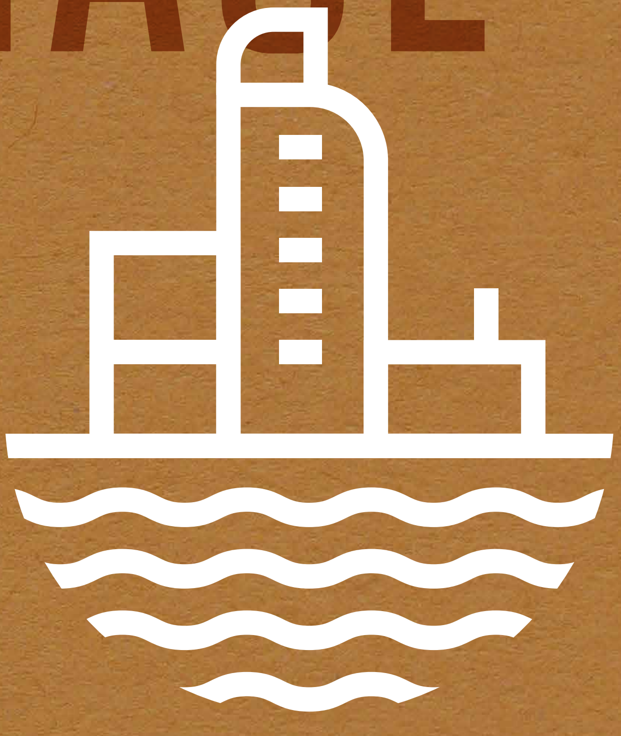
URBAN STORM DRAINAGE

VOLUME

3

CRITERIA MANUAL



STORMWATER QUALITY

Urban Storm Drainage Criteria Manual: Volume 3
Best Management Practices

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MILE HIGH FLOOD DISTRICT

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Urban Storm Drainage Criteria Manual
Volume 3, Stormwater Best Management Practices

By Mile High Flood District

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Urban Storm Drainage Criteria Manual Volume 3, Best Management Practices

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Preface

Contents

1.0 Acknowledgements

The Urban Storm Drainage Criteria Manual (USDCM), Volume 3, was first released in 1992 under the direction and leadership of Ben Urbonas, P.E., B.C.WRE. Although Mr. Urbonas retired from Mile High Flood District (MHFD) in 2008, he continued to serve as an advisor throughout the 2010 revision to Volume 3 and some of his ongoing work continued to inform updates in 2024, for which we are grateful. Each update builds upon the core philosophy, principles and practices developed by Mr. Urbonas and others. MHFD recognizes the significant contributions of those that continued to advance the state of the practice with ongoing updates to this manual. Notably, we recognize the work of Ken MacKenzie, P.E.

MHFD values stakeholder input in the development of criteria. Significant updates to this manual published in 2024 were the result of a process that included over 100 stakeholders including local and state governments, academics, consultants, engineers, landscape architects, suppliers, trade associations, manufacturers, and contractors. MHFD acknowledges and thanks all individuals and organizations that contributed to the development of this manual. The list of contributors is too long to acknowledge and thank everyone individually, for which we apologize.

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2.0 Purpose

Volume 3 of the Urban Storm Drainage Criteria Manual (USDCM) is designed to provide guidance for engineers, planners, landscape architects, developers, and Municipal Separate Storm Sewer System (MS4) permit holders in selecting designing, maintaining, and carrying out best management practices (BMPs) to minimize water quality and quantity impacts from stormwater runoff. Whereas Volumes 1 and 2 of this manual focus primarily on stormwater quantity management for drainage and flood control purposes, Volume 3 focuses on smaller, more frequently occurring events that have the greatest overall impact on the quality of receiving waters.

3.0 Overview

This manual is organized according to these topics:

- **Chapter 1: Stormwater Management and Planning.** In order to effectively design stormwater quality BMPs, it is important to understand the impacts of urbanization on receiving waters, as well as to understand the federal and state regulatory requirements under the Clean Water Act. Chapter 1 provides basic information on these topics and introduces UDFCD's approach to reducing the impacts of urban runoff through implementation of a holistic Four Step Process (see inset below). UDFCD continues to emphasize the importance of implementing all four steps in this process. Chapter 1 provides expanded guidance on Step 1 (Runoff Reduction), which has historically been implemented only minimally, but will be increasingly important to comply with new federal regulations and state stormwater discharge permits.

The Four-Step Process for Stormwater Quality Management

Step 1 **Employ Runoff Reduction Practices**: To reduce runoff peaks, volumes, and pollutant loads from urbanizing areas, implement Low Impact Development (LID) strategies, including measures to "minimize directly connected impervious areas" (MDCIA). These practices reduce unnecessary impervious areas and route runoff from impervious surfaces over permeable areas to slow runoff (increase time of concentration) and promote onsite storage and infiltration.

Step 2 **Implement BMPs that Provide a Water Quality Capture Volume (WQCV) with Slow Release:** After runoff has been reduced, the remaining runoff must be treated through capture and slow release of the WQCV. WQCV facilities may provide both water quality and runoff reduction benefits, depending on the BMP selected. This manual provides design guidance for BMPs providing treatment of the WQCV.

Step 3 **Stabilize Drainageways:** During and following urban development, natural drainageways are often subject to bed and bank erosion due to increases in the frequency, rate, duration, and volume of runoff. Although Steps 1 and 2 help to minimize these effects, some degree of drainageway stabilization is required. Many drainageways within UDFCD boundaries are included in major drainageway or outfall systems plans, identifying recommended channel stabilization measures. If this can be done early, it is far more likely that natural drainageway functions can be maintained with the addition of grade control to accommodate future development. It is also less costly to stabilize a relatively stable drainageway rather than to repair an unraveled channel.

Step 4 **Implement Site Specific and Other Source Control BMPs**: Frequently, site-specific needs or operations require source control BMPs. This refers to implementation of both structural and procedural BMPs.

- **Chapter 2: BMP Selection.** Long-term effectiveness of BMPs depends not only on proper engineering design, but also on selecting the right combination of BMPs for the site conditions. In addition to physical factors, other factors such as life cycle costs and long-term maintenance requirements are also important considerations for BMP selection. This chapter provides information to aid in BMP selection and provides the foundation for the *UD-BMP* and *BMP-REALCOST* design aid tools that accompany this manual.

- **Chapter 3: Calculation the WQCV and Volume Reduction.** Chapter 3 provides the computational procedures necessary to calculate the WQCV, forming the basis for design of many treatment BMPs. This chapter also covers the Excess Urban Runoff Volume (EURV) and full spectrum detention, developed to best replicate predevelopment peak flows. Additionally, procedures for quantifying runoff reduction due to the implementation of practices that reduce the effective imperviousness of the site are also provided. These procedures provide incentive to implement MDCIA practices and LID strategies.

- **Chapter 4: Treatment BMPs.** Chapter 4 provides design criteria for a variety of BMPs, generally categorized as conveyance practices and storage practices that provide treatment of the WQCV or EURV. A BMP Fact Sheet is provided for each BMP, providing step-by-step design criteria, design details, an accompanying design worksheet, and selection guidance related to factors such as performance expectations, site conditions and maintenance requirements.

- **Chapter 5: Source Control BMPs.** It is generally more effective to prevent pollutants from coming into contact with precipitation and/or from being transported in urban runoff than it is to remove these pollutants downstream. For this reason, guidance is provided on a variety of source control BMPs, which can be particularly beneficial for municipal operations and at industrial and commercial sites. Source controls and good housekeeping practices are also required under MS4 permits.

- **Chapter 6: BMP Maintenance.** Long-term effectiveness and safety of BMPs is dependent on both routine maintenance and periodic rehabilitation. Maintenance recommendations are provided for each post-construction treatment BMP in this manual.

- **Chapter 7: Construction BMPs.** Many different types of BMPs are available for use during construction. This chapter provides design details and guidance for appropriate use of these temporary BMPs.

Volume 3 BMPs

Treatment BMPs

Grass Swale
Grass Buffer
Bioretention/Rain Garden*
Green Roof
Extended Detention Basin
Retention Pond
Sand Filter
Constructed Wetland Pond
Constructed Wetland Channel
Permeable Pavement Systems
Underground BMPs

Source Control BMPs

Covering Outdoor Storage & Handling Areas
Spill Prevention, Containment and Control
Disposal of Household Waste
Illicit Discharge Controls
Good Housekeeping
Preventative Maintenance
Vehicle Maintenance, Fueling & Storage
Use of Pesticides, Herbicides and Fertilizers
Landscape Maintenance
Snow and Ice Management
Street Sweeping and Cleaning
Storm Sewer System Cleaning

**Referred to as Porous Landscape Detention in Previous Releases of Volume 3*

- **Glossary:** A glossary is included to provide users of Volume 3 with a basic understanding of terms used in this manual.

- **Bibliography:** Many references have been used to develop this Manual. The Bibliography provides a listing of these references for more detailed information on key topics.

4.0 Revisions to USDCM Volume 3

Volume 3 of the USDCM has been updated and expanded several times since it was first published in 1992 as our understanding of urban hydrology and BMP performance expanded, and as the design of various BMPs has been refined. Updates will continue as the needs of communities and regulatory requirements change, and as UDFCD continues to build, use, and monitor BMPs. In 2010, this major revision to Volume 3 was completed, including the following:

- Increased emphasis on runoff reduction, which is Step 1 of the Four Step Process. Although UDFCD has previously included runoff reduction as the first step in stormwater management, this step has not been routinely implemented. A significant change to the manual includes quantifying stormwater management facility sizing credits using quantitative methods when MDCIA and LID practices are implemented.

- Substantial revision to design criteria for several BMPs already in this manual and inclusion of BMPs not previously in this manual. Green roofs and Underground BMPs were added. Although UDFCD continues to strongly recommend treatment of runoff above ground, we also recognize the need to provide guidance related to underground BMPs when surface treatment is not practicable.

- Revision and expansion of the Construction BMPs chapter.

- Addition of supplemental guidance to promote more effective implementation of BMPs. This information is typically provided in the form of "call-out" boxes. While this manual remains focused on engineering design criteria, UDFCD also recognizes that it is helpful for designers to be aware of why certain criteria have been developed, how various practices can best be implemented on a site, opportunities to consider, and common problems to avoid.

- New Excel® worksheets to assist in BMP selection based on site-specific conditions, BMP design including integration of the EURV for use with full spectrum detention, and BMP performance expectations and life cycle costs.

5.0 Acronyms and Abbreviations

>	Greater Than
<	Less Than
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BOD	Biochemical Oxygen Demand
BMPs	Best Management Practices
CDPHE	Colorado Department of Public Health and Environment
CDPS	Colorado Discharge Permit System
cfs	Cubic Feet Per Second
COD	Chemical Oxygen Demand
CRS	Colorado Revised Statutes
CSO	Combined Sewer Overflow
CUHP	Colorado Urban Hydrograph Procedure
CWC	Constructed Wetland Channel
CWCB	Colorado Water Conservation Board
CWQCC	Colorado Water Quality Control Commission
CWQCD	Colorado Water Quality Control Division
DCIA	Directly Connected Impervious Areas
DO	Dissolved Oxygen
DRCOG	Denver Regional Council of Governments
DRURP	Denver Regional Urban Runoff Program
EDB	Extended Detention Basin
EMC	Event Mean Concentration
EPA	U.S. Environmental Protection Agency
ET	Evapotranspiration
EURV	Excess Urban Runoff Volume

fps	Feet per second
ft	Feet
FHWA	Federal Highway Administration
GB	Grass Buffer
GS	Grass Swale
H:V	Horizontal to Vertical Ratio of a Slope
HSG	Hydrologic Soil Group
i	Impervious Ratio of a Catchment (I_a/100)
I_a	Percent Imperviousness of Catchment
LEED	Leadership in Energy and Environmental Design
LID	Low Impact Development
MCM	Minimum Control Measure
mg/L	Milligrams per Liter
µg/L	Micrograms per Liter
MDCIA	Minimize Directly Connected Impervious Areas
MS4	Municipal Separate Storm Sewer System
MSDS	Material Safety Data Sheets
MWCOG	Metropolitan Washington Council of Governments
N/A	Not applicable
NPDES	National Pollution Discharge Elimination System
NPV	Net Present Value
NRCS	Natural Resources Conservation Services
NTIS	National Technical Information Service
NTU	Nephelometric turbidity units
NURP	Nationwide Urban Runoff Program
NVDPC	Northern Virginia District Planning Commission
PA	Porous Asphalt

Chapter 1
Stormwater Management and Planning

Contents

Figures

Tables

1.0 Introduction

The physical and chemical characteristics of stormwater runoff change as urbanization occurs, requiring comprehensive planning and management to reduce adverse effects on receiving waters. As stormwater flows across roads, rooftops, and other hard surfaces, pollutants are picked up and then discharged to streams and lakes. Additionally, the increased frequency, flow rate, duration, and volume of stormwater discharges due to urbanization can result in the scouring of rivers and streams, degrading the physical integrity of aquatic habitats, stream function, and overall water quality (EPA 2009). This chapter provides information fundamental to effective stormwater quality management and planning, including:

- An overview of the potential adverse impacts of urban stormwater runoff.
- A summary of key regulatory requirements for stormwater management in Colorado. These regulations set the minimum requirements for stormwater quality management. It is essential that those involved with stormwater management understand these requirements that shape stormwater management decisions at the construction and post-construction stages of development and redevelopment.
- UDFCD's Four Step Process to reduce the impacts of urban runoff.
- Discussion of on-site, sub-regional, and regional stormwater management alternatives at a planning level.

UDFCD highly recommends that engineers and planners begin the development process with a clear understanding of the seriousness of stormwater quality management from regulatory and environmental perspectives, and implement a holistic planning process that incorporates water quality upfront in the overall site development process. Chapters 2 and 3 provide BMP selection tools and detailed calculation procedures based on the concepts introduced in this chapter.

2.0 Urban Stormwater Characteristics

Numerous studies conducted since the late 1970s show stormwater runoff from urban and industrial areas can be a significant source of pollution (EPA 1983; Driscoll et al. 1990; Pitt et al. 2008). Stormwater impacts can occur during both the construction and post-construction phases of development. As a result, federal, state, and local regulations have been promulgated to address stormwater quality. Although historical focus of stormwater management was either flooding or chemical water quality, more recently, the hydrologic and hydraulic (physical) changes in watersheds associated with urbanization are recognized as significant contributors to receiving water degradation. Whereas only a few runoff events per year may occur prior to development, many runoff events per year may occur after urbanization (Urbonas et al. 1989). In the absence of controls, runoff peaks and volumes increase due to urbanization. This increased runoff is environmentally harmful, causing erosion in receiving streams and generating greater pollutant loading downstream. Figure 1-1 illustrates the many physical factors associated with stormwater runoff and the responses of receiving waters.

With regard to chemical water quality, Table 1-1 identifies a variety of pollutants and sources often found in urban settings such as solids, nutrients, pathogens, dissolved oxygen demands, metals, and oils. Several national data sources are available characterizing the chemical quality of urban runoff (e.g., EPA 1983; Pitt 2004). For purposes of this manual, Denver metro area data are the primary focus. In 1983, the Denver Regional Urban Runoff Program (DRURP) conducted by the Denver Regional Council of Governments (DRCOG), provided data for nine watersheds with various land uses for 15 constituents of concern and for U.S. Environmental Protection Agency (EPA) "Priority Pollutants." In 1992, additional urban stormwater monitoring was completed by UDFCD in support of the Stormwater National Pollutant Discharge Elimination System (NPDES) Part 2 Permit Application Joint Appendix (City of Aurora et al. 1992) for the Denver area communities affected by the Phase I stormwater regulation. Table 1-2 contains a summary of the results of these monitoring efforts, followed by a discussion of key findings from the DRURP study and other research since that time.

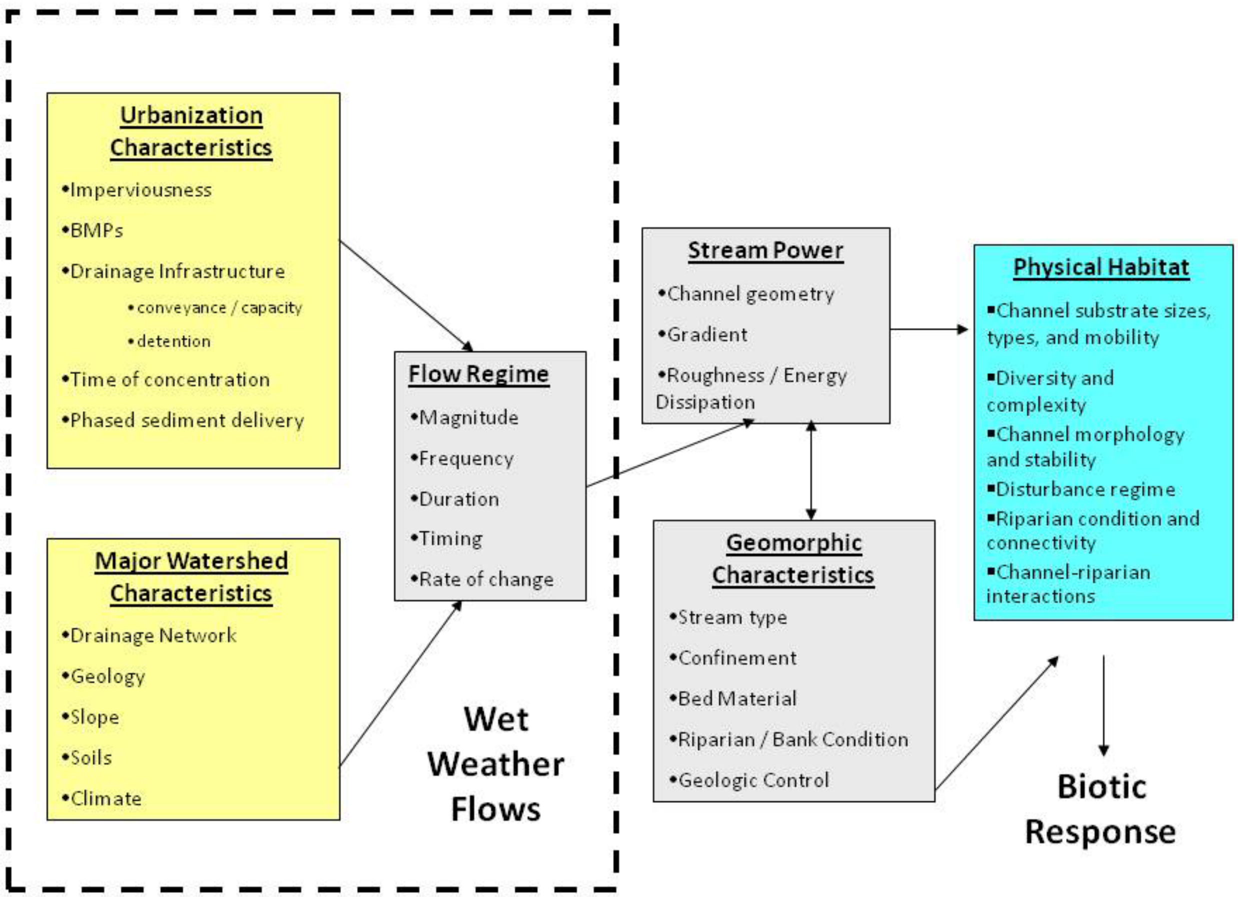

Figure 1-1. Physical effects of urbanization on streams and habitat

(Source: Roesner, L. A. and B. P. Bledsoe. 2003. *Physical Effects of Wet Weather Flows on Aquatic Habitats*. Water Environment Research Foundation: Alexandria, VA. Co-published by IA Publishing: United Kingdom.)

Table 1-1. Common urban runoff pollutant sources

(Adapted form: Horner, R.R., J.J. Skupien, E.H. Livingston and H.E. Shaver. 1994. *Fundamentals of Urban Runoff Management: Technical and Intuitional Issues*. Washington, DC: Terrene Institute and EPA.)

Pollutant Category Source	Solids	Nutrients	Pathogens	Dissolved Oxygen Demands	Metals	Oils	Synthetic Organics
Soil erosion	X	X		X	X		
Cleared vegetation	X	X		X			
Fertilizers		X	X	X			
Human waste	X	X	X	X			
Animal waste	X	X	X	X			
Vehicle fuels and fluids	X			X	X	X	X
Fuel combustion						X	
Vehicle wear	X			X	X		
Industrial and household chemicals	X	X		X	X	X	X
Industrial processes	X	X		X	X	X	X
Paints and preservatives					X	X	X
Pesticides				X	X	X	X
Stormwater facilities w/o proper maintenance[1]	X	X	X	X	X	X	X

Table 1-2. Event mean concentrations of constituents in Denver metropolitan area runoff
(based on Denver metropolitan area data collected as part of the Colorado Regulation 85 Nutrient Data Gap Analysis Report, 2013)

	Commercial			Residential			Industrial			Natural Grassland		
Analyte	n	Mean (95% CIs)	Median (95% CIs)	n	Mean (95% CIs)	Median (95% CIs)	n	Mean (95% CIs)	Median (95% CIs)	n	Mean (95% CIs)	Median (95% CIs)
Total Nitrogen (mg/L)	246	3.70 (3.33-4.06)	2.92 (2.75-3.20)	204	4.74 (4.34-5.13)	3.86 (3.59-4.40)	9	4.35 (2.58-6.12)	3.60 (1.20-5.70)	7	3.40 (1.90-4.90)	3.76 (1.49-4.11)
Total Kjeldahl Nitrogen (mg/L)	250	2.80 (2.50-3.09)	2.20 (2.03-2.40)	192	3.33 (3.00-3.66)	2.70 (2.47-3.00)	20	3.12 (2.29-3.95)	2.97 (2.01-4.2)	7	2.88 (1.56-4.21)	3.10 (1.30-3.26)
Nitrate Plus Nitrite (mg/L)	253	0.89 (0.79-0.99)	0.72 (0.63-0.78)	238	1.02 (0.91-1.12)	0.81 (0.76-0.94)	9	1.23 (0.78-1.68)	1.00 (0.30-1.60)	7	0.52 (0.23-0.80)	0.56 (0.09-0.66)
Phosphorus as P, Total (mg/L)	273	0.35 (0.29-0.42)	0.19 (0.17-0.24)	254	0.52 (0.48-0.57)	0.42 (0.38-0.46)	21	0.42 (0.27-0.58)	0.30 (0.17-0.41)	7	0.41 (0.25-0.58)	0.41 (0.21-0.53)
Phosphorus as P, Dissolved (mg/L)	192	0.13 (0.10-0.15)	0.07 (0.05-0.08)	233	0.24 (0.22-0.27)	0.19 (0.17-0.20)	9	0.34 (0.13-0.54)	0.18 (0.10-0.52)	7	0.13 (0.08-0.18)	0.15 (0.07-0.17)
Phosphorus, Ortho-P (mg/L)	136	0.15 (0.10-0.20)	0.06 (0.06-0.08)	97	0.22 (0.16-0.27)	0.15 (0.13-0.18)		NA	NA	7	0.13 (0.08-0.18)	0.12 (0.07-0.13)
TSS (mg/L)	280	219 (173-265)	85 (63-125)	270	221 (185-256)	122 (103-143)	9	502 (240-764)	370 (126-540)	7	397 (166-627)	257 (194-464)
TDS (mg/L)	9	149 (81-217)	117 (33-214)	7	146 (46-245)	95 (60-126)	9	84 (52-117)	75 (30-102)		NA	NA
COD (mg/L)	156	187 (159-215)	139 (114-162)	140	120 (105-136)	93 (80-108)		NA	NA	7	72 (51-94)	71 (42-71)
DOC (mg/L)	51	35 (24-45)	22 (17-34)	55	17 (13-21)	12 (10-14)		NA	NA	7	16 (6-27)	12 (9-12)
TOC (mg/L)	156	36 (28-44)	21 (18-27)	80	27 (23-31)	21 (18-25)	9	66 (48-84)	57 (24-82)	7	26 (11-42)	23 (13-23)
Cadmium, Total (ug/L)	147	NP	NP	119	NP	NP	9	NP	NP		NA	NA
Copper, Total (ug/L)	249	27 (20-34)	13 (12-16)	182	22 (19-25)	15 (11-20)	9	86 (31-141)	46 (39-86)	7	37 (-0.1-74)	20 (10-60)
Lead, Total (ug/L)	209	13 (10-16)	5 (5-6)	126	14 (11-17)	8 (5-10)	9	205 (3-408)	120 (63-160)		NA	NA
Zinc, Total (ug/L)	251	156 (120-192)	64 (55-80)	181	115 (99-131)	80 (68-110)	9	760 (280-1240)	520 (340-620)	7	101 (56-147)	90 (40-120)

Monitoring locations limited to Denver Metro area. 1980's lead data excluded from summary due to the phase-out of leaded gasoline.
CI = 95% confidence interval provided for mean and median values. n = number of samples. NP = Not provided due to large percentage of non-detects.

