Weather ❑ Routine, Wet Weather ❑ Complaint Response ❑ Other: ________________	
Weather Information	
Weather at time of this inspection: ❑ Clear ❑ Cloudy ❑ Raining ❑ Sleet ❑ Fog ❑ Snowing ❑ High Winds ❑ Other: ________________ Temperature: ________________	
Do you suspect that any physical changes or damages to the BMP may have occurred since the last inspection? ❑Yes ❑No If yes, provide description of physical changes or damages:	
Are there any storm water discharges at the time of inspection (i.e., discharge from an outlet)? ❑Yes ❑No If yes, provide location(s) and a description of storm water discharged from the site (presence of suspended sediment, turbid water, discoloration and/or oil sheen, odor, etc…)	
Prohibited Discharges	
Are there any prohibited discharges at the time of inspection and/or any signs of prohibited discharges since the last inspection (i.e., chemicals, oils, or other illicit discharges flowing into the BMP)? ❑Yes ❑No If yes, provide location(s) and a description:	
Inspector's Signature: ________________________________ Date: _________________	

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
General	Accessibility	Maintenance access to the EDB is not obstructed in any way.	❑Yes ❑No	
	Contaminants & Pollution	Trash and debris are not accumulated within or around the EDB and there is no evidence of oil, gasoline, contaminants, or other pollutants.	❑Yes ❑No	
	Erosion Control	Trickle channel, upstream/downstream channels, and berms show no signs of erosion.	❑Yes ❑No	
	Sedimentation	The contributing drainage area is stabilized and not contributing excessive amounts of sediment.	❑Yes ❑No	
	Structural Damage	There is no damage to the fence or gate that permits entry to the facility.	❑Yes ❑No	
Storm Water Inlets	Erosion Control	The inlet structure and energy dissipation area show no signs of erosion.	❑Yes ❑No	
	Structural Damage	The inlet structure is not damaged, clogged, or defective.	❑Yes ❑No	
Pretreatment Forebay	Clogging	The forebay outlet structure is not damaged, clogged, or defective.	❑Yes ❑No	
	Drainage	There is no standing water in the pretreatment forebay.	❑Yes ❑No	
	Sedimentation	There is not excessive sediment deposition in the pretreatment forebay.	❑Yes ❑No	
	Structural Damage	There is no damage that impacts the performance of the pretreatment forebay.	❑Yes ❑No	

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
Embankments & Side Slopes	Erosion Control	Embankment and side slopes are stabilized and not contributing sediment to the EDB.	❑Yes ❑No	
	Structural Damage	There is no evidence of rodent holes or water piping through dam or berm.	❑Yes ❑No	
Vegetation	Overgrowth	There is no overgrowth of weeds or nuisance vegetation within or around the EDB.	❑Yes ❑No	
	Tree Growth	Trees are not growing on or near berms or embankments.	❑Yes ❑No	
	Vegetation	All dead vegetation has been removed from the EDB.	❑Yes ❑No	
Spillway	Structural Damage	The spillway does not show signs of damage or erosion.	❑Yes ❑No	
	Structural Damage	Erosion control measures such as concrete, riprap, or concrete block mats are not damaged.	❑Yes ❑No	
Outlet Structure	Clogging	The trash rack, orifice plate, outlet pipe, and/or riser are free of sediment, debris and/or dead vegetation.	❑Yes ❑No	
	Erosion Control	Permanent erosion control measures at the outfall of the structure are not damaged or contributing excess sediment to the downstream channel.	❑Yes ❑No	
	Structural Damage	The outlet structure is not damaged, leaking, or showing signs of erosion or undercutting.	❑Yes ❑No	

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Example Inspection Form – Wet Detention Basin

General Information	
Site Name (if Applicable):	Type of BMP:
Location (Physical Address):	
Site Owner:	Phone Number:
Responsible Party:	Phone Number:
Date of Inspection:	Start/End Time:
Inspector's Name:	Inspector's Title:
Inspector's Contact Information (phone):	
Type of Inspection: ❑ Routine, Dry Weather ❑ Routine, Wet Weather ❑ Complaint Response ❑ Other: ________________	
Weather Information	
Weather at time of this inspection: ❑ Clear ❑ Cloudy ❑ Raining ❑ Sleet ❑ Fog ❑ Snowing ❑ High Winds ❑ Other: ________________ Temperature: ________________	
Do you suspect that any physical changes or damages to the BMP may have occurred since the last inspection? ❑Yes ❑No If yes, provide description of physical changes or damages:	
Are there any storm water discharges at the time of inspection (i.e., discharge from an outlet)? ❑Yes ❑No If yes, provide location(s) and a description of storm water discharged from the site (presence of suspended sediment, turbid water, discoloration and/or oil sheen, odor, etc…)	
Prohibited Discharges	
Are there any prohibited discharges at the time of inspection and/or any signs of prohibited discharges since the last inspection (i.e., chemicals, oils, or other illicit discharges flowing into the BMP)? ❑Yes ❑No If yes, provide location(s) and a description:	
Inspector's Signature: ________________________________ Date: _________________	

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
General	Accessibility	Maintenance access to the WDB is not obstructed in any way.	❑Yes ❑No	
	Contaminants & Pollution	Trash and debris are not accumulated within or around the WDB and there is no evidence of oil, gasoline, contaminants, or other pollutants.	❑Yes ❑No	
	Erosion Control	Upstream/downstream channels and berms show no signs of erosion.	❑Yes ❑No	
	Sedimentation	The contributing drainage area is stabilized and not contributing excessive amounts of sediment.	❑Yes ❑No	
	Structural Damage	There is no damage to the fence or gate that permits entry to the facility.	❑Yes ❑No	
Storm Water Inlets	Erosion Control	The inlet structure and energy dissipation area show no signs of erosion.	❑Yes ❑No	
	Structural Damage	The inlet structure is not damaged, clogged, or defective.	❑Yes ❑No	
Pretreatment Forebay	Sedimentation	There is not excessive sediment deposition in the pretreatment forebay.	❑Yes ❑No	
	Structural Damage	There is no damage that impacts the performance of the pretreatment forebay.	❑Yes ❑No	
Embankments & Side Slopes	Erosion Control	Embankments and side slopes are stabilized and not contributing sediment to the WDB.	❑Yes ❑No	
	Structural Damage	There is no evidence of rodent holes or water piping through embankment or berm.	❑Yes ❑No	

Primary Components	Inspection Item	Desired Conditions	Maintenance Needed?	Required Corrective Action/Notes
Wetpool Cell	Base Flow	A permanent pool of water is maintained within the wetpool cell.	❑Yes ❑No	
	Dewatering	If applicable, the pond drain is not damaged, clogged, or defective.	❑Yes ❑No	
	Erosion Control	The shoreline area including the safety wetland bench is stabilized and erosion is not present.	❑Yes ❑No	
	Vegetation	There is no evidence of undesirable vegetation or excessive algae blooms within the wetpool cell.	❑Yes ❑No	
Spillway	Structural Damage	The spillway does not show signs of damage or erosion.	❑Yes ❑No	
	Structural Damage	Erosion control measures such as concrete, riprap, or concrete block mats are not damaged.	❑Yes ❑No	
Outlet Structure	Clogging	The trash rack, orifice plate, outlet pipe, and/or riser are free of sediment, debris and/or dead vegetation.	❑Yes ❑No	
	Erosion Control	Permanent erosion control measures at the outfall of the structure are not damaged or contributing excess sediment to the downstream channel.	❑Yes ❑No	
	Structural Damage	The outlet structure is not damaged, leaking, or showing signs of erosion or undercutting.	❑Yes ❑No	