Selected findings of DRURP include:

- Urban runoff was identified as a significant source of stormwater pollutants including sediment, fecal indicator bacteria, nutrients, organic matter, and heavy metals (e.g., lead, zinc, cadmium). Sediment loading occurred regardless of the existence of major land disturbances causing erosion. In addition, nutrients from urban runoff were identified as a concern for lakes and reservoirs.

- Very few EPA Priority Pollutants were detected in runoff samples. Organic pollutants found were particularly sparse; the most commonly occurring was a pesticide. The most significant non-priority pollutant found was 2,4-D, which is an herbicide.

- Pollutant loading was not closely related to basin imperviousness or land use. Vague relationships between event mean concentrations and imperviousness were noted, but proved statistically insignificant. Concentrations of pollutants did not vary in a predictable or anticipated pattern.

- Non-storm urban runoff (e.g., dry weather discharges such as irrigation runoff) was also identified as a source of pollutants. This was not expected and was determined indirectly in the study analysis.

In addition to these pollutants, Urbonas and Doerfer (2003) have reported that atmospheric fallout is a significant contributor to urban runoff pollution in the Denver area. Snow and ice management activities also affect the quality of urban runoff since snow and ice may be contaminated by hydrocarbons, pet waste, deicing chemicals and sand.

Although Table 1-2 indicates that constituent concentrations in urban runoff in the metro Denver area are not necessarily greater than that for natural grasslands (background) for some constituents (e.g., TSS, TDS, TKN), it is important to recognize that the table does not provide data on pollutant loads, which are the product of runoff volume and pollutant concentrations. Runoff volume from urbanized areas is much greater than that from a natural grassland; therefore, resultant differences in pollutant loads are generally greater than the difference in concentrations.

Stormwater runoff issues can be discussed in general terms for both streams and lakes; however, there are some unique effects with regard to lakes. Some of these include:

- Lakes respond to cumulative pollutant loading over time in terms of days, weeks, and longer time frames, unlike streams, which typically show effects within hours or days.

- Floating trash and shore damage are notable visible impacts of stormwater on lakes.

- Nutrient enrichment from stormwater runoff can have a significant water quality impact on lakes. This can result in the undesirable growth of algae and aquatic plants, increasing BOD and depleting dissolved oxygen.

- Lakes do not flush contaminants as quickly as streams and act as sinks for nutrients, metals, and sediments. This means that lakes take longer to recover once contaminated.

With regard to construction-phase stormwater runoff, EPA reports sediment runoff rates from construction sites can be much greater than those from agricultural lands and forestlands, contributing large quantities of sediment over a short period of time, causing physical and biological harm to receiving waters (EPA 2005). Fortunately, a variety of construction-phase and post-construction BMPs are available to help minimize the impacts of urbanization. Proper selection, design, construction and maintenance of these practices are the focus of the remainder of this manual.

Additional Resources Regarding Urban Stormwater Issues and Management

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3.0 Stormwater Management Requirements under the Clean Water Act

3.1 Clean Water Act Basics

The Federal Water Pollution Control Act of 1972, as amended (33 U.S.C. 1251 et seq.) is commonly known as the Clean Water Act and establishes minimum stormwater management requirements for urbanized areas in the United States. At the federal level, the EPA is responsible for administering and enforcing the requirements of the Clean Water Act. Section 402(p) of the Clean Water Act requires urban and industrial stormwater be controlled through the NPDES permit program. Requirements affect both construction and post-construction phases of development. As a result, urban areas must meet requirements of Municipal Separate Storm Sewer System (MS4) permits, and many industries and institutions such as state departments of transportation must also meet NPDES stormwater permit requirements. MS4 permittees are required to develop a Stormwater Management Program that includes measurable goals and to implement needed stormwater management controls (i.e., BMPs). MS4 permittees are also required to assess controls and the effectiveness of their stormwater programs and to reduce the discharge of pollutants to the "maximum extent practicable." Although it is not the case for every state, the EPA has delegated Clean Water Act authority to the State of Colorado. The State must meet the minimum requirements of the federal program.

3.2 Colorado's Stormwater Permitting Program

The Colorado Water Quality Control Act (25-8-101 et seq., CRS 1973, as amended) established the Colorado Water Quality Control Commission (CWQCC) within the Colorado Department of Public Health and Environment (CDPHE) to develop water quality regulations and standards, classifications of state waters for designated uses, and water quality control regulations. The Act also established the Colorado Water Quality Control Division (CWQCD) to administer and enforce the Act and administer the discharge permit system, among other responsibilities. Violations of the Act are subject to significant monetary penalties, as well as criminal prosecution in some cases.

Colorado's stormwater management regulations have been implemented in two phases and are included in *Regulation No. 61 Colorado Discharge Permit System (CDPS) Regulations* (CWQCC 2009). After the 1990 EPA "Phase I" stormwater regulation became effective, Colorado was required to develop a stormwater program that covered specific types of industries and storm sewer systems for municipalities with populations of more than 100,000. Phase I affected Denver, Aurora, Lakewood, Colorado Springs, and the Colorado Department of Transportation (CDOT). Phase 1 requirements included inventory of stormwater outfalls, monitoring and development of municipal stormwater management requirements, as well as other requirements. Construction activities disturbing five or more acres of land were required to obtain construction stormwater discharge permits.

Phase II of Colorado's stormwater program was finalized in March 2001, establishing additional stormwater permitting requirements. Two major changes included regulation of small municipalities (≥ 10,000 and <100,000 population) in urbanized areas and requiring construction permits for sites disturbing one acre or more. The Phase II regulation resulted in a large number of new permit holders including MS4 permits for almost all of the metro Denver area communities. MS4 permit holders are required to develop, implement, and enforce a CDPS Stormwater Management Program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable, to protect water quality, and to satisfy the appropriate water quality requirements of the Colorado Water Quality Control Act (25-8-101 et seq., C.R.S.) and the Colorado Discharge Permit Regulations (Regulation 61).

The CWQCD administers and enforces the requirements of the CDPS stormwater program, generally including these general permit categories:

- **Municipal**: CDPS General Permit for Stormwater Discharges Associated with Municipal Separate Storm Sewer Systems (MS4s) (Permit No. COR-090000). The CWQCD has issued three municipal general permits:
    1. A permit for MS4s within the Cherry Creek Reservoir Basin,
    2. A permit for other MS4s statewide, and
    3. A permit specifically for non-standard MS4s. (Non-standard MS4s are publicly owned systems for facilities that are similar to a municipality, such as military bases and large education, hospital or prison complexes.)
- **Construction**: CDPS General Permit for Stormwater Discharges Associated with Construction Activity (Permit No. COR-030000).
- **Industrial**: CDPS General Permits are available for light industry, heavy industry, metal mining, sand and gravel, coal mining and the recycling industries.

The Phase II municipal MS4 permits require implementation of six minimum control measures (MCM):

1. Public education and outreach on stormwater impacts
2. Public involvement/participation
3. Illicit connections and discharge detection and elimination
4. Construction site stormwater management
5. Post-construction stormwater management in new development and redevelopment
6. Pollution prevention/good housekeeping for municipal operations

This manual provides guidance to address some of the requirements for measures 4, 5, and 6.

Resources for More Information on Colorado's Stormwater Regulations

CDPHE Stormwater Permitting Website: www.colorado.gov/pacific/cdphe/wqcd

See the CDPHE Regulation No. 61 Colorado Discharge Permit System Regulations and Colorado's Stormwater Program Fact Sheet both located on this website.

Common Stormwater Management Terms

Best Management Practice (BMP): A device, practice, or method for removing, reducing, retarding, or preventing targeted stormwater runoff constituents, pollutants, and contaminants from reaching receiving waters. (Some entities use the terms "Stormwater Control Measure," "Stormwater Control," or "Management Practice.")

Low Impact Development (LID): LID is a comprehensive land planning and engineering design approach to managing stormwater runoff with the goal of mimicking the pre-development hydrologic regime. LID emphasizes conservation of natural features and use of engineered, on-site, small-scale hydrologic controls that infiltrate, filter, store, evaporate, and detain runoff close to its source. The terms Green Infrastructure and Better Site Design are sometimes used interchangeably with LID.

LID Practice: LID practices are the individual techniques implemented as part of overall LID development or integrated into traditional development, including practices such as bioretention, green roofs, permeable pavements and other infiltration-oriented practices.

Minimizing Directly Connected Impervious Area (MDCIA): MDCIA includes a variety of runoff reduction strategies based on reducing impervious areas and routing runoff from impervious surfaces over grassy areas to slow runoff and promote infiltration. The concept of MDCIA has been recommended by UDFCD as a key technique for reducing runoff peaks and volumes following urbanization. MDCIA is a key component of LID.

Maximum Extent Practicable (MEP): MS4 permit holders are required to implement stormwater programs to reduce pollutant loading to the maximum extent practicable. This narrative standard does not currently include numeric effluent limits.

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) owned or operated by an MS4 permittee and designed or used for collecting or conveying stormwater.

Nonpoint Source: Any source of pollution that is not considered a "point source." This includes anthropogenic and natural background sources.

Point Source: Any discernible, confined and discrete conveyance from which pollutants are or may be discharged. Representative sources of pollution subject to regulation under the NPDES program include wastewater treatment facilities, most municipal stormwater discharges, industrial dischargers, and concentrated animal feeding operations. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture.

Water Quality Capture Volume (WQCV): This volume represents runoff from frequent storm events such as the 80th percentile storm. The volume varies depending on local rainfall data. Within the UDFCD boundary, the WQCV is based on runoff from 0.6 inches of precipitation.

Excess Urban Runoff Volume (EURV): EURV represents the difference between the developed and pre-developed runoff volume for the range of storms that produce runoff from pervious land surfaces (generally greater than the 2-year event). The EURV is relatively constant for a given imperviousness over a wide range of storm events.

Full Spectrum Detention: This practice utilizes capture and slow release of the EURV. UDFCD found this method to better replicate historic peak discharges for the full range of storm events compared to multi-stage detention practices.

3.2.1 Construction Site Stormwater Runoff Control

Under the Construction Program, permittees are required to develop, implement, and enforce a pollutant control program to reduce pollutants in stormwater runoff to their MS4 from construction activities that result in land disturbance of one or more acres. MS4 permittees frequently extend this requirement to smaller areas of disturbance if the total site acreage is one acre or larger or if it drains to an environmentally sensitive area. See Chapter 7 for detailed information on construction BMPs.

3.2.2 Post-construction Stormwater Management

Under the post-construction stormwater management in new development and redevelopment provisions, the MS4 General Permit (CWQCD 2008) requires the permittee to develop, implement, and enforce a program to address stormwater runoff from 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 the MS4. The program must ensure controls are in place that would prevent or minimize water quality impacts. See Chapter 4, Treatment BMPs and Chapter 5, Source Control BMPs, for detailed information on post-construction BMPs.

Redevelopment

The EPA Stormwater Phase 2 Final Rule Fact Sheet 2.7 states that redevelopment projects alter the footprint of an existing site or building in such a way that that there is a disturbance of equal to or greater than one acre of land.

This means that a "roadway rehabilitation" project, for example, where pavement is removed and replaced with essentially the same footprint would not be considered "redevelopment", whereas a "roadway widening project", where additional pavement (or other alterations to the footprint, pervious or impervious) equal to or in excess of one acre would be considered "redevelopment".

Although MS4 general permits have historically focused on water quality, it is noteworthy that there has been increased emphasis on reducing stormwater runoff volumes through use of Low Impact Development (LID) techniques. For example, MS4 permit language for some Phase I municipalities has also included the following:

> Implement and document strategies which include the use of structural and/or non-structural BMPs appropriate for the community, that address the discharge of pollutants from new development and redevelopment projects, or that follow principles of low-impact development to mimic natural (i.e., pre-development) hydrologic conditions at sites to minimize the discharge of pollutants and prevent or minimize adverse in-channel impacts associated with increased imperviousness (City and County of Denver 2008 MS4 permit).

Similarly, at the national level, the Energy Independence and Security Act of 2007 (Pub.L. 110-140) includes Section 438, Storm Water Runoff Requirements for Federal Development Projects. This section requires:

> …any sponsor of any development or redevelopment project involving a federal facility with a footprint that exceeds 5,000 square feet 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 the temperature, rate, volume, and duration of flow.

Finally, in October 2009, EPA issued a notice in the Federal Register (Federal Register Vol. 74, No. 209, 56191-56193) expressing its intent to implement new comprehensive stormwater regulations for new developments and redevelopments by 2012. EPA intends to propose requirements, including design or performance standards, for stormwater discharges from, at a minimum, newly developed and redeveloped sites. In the notice, EPA cites the National Research Council (2008) recommendations that "EPA address stormwater discharges from impervious land cover and promote practices that harvest, infiltrate and evapotranspirate stormwater to reduce or prevent it from being discharged, which is critical to reducing the volume and pollutant loading to our nation's waters."

Although it is important to be aware of increased regulatory emphasis on volume control, it is also noteworthy that UDFCD guidance has recommended volume reduction as the first step in urban stormwater quality management since the initial release of the USDCM Volume 3, in 1992. Chapter 2 of this manual provides the designer with additional tools to encourage site designs that better incorporate volume reduction, based on site-specific conditions.

3.2.3 Pollution Prevention/Good Housekeeping

Under the Pollution Prevention/Good Housekeeping requirements, permittees are required to develop and implement an operation and maintenance/training program with the ultimate goal of preventing or reducing pollutant runoff from municipal operations. Chapter 5 provides information on source controls and non-structural BMPs that can be used in support of some of these requirements. Stormwater managers must also be aware that non-stormwater discharges to MS4s are not allowed, with the exception of certain conditions specified in the MS4 permit.

3.3 Total Maximum Daily Loads and Stormwater Management

Section 303(d) of the Clean Water Act requires states to develop a list of water bodies that are not attaining water quality standards for their designated uses, and to identify relative priorities for addressing the impaired water bodies. States must then develop Total Maximum Daily Loads (TMDLs) to assign allowable pollutant loads to various sources to enable the water body to meet the designated uses established for that water body. (For more information about the TMDL program, see http://www.epa.gov/owow/tmdl.) Implementation plans to achieve the loads specified under TMDLs commonly rely on BMPs to reduce pollutant loads associated with stormwater sources.

In the context of this manual, it is important for designers, planners and other stormwater professionals to understand TMDLs because TMDL provisions can directly affect stormwater permit requirements and BMP selection and design. EPA provides this basic description of TMDLs:

> A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that load among the various sources of that pollutant. Pollutant sources are characterized as either regulated stormwater, sometimes called "point sources" that receive a waste load allocation (WLA), or nonpoint sources that receive a load allocation (LA). Point sources include all sources subject to regulation under the NPDES program (e.g., wastewater treatment facilities, most municipal stormwater discharges and concentrated animal feeding operations). Nonpoint sources include all remaining sources of the pollutant, as well as anthropogenic and natural background sources. TMDLs must also account for seasonal variations in water quality, and include a margin of safety (MOS) to account for uncertainty in predicting how well pollutant reductions will result in meeting water quality standards.

The TMDL calculation is:

$$\text{TMDL} = \Sigma\text{WLA} + \Sigma\text{LA} + \text{MOS} \quad \text{Equation 1-1}$$

Where:

ΣWLA = the sum of waste load allocations (point sources),

ΣLA = the sum of load allocations (nonpoint sources and background)

MOS = the margin of safety.

Although states are primarily responsible for developing TMDLs, EPA is required to review and approve or disapprove TMDLs. EPA has developed a basic "TMDL Review Checklist" with the minimum recommended elements that should be present in a TMDL document.

Once EPA approves a TMDL, there are varying degrees of impact to communities involved in the process, generally differentiated among whether point sources or non-point sources of pollution are identified in the TMDL. Permitted stormwater discharges are considered point sources. Essentially, this means that wastewater or stormwater permit requirements consistent with waste load allocations must be implemented and are enforceable under the Clean Water Act through NPDES permits.

If the MS4 permittee discharges into a waterbody with an approved TMDL that includes a pollutant-specific waste load allocation under the TMDL, then the CWQCD can amend the permit to include specific requirements related to that TMDL. For example, the permit may be amended to require specific BMPs, and compliance schedules to implement the BMPs may be required. Numeric effluent limits may also be incorporated under these provisions. TMDLs can have substantive effects on MS4 permit requirements. As an example, the City and County of Denver's MS4 permit has additional requirements to control *E. coli* related to the *E. coli* TMDL approved for the South Platte River (Segment 14). Information on 303(d) listings and priorities for TMDL development can be obtained from the EPA and CWQCC websites (http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm and www.colorado.gov/pacific/cdphe/impaired-waters).

EPA's Recommended TMDL Checklist
(http://www.epa.gov/owow/tmdl/overviewoftmdl.html)

- Identification of Waterbody, Pollutant of Concern, Pollutant Sources, and Priority Ranking
- Applicable Water Quality Standard & Numeric Water Quality Target[1]
- Loading Capacity[1]
- Load Allocations and Waste Load Allocations[1]
- Margin of Safety[1]
- Consideration of Seasonal Variation[1]
- Reasonable Assurance for Point Sources/Non-point Sources
- Monitoring Plan to Track TMDL Effectiveness
- Implementation Plan
- Public Participation

[1] Legally required components under 40 C.F.R. Part 130

4.0 Four Step Process to Minimize Adverse Impacts of Urbanization

UDFCD has long recommended a Four Step Process for receiving water protection that focuses on reducing runoff volumes, treating the water quality capture volume (WQCV), stabilizing streams, and implementing long-term source controls. The Four Step Process pertains to management of smaller, frequently occurring events, as opposed to larger storms for which drainage and flood control infrastructure are sized. Implementation of these four steps helps to achieve stormwater permit requirements described in Section 3. Added benefits of implementing the complete process can include improved site aesthetics through functional landscaping features that also provide water quality benefits. Additionally, runoff reduction can decrease required storage volumes, thus increasing developable land. An overview of the Four Step Process follows, with Chapters 2 and 3 providing BMP selection tools and quantitative procedures for completing these steps.

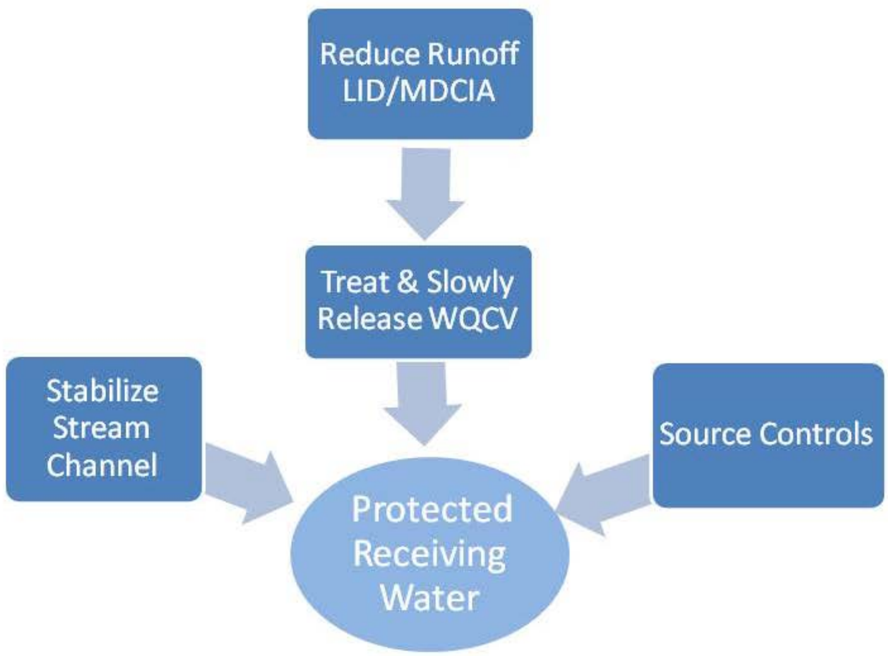

Figure 1-2. The four step process for stormwater quality management

4.1 Step 1. Employ Runoff Reduction Practices

To reduce runoff peaks, volumes, and pollutant loads from urbanizing areas, implement LID strategies, including MDCIA. For every site, look for opportunities to route runoff through vegetated areas, where possible by sheet flow. LID practices reduce unnecessary impervious areas and route runoff from impervious surfaces over permeable areas to slow runoff (increase time of concentration) and promote infiltration. When LID/MDCIA techniques are implemented throughout a development, the effective imperviousness is reduced, thereby potentially reducing sizing requirements for downstream facilities.

Differences between LID and Conventional Stormwater Quality Management

Low Impact Development (LID) is a comprehensive land planning and engineering design approach to managing stormwater runoff with a goal of replicating the pre-development hydrologic regime of urban and developing watersheds. Given the increased regulatory emphasis on LID, volume reduction and mimicking pre-development hydrology, questions may arise related to the differences between conventional stormwater management and LID. For example, Volume 3 has always emphasized MDCIA as the first step in stormwater quality planning and has provided guidance on LID techniques such as grass swales, grass buffers, permeable pavement systems, bioretention, and pollution prevention (pollutant source controls). Although these practices are all key components of LID, LID is not limited to a set of practices targeted at promoting infiltration. Key components of LID, in addition to individual BMPs, include practices such as:

- An overall site planning approach that promotes conservation design at both the watershed and site levels. This approach to development seeks to "fit" a proposed development to the site, integrating the development with natural features and protecting the site's natural resources. This includes practices such as preservation of natural areas including open space, wetlands, soils with high infiltration potential, and stream buffers. Minimizing unnecessary site disturbances (e.g., grading, compaction) is also emphasized.
- A site design philosophy that emphasizes multiple controls distributed throughout a development, as opposed to a central treatment facility.
- The use of swales and open vegetated conveyances, as opposed to curb and gutter systems.
- Volume reduction as a key hydrologic objective, as opposed to peak flow reduction being the primary hydrologic objective. Volume reduction is emphasized not only to reduce pollutant loading and peak flows, but also to move toward hydrologic regimes with flow durations and frequencies closer to the natural hydrologic regime.

Even with LID practices in place, most sites will also require centralized flood control facilities. In some cases, site constraints may limit the extent to which LID techniques can be implemented, whereas in other cases, developers and engineers may have significant opportunities to integrate LID techniques that may be overlooked due to the routine nature and familiarity of conventional approaches. This manual provides design criteria and guidance for both LID and conventional stormwater quality management, and provides additional facility sizing credits for implementing Step 1, Volume Reduction, in a more robust manner.

Key LID techniques include:

- **Conserve Existing Amenities**: During the planning phase of development, identify portions of the site that add value and should be protected or improved. Such areas may include mature trees, stream corridors, wetlands, and Type A/B soils with higher infiltration rates. In order for this step to provide meaningful benefits over the long-term, natural areas must be protected from compaction during the construction phase. Consider temporary construction fence for this purpose. In areas where disturbance cannot practically be avoided, rototilling and soil amendments should be integrated to restore the infiltration capacity of areas that will be restored with vegetation.
- **Minimize Impacts**: Consider how the site lends itself to the desired development. In some cases, creative site layout can reduce the extent of paved areas, thereby saving on initial capital cost of pavement and then saving on pavement maintenance, repair, and replacement over time. Minimize

Photograph 1-1. **Permeable Pavement**. Permeable pavement consists of a permeable pavement layer underlain by gravel and sand layers in most cases. Uses include parking lots and low traffic areas, to accommodate vehicles while facilitating stormwater infiltration near its source. Photo coustesey of Bill Wenk.

imperviousness, including constructing streets, driveways, sidewalks and parking lot aisles to the minimum widths necessary, while still providing for parking, snow management, public safety and fire access. When soils vary over the site, concentrate new impervious areas over Type C and D soils, while preserving Type A and B soils for landscape areas and other permeable surfaces. Maintaining natural drainage patterns, implementing sheet flow (as opposed to concentrated flow), and increasing the number and lengths of flow paths will all reduce the impact of the development.

Permeable pavement techniques and green roofs are common LID practices that may reduce the effects of paved areas and roofs:

- **Permeable Pavement**: The use of various permeable pavement techniques as alternatives to paved areas can significantly reduce site imperviousness.

- **Green Roofs**: Green roofs can be used to decrease imperviousness associated with buildings and structures. Benefits of green roofs vary based on design of the roof. Research is underway to assess the effectiveness of green roofs in Colorado's semi-arid climate.

Photograph 1-2. Grass Buffer. This roadway provides sheet flow to a grass buffer. The grass buffer provides filtration, infiltration, and settling to reduce runoff pollutants.

- **Minimize Directly Connected Impervious Areas (MDCIA)**: Impervious areas should drain to pervious areas. Use non-hardened drainage conveyances where appropriate. Route downspouts across pervious areas, and incorporate vegetation in areas that generate and convey runoff. Three key BMPs include:

  - **Grass Buffers**: Sheet flow over a grass buffer slows runoff and encourages infiltration, reducing effects of the impervious area.

  - **Grass Swales**: Like grass buffers, use of grass swales instead of storm sewers slows runoff and promotes infiltration, also reducing the effects of imperviousness.

  - **Bioretention (rain gardens)**: The use of distributed on-site vegetated features such as rain gardens can help maintain natural drainage patterns by allowing more infiltration onsite. Bioretention can also treat the WQCV, as described in the Four Step Process.

Photograph 1-3. Grass Swale. This densely vegetated grass swale is designed with channel geometry that forces the flow to be slow and shallow, facilitating sedimentation while limiting erosion.

Historically, this critical volume reduction step has often been overlooked by planners and engineers, instead going straight to WQCV requirements, despite WQCV reductions allowed based on MDCIA. Chapter 3 extends reductions to larger events and provides a broader range of reductions to WQCV sizing requirements than were previously recommended by UDFCD, depending on the extent to which Step 1 has been implemented. Developers should anticipate more stringent requirements from local governments to implement runoff reduction/MDCIA/LID measures (in addition to WQCV capture), given changes in state and federal stormwater regulations. In addition to benefiting the environment through reduced hydrologic and water quality impacts, volume reduction measures can also have the added economic benefit to the developer of increasing the area of developable land by reducing required detention volumes and potentially reducing both capital and maintenance costs.

Practical Tips for Volume Reduction and Better Integration of Water Quality Facilities
(Adapted from: Denver Water Quality Management Plan, WWE et al. 2004)

- **Consider stormwater quality needs early in the development process.** When left to the end of the site development process, stormwater quality facilities will often be shoe-horned into the site, resulting in few options. When included in the initial planning for a project, opportunities to integrate stormwater quality facilities into a site can be fully realized. Dealing with stormwater quality after major site plan decisions have been made is too late and often makes implementation of LID designs impractical.

- **Take advantage of the entire site when planning for stormwater quality treatment.** Stormwater quality and flood detention is often dealt with only at the low corner of the site, and ignored on the remainder of the site. The focus is on draining runoff quickly through inlets and storm sewers to the detention facility. In this "end-of-pipe" approach, all the runoff volume is concentrated at one point and designers often find it difficult to fit the required detention into the space provided. This can lead to use of underground BMPs that can be difficult to maintain or deep, walled-in basins that detract from a site and are also difficult to maintain. Treating runoff over a larger portion of the site reduces the need for big corner basins and allows implementation of LID principles.

- **Place stormwater in contact with the landscape and soil**. Avoid routing storm runoff from pavement to inlets to storm sewers to offsite pipes or concrete channels. The recommended approach places runoff in contact with landscape areas to slow down the stormwater and promote infiltration. Permeable pavement areas also serve to reduce runoff and encourage infiltration.

- **Minimize unnecessary imperviousness, while maintaining functionality and safety.** Smaller street sections or permeable pavement in fire access lanes, parking lanes, overflow parking, and driveways will reduce the total site imperviousness.

- **Select treatment areas that promote greater infiltration.** Bioretention, permeable pavements, and sand filters promote greater volume reduction than extended detention basins, since runoff tends to be absorbed into the filter media or infiltrate into underlying soils. As such, they are more efficient at reducing runoff volume and can be sized for smaller treatment volumes than extended detention basins.

4.2 Step 2. Implement BMPs That Provide a Water Quality Capture Volume with Slow Release

After runoff has been minimized, the remaining runoff should be treated through capture and slow release of the WQCV. WQCV facilities may provide both water quality and volume reduction benefits, depending on the BMP selected. This manual provides design guidance for BMPs providing treatment of the WQCV, including permeable pavement systems with subsurface storage, bioretention, extended detention basins, sand filters, constructed wetland ponds, and retention ponds. Green roofs and some underground BMPs may also provide the WQCV, depending on the design characteristics. Chapter 3 provides background information on the development of the WQCV for the Denver metropolitan area as well as a step-by-step procedure to calculate the WQCV.

4.3 Step 3. Stabilize Streams

During and following development, natural streams are often subject to bed and bank erosion due to increases in frequency, duration, rate, and volume of runoff. Although Steps 1 and 2 help to minimize these effects, some degree of stream stabilization is required. Many streams within UDFCD boundaries are included in major drainageway or outfall systems plans, identifying needed channel stabilization measures. These measures not only protect infrastructure such as utilities, roads and trails, but are also important to control sediment loading from erosion of the channel itself, which can be a significant source of sediment and associated constituents, such as phosphorus, metals and other naturally occurring constituents. If stream stabilization is implemented early in the development process, it is far more likely that natural stream characteristics can be maintained with the addition of grade control to accommodate future development. Targeted fortification of a relatively stable stream is typically much less costly than repairing an unraveled channel. The *Open Channels* chapter in Volume 1 of this manual provides guidance on stream stabilization.

4.4 Step 4. Implement Site Specific and Other Source Control BMPs

Site specific needs such as material storage or other site operations require consideration of targeted source control BMPs. This is often the case for new development or significant redevelopment of an industrial or commercial site. Chapter 5 includes information on source control practices such as covering storage/handling areas and spill containment and control.

5.0 Onsite, Subregional and Regional Stormwater Management

Stormwater quality BMPs should be implemented as close to the source as practicable. This results in smaller BMPs (in parallel or in series) that are distributed throughout a site rather than the "end of pipe" alternative. Whereas flood control is best handled on a regional basis, stormwater quality is best managed when stormwater is viewed as a resource and distributed throughout the site. When the watershed of a BMP is so big that a base flow is present, this both limits the type of BMP appropriate for use and complicates the design. The treatment provided by a regional BMP will also vary when base flows differ from that assumed during design.

Whereas flood control is best handled on a regional basis, stormwater quality is best managed as a resource and distributed throughout the site.

Although not preferred, WQCV facilities may be implemented regionally (serving a major drainageway with a drainage area between 130 acres and one square mile) or subregionally (serving two or more development parcels with a total drainage area less than 130 acres). Drainage master plans should be consulted to determine if regional or subregional facilities are already planned or in place for new developments or redevelopments. Life-cycle costs of onsite, subregional, and regional facilities, including long-term maintenance responsibilities, should be part of the decision-making process when selecting the combinations of facilities and channel improvements needed to serve a development or redevelopment. Potential benefits of regional/subregional facilities include consolidated maintenance efforts, economies of scale for larger facilities as opposed to multiple onsite WQCV facilities, simplified long-term adequate assurances for operation and maintenance for public facilities, and potential integration with flood control facilities. Additionally, regional storage-based facilities may be beneficial in areas where onsite BMPs are not feasible due to geotechnical or land use constraints or when retrofitting an existing flood control facility in a fully developed watershed.

One of the most common challenges regarding regional facilities relates to the timing of funding for construction of the facilities. Often, regional facilities are funded by revenues collected from new development activities. New developments (and revenues) are required to fund construction of the water quality facility, but the water quality facility is needed upfront to provide protection for new development. This timing problem can be solved by constructing onsite water quality facilities for new development that occur before a regional facility is in place. These onsite BMPs are temporary in that they can be converted to developable land once the regional facility is constructed. Another option is to build a smaller interim regional facility that can be expanded with future development.

When regional water quality facilities are selected, BMPs are still required onsite to address water quality and channel stability for the reach of the drainageway upstream of the regional facility. In accordance with MS4 permits and regulations, BMPs must be implemented prior to discharges to a State Water from areas of "New Development and Significant Redevelopment." Therefore, if a regional BMP is utilized downstream of a discharge from a development into a State Water, additional BMPs are required to protect the State Water between the development site and the regional facility. However, these BMPs may not have to be as extensive as would normally be required, as long as they are adequate to protect the State Water upstream of the regional BMP. Although the CWQCD does not require onsite WQCV per se, MS4 permits contain conditions that require BMPs be implemented to the Maximum Extent Practicable to prevent "pollution of the receiving waters in excess of the pollution permitted by an applicable water quality standard or applicable antidegradation requirement." Additional requirements may also apply in the case of streams with TMDLs. As a result, MS4 permit holders must have a program in place that requires developers to provide adequate onsite measures so that the MS4 permit holder remains in compliance with their permit and meets the conditions of current regulations.

State Waters

State Waters are any and all surface and subsurface waters which are contained in or flow in or through this State, but does not include waters in sewage systems, waters in treatment works of disposal systems, waters in potable water distribution systems, and all water withdrawn for use until use and treatment have been completed (from Regulation 61, Colorado Discharge Permit System Regulations).

When a regional or subregional facility is selected to treat the WQCV for a development, the remaining three steps in the Four Step Process should still be implemented. For example, minimizing runoff volumes on the developed property by disconnecting impervious area and infiltrating runoff onsite (Step 1) can potentially reduce regional WQCV requirements, conveyance system costs, and costs of the regional/subregional facility. Stream stabilization requirements (Step 3) must still be evaluated and implemented, particularly if identified in a master drainage plan. Finally, specific source controls (Step 4 BMPs) such as materials coverage should be implemented onsite, even if a regional/subregional facility is provided downstream. Although UDFCD does not specify minimum onsite treatment requirements when regional/subregional facilities are used, some local governments (e.g., Arapahoe County) have specific requirements related to the minimum measures that must be implemented to minimize directly connected impervious area.

Chapter 2 provides a BMP selection tool to help planners and engineers determine whether onsite, subregional or regional strategies are best suited to the given watershed conditions.

6.0 Conclusion

Urban stormwater runoff can have a variety of chemical, biological, and physical effects on receiving waters. As a result, local governments must comply with federal, state and local requirements to minimize adverse impacts both during and following construction. UDFCD criteria are based on a Four Step Process focused on reducing runoff volumes, treating the remaining WQCV, stabilizing receiving drainageways and providing targeted source controls for post-construction operations at a site. Stormwater management requirements and objectives should be considered early in the site development process, taking into account a variety of factors, including the effectiveness of the BMP, long-term maintenance requirements, cost and a variety of site-specific conditions. The remainder of this manual provides guidance for selecting, designing, constructing and maintaining stormwater BMPs.

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Chapter 2
BMP Selection

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1.0 BMP Selection

This chapter provides guidance on factors that should be considered when selecting BMPs for new development or redevelopment projects. This guidance is particularly useful in the planning phase of a project. BMP selection involves many factors such as physical site characteristics, treatment objectives, aesthetics, safety, maintenance requirements, and cost. Typically, there is not a single answer to the question of which BMP (or BMPs) should be selected for a site; there are usually multiple solutions ranging from stand alone BMPs to treatment trains that combine multiple BMPs to achieve the water quality objectives. Factors that should be considered when selecting BMPs are the focus of this chapter.

1.1 Physical Site Characteristics

The first step in BMP selection is identification of physical characteristics of a site including topography, soils, contributing drainage area, groundwater, baseflows, wetlands, existing drainageways, and development conditions in the tributary watershed (e.g., construction activity). A fundamental concept of Low Impact Development (LID) is preservation and protection of site features including wetlands, drainageways, soils that are conducive to infiltration, tree canopy, etc., that provide water quality and other benefits. LID stormwater treatment systems are also designed to take advantage of these natural resources. For example, if a portion of a site is known to have soils with high permeability, this area may be well-suited for rain gardens or permeable pavement. Areas of existing wetlands, which would be difficult to develop from a Section 404 permitting perspective, could be considered for polishing of runoff following BMP treatment, providing additional water quality treatment for the site, while at the same time enhancing the existing wetlands with additional water supply in the form of treated runoff.

Some physical site characteristics that provide opportunities for BMPs or constrain BMP selection include:

- **Soils:** Soils with good permeability, most typically associated with Hydrologic Soil Groups (HSGs) A and B provide opportunities for infiltration of runoff and are well-suited for infiltration-based BMPs such as rain gardens, permeable pavement systems, sand filter, grass swales, and buffers, often without the need for an underdrain system. Even when soil permeability is low, these types of BMPs may be feasible if soils are amended to increase permeability or if an underdrain system is used. In some cases, however, soils restrict the use of infiltration based BMPs. When soils with moderate to high swell potential are present, infiltration should be avoided to minimize damage to adjacent structures due to water-induced swelling. In some cases, infiltration based designs can still be used if an impermeable liner and underdrain system are included in the design; however, when the risk of damage to adjacent infrastructure is high, infiltration based BMPs may not be appropriate. In all cases, consult with a geotechnical engineer when designing infiltration BMPs near structures. Consultation with a geotechnical engineer is necessary for evaluating the suitability of soils for different BMP types and establishing minimum distances between infiltration BMPs and structures.

- **Watershed Size**: The contributing drainage area is an important consideration both on the site level and at the regional level. On the site level, there is a practical minimum size for certain BMPs, largely related to the ability to drain the WQCV over the required drain time. For example, it is technically possible to size the WQCV for an extended detention basin for a half-acre site; however, designing a functional outlet to release the WQCV over a 40-hour drain time is practically impossible due to the very small orifices that would be required. For this size watershed, a filtering BMP, such as a rain garden, would be more appropriate. At the other end of the spectrum, there must be a limit on the maximum drainage area for a regional facility to assure adequate treatment of rainfall events that may produce runoff from only a portion of the area draining to the BMP. If the overall drainage area is too large, events that produce runoff from only a portion of the contributing area will pass through the BMP outlet (sized for the full drainage area) without adequate residence time in the BMP. As a practical limit, the maximum drainage area contributing to a water quality facility should be no larger than one square mile.

- **Groundwater**: Shallow groundwater on a site presents challenges for BMPs that rely on infiltration and for BMPs that are intended to be dry between storm events. Shallow groundwater may limit the ability to infiltrate runoff or result in unwanted groundwater storage in areas intended for storage of the WQCV (e.g., porous sub-base of a permeable pavement system or in the bottom of an otherwise dry facility such as an extended detention basin). Conversely, for some types of BMPs such as wetland channels or constructed wetland basins, groundwater can be beneficial by providing saturation of the root zone and/or a source of baseflow. Groundwater quality protection is an issue that should be considered for infiltration-based BMPs. Infiltration BMPs may not be appropriate for land uses that involve storage or use of materials that have the potential to contaminate groundwater underlying a site (i.e., "hot spot" runoff from fueling stations, materials storage areas, etc.). If groundwater or soil contamination exists on a site and it will not be remediated or removed as a part of construction, it may be necessary to avoid infiltration-based BMPs or use a durable liner to prevent infiltration into contaminated areas.

- **Base Flows**: Base flows are necessary for the success of some BMPs such as constructed wetland ponds, retention ponds and wetland channels. Without baseflows, these BMPs will become dry and unable to support wetland vegetation. For these BMPs, a hydrologic budget should be evaluated. Water rights are also required for these types of BMPs in Colorado.

- **Watershed Development Activities (or otherwise erosive conditions)**: When development in the watershed is phased or when erosive conditions such as steep slopes, sparse vegetation, and sandy soils exist in the watershed, a treatment train approach may be appropriate. BMPs that utilize filtration should follow other measures to collect sediment loads (e.g., a forebay). For phased developments, these measures must be in place until the watershed is completely stabilized. When naturally erosive conditions exist in the watershed, these measures should be permanent. The designer should consider existing, interim and future conditions to select the most appropriate BMPs.

1.2 Space Constraints

Space constraints are frequently cited as feasibility issues for BMPs, especially for high-density, lot-line-to-lot-line development and redevelopment sites. In some cases, constraints due to space limitations arise because adequate spaces for BMPs are not considered early enough in the planning process. This is most common when a site plan for roads, structures, etc., is developed and BMPs are squeezed into the remaining spaces. The most effective and integrated BMP designs begin by determining areas of a site that are best suited for BMPs (e.g., natural low areas, areas with well-drained soils) and then designing the layout of roads, buildings, and other site features around the existing drainage and water quality resources of the site. Allocating a small amount of land to water quality infrastructure during early planning stages will result in better integration of water quality facilities with other site features.

1.3 Targeted Pollutants and BMP Processes

BMPs have the ability to remove pollutants from runoff through a variety of physical, chemical and biological processes. The processes associated with a BMP dictate which pollutants the BMP will be effective at controlling. Primary processes include peak attenuation, sedimentation, filtration, straining, adsorption/absorption, biological uptake and hydrologic processes including infiltration and evapotranspiration. Table 2-1 lists processes that are associated with BMPs in this manual. For many sites, a primary goal of BMPs is to remove gross solids, suspended sediment and associated particulate fractions of pollutants from runoff. Processes including straining, sedimentation, and infiltration/filtration are effective for addressing these pollutants. When dissolved pollutants are targeted, other processes including adsorption/absorption and biological uptake are necessary. These processes are generally sensitive to media composition and contact time, oxidation/reduction potential, pH and other factors. In addition to pollutant removal capabilities, many BMPs offer channel stability benefits in the form of reduced runoff volume and/or reduced peak flow rates for frequently occurring events. Brief descriptions of several key processes, generally categorized according to hydrologic and pollutant removal functions are listed below:

Hydrologic Processes

1. **Flow Attenuation**: BMPs that capture and slowly release the WQCV help to reduce peak discharges. In addition to slowing runoff, volume reduction may also be provided to varying extents in BMPs providing the WQCV.

2. **Infiltration:** BMPs that infiltrate runoff reduce both runoff peaks and surface runoff volumes. The extent to which runoff volumes are reduced depends on a variety of factors such as whether the BMP is equipped with an underdrain and the characteristics and long-term condition of the infiltrating media. Examples of infiltrating BMPs include (unlined) sand filters, bioretention and permeable pavements. Water quality treatment processes associated with infiltration can include filtration and sorption.

3. **Evapotranspiration**: Runoff volumes can be reduced through the combined effects of evaporation and transpiration in vegetated BMPs. Plants extract water from soils in the root zone and transpire it to the atmosphere. Evapotranspiration is the hydrologic process provided by vegetated BMPs, whereas biological uptake may help to reduce pollutants in runoff.

Pollutant Removal/Treatment Processes

1. **Sedimentation:** Gravitational separation of particulates from urban runoff, or sedimentation, is a key treatment process by BMPs that capture and slowly release runoff. Settling velocities are a function of characteristics such as particle size, shape, density, fluid density, and viscosity. Smaller particles under 60 microns in size (fine silts and clays) (Stahre and Urbonas, 1990) can account for approximately 80% of the metals in stormwater attached or adsorbed along with other contaminants and can require long periods of time to settle out of suspension. Extended detention allows smaller particles to agglomerate into larger ones (Randall et al, 1982), and for some of the dissolved and liquid state pollutants to adsorb to suspended particles, thus removing a larger proportion of them through sedimentation. Sedimentation is the primary pollutant removal mechanism for many treatment BMPs including extended detention basins, retention ponds, and constructed wetland basins.

2. **Straining**: Straining is physical removal or retention of particulates from runoff as it passes through a BMP. For example, grass swales and grass buffers provide straining of sediment and coarse solids in runoff. Straining can be characterized as coarse filtration.

3. **Filtration**: Filtration removes particles as water flows through media (often sand or engineered soils). A wide variety of physical and chemical mechanisms may occur along with filtration, depending on the filter media. Metcalf and Eddy (2003) describe processes associated with filtration as including straining, sedimentation, impaction, interception, adhesion, flocculation, chemical adsorption, physical adsorption, and biological growth. Filtration is a primary treatment process

provided by infiltration BMPs. Particulates are removed at the ground surface and upper soil horizon by filtration, while soluble constituents can be absorbed into the soil, at least in part, as the runoff infiltrates into the ground. Site-specific soil characteristics, such as permeability, cation exchange potential, and depth to groundwater or bedrock are important characteristics to consider for filtration (and infiltration) BMPs. Examples of filtering BMPs include sand filters, bioretention, and permeable pavements with a sand filter layer.

4. **Adsorption/Absorption**: In the context of BMPs, sorption processes describe the interaction of waterborne constituents with surrounding materials (e.g., soil, water). Absorption is the incorporation of a substance in one state into another of a different state (e.g., liquids being absorbed by a solid). Adsorption is the physical adherence or bonding of ions and molecules onto the surface of another molecule. Many factors such as pH, temperature and ionic state affect the chemical equilibrium in BMPs and the extent to which these processes provide pollutant removal. Sorption processes often play primary roles in BMPs such as constructed wetland basins, retention ponds, and bioretention systems. Opportunities may exist to optimize performance of BMPs through the use of engineered media or chemical addition to enhance sorption processes.

5. **Biological Uptake:** Biological uptake and storage processes include the assimilation of organic and inorganic constituents by plants and microbes. Plants and microbes require soluble and dissolved constituents such as nutrients and minerals for growth. These constituents are ingested or taken up from the water column or growing medium (soil) and concentrated through bacterial action, phytoplankton growth, and other biochemical processes. In some instances, plants can be harvested to remove the constituents permanently. In addition, certain biological activities can reduce toxicity of some pollutants and/or possible adverse effects on higher aquatic species. Unfortunately, not much is understood yet about how biological uptake or activity interacts with stormwater during the relatively brief periods it is in contact with the biological media in most BMPs, with the possible exception of retention ponds between storm events (Hartigan, 1989). Bioretention, constructed wetlands, and retention ponds are all examples of BMPs that provide biological uptake.

When selecting BMPs, it is important to have realistic expectations of effluent pollutant concentrations. The International Stormwater BMP Database (www.bmpdatabase.org) provides BMP performance information that is updated periodically and summarized in Table 2-2. BMPs also provide varying degrees of volume reduction benefits. Both pollutant concentration reduction and volume reduction are key components in the whole life cycle cost tool *BMP-REALCOST.xls* (Roesner and Olson 2009) discussed later in this chapter.

It is critical to recognize that for BMPs to function effectively, meet performance expectations, and provide for public safety, BMPs must:

1. Be designed according to UDFCD criteria, taking into account site-specific conditions (e.g., high groundwater, expansive clays and long-term availability of water).

2. Be constructed as designed. This is important for all BMPs, but appears to be particularly critical for permeable pavements, rain gardens and infiltration-oriented facilities.

3. Be properly maintained to function as designed. Although all BMPs require maintenance, infiltration-oriented facilities are particularly susceptible to clogging without proper maintenance. Underground facilities can be vulnerable to maintenance neglect because maintenance needs are not evident from the surface without special tools and procedures for access. Maintenance is not only essential for proper functioning, but also for aesthetic and safety reasons. Inspection of facilities is an important step to identify and plan for needed maintenance.

Table 2-1. Primary, Secondary and Incidental Treatment Process Provided by BMPs

	Hydrologic Processes			**Treatment Processes**				
	Peak	Volume		Physical			Chemical	Biological
UDFCD BMP	Flow Attenuation	Infiltration	Evapo-transpiration	Sedimentation	Filtration	Straining	Adsorption/ Absorption	Biological Uptake
Grass Swale	I	S	I	S	S	P	S	S
Grass Buffer	I	S	I	S	S	P	S	S
Constructed Wetland Channel	I	N/A	P	P	S	P	S	P
Green Roof	P	S	P	N/A	P	N/A	I	P
Permeable Pavement Systems	P	P	N/A	S	P	N/A	N/A	N/A
Bioretention	P	P	S	P	P	S	S[1]	P
Extended Detention Basin	P	I	I	P	N/A	S	S	I
Sand Filter	P	P	I	P	P	N/A	S[1]	N/A
Constructed Wetland Pond	P	I	P	P	S	S	P	P
Retention Pond	P	I	P	P	N/A	N/A	P	S
Underground BMPs	Variable	N/A	N/A	Variable	Variable	Variable	Variable	N/A

Notes:

P = Primary; S = Secondary, I = Incidental; N/A = Not Applicable

[1] Depending on media

Table 2-2. BMP Effluent EMCs (Source: International Stormwater BMP Database, August

		Solids and Nutrients (milligrams/liter)								
BMP Category	Sample Type	Total Suspended Solids	Total Dissolved Solids	Nitrogen, Total	Total Kjeldahl Nitrogen (TKN)	Nitrogen, Ammonia as N	Nitrogen, Nitrate (NO3) as N*	Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N*	Phosphorus as P, Total	Phosphorus, Orthophosphate as P
Bioretention (w/Underdrain)	Inflow	44.6 (41.8-53.3, n= 6)	NC	1.46 (1.24-1.63, n= 7)	1.22 (1.00-1.33, n= 8)	0.19 (0.16-0.23, n= 8)	NC	0.30 (0.25-0.38, n= 10)	0.13 (0.12-0.17, n= 12)	0.04 (0.01-0.10, n= 7)
	Outflow	12.9 (6.8-17.3, n= 6)	NC	1.15 (0.92-2.98, n= 7)	0.94 (0.60-2.09, n= 8)	0.06 (0.05-0.38, n= 8)	NC	0.21 (0.14-0.29, n= 10)	0.13 (0.08-0.19, n= 12)	0.06 (0.03-0.33, n= 7)
Grass Buffer	Inflow	52.3 (50.0-63.3, n= 14)	57.5 (32.0-89.3, n= 12)	NC	1.40 (1.15-2.10, n= 13)	0.38 (0.23-0.64, n= 10)	0.44 (0.42-0.92, n= 13)	NC	0.18 (0.09-0.25, n= 14)	0.04 (0.03-0.06, n= 10)
	Outflow	22.3 (15.0-28.3, n= 14)	88.0 (73.3-110.0, n= 12)	NC	1.20 (0.95-1.50, n= 13)	0.25 (0.13-0.36, n= 9)	0.33 (0.23-0.78, n= 13)	NC	0.30 (0.11-0.56, n= 14)	0.10 (0.05-0.29, n= 10)
Grass Swale	Inflow	54.5 (30.5-76.5, n= 15)	79.5 (64.2-100.1, n= 12)	NC	1.83 (1.40-2.11, n= 12)	0.06 (0.02-0.09, n= 4)	0.41 (0.23-0.78, n= 12)	0.25 (0.19-0.37, n= 4)	0.22 (0.13-0.29, n= 15)	0.04 (0.03-0.04, n= 3)
	Outflow	18.0 (8.9-39.5, n= 19)	71.0 (34.9-85.0, n= 10)	0.60 (0.55-1.34, n= 6)	1.23 (0.41-1.48, n= 16)	0.05 (0.03-0.06, n= 8)	0.29 (0.21-0.66, n= 15)	0.22 (0.18-0.31, n= 8)	0.23 (0.19-0.31, n= 19)	0.10 (0.08-0.12, n= 7)
Detention Basin (aboveground extended det.)	Inflow	59.5 (17.8-83.8, n= 18)	88.5 (85.0-98.8, n= 6)	1.05 (1.04-1.25, n= 3)	1.32 (0.77-1.70, n= 10)	0.08 (0.04-0.10, n= 5)	0.45 (0.30-0.90, n= 8)	0.23 (0.17-0.50, n= 5)	0.20 (0.18-0.30, n= 17)	NC
	Outflow	22.0 (11.6-28.5, n= 20)	85.0 (54.3-113.5, n= 6)	2.54 (1.7-2.69, n= 3)	1.66 (0.86-1.95, n= 10)	0.09 (0.07-0.10, n= 5)	0.40 (0.27-0.85, n= 8)	0.17 (0.08-0.43, n= 6)	0.20 (0.13-0.26, n= 18)	NC
Media Filters (various types)	Inflow	44.0 (32.0-75.0, n= 21)	42.0 (28.4-59.0, n= 13)	1.51 (0.73-1.80, n= 5)	1.53 (0.87-2.00, n= 17)	0.34 (0.08-1.12, n= 11)	0.38 (0.23-0.57, n= 16)	0.33 (0.23-0.51, n= 6)	0.20 (0.13-0.33, n= 21)	0.02 (0.02-0.06, n= 7)
	Outflow	8.0 (5.0-17.0, n= 21)	55.0 (46.0-62.0, n= 13)	0.63 (0.43-1.41, n= 4)	0.80 (0.50-1.22, n= 17)	0.11 (0.04-0.15, n= 10)	0.66 (0.39-0.73, n= 16)	0.43 (0.05-1.00, n= 5)	0.11 (0.06-0.15, n= 21)	0.02 (0.02-0.06, n= 7)
Retention Pond (aboveground wet pond)	Inflow	44.5 (24.0-88.3, n= 40)	89.0 (59.3-127.5, n= 9)	1.71 (1.07-2.36, n= 19)	1.18 (0.77-1.42, n= 28)	0.09 (0.04-0.15, n= 23)	0.43 (0.32-0.69, n= 15)	0.27 (0.11-0.55, n= 24)	0.23 (0.14-0.39, n= 38)	0.09 (0.07-0.21, n= 26)
	Outflow	12.1 (7.9-19.7, n= 40)	151.3 (70.8-182.0, n= 9)	1.31 (1.01-1.54, n= 19)	0.99 (0.76-1.29, n= 30)	0.07 (0.04-0.17, n= 24)	0.19 (0.13-0.26, n= 15)	0.05 (0.02-0.20, n= 24)	0.11 (0.07-0.19, n= 40)	0.05 (0.02-0.08, n= 27)
Wetland Basin	Inflow	39.6 (24.0-56.8, n= 14)	NA	1.54 (1.07-2.16, n= 6)	1.10 (0.77-1.30, n= 4)	0.10 (0.04-0.13, n= 8)	0.32 (0.32-0.44, n= 5)	0.46 (0.11-0.63, n= 7)	0.12 (0.14-0.27, n= 11)	0.04 (0.07-0.13, n= 5)
	Outflow	12.0 (8.5-17.5, n= 16)	NC	1.16 (0.98-1.39, n= 6)	1.00 (0.90-1.14, n= 8)	0.06 (0.04-0.10, n= 8)	0.12 (0.10-0.16, n= 7)	0.17 (0.05-0.34, n= 7)	0.08 (0.05-0.14, n= 13)	0.06 (0.02-0.25, n= 7)
Permeable Pavement**	Inflow	23.5 (16.0-45.3, n = 5)	NA	NC	2.40 (1.80-3.30, n = 3)	NC	NC	0.59 (0.27-0.80, n = 5)	0.12 (0.10-0.13, n = 5)	NC
	Outflow	29.1 (16.3-34.0, n = 7)	NA	NC	1.05 (0.90-1.33, n = 7)	NC	NC	1.24 (1.21-1.39, n = 4)	0.13 (0.10-0.19, n = 5)	NC

*Some BMP studies include analyses for both NO2/NO3 and NO3; therefore, these analytes are reported separately, even though results are expected to be comparable in stormwater runoff.

Table Notes provided below part 2 of this table.

BMP Category	Sample Type	Metals (micrograms/liter) Arsenic, Diss.	Arsenic, Total	Cadmium, Diss.	Cadmium, Total	Chromium, Diss.	Chromium, Total	Copper, Diss.	Copper, Total	Lead, Diss.	Lead, Total	Nickel, Diss.	Nickel, Total	Zinc, Diss.	Zinc, Total
Bioretention (w/Underdrain)	Inflow	NA	NC	NC	NC	NC	NC	NC	19.5 (15.3-35.8, n= 3)	NC	NC	NC	NC	NC	68.0 (51-68.5, n= 5)
	Outflow	NA	NC	NC	NC	NC	NC	NC	10.0 (7.3-16.8, n= 3)	NC	NC	NC	NC	NC	8.5 (5.0-35.0, n= 5)
Grass Buffer	Inflow	0.8 (0.5-1.2, n= 12)	1.1 (0.9-2.3, n= 12)	0.2 (0.1-0.2, n= 12)	0.4 (0.3-0.8, n= 12)	2.4 (1.1-4.5, n= 12)	4.9 (2.9-7.4, n= 13)	12.9 (6.8-17.3, n= 12)	21.2 (15.0-41.0, n= 13)	0.9 (0.5-2.0, n= 12)	11.0 (6-35, n= 13)	2.9 (1.1-3.2, n= 12)	4.8 (3.4-8.4, n= 12)	37.8 (12.8-70, n= 12)	100.5 (53.0-245.0, n= 13)
	Outflow	1.2 (0.5-2.4, n= 12)	2.0 (0.7-3.0, n= 12)	0.1 (0.1-0.2, n= 12)	0.2 (0.1-0.2, n= 12)	2.3 (1.0-3.8, n= 12)	2.9 (2.0-5.5, n= 13)	7.1 (4.8-11.6, n= 12)	8.3 (6.4-12.5, n= 13)	0.5 (0.5-1.3, n= 12)	3.2 (1.8-6.0, n= 13)	2.1 (2.0-2.3, n= 12)	2.6 (2.2-3.2, n= 12)	19.8 (10.7-24.3, n= 12)	25.5 (15.0-57.9, n= 13)
Grass Swale	Inflow	0.6 (0.5-2.2, n= 9)	1.7 (1.6-2.7, n= 9)	0.3 (0.1-0.4, n= 13)	0.5 (0.4-0.9, n= 14)	2.2 (1.1-3.3, n= 7)	6.1 (3.6-8.3, n= 7)	10.6 (8.1-15.0, n= 13)	33.0 (26-34, n= 13)	1.4 (0.6-6.7, n= 13)	21.6 (12.5-46.4, n= 14)	5.1 (4.5-6.6, n= 6)	8.7 (7-12.5, n= 6)	40.3 (35.3-109.0, n= 13)	149.5 (43.8-244.3, n= 15)
	Outflow	0.6 (0.6-1.2, n= 8)	1.2 (0.9-1.7, n= 8)	0.2 (0.1-0.2, n= 12)	0.3 (0.2-0.4, n= 13)	1.1 (1.0-3.0, n= 6)	3.5 (1.7-5.0, n= 6)	8.6 (5.5-9.7, n= 13)	14.0 (6.7-18.5, n= 17)	1.0 (0.5-4.1, n= 13)	10.5 (1.7-12.0, n= 18)	2.0 (2.0-2.3, n= 5)	4.0 (3.1-4.5, n= 5)	22.6 (20.1-33.2, n= 13)	55.0 (20.6-65.4, n= 19)
Detention Basin (aboveground extended det.)	Inflow	1.1 (0.9-1.2, n= 5)	2.1 (1.3-2.6, n= 6)	0.3 (0.2-0.4, n= 8)	0.6 (0.3-1.2, n= 11)	2.6 (2.0-3.2, n= 3)	5.6 (5.0-6.5, n= 6)	5.8 (2.6-11.8, n= 8)	10.0 (4.8-33.5, n= 11)	1.0 (0.5-1.4, n= 8)	10.0 (1.5-41.0, n= 11)	2.9 (1.9-3.9, n= 4)	6.3 (5-9.4, n= 5)	16.4 (6.1-53.5, n= 8)	125.0 (21.5-225.3, n= 11)
	Outflow	1.2 (0.9-1.2, n= 5)	1.7 (1.1-1.9, n= 6)	0.3 (0.2-0.4, n= 9)	0.4 (0.2-0.6, n= 12)	1.9 (1.7-3.0, n= 4)	2.9 (1.9-3.8, n= 6)	9.0 (3.0-13.0, n= 9)	11.0 (6.2-20.1, n= 12)	1.0 (0.5-1.3, n= 9)	9.5 (1.3-18.6, n= 12)	3.1 (2.0-3.2, n= 5)	4.3 (3.2-5.4, n= 6)	19.0 (7.8-54.0, n= 9)	48.5 (19.1-94.0, n= 13)
Media Filters (various types)	Inflow	0.7 (0.5-1.1, n= 12)	1.1 (0.6-1.6, n= 12)	0.2 (0.2-0.2, n= 14)	0.4 (0.2-1.0, n= 17)	1.0 (1.0-1.0, n= 13)	2.1 (1.4-4.0, n= 13)	6.2 (5.4-7.4, n= 13)	13.5 (8.8-16.4, n= 18)	1.1 (1.0-2.0, n= 14)	9.0 (5.3-22.0, n= 17)	2.0 (2.0-2.7, n= 13)	3.9 (3.3-4.8, n= 13)	42.7 (28.5-79.2, n= 14)	86.0 (51.8-106.0, n= 19)
	Outflow	0.7 (0.6-1.1, n= 12)	1.1 (0.7-1.6, n= 12)	0.2 (0.2-0.2, n= 13)	0.2 (0.1-0.7, n= 17)	1.0 (1.0-1.0, n= 13)	1.0 (1.0-1.9, n= 13)	5.8 (3.1-8.3, n= 13)	7.3 (4.3-9.6, n= 18)	1.0 (1.0-1.0, n= 13)	1.6 (1.0-4.4, n= 17)	2.0 (2.0-2.6, n= 13)	2.9 (2.0-3.9, n= 13)	12.5 (6.7-49.0, n= 13)	20.0 (8.6-35.0, n= 19)
Retention Pond (aboveground wet pond)	Inflow	NC	1.0 (1.0-1.4, n= 3)	0.2 (0.2-0.4, n= 3)	1.0 (0.3-2.6, n= 20)	5.9 (1.6-10.0, n= 4)	5.0 (3.0-7.4, n= 12)	7.0 (6.0-9.5, n= 7)	6.3 (4.3-10.6, n= 26)	2.0 (1.0-5.1.0, n= 11)	9.7 (4-28, n= 33)	10.0 (6.2-10.0, n= 3)	6.5 (3.6-9, n= 8)	30.0 (15.5-42.6, n= 8)	51.8 (43.9-78.1, n= 32)
	Outflow	NC	1.0 (0.8-1.0, n= 3)	0.2 (0.2-0.4, n= 3)	0.4 (0.2-2.5, n= 20)	5.5 (1.0-10.0, n= 4)	2.2 (1.4-5.3, n= 12)	5.0 (4.7-5.8, n= 7)	5.4 (3.0-6.2, n= 26)	1.2 (1.0-4.9, n= 12)	4.7 (1.6-10.0, n= 33)	10.0 (7.2-10.0, n= 3)	2.5 (2.0-5.5, n= 9)	12.5 (9.4-28.6, n= 8)	26.0 (12.0-37.0, n= 33)
Wetland Basin	Inflow	NA	NA	NC	0.3 (0.3-0.4, n= 3)	NA	NA	NC	10.5 (4.3-15.9, n= 4)	NC	16.0 (4.0-23.8, n= 4)	NA	NA	NC	51.0 (43.9-120.8, n= 7)
	Outflow	NA	NA	0.5 (0.3-0.5, n= 3)	0.3 (0.1-0.5, n= 5)	NA	NA	5.0 (5.0-5.7, n= 3)	4.5 (3.3-5.0, n= 6)	1.0 (0.8-1.0, n= 3)	1.0 (1.0-2.5, n= 6)	NA	NA	11.0 (11.0-13.1, n= 3)	15.0 (5.0-28.9, n= 9)
Permeable Pavement**	Inflow	NA	NC	NC	NA	NC	NC	5.0 (2.5-6.4, n =3)	7.0 (4.5-19.4, n = 3)	0.1 (0.03-0.3, n = 3)	2.5 (1.3-15.1, n = 3)	NC	NC	25.0 (19.0-27.5, n = 3)	50.0 (45.0-51.0, n = 5)
	Outflow	NA	NC	NC	0.3 (0.3-0.4, n =3)	NC	NC	6.2 (4.5-6.4, n =4)	9.0 (3.0-14.7, n = 5)	0.3 (0.04-0.5, n = 4)	2.5 (1.3-9.5, n = 7)	NC	NC	14.6 (13.5-16.0, n = 4)	22.0 (20.0-31.6, n = 7)

Table Key

Sample Type	Analyte	Description
Inflow	52.3	= Median inflow value
	(50-63.3, n= 14)	= Interquartile range, sample size
Outflow	22.3	= Median outflow value
	(15-28.3, n= 14)	= Interquartile range, sample size

NA = Not available; studies containing 3 or more storms not available.
NC = Not calculated because fewer than 3 BMP studies for this category.
Interquartile Range = 25th percentile to 75th percentile values, calculated in Excel, which uses linear interpolation to calculate percentiles. For small sample sizes (particularly n<5), interquartile values may vary depending on statistical package used.

Table Notes:

**Permeable pavement data should be used with caution due to limited numbers of BMP studies and small numbers of storm events typically monitored at these sites. "Inflow" values are typically outflows monitored at a reference conventional paving site.

Descriptive statistics calculated by weighting each BMP study equally. Each BMP study is represented by the median analyte value reported for all storms monitored at each BMP (i.e., "n" = number of BMP studies, as opposed to number of storm events). Depending on the analysis objectives, researchers may also choose to use a storm-weighted analysis approach, a unit treatment process-based grouping of studies, or other screening based on design parameters and site-specific characteristics.

Analysis based on August 2010 BMP Database, which contains substantial changes relative to the 2008 BMP Database. Multiple BMPs have been recategorized into new BMP categories; therefore, the 2008 and 2010 data analysis are not directly comparable for several BMP types.

This table contains descriptive statistics only. Values presented in this table should not be used to draw conclusions related to statistically significant differences in performance for BMP categories. (Hypothesis testing for BMP Categories is provided separately in other BMP Database summaries available at www.bmpdatabase.org.)

These descriptive statistics are based on different statistical measures than those used in the 2008 BMP Database tabular summary. Be aware that results will vary depending on whether a "BMP Weighted" (one median or average value represents each BMP) or "Storm Weighted" (all storms for all BMPs included in statistical calculations) approach is used, as well as whether the median or another measure of central tendency is used. Several BMP Database publications in 2010 have focused on the storm-weighted approach, which may result in some differences between this table and other published summaries.

Values below detection limits replaced with 1/2 of detection limit.

1.4 Storage-Based Versus Conveyance-Based

BMPs in this manual generally fall into two categories: 1) storage-based and 2) conveyance-based. Storage-based BMPs provide the WQCV and include bioretention/rain gardens, extended detention basins, sand filters, constructed wetland ponds, retention ponds, and permeable pavement systems. Conveyance-based BMPs include grass swales, grass buffers, constructed wetlands channels and other BMPs that improve quality and reduce volume but only provide incidental storage. Conveyance-based BMPs can be implemented to help achieve objectives in Step 1 of the Four Step Process. Although conveyance BMPs do not satisfy Step 2 (providing the WQCV), they can reduce the volume requirements of Step 2. Storage-based BMPs are critical for Step 2 of the Four Step Process. Site plans that use a combination of conveyance-based and storage-based BMPs can be used to better mimic pre-development hydrology.

1.5 Volume Reduction

BMPs that promote infiltration or that incorporate evapotranspiration have the potential to reduce the volume of runoff generated. Volume reduction is a fundamental objective of LID. Volume reduction has many benefits, both in terms of hydrology and pollution control. While stormwater regulations have traditionally focused on runoff peak flow rates, emerging stormwater regulations require BMPs to mimic the pre-development hydrologic budget to minimize effects of hydromodification. From a pollution perspective, decreased runoff volume translates to decreased pollutant loads. Volume reduction has economic benefits, including potential reductions in storage requirements for minor and major events, reduced extent and sizing of conveyance infrastructure, and cost reductions associated with addressing channel stability issues. UDFCD has developed a computational method for quantifying volume reduction. This is discussed in detail in Chapter 3.

Hydromodification

The term hydromodification refers to altered hydrology due to increased imperviousness combined with constructed of conveyance systems (e.g., pipes) that convey stormwater efficiently to receiving waters. Hydromodification produces increased peaks, volume, frequency, and duration of flows, all of which can result in stream degradation, including stream bed down cutting, bank erosion, enlarged channels, and disconnection of streams from the floodplain. These factors lead to loss of stream and riparian habitat, reduced aquatic diversity, and can adversely impact the beneficial uses of our waterways.

Infiltration-based BMPs can be designed with or without underdrains, depending on soil permeability and other site conditions. The most substantial volume reductions are generally associated with BMPs that have permeable sub-soils and allow infiltration to deeper soil strata and eventually groundwater. For BMPs that have underdrains, there is still potential for volume reduction although to a lesser degree. As runoff infiltrates through BMP soils to the underdrain, moisture is retained by soils. The moisture eventually evaporates, or is taken up by vegetation, resulting in volume reduction. Runoff that drains from these soils via gravity to the underdrain system behaves like interflow from a hydrologic perspective with a delayed response that reduces peak rates. Although the runoff collected in the underdrain system is ultimately discharged to the surface, on the time scale of a storm event, there are volume reduction benefits.

Although effects of evapotranspiration are inconsequential on the time scale of a storm event, on an annual basis, volume reduction due to evapotranspiration for vegetated BMPs such as retention and constructed wetland ponds can be an important component of the hydrologic budget. Between events, evapotranspiration lowers soil moisture content and permanent pool storage, providing additional storage capacity for subsequent events.

Other surface BMPs also provide volume reduction through a combination of infiltration, use by the vegetation and evaporation. Volume reduction provided by a particular BMP type will be influenced by site-specific conditions and BMP design features. National research is ongoing with regard to estimating volume reduction provided by various BMP types. Based on analysis of BMP studies contained in the International Stormwater BMP Database, Geosyntec and WWE (2010) reported that normally-dry vegetated BMPs (filter strips, vegetated swales, bioretention, and grass lined detention basins) appear to have substantial potential for volume reduction on a long-term basis, on the order of 30 percent for filter strips and grass-lined detention basins, 40 percent for grass swales, and greater than 50 percent for bioretention with underdrains. Bioretention facilities without underdrains would be expected to provide greater volume reduction.

1.6 Pretreatment

Design criteria in this manual recommend forebays for extended detention basins, constructed wetland basins, and retention ponds. The purpose of forebays is to settle out coarse sediment prior to reaching the main body of the facility. During construction, source control including good housekeeping can be more effective than pre-treatment. It is extremely important that high sediment loading be controlled for BMPs that rely on infiltration, including permeable pavement systems, rain gardens, and sand filter extended detention basins. These facilities should not be brought on-line until the end of the construction phase when the tributary drainage area has been stabilized with permanent surfaces and landscaping.

1.7 Treatment Train

The term "treatment train" refers to multiple BMPs in series (e.g., a disconnected roof downspout draining to a grass swale draining to a constructed wetland basin.) Engineering research over the past decade has demonstrated that treatment trains are one of the most effective methods for management of stormwater quality (WERF 2004). Advantages of treatment trains include:

- **Multiple processes for pollutant removal**: There is no "silver bullet" for a BMP that will address all pollutants of concern as a stand-alone practice. Treatment trains that link together complementary processes expand the range of pollutants that can be treated with a water quality system and increase the overall efficiency of the system for pollutant removal.

- **Redundancy**: Given the natural variability of the volume, rate and quality of stormwater runoff and the variability in BMP performance, using multiple practices in a treatment train can provide more consistent treatment of runoff than a single practice and provide redundancy in the event that one component of a treatment train is not functioning as intended.

- **Maintenance**: BMPs that remove trash, debris, coarse sediments and other gross solids are a common first stage of a treatment train. From a maintenance perspective, this is advantageous since this first stage creates a well-defined, relatively small area that can be cleaned out routinely. Downgradient components of the treatment train can be maintained less frequently and will benefit from reduced potential for clogging and accumulation of trash and debris.

1.8 Online Versus Offline Facility Locations

The location of WQCV facilities within a development site and watershed requires thought and planning. Ideally this decision-making occurs during a master planning process. Outfall system plans and other reports may depict a recommended approach for implementing WQCV on a watershed basis. Such reports may call for a few large regional WQCV facilities, smaller sub-regional facilities, or an onsite approach. Early in the development process, it is important to determine if a master planning study has been completed that addresses water quality and to attempt to follow the plan's recommendations.

When a master plan identifying the type and location of water quality facilities has not been completed, a key decision involves whether to locate a BMP online or offline. Online refers to locating a BMP such that all of the runoff from the upstream watershed is intercepted and treated by the BMP. A single online BMP should be designed to treat both site runoff and upstream (offsite) runoff. Locating BMPs offline requires that all onsite catchment areas flow though a BMP prior to combining with flows from the upstream (offsite) watershed. Be aware, when water quality BMPs are constructed in "Waters of the State" they must be accompanied by upstream treatment controls and source controls.

When water quality BMPs are constructed in "Waters of the State," they must be accompanied by upstream treatment and source controls.

Online WQCV facilities are only recommended if the offsite watershed has less impervious area than that of the onsite watershed. Nevertheless, online WQCV facilities must be sized to serve the entire upstream watershed based on future development conditions. This recommendation is true even if upstream developments have installed their own onsite WQCV facilities. The only exception to this criterion is when multiple online regional or sub-regional BMPs are constructed in series and a detailed hydrologic model is prepared to show appropriate sizing of each BMP. The maximum watershed recommended for a water quality facility is approximately one square mile. Larger watersheds can be associated with decreased water quality.

1.9 Integration with Flood Control

In addition to water quality, most projects will require detention for flood control, whether on-site, or in a sub-regional or regional facility. In many cases, it is efficient to combine facilities since the land requirements for a combined facility are lower than for two separate facilities. Wherever possible, it is recommended WQCV facilities be incorporated into flood control detention facilities.

Local jurisdictions in the Denver area use different approaches for sizing volumes within a combined water quality and quantity detention facility. This varies from requiring no more than the 100-year detention volume, even though the WQCV is incorporated within it, to requiring the 100-year detention volume plus the full WQCV. This manual does not stipulate or recommend which policy should be used. When a local policy has not been established, UDFCD suggests the following approach:

- **Water Quality**: The full WQCV is to be provided according to the design procedures documented in this manual.

- **Minor Storm (not EURV)**: The full WQCV, plus the full minor storm detention volume, is to be provided.

- **100-Year Storm**: One-half the WQCV plus the full 100-year storm event volume should be provided for volumes obtained using the empirical equations or the FAA Method. When the analysis is done using hydrograph routing methods, each level of controls needs to be accounted for and the resultant 100-year control volume used in final design.
- **100-Year Storm using Full Spectrum Detention**: The full 100-year storm event volume should be provided according to the design protocol provided in the *Storage* chapter of Volume 2.

The *Storage* chapter in Volume 2 provides design criteria for full spectrum detention, which shows more promise in controlling the peak flow rates in receiving waterways than the multi-stage designs described above. Full spectrum detention not only addresses the WQCV for controlling water quality and runoff from frequently occurring runoff events, but also extends that control for all return periods through the 100-year event and closely matches historic peak flows downstream.

Finally, designers should also be aware that water quality BMPs, especially those that promote infiltration, could result in volume reductions for flood storage. These volume reductions are most pronounced for frequently occurring events, but even in the major event, some reduction in detention storage volume can be achieved if volume-reduction BMPs are widely used on a site. Additional discussion on volume reduction benefits, including a methodology for quantifying effects on detention storage volumes, is provided in Chapter 3.

1.9.1 Sedimentation BMPs

Combination outlets are relatively straightforward for most BMPs in this manual. For BMPs that utilize sedimentation (e.g. EDBs, constructed wetland ponds, and retention ponds) see BMP Fact Sheet T-12. This Fact Sheet shows examples and details for combined quality/quantity outlet structures.

1.9.2 Infiltration/Filtration BMPs

For other types of BMPs (e.g. rain gardens, sand filters, permeable pavement systems, and other BMPs utilizing processes other than sedimentation), design of a combination outlet structure generally consists of multiple orifices to provide controlled release of WQCV as well as the minor and major storm event. Incorporation of full spectrum detention into these structures requires reservoir routing. The *UD-Detention* worksheet available at www.udfcd.org can be used for this design. When incorporating flood control into permeable pavement systems, the design can be simplified when a near 0% slope on the pavement surface can be achieved. The flatter the pavement the fewer structures required. This includes lateral barriers as well as outlet controls since each pavement cell typically requires its own outlet structure. When incorporating flood control into a rain garden, the flood control volume can be placed on top of or downstream of the rain garden. Locating the flood control volume downstream can reduce the total depth of the rain garden, which will result in a more attractive BMP, and also benefit the vegetation in the flood control area because inundation and associated sedimentation will be less frequent, limited to events exceeding the WQCV.

1.10 Land Use, Compatibility with Surroundings, and Safety

Stormwater quality areas can add interest and diversity to a site, serving multiple purposes in addition to providing water quality functions. Gardens, plazas, rooftops, and even parking lots can become amenities and provide visual interest while performing stormwater quality functions and reinforcing urban design goals for the neighborhood and community. The integration of BMPs and associated landforms, walls, landscape, and materials can reflect the standards and patterns of a neighborhood and help to create lively, safe, and pedestrian-oriented districts. The quality and appearance of stormwater quality facilities should reflect the surrounding land use type, the immediate context, and the proximity of the site to important civic spaces. Aesthetics will be a more critical factor in highly visible urban commercial and office areas than at a heavy industrial site. The standard of design and construction should maintain and enhance property values without compromising function (WWE et al. 2004).

Public access to BMPs should be considered from a safety perspective. The highest priority of engineers and public officials is to protect public health, safety, and welfare. Stormwater quality facilities must be designed and maintained in a manner that does not pose health or safety hazards to the public. As an example, steeply sloped and/or walled ponds should be avoided. Where this is not possible, emergency egress, lighting and other safety considerations should be incorporated. Facilities should be designed to reduce the likelihood and extent of shallow standing water that can result in mosquito breeding, which can be a nuisance and a public health concern (e.g., West Nile virus). The potential for nuisances, odors and prolonged soggy conditions should be evaluated for BMPs, especially in areas with high pedestrian traffic or visibility.

1.11 Maintenance and Sustainability

Maintenance should be considered early in the planning and design phase. Even when BMPs are thoughtfully designed and properly installed, they can become eyesores, breed mosquitoes, and cease to function if not properly maintained. BMPs can be more effectively maintained when they are designed to allow easy access for inspection and maintenance and to take into consideration factors such as property ownership, easements, visibility from easily accessible points, slope, vehicle access, and other factors. For example, fully consider how and with what equipment BMPs will be maintained in the future. Clear, legally-binding written agreements assigning maintenance responsibilities and committing adequate funds for maintenance are also critical (WWE et al. 2004). The MS4 permit holder may also require right of access to perform emergency repairs/maintenance should it become necessary.

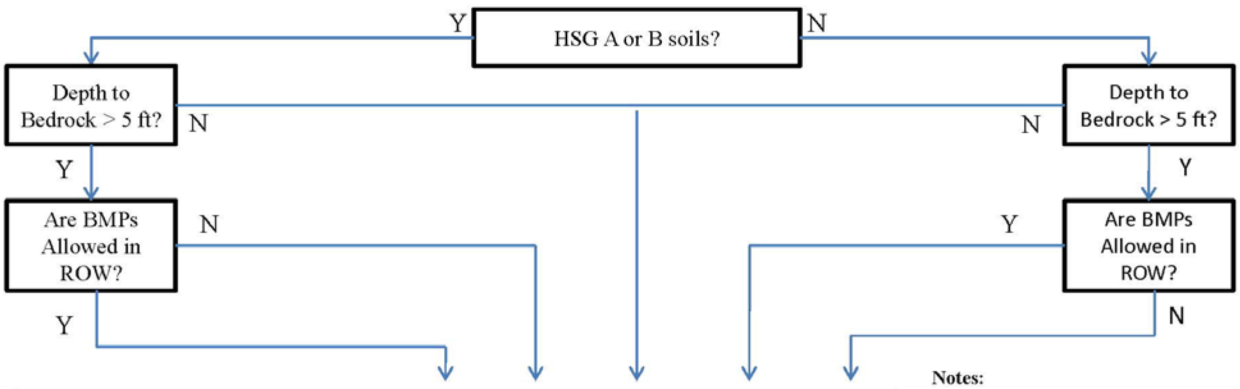
Sustainability of BMPs is based on a variety of considerations related to how the BMP will perform over time. For example, vegetation choices for BMPs determine the extent of supplemental irrigation required. Choosing native or drought-tolerant plants and seed mixes (as recommended in the *Revegetation* chapter of Volume 2) helps to minimize irrigation requirements following plant establishment. Other sustainability considerations include watershed conditions. For example, in watersheds with ongoing development, clogging of infiltration BMPs is a concern. In such cases, a decision must be made regarding either how to protect and maintain infiltration BMPs, or whether to allow use of infiltration practices under these conditions.

1.12 Costs

Costs are a fundamental consideration for BMP selection, but often the evaluation of costs during planning and design phases of a project focuses narrowly on up-front, capital costs. A more holistic evaluation of life-cycle costs including operation, maintenance and rehabilitation is prudent and is discussed in greater detail in Section 4 of this chapter. From a municipal perspective, cost considerations are even broader, involving costs associated with off-site infrastructure, channel stabilization and/or rehabilitation, and protection of community resources from effects of runoff from urban areas.

2.0 BMP Selection Tool

To aid in selection of BMPs, UDFCD has developed a BMP selection tool (*UD-BMP*) to guide users of this manual through many of the considerations identified above and to determine what types of BMPs are most appropriate for a site. This tool helps to screen BMPs at the planning stages of development and can be used in conjunction with the *BMP-REALCOST* tool described in Section 4. Simplified schematics of the factors considered in the *UD-BMP* tool are provided in Figures 2-1, 2-2, and 2-3, which correspond to highly urbanized settings, conventional developments, and linear construction in urbanized areas. Separate figures are provided because each setting or type of development presents unique constraints. Highly urbanized sites are often lot-line to lot-line developments or redevelopments with greater than 90 percent imperviousness with little room for BMPs. Linear construction typically refers to road and rail construction.



Step 1—Runoff Reduction Practices					
Permeable Pavement—Full Infiltration[4]	●	●			
Permeable Pavement—Partial or No Infiltration[4]			●	●	●
Green Roof	●	●[1]	●[1]	●[1]	●[1]
Step 2—Provide WQCV with Slow Release					
Permeable Pavement—Full Infiltration[4]	●	●			
Permeable Pavement --Partial or No Infiltration[4]			●	●	●
Bioretention—Full Infiltration[4]	●	●			
Bioretention—Partial or No Infiltration[4]			●	●	●
Green Roof with Full WQCV	●[1]	●[1]	●[1]	●[1]	●[1]
Underground BMPs with Full WQCV		●[2]			●[2]
Regional Water Quality Treatment	●[3]	●[3]	●[3]	●[3]	●[3]

Notes:

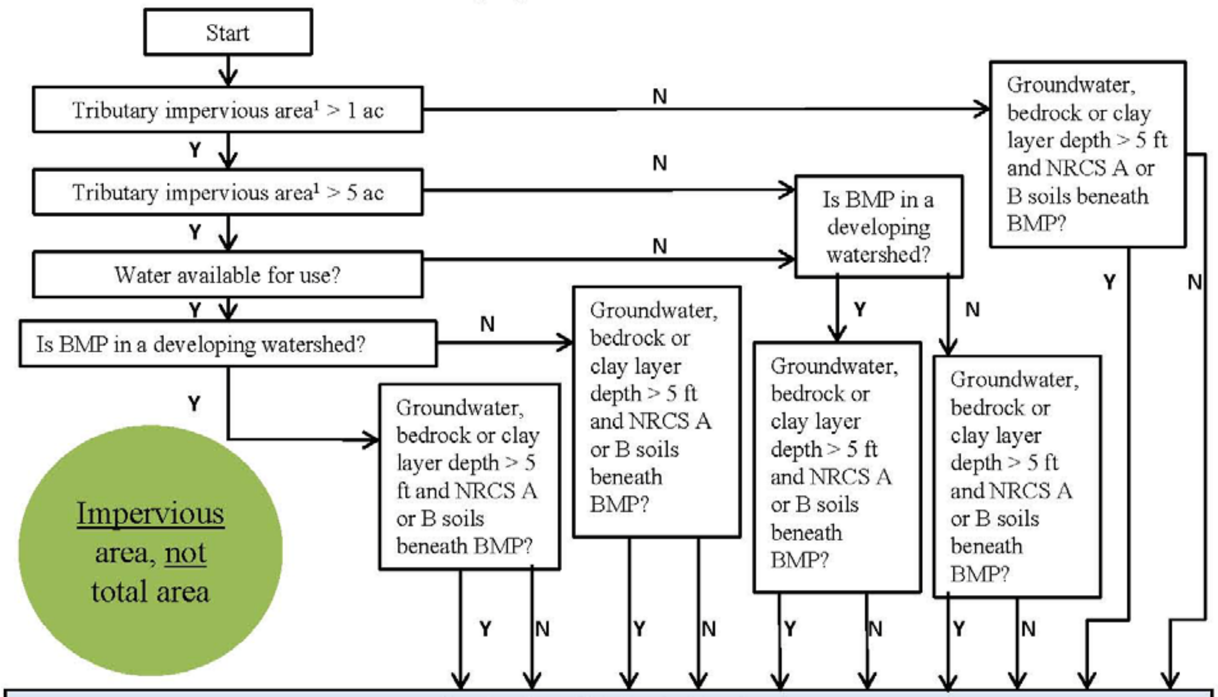
[1] In the Front Range of Colorado, irrigation, at least periodically in dry times, will be required to sustain a green roof.

[2] Underground BMPs should only be considered when surface-based BMPs are not practicable and only when approved by the local jurisdiction. See the Underground BMP Fact Sheet for additional restrictions on use.

[3] If a regional facility will be used to provide the WQCV, some degree of onsite treatment/MDCIA will still likely be required.

[4] No Infiltration = underdrain and liner
Partial Infiltration = underdrain and no liner
Full Infiltration = no underdrain and no liner

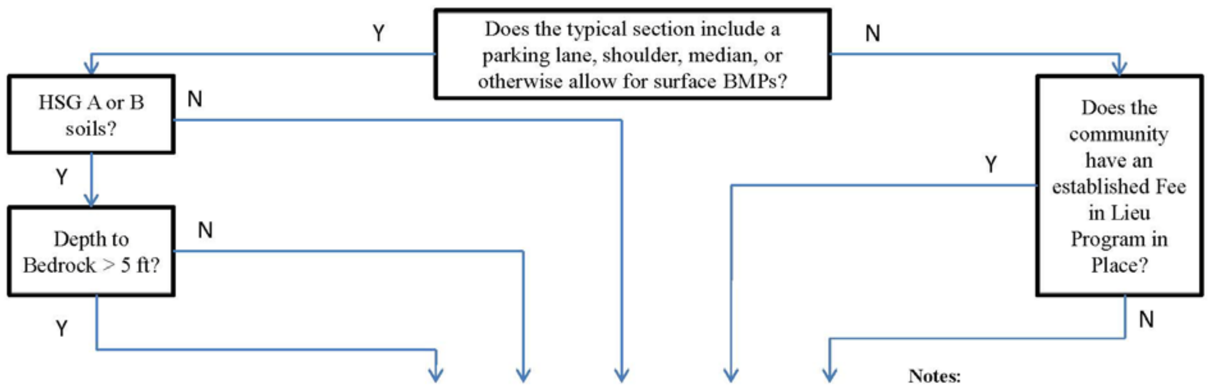
Figure 2-1. BMP Decision Tree for Highly Urbanized Sites



Step 1—Runoff Reduction Practices										
Grass Swale	●	●	●	●	●	●	●	●	●	●
Grass Buffer	●	●	●	●	●	●	●	●	●	●
Constructed Wetland Channel[2]	●[2]	●[2]	●[2]	●[2]						
Permeable Pavement—Full Infiltration[5]			●[6]				●[6]		●	
Permeable Pavement—No or Partial Infiltration[5]				●[6]				●[6]		●
Green Roof	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3]	●[3]
Step 2—Provide WQCV with Slow Release										
Permeable Pavement — Full Infiltration[5]			●[6]				●[6]		●	
Permeable Pavement – No or Partial Infiltration[5]				●[6]				●[6]		●
Bioretention—Full Infiltration[5]			●[6]				●[6]		●	
Bioretention—No or Partial Infiltration[5]				●[6]				●[6]		●
Extended Dry Detention Basin	●		●		●		●			
Constructed Wetland Basin[2]	●	●	●	●						
Retention Pond	●	●	●	●						
Sand Filter Extended Detention--Full Infiltration[5]			●				●		●	
Sand Filter Extended Detention--No or Partial Infiltration[5]				●				●		●
Green Roof	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3,6]	●[3]	●[3]
Regional Water Quality Treatment	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]

Notes: [1] "Tributary impervious area" refers to the impervious area draining to the BMP, **not** the total area of the project site.
[2] For a successful wetland channel or basin, a water source (groundwater or baseflow) will be required.
[3] In the Front Range of Colorado, irrigation, at least periodically in dry times, will be required to sustain a green roof.
[4] If a regional facility will be used to provide the WQCV, some degree of onsite treatment/MDCIA will still likely be required.
[5] No Infiltration = underdrain and liner, Partial Infiltration = underdrain and no liner, Full Infiltration = no underdrain and no liner.
[6] Consider this BMP for a portion of your site. It's best suited for impervious tributary areas of approximately one acre or less.

Figure 2-2. BMP Decision Tree for Conventional Development Sites



Step 1—Runoff Reduction Practices					
Permeable Pavement—Full Infiltration[3]	●				
Permeable Pavement—Partial or No Infiltration[3]		●	●		
Biofiltration Tree Planter	●	●	●	●	●
Step 2—Provide WQCV with Slow Release					
Permeable Pavement—Full Infiltration[3]	●				
Permeable Pavement –Partial or No Infiltration[3]		●	●		
Bioretention—Full Infiltration[3]	●				
Bioretention—Partial or No Infiltration[4]		●	●		
Fee in Lieu/Offsite Mitigation				●[4]	
Underground BMPs with Full WQCV				●[1]	●[1]
Regional Water Quality Treatment	●[2]	●[2]	●[2]	●[2]	●[2]

Notes:

[1] Underground BMPs should only be considered when surface-based BMPs are not practicable and only when approved by the local jusisdiction. See the Underground BMP Fact Sheet for additional restrictions on use.

[2] If a regional facility will be used to provide the WQCV, some degree of onsite treatment/MDCIA will still likely be required.

[3]No Infiltration = underdrain and liner
Partial Infiltration = underdrain and no liner
Full Infiltration = no underdrain and no liner

[4] Only recommended when the community has an established program for "Fee in Lieu"

Figure 2-3. BMP Decision Tree for Linear Construction in Urbanized Areas

3.0 Life Cycle Cost and BMP Performance Tool

The importance of cost effective BMP planning and selection is gaining recognition as agencies responsible for stormwater management programs continue to face stricter regulations and leaner budgets. The goal of the *BMP-REALCOST* tool is to help select BMPs that meet the project objectives at the lowest unit cost, where the project objectives are quantifiable measures such as reducing pollutant loads or runoff volumes to a receiving water. To do so, UDFCD has developed an approach that provides estimates for both the whole life costs and performance of BMPs. The approach was developed to be most effective at the large-scale, planning phase; however, it can also be applied to smaller scales during the design phase, perhaps with minor loss of accuracy. The *BMP-REALCOST* spreadsheet tool incorporates this approach and requires minimal user inputs in order to enhance its applicability to planning level evaluations. An overview of the general concepts providing the underlying basis of the tool follows.

3.1 BMP Whole Life Costs

Whole life costs (also known as life cycle costs) refer to all costs that occur during the economic life of a project. This method of cost estimating has gained popularity in the construction and engineering fields over the past few decades and the American Society of Civil Engineers (ASCE) encourages its use for all civil engineering projects. Generally, the components of the whole life cost for a constructed facility include construction, engineering and permitting, contingency, land acquisition, routine operation and maintenance, and major rehabilitation costs minus salvage value. In addition, UDFCD recommends the cost of administering a stormwater management program also be included as a long-term cost for BMPs. Reporting whole life costs in terms of net present value (NPV) is an effective method for comparing mutually exclusive alternatives (Newnan 1996).

To understand the value of using whole life cost estimating, one must first realize how the various costs of projects are generally divided amongst several stakeholders. For example, a developer is typically responsible for paying for the "up front" costs of construction, design, and land acquisition; while a homeowners' association or stormwater management agency becomes responsible for all costs that occur after construction. Many times, the ratios of these costs are skewed one way or another, with BMPs that are less expensive to design and construct having greater long-term costs, and vice versa. This promotes a bias, depending on who is evaluating the BMP cost effectiveness. Whole life cost estimating removes this bias; however, successful implementation of the concept requires a cost-sharing approach where the whole life costs are equitably divided amongst all stakeholders.

The methods incorporated into the *BMP-REALCOST* tool for estimating whole life costs are briefly described below. All cost estimates are considered "order-of-magnitude" approximations, hence UDFCD's recommendation of using this concept primarily at the planning level.

- **Construction Costs:** Construction costs are estimated using a parametric equation that relates costs to a physical parameter of a BMP; total storage volume (for storage-based BMPs), peak flow capacity (for flow-based or conveyance BMPs) or surface area (for permeable pavements).

- **Contingency/Engineering/Administration Costs:** The additional costs of designing and permitting a new BMP are estimated as a percentage of the total construction costs. For Denver-area projects, a value of 40% is recommended if no other information is available.

- **Land Costs:** The cost of purchasing land for a BMP is estimated using a derived equation that incorporates the number of impervious acres draining to the BMP and the land use designation in which the BMP will be constructed.

- **Maintenance Costs:** Maintenance costs are estimated using a derived equation that relates average annual costs to a physical parameter of the BMP.

- **Administration Costs:** The costs of administering a stormwater management program are estimated as percentage of the average annual maintenance costs of a BMP. For Denver-area projects, a value of 12% is recommended if no other information is available.

- **Rehabilitation/Replacement Costs:** After some period of time in operation, a BMP will require "major" rehabilitation. The costs of these activities (including any salvage costs or value) are estimated as a percentage of the original construction costs and applied near the end of the facility's design life. The percentages and design lives vary according to BMP.

3.2 BMP Performance

The performance of structural BMPs can be measured as the reduction in stormwater pollutant loading, runoff volume and runoff peak flows to the receiving water. It is generally acknowledged that estimating BMP performance on a storm-by-storm basis is unreliable, given the inherent variability of stormwater hydrologic and pollutant build-up/wash off processes. Even if the methods to predict event-based BMP performance were available, the data and computing requirements to do so would likely not be feasible at the planning level. Instead, UDFCD recommends an approach that is expected to predict long-term (i.e. average annual) BMP pollutant removal and runoff volume reduction with reasonable accuracy, using BMP performance data reported in the International Stormwater BMP Database (as discussed in Section 1.3).

3.3 Cost Effectiveness

The primary outputs of the *BMP-REALCOST* tool include net present value (NPV) of the whole life costs of the BMP(s) implemented, the average annual mass of pollutant removed (P_R, lbs/year) and the average annual volume of surface runoff reduced (R_R, ft^3/year). These reported values can then be used to compute a unit cost per lb of pollutant (C_P) or cubic feet of runoff (C_R) removed over the economic life (n, years) of the BMP using Equations 2-1 and 2-2, respectively.

$$C_P = \frac{NPV}{nP_R} \qquad \text{Equation 2-1}$$

$$C_R = \frac{NPV}{nR_R} \qquad \text{Equation 2-2}$$

4.0 Conclusion

A variety of factors should be considered when selecting stormwater management approaches for developments. When these factors are considered early in the design process, significant opportunities exist to tailor stormwater management approaches to site conditions. Two worksheets are available at www.udfcd.org for the purpose of aiding in the owner or engineer in the proper selection of treatment BMPs. The *UD-BMP* tool provides a list of BMPs for consideration based on site-specific conditions. *BMP-REALCOST* provides a comparison of whole life cycle costs associated with various BMPs based on land use, watershed size, imperviousness, and other factors.

5.0 References

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Chapter 3
Calculating the WQCV and Volume Reduction

Contents

Tables

Figures

1.0 Introduction

This chapter presents the hydrologic basis and calculations for the Water Quality Capture Volume (WQCV) and discusses the benefits of attenuating this volume or that of the Excess Urban Runoff Volume (EURV). This chapter also describes various methods for quantifying volume reduction when using Low Impact Development (LID) practices. Use of these methods should begin during the planning phase for preliminary sizing and development of the site layout. The calculations and procedures in this chapter allow the engineer to calculate the WQCV and more accurately quantify potential volume reduction benefits of stormwater control measures (BMPs).

2.0 Hydrologic Basis of the WQCV

2.1 Development of the WQCV

The purpose of designing control measures based on the WQCV is both to improve water quality and reduce hydromodification and the associated impacts on receiving waters. (These impacts are described in Chapter 1.) Although flow-based BMPs can remove pollutants, in order to offset the hydrologic impacts of urbanization including increases to flow, volume, duration, and frequency, BMPs must be designed to reduce (infiltrate) a significant portion of the WQCV or to treat and slowly release the WQCV. This section provides a brief background on the development of the WQCV.

The WQCV is based on an analysis of rainfall and runoff characteristics for 36 years of record at the Denver Stapleton Rain Gage (1948-1984) conducted by Urbonas, Guo, and Tucker (1989) and documented in *Sizing a Capture Volume for Stormwater Quality Enhancement* (available at www.MHFD.org). In 2019, Mile High Flood District (MHFD) repeated this analysis for an extended period of record, including data from 1985 - 2013, using the Water Quality Capture Optimization and Statistical Model (WQ-COSM), Version 2.0 (Urban Watersheds Research Institute [UWRI] 2012). Results of the updated WQ-COSM analysis were essentially unchanged from the earlier analysis by Urbonas et al. for the mean storm depth, the 80^{th} percentile runoff-producing event and the overall percentile distribution of rainfall depths.

Table 3-1 summarizes the relationship between total storm depth and the annual number of storms based on the updated WQ-COSM analysis. Development of the WQCV disregards storm events with no anticipated runoff, events 0.1 inches and smaller. As the table shows, these small storms that do not produce significant runoff represent 45 of the 74 storm events that occur on an average annual basis, or 61% of rainfall events. Urbonas et al. (1989) identified the runoff produced from a precipitation event of 0.6 inches as the optimal target for the WQCV, where treating larger volumes has a diminishing return of investment in terms of the number of storms captured and treated. The 0.6-inch precipitation depth corresponds to the 80^{th} percentile of runoff-producing storms. The WQCV for a given watershed will vary depending on the imperviousness and the drain time of the BMP, but assuming 0.1 inches of depression storage for impervious areas, the maximum capture volume required is approximately 0.5 inches over the area of the watershed. Urbonas et al. (1989) concluded treating and detaining the volume of runoff produced from impervious areas during these storms can significantly improve water quality.

Using WQCV and Flood Control Hydrology

Channels are typically designed for an event that is large and infrequent, such as the 100-year event. A common misconception is that these large events are also responsible for most of the erosion within the stream. Instead, the *effective discharge*, by definition, is the discharge that transports the most sediment on an annual basis and this is a good estimate of the *channel-forming flow* or the discharge that shapes the stream through sediment transport and erosion. The effective discharge does not correlate with a specific return period, but often is characterized as a magnitude between the annual (1-year) event and the 5-year peak flow, depending on watershed-specific characteristics.

The typical flood control facility design may include peak reduction of the 5- or 10-year storm event as well as the 100-year event. Widespread use of minor and major event detention reduces flooding of streets and streams. However, this practice does little to limit the frequency of channel-forming flows. MHFD recommends *Full Spectrum Detention,* a concept developed to replicate historic peak flows for a broad spectrum of storm events. This method is described in more detail in the *Storage* chapter of Volume 2 of the USDCM.

Widespread use of full spectrum detention would, in theory, improve channel stability and reduce erosion; however, full spectrum detention does not necessarily reduce volume, duration, and frequency, which also contribute to instability.

Therefore, this manual provides a variety of BMPs that provide the WQCV and address hydrologic effects of urbanization through storage, infiltration, and/or evapotranspiration.

Table 3-1. Number of Rainfall Events in the Denver Area.

(Adapted from Urbonas et al. 1989, updated with additional data [1985 – 2013] by MHFD 2019)

Total Rainfall Depth (inches)	Average Annual Number of Storm Events	Percent of Total Storm Events	Percentile of Runoff-producing Storms
0.0 to 0.1	45	60.9%	0.0%
0.1 to 0.5	22	29.4%	75.2%
≤ 0.6	**68**	**92.2%**	**80%**
0.5 to 1.0	4.6	6.3%	91.1%
1.0 to 1.5	1.5	2.1%	96.6%
1.5 to 2.0	0.6	0.8%	98.6%
2.0 to 3.0	0.2	0.3%	99.4%
3.0 to 4.0	0.15	0.2%	99.9%
4.0 to 5.0	0.015	<0.1%	100%
> 5.0	0	<0.1%	100%
TOTAL:	**74**	**100%**	**100%**

2.2 Optimizing the Capture Volume

Optimizing the capture volume is critical. If the capture volume is too small, the effectiveness of the BMP will be reduced due to the frequency of storms exceeding the capacity of the facility and allowing some volume of runoff to bypass treatment. On the other hand, if the capture volume for a BMP that provides treatment through sedimentation is too large, the smaller runoff events may pass too quickly through the facility, without the residence time needed to provide treatment.

Small, frequently occurring storms account for the predominant number of events that result in stormwater runoff from urban catchments. Consequently, these frequent storms also account for a significant portion of the annual pollutant loads. Capture and treatment of the stormwater from these small and frequently occurring storms is the recommended design approach for water quality enhancement, as opposed to flood control facility designs that focus on less frequent, larger events.

The analysis of precipitation data at the Denver Stapleton Rain Gage revealed a relationship between the percent imperviousness of a watershed and the capture volume needed to significantly reduce stormwater pollutants (Urbonas, Guo, and Tucker, 1990). Subsequent studies (Guo and Urbonas, 1996 and Urbonas, Roesner, and Guo, 1996) of precipitation resulted in a recommendation by the Water Environment Federation and American Society of Civil Engineers (1998) that stormwater quality treatment facilities (i.e., post-construction BMPs) be based on the capture and treatment of runoff from storms ranging in size from "mean" to "maximized[1]" storms. The "mean" and "maximized" storm events represent the 70th and 90th percentile storms, respectively. Based on these studies, water quality facilities for the Colorado Front Range should capture and treat the 80th percentile runoff-producing event. Capturing and properly treating this volume should remove between 80 and 90% of the annual total suspended solids (TSS) load, while doubling the capture volume was estimated to increase the removal rate by only 1 to 2%.

2.3 Attenuation of the WQCV (BMP Drain Time)

The WQCV must be released over an extended period to provide effective pollutant removal for post-construction BMPs that use sedimentation (i.e., extended detention basin, retention ponds and constructed wetland ponds). A field study of basins with extended detention in the Washington, D.C. area identified an average drain time of 24 hours to be effective for extended detention basins. This generally equates to a 40-hour drain time for the brim-full basin. Retention ponds and constructed wetland basins have reduced drain times (12 hours and 24 hours, respectively) because the hydraulic residence time of the effluent is essentially increased due to the mixing of the inflow with the permanent pool.

When pollutant removal is achieved primarily through filtration such as in a sand filter or rain garden BMP, MHFD still recommends an extended drain time to promote stability of the receiving stream. In addition to counteracting hydromodification, attenuation in filtering BMPs can also improve pollutant removal by increasing contact time, which aids adsorption/absorption processes. The minimum recommended drain time for a post-construction BMP is 12 hours; however, this minimum value should only be used for BMPs where filtration is the primary treatment process, sometimes referred to as "filtration BMPs."

2.4 Excess Urban Runoff Volume (EURV) and Full Spectrum Detention

The EURV represents the difference in stormwater runoff volume between the developed and pre-developed runoff volume for the range of storms that produce runoff from pervious land surfaces. The EURV is relatively constant volume for a given imperviousness regardless of recurrence interval. Consistent with the concept of treating and slowly releasing the WQCV, the EURV is a greater volume than the WQCV and is detained over a longer time. It typically accommodates the recommended drain time of the WQCV and is used to better replicate peak discharge in receiving waters for runoff events exceeding the WQCV. The EURV is associated with full spectrum detention which refers to a design method that includes slow release of the EURV as well as flood control detention. Designing a detention basin to capture the EURV and release it very slowly results in reduced flow rates for frequent storm events and thus reduced erosion. This method, however, does not address volume and duration which also contribute to stream and stability. This is why volume reduction practices are also necessary.

For additional information on the EURV and full spectrum detention, including calculation procedures, please refer to the *Storage* chapter of Volume 2.

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[1] The term "maximized storm" refers to the optimization of the storage volume of a BMP. The WQCV for the "maximized" storm represents the point of diminishing returns in terms of the number of storm events and volume of runoff fully treated versus the storage volume provided.

3.0 Calculation of the WQCV

The WQCV is calculated as a function of imperviousness and BMP type using Equation 3-1 and Table 3-2, and as shown in Figure 3-1:

$$WQCV = a(0.91I^3 - 1.19I^2 + 0.78I)$$ **Equation 3-1**

Where:

WQCV = Water Quality Capture Volume (watershed-inches)

a = Coefficient corresponding to BMP type and based on WQCV design drain time (Table 3-2)

I = Imperviousness (percent expressed as a decimal) Note: At a planning level, the watershed imperviousness can be estimated based on the zoned density. When finalizing design, calculate imperviousness based on the site plan.

Table 3-2. Drain Time Coefficients for WQCV Calculations

Drain Time (hours)	Coefficient, a
12 hours (filtration BMPs and retention ponds)	0.8
24 hours (constructed wetland ponds)	0.9
40 hours (extended detention)	1.0
No attenuation (e.g., grass buffer or swale)	1.0

Figure 3-2, which illustrates the relationship between imperviousness and WQCV for various drain times, is appropriate for use in Colorado's high plains near the foothills. For areas beyond this region, use WQ-COSM (UWRI 2013) and local rainfall data to determine precipitation depth for WQCV event.

After calculating WQCV in watershed-inches, convert this to a volume using Equation 3-2. Note that the area in this equation is the entirety of the area tributary to the control measure. This is regardless of the volume treated upstream.

$$V = \frac{WQCV}{12} A$$ **Equation 3-2**

Where:

V = required storage volume (acre-feet)

A = watershed tributary area upstream (acres)

WQCV = Water Quality Capture Volume (watershed-inches)

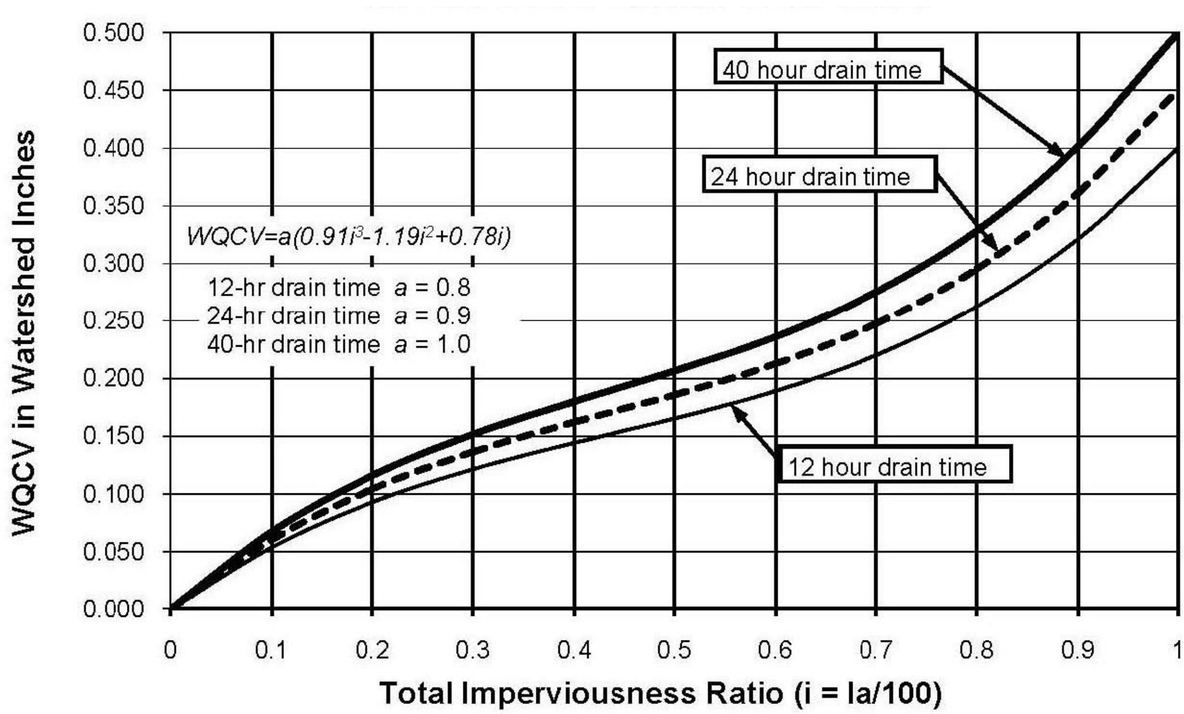

Figure 3-1. Water Quality Capture Volume (WQCV) Based on BMP Drain Time

4.0 Quantifying Volume Reduction

Runoff volume reduction is an important part of the Four Step Process for stormwater management as discussed in Chapter 1 and is fundamental to effectively manage stormwater runoff. Quantifying volume reduction associated with LID practices and other BMPs is important for watershed master planning as well as conceptual and final site design. It is also important in a regulatory context with the Runoff Reduction Standard that is included in the 2016 General MS4 Permit. A variety of approaches have been developed in the past to quantify volume reduction including “Level 1” and “Level 2” MDCIA curves for watershed-level models, Effective Imperviousness curves developed from modeling for site-level design, and others. The hydrologic response of watersheds and sites utilizing MDCIA and other volume reduction practices is an area of ongoing monitoring and research in the field of urban hydrology. Methods of quantifying runoff reduction are evolving and improving. The approaches recommended in this section are backed by physically-based modeling of rainfall-runoff, using input parameters that can be easily measured or estimated. These methods have been compared with field data from infiltration tests on receiving pervious areas including swales and provide good agreement with field data.

The approach recommended in this section is based on the Four-Component Land Use Model that is used by the Colorado Urban Hydrograph Procedure (CUHP) and the EPA Stormwater Management Model (SWMM). This conceptual model, illustrated in Figure 3-3, represents a drainage area by four components:

- Directly Connected Impervious Area (DCIA) – DCIA is impervious area that drains to the storm drain system or stream without flowing over surfaces that would allow for infiltration.

- Unconnected Impervious Area (UIA) – UIA is impervious area that drains to a receiving pervious area, where there is an opportunity for infiltration.
- Receiving Pervious Area (RPA) – RPA is pervious area that receives runoff from UIA and allows for infiltration.
- Separate Pervious Area (SPA) – SPA is pervious area that does not receive runoff from impervious surfaces.

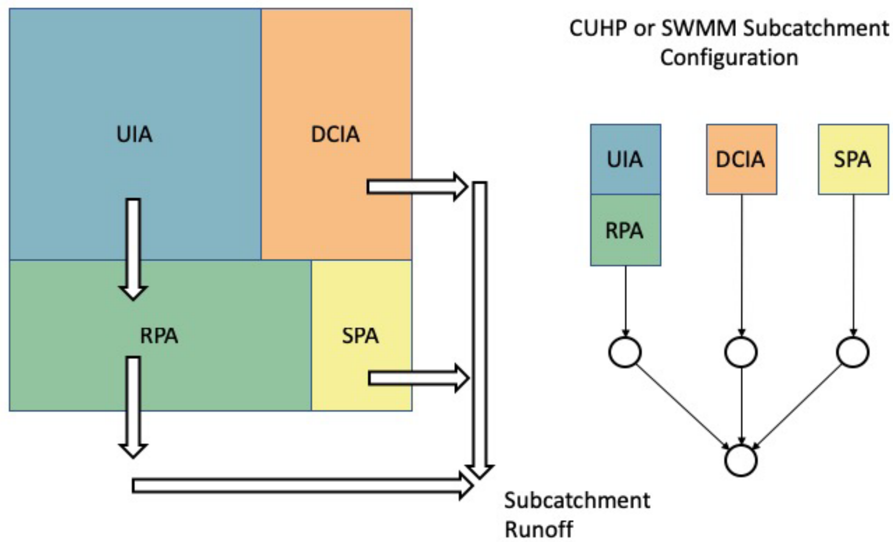

Figure 3-2. Four Component Land Use Model

Photograph 3-1. Separate Pervious Area (SPA) is permeable but does not receive runoff from impervious areas, such as the tree lawn in this photo. The drive and street are examples of DCIA.

Photograph 3-2. Directly Connected Impervious Area (DCIA) drains directly to a storm drain inlet with no opportunities for infiltration.

Photograph 3-3. Unconnected impervious area (UIA) draining to receiving pervious area (RPA). Vegetated buffer strips and/or raingardens are common ways to disconnect impervious area in parking lots.

Three approaches for quantifying runoff volume reduction are discussed in this section:

- Level 1 and 2 MDCIA: MHFD has developed curves for approximating LID effects at early planning stages. Level 1 and 2 MDCIA curves allow users to evaluate runoff reduction for two conceptual levels of LID implementation, described below. Only use these curves at early planning stages. Once the four land use fractions can be quantified, apply a more detailed method (CUHP-SWMM or the UD-BMP Runoff Reduction spreadsheet).

- CUHP and EPA SWMM: Use this approach to explicitly model directly connected and unconnected impervious areas, vegetated conveyances and BMPs, including LID practices. This method is appropriate at scales ranging from several acres (block or neighborhood scale) to several square miles (watershed scale, with appropriate sub-basin discretization).

- UD-BMP Runoff Reduction spreadsheet: This spreadsheet was developed by MHFD based on thousands of SWMM scenarios with variations of total area, ratio of UIA to RPA, hydrologic soil group, slope, roughness, depression storage, and length-to-width ratio. This approach is best-suited for small watersheds, where UIA-RPA pairs total less than 1 acre and sheet flow conditions prevail.

Infiltration Parameters for Runoff Reduction Analysis

Infiltration parameters used to evaluate runoff reduction from frequently occurring storms may vary from infiltration parameters for modeling larger flood events. A degree of conservatism is appropriate for flood modeling to account for unknowns including antecedent moisture conditions, heterogeneity of subsurface conditions, compaction of pervious areas, and others. When evaluating infiltration associated with frequent events, rates somewhat higher than those in the *Runoff* chapter that are based on Hydrologic Soil Groups (HSGs) are appropriate.

As an example, a Fondis Silt Loam soil is classified as HSG C, which corresponds to a final infiltration rate of 0.5 inches per hour in Table 6-7 of the *Runoff* chapter of Volume 1. Based on the NRCS Web Soil Survey, the saturated hydraulic conductivity (final infiltration rate) is 1.3 inches per hour. The value from Table 6-7 of the *Runoff* chapter (0.5 inches per hour) is appropriate for evaluating flood events, where it is appropriate to be more conservative, while the saturated hydraulic conductivity from the Web Soil Survey (1.3 inches per hour) may be appropriate for evaluating water quality events.

To determine appropriate infiltration rates for evaluating volume reduction from small storm events, use information on saturated hydraulic conductivity from the NRCS Web Soil Survey or data from a geotechnical report. Field measurements of infiltration rates using an infiltrometer also provide useful site-specific data for quantifying volume reduction.

4.1 Watershed/Master Planning-level Volume Reduction Method

For watershed-level assessments and master planning, CUHP provides options for users to model effects of LID through the "D" and "R" curves that are embedded in the model. The "D" curve relates the ratio of DCIA to total impervious area ($D = A_{DCIA}/A_{Imp}$). The "R" curve relates the ratio of RPA to total pervious area ($R = A_{RPA}/A_{Perv}$). Since site-level details (i.e., specific percentages of DCIA, UIA, RPA and SPA for a parcel or site-level drainage basin) are not generally known at the master planning level, MHFD has developed default values for D and R in CUHP based on SWMM modeling and analysis of typical developments in the Denver metropolitan area. For any given value of total imperviousness, the

CUHP model assigns values of D and R based on overall imperviousness and typical development patterns for two levels of LID implementation, MDCIA Level 1 and MDCIA Level 2:

> **MDCIA Level 1.** The primary intent is to direct the runoff from impervious surfaces to flow over grass-covered areas and/or permeable pavement, and to provide sufficient travel time to facilitate the removal of suspended solids before runoff leaves the site, enters a curb and gutter system, or enters another stormwater collection system. Thus, at Level 1, to the extent practical, impervious surfaces are designed to drain over grass buffer strips or other pervious surfaces before reaching a stormwater conveyance system.

> **MDCIA Level 2.** As an enhancement to Level 1, Level 2 replaces solid street curb and gutter systems with no curb or slotted curbing, low-velocity grass-lined swales and pervious street shoulders, including pervious rock-lined swales. Conveyance systems and storm drain inlets are still needed to collect runoff at downstream intersections and crossings where stormwater flow rates exceed the capacity of the swales. Small culverts will be needed at street crossings and at individual driveways. The primary difference between Levels 1 and 2 is that for Level 2, a pervious conveyance system (i.e., swales) is provided rather than continuous pipes. Disconnection of roof drains and other lot-level impervious areas is essentially the same for both Levels 1 and 2.

Figure 3-3 and Figure 3-4 provide effective imperviousness values for Level 1 and Level 2. Because rainfall intensity varies with return interval, the effective imperviousness also varies, as demonstrated by the separate curves for the 2-, 10- and 100-year return intervals. Effective impervious values from these figures are appropriate only as an estimate of the WQCV. These figures should not be used for final design. Figure 3-3 and Figure 3-4 are intended for use at the planning level before the specific D and R relationships in CUHP are known.

Note that the reductions in effective imperviousness shown in Figure 3-3 and Figure 3-4 are relatively modest, ranging from little to no benefit for large events up to a reduction of approximately 12% (from 50% to 38%) for Level 2 MDCIA during the 2-year event. At a more advanced stage of design and when site-specific disconnected areas, receiving pervious areas, flow paths, and other design details are available, the site-level methods in Sections 4.2 and 4.3 will better quantify volume reduction. Results will typically show greater reductions in effective imperviousness for aggressive LID implementation than reflected in the default D and R relationships used to create Figure 3-3 and Figure 3-4. Even so, it is unlikely that conveyance-based BMPs alone will provide adequate pollutant removal and volume reduction for most project sites, and a storage-based BMP will also be required.

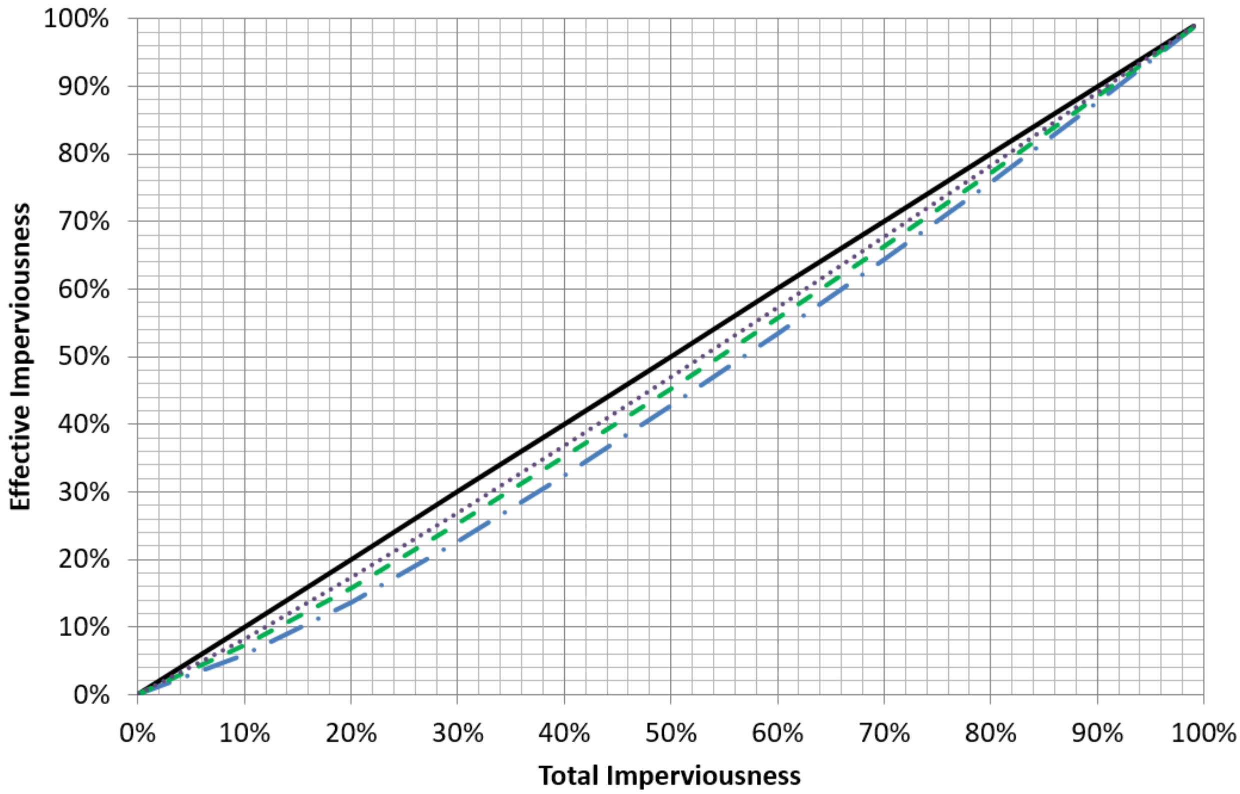

Figure 3-3. Effective Imperviousness Adjustments for Level 1 MDCIA

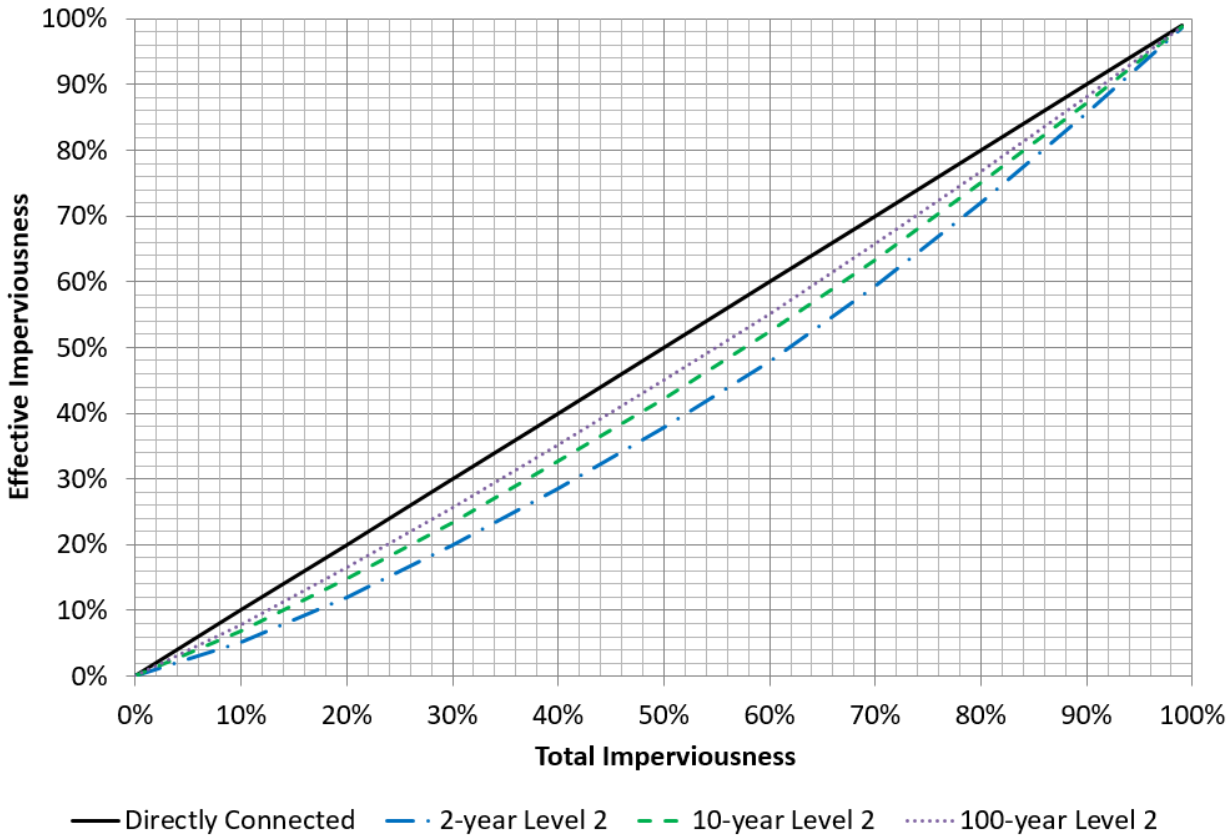

Figure 3-4. Effective Imperviousness Adjustments for Level 2 MDCIA

4.2 CUHP-SWMM Modeling of Volume Reduction

CUHP-SWMM is used for MHFD master plans at the watershed scale and for planning and design of infrastructure at the master development and filing scales. CUHP-SWMM can be applied at a lot or block scale as well, but simplified modeling methods, including UD-BMP, UD-Rational and/or UD-Detention (all of which are available at MHFD.org, are more common at the finer scales. The CUHP-SWMM approach uses CUHP to perform hydrologic calculations and SWMM to route hydrographs and represent detention and water quality features. The following sections provide methods to account for runoff reduction using CUHP-SWMM.

4.2.1 CUHP Imperviousness Parameters

Using standard settings, CUHP performs calculations that make implicit assumptions about connected and unconnected fractions of impervious area for typical development in the metropolitan area. The default assumptions in CUHP are for "incidental" disconnection of impervious area, typical of a development that is not intentionally designed with LID features. For watersheds or developments with deliberate implementation of LID to reduce runoff rates and volumes, the Subcatchment Override Parameters provide a way to specify the fractions of DCIA and RPA represented in Figure 3-2:

- The Directly Connected Impervious Fraction (DCIF) is a decimal fraction (e.g. 0.5 = 50%). The DCIF is equal to the percent of the impervious area that is directly connected to the drainage system. Based on the conceptual model in Figure 3-2, DCIF = DCIA/(UIA+DCIA).
- The Receiving Pervious Fraction (RPF) is the decimal fraction of receiving pervious area to total

pervious area. Based on the conceptual model in Figure 3-3, RPF = RPA/(SPA+RPA).

Peak runoff rates and volumes can vary significantly depending on these fractions, so the engineer should avoid overestimating the amount of RPA in a watershed. A common error in defining RPA is assuming that the entirety of drainage corridors, water quality features, and detention features act as RPA. Consider only the portion wetted by the design event. For example, the RPA associated with a drainage swale receiving runoff from an impervious area (UIA) would be the wetted perimeter of the swale for the design event multiplied by the length of the swale. This means a trapezoidal swale typically will be more efficient at reducing volume than a triangular swale. Upper portions of the swale side slopes that are not wetted by the design event are SPA, not RPA.

Along with accurately representing the extents and locations of RPAs to account for infiltration losses due to disconnected area, selection of soil infiltration parameters for pervious areas also may have significant effects on peak runoff rates and volumes. The values for infiltration parameters presented in Table 6-7 of the *Runoff* chapter of the USDCM for Hydrologic Soil Groups A, B and C/D are appropriate for flood modeling. For water quality events and channel forming events, infiltration rates for pervious areas may be adjusted based on site-specific data or soil permeability data from the NRCS Web Soil Survey to more accurately represent infiltration capabilities of pervious areas.

4.2.2 Conveyance Losses

EPA SWMM provides several options for evaluating conveyance losses that occur with permeable conveyances including vegetated swales and buffers. The option that is most compatible with the CUHP-SWMM modeling approach recommended by MHFD is the constant loss rate approach, which specifies constant infiltration rates for conveyance elements based on soil characteristics. To use this approach, the constant infiltration rate for the conveyance element (link) should be set to the saturated hydraulic conductivity for the type of soil underlying the swale or buffer area. Determine this value based on field measurements. In areas where the NRCS Web Soil Survey provides reliable data (e.g., undeveloped land), the Soil Survey may also be used for this purpose. In reality, infiltration will begin at an initial rate and decay to the final rate (saturated hydraulic conductivity); however, sensitivity analysis using typical decay coefficients from the *Runoff* chapter shows that the decay to the final rate is fairly rapid and that over a multi-hour runoff event, the saturated hydraulic conductivity is a reasonable and slightly conservative estimate of infiltration potential.

4.2.3 Detention and Water Quality Features

SWMM provides a seepage option for storage nodes to account for infiltration that occurs while runoff is stored in a water quality or detention facility. When using this option, the infiltration rate should be set to the saturated hydraulic conductivity based on field testing of the underlying soils. If evaluating long-term performance, consider further reducing the rate to account for clogging of pores due to sedimentation that will occur over time. Only use seepage losses in detention and water quality features when evaluating water quality events (not flood events) and when supporting infiltration data are available to justify parameter selection. Additionally, where underdrains are used, do not equate flow discharged from underdrain with infiltration.

4.3 UD-BMP Runoff Reduction Spreadsheet

Another approach for quantifying site-scale volume reduction is a simplified approach that is based on SWMM modeling of thousands of variations of UIA and RPA combinations with varying slopes, geometry, infiltration characteristics, roughness and depression storage. Based on this modeling analysis, MHFD developed a multi-variable regression equation that calculates volume reduction for the WQCV based on input parameters including UIA, RPA, DCIA, and SPA, Hydrologic Soil Groups, the average RPA slope and the UIA:RPA interface width (Piza and Rapp 2018). The regression equation is incorporated into the UD-BMP workbook on the Runoff Reduction tab. The spreadsheet provides a simple tool that can be used to demonstrate compliance with the Runoff Reduction Standard in the MS4 General Permit. This spreadsheet is intended for application at the site scale rather than the watershed scale. Additional information on this spreadsheet, including a design example, are located in Fact Sheet T-0, *Quantifying Runoff Reduction* which is in Chapter 4 of this manual.

4.4 Other Types of Credits for Volume Reduction BMPs/LID

In addition to facility sizing reduction credits following the quantitative procedures in Section 4.0, communities can also consider other incentives to encourage volume reduction practices. Such incentives will depend on the policies and objectives of local governments. Representative examples include:

- Stormwater utility fee credits.
- Lower stormwater system development fees with certain minimum criteria.
- Density bonuses that allow greater residential densities with the implementation of LID techniques.
- Variances for requirements such as number of required parking spaces or road widths.
- Flexibility in bulk, dimensional and height restrictions, allowing greater building heights and floor area ratios, reduced setbacks and others.
- Fast-tracking the review process to provide priority status to LID projects with decreased time between receipt and review. If LID projects typically result in a longer review process, ensure equal status.
- Publicity, such as providing recognition on websites, at Council meetings and in utility mailers.
- Opportunities for grant funding for large public projects serving as demonstration projects.
- Sustainable SITES Initiative or LEED credits.
- Flexibility with landscaping requirements (i.e. allowing vegetated BMPs to count toward landscape requirements or allowing BMPs in the right-of-way).

5.0 Example Calculation of WQCV

Calculate the WQCV for a 1.0-acre sub-watershed with a total area-weighted imperviousness of 50% that drains to a rain garden:

1. Determine the appropriate drain time for the type of BMP. For a rain garden, the required drain time is 12 hours. The corresponding coefficient, *a*, from Table 3-2 is 0.8.

2. Either calculate or use Figure 3-2 to find the WQCV based on the drain time of 12 hours (a = 0.8) and total imperviousness = 50% (I = 0.50 in Equation 3-1):

   $$\text{WQCV} = 0.8(0.91(0.50)^3 - 1.19(0.50)^2 + 0.78(0.50))$$

   $$\text{WQCV} = 0.17 \text{ watershed-inches}$$

Calculate the WQCV in cubic feet using the total area of the sub-watershed and appropriate unit conversions:

$$WQCV = 0.17\ w.s.in. \cdot 1\ ac \cdot \frac{1\ ft}{12\ in} \cdot \frac{43560\ ft^2}{1\ ac} \approx 600\ ft^3$$

6.0 Conclusion

This chapter provides the computational procedures necessary to calculate the WQCV and adjust imperviousness values used in these calculations due to implementation of LID/MDCIA in the tributary watershed. The resulting WQCV can then be combined with BMP-specific design criteria in Chapter 4 to complete the BMP design(s).

7.0 References

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CHAPTER 4
TREATMENT SCMS

Contents

Tables

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1.0 OVERVIEW

MHFD has established design criteria, procedures, and details for stormwater control measures (SCMs) providing treatment of post-construction urban runoff. SCMs provide treatment through a variety of hydrologic, physical, biological, and chemical processes. Functions provided by SCMs include runoff volume reduction, treatment, and slow release of the water quality capture volume (WQCV) in keeping with Steps 1 and 2 of the Four Step Process discussed in Chapter 1 of Volume 3. These SCMs can be designed to meet design standards in the Colorado Municipal Separate Storm Sewer System (MS4) General Permit related to runoff reduction, WQCV, and pollutant removal. Some SCMs may be capable of meeting permit standards as stand-alone practices, while others can help to satisfy the standards through a treatment train approach.

This chapter builds on concepts and procedures introduced in Chapters 1 through 3 and provides design procedures for treatment SCMs. Table 4-1 provides a qualitative overview of key aspects of the post-construction treatment SCMs included in this chapter. The table includes the degree to which the SCMs provide various functions, general effectiveness for treating targeted pollutants, and other considerations such as life-cycle costs. The table indicates which functions are provided by different types of SCMs. This distinction is important because not all SCMs provide the same functions, and some are best used as a component of a treatment train rather than as a stand-alone practice. In general, designers should first evaluate and maximize opportunities for runoff reduction SCMs followed by treatment of the Water Quality Event (WQE) using infiltration, filtration, or sedimentation processes. SCMs such as basins that store and release runoff as surface discharges can provide effective treatment and are appropriate on many sites, especially when combined with upgradient runoff reduction measures and full spectrum detention.

Wherever practical, use combinations of SCMs in a treatment train approach. For example, SCMs that provide sedimentation functions can potentially improve the lifespan and reduce the maintenance frequency of filtration-based SCMs when the two SCMs are paired in series. Table 4-1 is based primarily on the International Stormwater BMP Database (www.bmpdatabase.org) and is intended for general guidance only. Specific SCM designs and site-specific conditions may result in performance that differs from the general information provided in the table. SCM performance and monitoring results can also vary widely depending on the monitoring protocols, analytical methods, and many other variables. In some cases, SCMs may be able to reduce pollutant concentrations, but this does not necessarily mean that the SCMs are able to treat runoff to numeric stream standards. For example, various studies have indicated that bioretention systems, media filters, and retention ponds may be able to reduce fecal indicator bacteria concentrations and loads in urban runoff, but not necessarily meet instream primary contact recreational standards based on concentrations at the end of pipe.

After reviewing physical site constraints, the surrounding environment, treatment objectives, master plans, and other factors, the designer can select

SCMS IN VOLUME 3

Runoff Reduction

- Receiving Pervious Areas including Grass Swales and Buffers
- Roof Systems (Green Roofs/Blue Roofs[1])

Filtration and Infiltration

- Bioretention Systems
- Sand Filters
- Permeable Pavement Systems
- Manufactured Treatment Devices (Filtration)

Sedimentation

- Extended Detention Basins
- Retention Ponds and Constructed Wetland Ponds
- Manufactured Treatment Devices (Sedimentation)

[1] Blue Roofs are designed for flow attenuation rather than volume reduction

TERMINOLOGY

The term "stormwater control measure" (SCM) refers to any practice or method used to prevent or reduce the discharge of pollutants to waters of the State. SCMs include, but are not limited to, best management practices (BMPs), green infrastructure (GI), green stormwater infrastructure (GSI), and low impact development (LID).

the SCMs for implementation at the site and complete the engineering calculations and specifications for the selected SCMs. Where feasible, distribute SCMs throughout the site to maximize opportunities for infiltration and enhance community values rather than funneling all of the runoff from a site to a single SCM.

This chapter is intended to provide guidance and criteria that can be used by engineers to develop innovative designs. The chapter conveys information on how individual components within a SCM function and contribute to the overall treatment process of the SCM. The front section includes guidance and criteria for key components of SCMs that are common to many different SCM types and addresses topics related to how the SCM fits into its surrounding land uses (e.g., adding community value), site evaluation, SCM inflows, section development (aggregate sizes, media, underdrains, and related concepts), and SCM outflows. These foundational concepts are followed by fact sheets that provide guidance, design procedures, and criteria for specific SCMs. Designers should look for creative ways to incorporate SCMs into the overall landscape of the site by striving to achieve the intent of the criteria in a way that works well with site constraints. This chapter provides SCM guidance and criteria that can be used in conjunction with the WQCV and runoff reduction calculations in Chapter 3 to properly size and design an SCM based on a site's unique conditions to manage the 80th percentile runoff-producing event and satisfy MS4 permit standards for post-construction water quality treatment. For sites that drain to impaired or sensitive receiving waters or that include onsite industrial operations requiring additional treatment, implementation measures that go beyond the minimum criteria provided in the fact sheets in this chapter may be required. Additionally, local governments may have additional or different design standards than those presented in this chapter.

TIPS FOR USING THIS CHAPTER IN CONJUNCTION WITH SCM FACT SHEETS

- Use Chapters 1-3 and site assessment guidance in this chapter to select SCM type(s) for a site.
- After SCM selection, begin the design process to size the SCM. For design volumes and flow rates, cross-reference to:
  - » Chapter 3 for WQCV and WQE calculations
  - » Chapter 12 *Storage*, Volume 2 for EURV designs that integrate water quality and flood control
- Use MHFD design workbooks to complete calculations.
- For filtration/infiltration systems, use Section 4, *Filtration and Infiltration Systems*, to select section type (full infiltration, partial infiltration, no infiltration)
- Use this chapter to design SCM components:
  - » Section 5 *Inflow Features*
  - » Section 6 *Outflow Features*
- For vegetated SCMs, see Section 7 of this chapter for soil, vegetation, and irrigation guidance.
- See Chapter 6 *Maintenance* to understand long-term maintenance commitments for selected SCMs.

TABLE 4-1. GENERAL OVERVIEW OF SCMS INCLUDED IN VOLUME 3

SCM Applicability	Runoff Reduction SCMs			Filtration SCMs					Sedimentation SCMs			
	RPAs, Grass Buffers & Swales (T-1)	Green Roofs (T-2)	Blue Roofs (T-2)	Bioretention (T-3)	Sand Filters (T-4)	Permeable Pavement Systems (T-5)	High Rate Media Filtration MTD (T-8)	High Rate Biofiltration MTD (T-8)	Extended Detention Basins (T-6)	Retention Ponds (T-7)	Const. Wetland Ponds (T-7)	Hydrodynamic Separator MTD (T-8)
MS4 Permit Applicability (design dependent)												
Meets Runoff Reduction Standard	Potential[1]	Potential[1]	No	Potential[1]	Potential[1]	Potential[1]	No[2]	No[2]	No	No	No	No
Meets WQCV Capture Standard	No	Yes[1]	Potential[1]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No
Meets Pollutant Removal Standard	No	No	No	Yes[3]	Yes[3]	Yes[3]	Yes[4]	Yes[4]	Yes[3]	Yes[3]	Yes[3]	No[4]
Typical Effectiveness for Targeted Pollutants[5]												
Sediment/Solids	Medium	Low	Low	High	High	High	High	High	Medium-High	High	High	Medium
Total Phosphorus	Low-Medium[7]	Low	Low	Low-Medium[7]	Medium	Medium	High[6]	High[6]	Medium	Medium-High	Medium-High	Low
Total Nitrogen	Low[7]	Low	Low	Low-Medium[7]	Low	Medium	Medium	Medium	Low	Medium	Medium	Low
Total Metals	Medium	Low	Low	High	High	Medium	High	High	Medium	Medium-High	Medium-High	Low
Bacteria	Low	Low	Low	Medium[1]	Medium	Medium	Low-Medium	Low-Medium	Low	Medium	Medium	Low
Common Applications												
Runoff Reduction (General "Step 1")	Yes	Yes	No	Potential[1]	Potential[1]	Potential[1]	No	No[2]	No	No	No	No
Used as Pretreatment (in Treatment Train)	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes
Primary Treatment	Potential[1]	Potential[1]	Potential[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Integration with Flood Control	No	No	Potential[1]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No

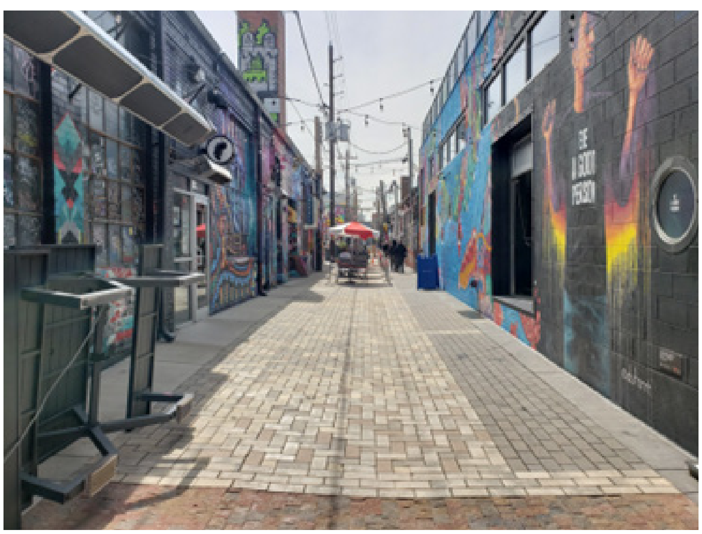
[1] Design dependent. See discussion in individual fact sheets. For runoff reduction, selection of full-infiltration, partial or no-infiltration sections affect whether runoff reduction is provided in some SCMs.
[2] The Runoff Reduction Standard is not typically met with HRMF or HRBF devices sold as-is. HRMFs and HRBFs can be designed/retrofitted with additional appurtenances, such as extra underdrain pipe(s) or a chamber on the downstream side of the device, which will detain and regulate the release of treated stormwater and allow for infiltration.
[3] Meets Pollutant Removal Standard when designed to treat the WQCV.
[4] Typical effectiveness for HDSs is based on New Jersey Department of Environmental Protection laboratory testing protocol for HDSs (NJDEP 2021), with testing requirements for specific composition and graduation, average particle size, influent concentration, required inflow rates, and other parameters. Filtration MTD performance varies based on proprietary media/filter design and targeted pollutants. "Typical" effectiveness descriptions are based on a combination of Washington Ecology's approved treatment technologies based on the Technology Assessment Protocol-Ecology (TAPE) use designation and the International Stormwater BMP Database 2020 Summary Statistics.
[5] Based on experience in Colorado supported by analysis of concentration data from the International Stormwater BMP Database (www.bmpdatabase.org)(Clary et al. 2020). Performance for particulate forms of pollutants is typically higher than for dissolved forms.
[6] Total phosphorus removal is typically high when it is specifically targeted for removal with proprietary media.
[7] When runoff volume reduction is considered, nutrients loads can be reduced. Nutrient concentrations may increase or not be reduced at discharge, depending on maintenance practices, soil conditions, and other site-specific factors.

2.0 COMMUNITY VALUES

SCMs are beneficial for protection of public health, safety, and welfare and are required by local governments that are MS4 permittees; however, these types of facilities also have significant visual and experiential impacts on their surrounding environments. These impacts can be negative or positive depending on planning and design factors including selection of the most appropriate types of SCMs for the site; proper siting of features; design details, materials, and finishes of major elements; grading/landforms; vegetation; scale; and user experience. As SCMs become more commonplace in urban and suburban environments, it is important to understand the influence these features have in the landscape and how important good design is to a positive outcome. It is important to consider how investments in water quality treatment can provide value to the community beyond the primary treatment objectives.

Some important aspects of design to achieve broader community values include:

- **Context:** The surrounding environment should greatly influence the design of associated SCMs. Aesthetics, complementary uses or opportunities, and existing features including trees, walkway widths, adjacent buildings characteristics and other factors should play a primary role in SCM selection and design. If an SCM is in a dense, bustling commercial area dominated by buildings and hardscape, a more ordered and structured approach may be suitable given the surrounding urban fabric and need to fit into more constrained spaces. If an SCM is in a less-dense, suburban context dominated by open vegetated landscape areas, a softer approach is likely more compatible. Contextual influences determine which designs appear to “fit-in” versus clash with their surroundings. Exercise extra care when designing in unique settings such as underserved communities and historical/special districts, or when adjacent to parks and open spaces, pedestrian zones, and important civic and cultural landscapes. An incompatible SCM placed into a high value landscape can greatly diminish human experiences and civic value within the entire area.
- **Scale:** The mass and scale of an SCM can have a significant influence on its compatibility with a site. In the planning and design of SCMs, take cues from the surrounding context - avoiding large monolithic forms (such as walls, pipe features, etc.) that dominate the site/space unless there is a purposeful design objective to be achieved by emphasizing the structure’s architecture. When large features/SCMs are necessary, consider breaking up large masses of walls or structures into multiple smaller elements, steps, levels, or sections to reduce the scale of the feature. Incorporating vegetation into or adjacent to the SCM can help to modify the apparent scale of these facilities in the environment by screening and breaking up the visual mass of large structures.



Photograph 4-1. Permeable pavement in an alleyway provides filtration in a space-constrained environment and provides a multi-functional area valued for more than just stormwater treatment.

Photograph 4-2. Full spectrum bioretention system at River Run Park creates a natural area that complements the manicured upland turf grass areas and provides a transition from the urban environment to the river.

Photograph 4-3. Choice of materials for bioretention system is compatible with landscaping and aesthetics of neighborhood.

Photograph 4-4. Retention pond with trails and picnic shelters creates an open space amenity in multi-family development.

- **Materials:** Materials and finishes play an important role in how infrastructure is integrated with its setting. Early in the design process, make decisions about whether an SCM should blend into its surroundings, complement nearby features, or be prominently visible. If blending into the setting is a desired objective, think about the effect of the feature's colors, texture, and material qualities in relation to its surroundings. In a more naturalized setting, using neutral colors, natural materials, and irregular textures helps a feature to blend in. For cast-in-place concrete structures, consider form liners, exposed aggregate finishes, and sand blasting to help add texture and tactile qualities, soften hard edges, and reduce stark contrasts between constructed and natural site elements. Conversely, in highly urban areas, the look of smooth concrete with crisp forms may be a more appropriate way to integrate the feature into the architectural context. Thoughtful use of tones and color is important to complement material choices. Color variation can be achieved in many ways via material or finish selection, or with the use of stains and/or integral coloring agents. In public areas, graffiti is common and should be considered when making material decisions. Heavy textures and specialized coatings can help reduce graffiti or make regular removal easier.

- **User Experience:** SCMs can be designed to enhance the experiences of people by way of appearance from near or afar, the sounds and aesthetic qualities of moving water, interpretive and educational opportunities, integration into landscapes, providing trails and gathering areas, or simply by not diminishing an otherwise nice place. This can often be achieved by considering ways to engage the curiosities of people, their movement near or on surfaces, seating, shade, or any other way to create a positive experience for a passer-by. A well designed SCM can become a popular destination for people to sit, walk across, learn something from, or be near water and interesting vegetation. Tree canopy can provide shade that enhances the user experience and helps mitigate urban heat island effects. Additionally, vegetation can provide ecosystem services (e.g., insects, birds). An experiential program can help create community values in many ways. This objective always needs to be balanced with safety-first design, and designers must avoid designs that invite people to access places where there are inherent hazards (high velocities, entrapments, drop-offs, etc.).

The SCM fact sheets that follow in this chapter provide information related to community values for design opportunities and recommendations specific to each type of SCM.

3.0 SITE ASSESSMENT

Site assessment is the first step in developing a stormwater management strategy for a project or development site. As discussed in Chapter 1, considering stormwater quality needs early in the development process based on site conditions typically leads to better stormwater management. Site conditions related to existing and proposed topography and drainage patterns, hydrology, soils, groundwater, bedrock geology, vegetation and ecological resources, utilities, and other factors must be known to determine which SCM or combination of SCMs will be most effective. Planners and designers must conduct investigations to characterize site conditions and constraints to understand the surface and subsurface characteristics of a site. Whether the SCMs selected for a site rely on infiltration or rely on storage and slow release of runoff, diligent site assessment is needed to evaluate site conditions that affect SCM selection, design, and performance. Typical site assessments and data may include:

- Topographic surveys of the project site, upstream areas that drain into the site, existing stream networks, existing SCMs, and downstream conveyance systems or overland flow paths.
- Natural Resource Conservation Service (NRCS) soils mapping.
- Geologic mapping from Colorado Geologic Survey (CGS) and other sources.
- Geotechnical exploratory borings and soils characterizations.
- Topsoil texture and agronomic properties.
- Infiltration test measurements for surface and subsoil characterization.
- Groundwater elevation data.
- Floodplain/floodway mapping from the Federal Emergency Management Agency and/or MHFD.
- Fluvial hazard zones and areas of geomorphic or geotechnical instability.
- Vegetation assessment including wetland and aquatic resources delineation.
- Evaluation of presence/absence of habitat for threatened or endangered species and other regulated species such as migratory birds.
- Studies of potential areas of contamination.
- Mapping of subsurface utilities including utility locates.
- Mapping of existing or proposed above-ground utilities and infrastructure in the vicinity of the SCM.
- Information on receiving water quality conditions such as impairment listings on Colorado's 303(d) List and total maximum daily loads (TMDLs) for receiving waters. Local governments may have specific pollutant reduction targets due to TMDLs.

FSD AND INFILTRATION/ FILTRATION SCMS

FSD can be combined with a variety of SCMs. When FSD is integrated with a filtration- or infiltration-based SCM such as bioretention or a sand filter, design the outlet to release the additional volumes associated with the EURV and 100-year storage via surface outlets consisting of orifices and/or weirs. The surface release of the EURV and 100-year volume helps to manage the hydraulic loading on the filter material and/or infiltration surface, which is primarily intended for treatment of the WQCV.

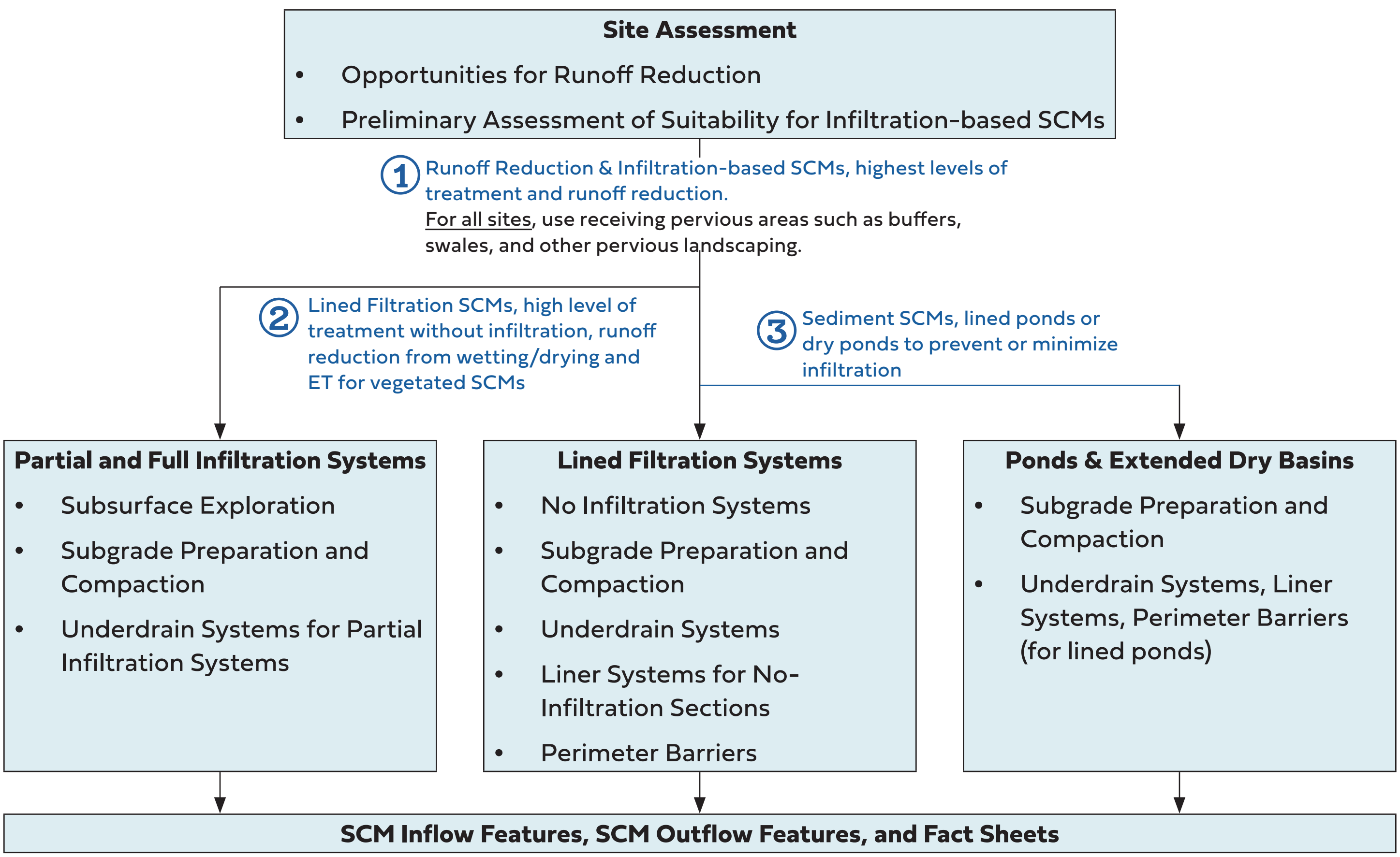
For SCMs that rely on infiltration as a primary outflow mechanism, such as bioretention, permeable pavements, grass buffers, and swales, subsurface investigations must be conducted to ensure that the soils will be suitable for infiltration of stormwater runoff over the life of the SCM. These investigations and design aspects of different types of infiltration sections are addressed in Section 4.0 *Filtration and Infiltration Systems*. Section 7.0 of this chapter addresses site assessment and design considerations for topsoil, vegetation, and irrigation.

Figure 4-1 provides a flow chart that explains how the initial site assessment leads to decisions that affect SCM selection and design (additional guidance on SCM selection is provided in Chapter 2 of Volume 3). The numbering on Figure 4-1 is provided to indicate an order of preference for the various types of SCMs, focusing first on infiltration-based SCMs that provide a high level of treatment and runoff reduction, then on filtration-based SCMs that are lined, and finally on sedimentation-based SCMs. Runoff reduction practices that direct runoff from impervious surfaces to receiving pervious areas (e.g., Step 1) should be implemented on all projects whether the primary SCM uses an infiltration, filtration, or sedimentation approach.

Use the data from the initial site assessment to first consider if the site is suitable for infiltration-based SCMs because these types of SCMs provide the most runoff reduction and high levels of treatment for many types of pollutants. If full or partial infiltration-based SCMs cannot meet all of the water quality requirements for a site or are not feasible on a site, next consider filtration-based SCMs that are lined to prevent infiltration. The physical and biochemical processes in these SCMs provide higher levels of treatment than sedimentation-based SCMs. Lastly, consider sedimentation-based SCMs including extended detention (dry) basins (EDBs), retention ponds, or constructed wetland ponds.

Depending on the results of the site assessment and the types of SCMs selected, different sections of Chapter 4 will be needed for design. Figure 4-1 lists the key sections of this chapter used for design of different types of SCMs. To design an SCM, the engineer should use the sections of this chapter listed in Figure 4-1 in conjunction with the fact sheets specific to the types of SCMs selected.

FIGURE 4-1. APPLICABLE SCM TYPES BASED ON SITE ASSESSMENT AND RELEVANT SECTIONS OF CHAPTER 4 FOR SCM DESIGN



3.1 OPPORTUNITIES FOR RUNOFF REDUCTION

Site assessments should include evaluation of opportunities for infiltration-based SCMs because these types of SCMs reduce the *rate, volume, and frequency* of runoff, while SCMs that store and release the WQCV primarily affect *the rate*. Additionally, SCMs that provide runoff reduction help to reduce pollutant loads (considering volume reduction in addition to concentration reduction). Vegetated SCMs slow and filter runoff and reduce the volume of stormwater runoff through infiltration, depression storage, and evapotranspiration. Permeable pavements and sand filters reduce runoff through infiltration without the vegetative component. To reduce the volume of runoff, impervious areas are "disconnected" to drain to receiving pervious areas (RPAs) such as buffers, swales, and other pervious areas instead of directly to gutters and storm drains. Runoff reduction practices described in this chapter may be used to meet the Runoff Reduction Standard in MS4 permits or to reduce the size of the WQCV required for other SCMs in a treatment train.

Runoff reduction is the first step of the Four Step Process for minimizing adverse impacts of urbanization as detailed in Chapter 1, *Stormwater Management and Planning*. Minimizing directly connected impervious areas (MDCIA) by allowing runoff from impervious areas to sheet flow through vegetation reduces pollutant loading to the receiving waters and helps mimic predevelopment hydrology. Runoff reduction approaches include conserving natural features such as trees, riparian corridors, and areas with permeable soils, as well as avoiding unnecessary impacts by not adding more impervious areas than necessary. These practices enhance site aesthetics and can be amenities that connect the built and natural environments when integrated with landscaping.

During a site assessment, it is important to identify stream corridors and other areas that can be preserved to provide canopy interception, depression storage, and infiltration and to identify areas with soils that are most suitable for infiltration-based SCMs. This information should be gathered and analyzed as a part of the layout of roads and buildings so that features that reduce the volume, rate, and frequency of stormwater runoff can be preserved to the extent practical and created where these types of SCMs will be most effective.

SUITABILITY FOR INFILTRATION-BASED SCMS

Infiltration-based SCMs can be used in many settings; however, the effects of infiltration on surrounding structures and infrastructure must be carefully evaluated. Consult with a geotechnical engineer when designing infiltration-based SCMs adjacent to roadways, building foundations, or near steep slopes.

Some infiltration can be achieved even on low permeability sites by using a partial infiltration section. A no infiltration section with a liner and underdrain may be used in situations where infiltration into underlying soils must be avoided, providing treatment by filtration.

3.2 PRELIMINARY ASSESSMENT OF SUITABILITY FOR INFILTRATION-BASED SCMS

Perform assessments in the early planning stages of site development to determine if the site is suitable for infiltration-based approaches that reduce the volume of stormwater runoff. This preliminary assessment will help inform the detail appropriate for the initial subsurface investigation described in Section 4.2.1. Because infiltration-based SCMs provide many benefits such as reducing runoff, achieving a high level of treatment, and adding value to the surrounding community, MHFD strongly encourages planners and engineers to integrate these types of SCMs into the early planning stages of a project. Without early coordination between site planners and stormwater designers, site layout constraints may result in using a less functional SCM.

Prior to conducting subsurface explorations, review geologic and geotechnical information to assess near-surface soil, bedrock, and groundwater conditions that may be encountered, along with anticipated ranges of infiltration rates for those materials. Obtain available hydrologic and geologic information on the near-surface soils and bedrock from published NRCS data, USGS maps, CGS maps, and other sources (Hart, 1974; Himmelreich, 1999; Noe et al., 1995; White et al., 2008). Identify any areas of known or suspected contamination on or near the site that may have the potential to affect water quality either through soils that are exposed during construction of the site or from infiltration of runoff into soils with existing contamination. Review any Environmental Site Assessments (ESAs) conducted for the site and consider hiring an environmental professional to perform a Phase I ESA if a recent one is not available. Potential resources for screening for known or suspected contamination are provided in Table 4-2. This information aids in planning detailed site investigations which may include geotechnical borings, soil testing, and infiltration measurements.

In addition to assessing subsurface conditions, stability of the upstream drainage areas and anticipated sediment loads are also factors that affect suitability of filtration and infiltration-based SCMs for a site. Where high sediment loads are present, such practices may require additional pretreatment to reduce sediment loads.

TABLE 4-2. RESOURCES FOR IDENTIFICATION OF KNOWN OR SUSPECTED CONTAMINATION ON PROJECT SITES AND WITHIN A 1-MILE RADIUS [1]

MAP/DATABASE	DESCRIPTION
CDPHE Environmental Records Map	Colorado Department of Public Health and Environment (CDPHE) Database and map including solid waste facilities, Voluntary Cleanup (VCUP) sites, sites with institutional controls such as covenants required by the state, brownfield sites, National Priority List (NPL) sites, Resource Conservation and Recovery Act (RCRA) sites, Uranium Mill Tailings Remedial Action (UMTRA) program sites.
OPS Petroleum Release Events in Colorado	Underground Storage Tank (UST) system and Aboveground Storage Tank (AST) system petroleum release events, with their associated locations, contacts for remediation, and status in relation to currently being investigated, assessed, remediated, obtaining closure, or closed, dating back to 1986. Data provided by the State of Colorado, Department of Labor and Employment, Division of Oil and Public Safety (OPS).
Denver Area Historical Fill Areas	Database and mapping of historical fill sites in and near Denver, including portions of Commerce City, including historical dump sites.
Sanborn Fire Insurance Rate Maps of Colorado	The Sanborn Fire Insurance Maps of Colorado is a digital collection of Sanborn fire insurance maps of cities across Colorado. The collection contains 346 maps of 79 principal cities in 52 counties covering the years 1883-1922. These maps are useful for identifying historical land uses associated with potential contamination.

[1] These resources are provided for reference purposes only. This is not intended to be a comprehensive list of resources. Use these as an initial screening tool only. If there is known or suspected contamination on or near a site, identify such conditions through appropriate tools including the ones listed above, others, or an Environmental Site Assessment conducted by a qualified environmental professional and coordinate, as necessary, with appropriate regulatory agencies.

4.0 FILTRATION AND INFILTRATION SYSTEMS

Filtration and infiltration systems reduce runoff volume and pollutants by filtering runoff through porous media and, when conditions are suitable, infiltrating the runoff into the underlying soils. In areas where infiltration is undesirable, locate systems where more favorable conditions exist or design systems with impermeable liners.

To evaluate the potential to use infiltration-based SCMs, consult with a geotechnical engineer during the initial site assessment and consider the risks of infiltration, even when an impermeable liner is used, based on subgrade conditions and potential structure impacts as described herein. Table 4-3 summarizes applicable SCM filtration and infiltration approaches for the three basic subsurface cross sections that are shown in Figure 4-2. These cross-sections and the discussion below apply to bioretention, sand filters and permeable pavements.

TABLE 4-3. SUBSURFACE CONDITIONS AND APPLICABLE SCM FILTRATION AND INFILTRATION SYSTEMS

SUBSURFACE CONDITIONS AND RISKS OF INFILTRATION[1]	APPLICABLE SCM APPROACH			
	FULL INFILTRATION SYSTEM (NO LINER OR UNDERDRAIN)	PARTIAL INFILTRATION SYSTEM (UNDERDRAIN, NO LINER)	NO INFILTRATION SYSTEM (LINER AND UNDERDRAIN)	AVOID (LOCATE SCM IN AN AREA WITH LOWER RISK)
Low to moderate risks	Must verify adequate subgrade infiltration rates	Acceptable		
Moderate risks			Requires careful QA/QC to ensure liner integrity	Consider an alternative SCM location
High risks				Find alternative SCM location

[1] Verify with geotechnical engineer.

4.1 TYPES OF FILTRATION AND INFILTRATION SYSTEMS

4.1.1 FULL INFILTRATION SYSTEMS

Full infiltration systems can be used when the measured infiltration rate is at least 1 inch per hour and the subgrade of the SCM is approximately 3 feet or more above seasonal high groundwater or bedrock. When seasonal high groundwater is within 5 feet of the subgrade, consider more detailed monitoring of groundwater conditions before selecting a full infiltration system. Measure infiltration rates at the approximate depth of the proposed infiltration surface per Section 4.2 *Subsurface Exploration*. The minimum rate of 1 inch per hour accounts for some uncertainty in subsurface conditions and potential for some limited inadvertent compaction during construction. However, infiltration rates are critical to these SCMs so take measures to avoid mixing, disturbing, and compacting soils unnecessarily in the SCM area. In some cases where the SCM has little run-on (e.g., a permeable pavement system with a low ratio of UIA:RPA), a full infiltration system may be used with lower measured infiltration rates at the discretion of the designer.

A conservative design of a full infiltration system could use the partial infiltration section with the addition of a valve or removable plate or plug at the underdrain outlet. If infiltration rates are lower than expected following construction or decline significantly over time, the valve could be opened, or plate/plug removed, to allow the system to operate as a partial infiltration section.

4.1.2 PARTIAL INFILTRATION SYSTEMS

Partial infiltration systems are applicable in many settings when the conditions listed in Section 4.1.1 do not exist. Partial infiltration systems do not include impermeable liners and allow for infiltration but do include an underdrain system to collect and drain water that that does not infiltrate into the subgrade. MHFD recommends a partial infiltration system where infiltration rates do not meet the criteria for a full infiltration system and a no infiltration system is not warranted.

4.1.3 NO INFILTRATION SYSTEMS

No infiltration systems include an underdrain and an impermeable liner intended to prevent infiltration of stormwater into the subgrade soils. Consider using a no infiltration system when any of the following conditions exist:

- The site is a stormwater "hotspot" (e.g., an area where pollutants may be highly concentrated such as an industrial storage area or drive-through lane) and infiltration could result in contamination of groundwater.
- The site is located above or adjacent to contaminated soils or groundwater where infiltration could mobilize those contaminants, resulting in groundwater contamination or pollutant mobilization.
- The facility is located over potentially expansive soils or bedrock that could swell due to infiltration, or potentially collapsible soils that could settle due to infiltration, potentially damaging adjacent structures including buildings and/or overlying hardscape areas or pavement.
- The facility is located above the foundation wall backfill placed against buildings with basements or below-grade levels. For this condition, a liner may only need to extend 10 feet beyond the wall before transitioning from a lined system to a partial or full infiltration system.
- The facility is located at the top of or on a slope steeper than 3 (horizontal):1 (vertical) that could become unstable when the soils are saturated. During the geotechnical investigation, evaluate the potential for landslides triggered by saturation of the site soils in such cases.

Depending on the severity of consequences of a no infiltration section liner leaking over time (i.e., structural damage, spreading of contamination, shallow groundwater conditions that may float the liner resulting in ground heave, etc.), even a no infiltration section may not be appropriate. In these cases, move the SCM away from the conditions of concern as indicated for high risks in Table 4-3.

4.2 SUBSURFACE EXPLORATION

Subsurface exploration provides valuable site characterization for determining the appropriate type of subsurface filtration and infiltration system for a given location. If the location is constrained by shallow bedrock or shallow groundwater, a no infiltration, partial infiltration section, or store-and-release SCMs may be more suitable than SCMs that rely on infiltration

HIGH, MODERATE, AND LOW RISKS

Infiltration of stormwater has the potential to cause damages in some settings, and the potential for damages defines the level of risk. High risk is generally defined by the potential for major structural damage (i.e., swelling soils heaving foundations or roads). Moderate risk is defined by the potential for lesser damage that can be mitigated be using a lined system. Low risk areas are those where infiltration is acceptable and the risks primarily arise from uncertainty in actual infiltration rates rather than the potential for structural damage.

into the subgrade as the primary outlet. Low permeability soils may also present challenges for infiltration-based SCMs; however, when properly designed, partial infiltration-based SCMs with underdrains can still provide significant runoff reduction, even in areas with less permeable soils.

Apply the following guidelines to characterize infiltration capabilities of a site and as a preliminary step in determining the appropriate type of filtration and infiltration system:

- Drill exploratory borings or excavate exploratory pits to characterize subsurface conditions beneath the subgrade and develop requirements for subgrade preparation. The borings or pits will identify changes in subsurface conditions spatially and with depth, particularly with respect to physical properties and hydrologic soil groups.
  - Drill or excavate at least one boring or pit for every 160,000 ft^2 of site area and at least two borings or pits for sites less than 160,000 ft^2.
  - Extend borings or pits to a depth of at least 5 feet into the subgrade below the bottom of the base of the SCM. Extend borings at least 25 feet below the bottom of the SCM in areas where there is a possibility of encountering potentially expansive soils or bedrock that could affect structures.
  - Additional borings or pits at various depths may be recommended by the geotechnical engineer in areas where soil types may change, in low-lying areas where subsurface drainage may collect, or where the water table is likely within 8 feet below the planned bottom of the base or top of subgrade of the SCM.
- Perform laboratory tests on samples obtained from the borings or pits to initially characterize the subgrade and use the information to recommend the possible infiltration section type. For permeable pavements, assess subgrade conditions for supporting traffic loads. Consider the following tests:
  - Moisture content (ASTM D2216), dry density (ASTM D7263), Atterberg limits (ASTM D4318), gradation (ASTM D6913), and hydrometer analysis (ASTM D7928) as needed to characterize the hydrologic soil type and engineering index properties of the subgrade soils.
  - Swell-consolidation (ASTM D4546) for assessing the swell potential of clayey soil or bedrock.
  - R-value (ASTM D2844) and/or 96-hour soaked California bearing ratio (CBR) (ASTM D1883) for assessing subgrade soils for permeable-pavement traffic loading.

Laboratory hydraulic conductivity tests may also be considered for assessing infiltration rates and hydrologic soil type, although field hydraulic tests generally will provide more accurate results.

A geotechnical engineer should determine the appropriate test method based on the soil type and the intended purpose of the SCM. Field infiltration tests or percolation tests can be considered for initial assessment. However, more definitive testing is necessary for final design of the SCM. Additional guidance follows for initial assessment and final design.

INVOLVE A GEOTECHNICAL ENGINEER

SCMs used for infiltration adjacent to buildings, hardscape, or conventional pavement areas can adversely impact those structures if protective measures are not provided. Oversaturated subgrade soil can cause structures to settle or result in moisture-related problems. Wetting of expansive soils or bedrock can cause those materials to swell, resulting in structural movements.

Consult with a qualified geotechnical engineer when planning an infiltration-based SCM. This is necessary to select the appropriate system type and establish minimum distances between the SCM and structures of concern or provide recommended measures to mitigate potential impacts. A geotechnical engineer also can assist in estimating the range of surface and subgrade infiltration rates to be used for design based on laboratory testing that identifies the hydrologic soil type and field infiltration testing that estimates in-situ rates of infiltration.

4.2.1 INITIAL ASSESSMENT

For initial assessment of filtration SCMs, a percolation test method such as that used by the State of Michigan (SEMCOG, 2008) can be performed in open boreholes or pits following exploration to initially assess the range of infiltration rates for the subgrade soils for facilities that will infiltrate water from engineered media to the subgrade soils. This is particularly useful for sites where the location of the SCM and the subgrade soil horizon beneath the SCM have not yet been identified and/or exposed by excavation. Testing should be conducted for locations of all SCMs that may have a full infiltration system.

Other infiltration testing methods (such as a Turf-Tec infiltrometer or similar device) may be used for preliminary characterization of comparative infiltration rates or to help determine the most appropriate lower-infiltration area to perform the more definitive ASTM D3385 or ASTM D8152 tests discussed below. These methods are suitable for runoff reduction practices infiltrating flows from the land surface when properly applied but are not acceptable for quantification of infiltration rates for design of SCMs with partial or full infiltration sections.

4.2.2 FINAL DESIGN

For final design of a full infiltration SCM, perform the Modified Philip Dunne infiltrometer test (ASTM D8152) or double-ring infiltrometer tests (ASTM D3385):

- Perform at least one test for every 10,000 ft^2 of SCM area and no fewer than two tests per SCM location.
- Locate tests within the footprint of the planned SCM at the elevation of the proposed subgrade, if possible. This may require excavation of test pits to reach the subgrade.
- When feasible, conduct tests near the locations of completed borings so the test results can be compared to the subsurface conditions encountered below the subgrade horizon in the borings.
- Locate at least one test near the boring or pit showing the most unfavorable subgrade conditions for infiltration. The boring or pit can be one of those completed as part of the initial assessment, or a boring or pit from supplemental exploration that may be needed for final design.

Consult a qualified geotechnical engineer to see if additional exploration is needed.

Infiltration rate for design should be based on careful assessment of the subgrade conditions, classification of the hydrologic soil groups based on exploration and laboratory testing, and field infiltration testing. Be aware that actual infiltration rates are highly variable dependent on soil type, in-place density, moisture content, and degree of compaction (including over-compaction that can occur during construction), as well as other environmental and construction influences. Actual infiltration rates can differ by an order of magnitude or more from those indicated by infiltration or permeability testing, and a reasonable degree of conservatism is necessary when selecting the design infiltration rate.

4.3 FILTRATION AND INFILTRATION SECTION DEVELOPMENT

4.3.1 GENERAL CONSIDERATIONS

General requirements, design considerations, and construction considerations for filtration and infiltration-based SCMs are presented below. See specific SCM fact sheets for additional guidance and criteria. To the extent that guidance in the fact sheets differs from the general guidance in this section, follow the more-detailed guidance in the fact sheet. General differences between sections developed for no infiltration, partial infiltration, and full infiltration types are shown on Figure 4-2 and summarized below. Further detail and material specifications are provided in the next section.

- A **full infiltration section** is designed to infiltrate all of the WQCV into the subgrade and does not include an underdrain system or a liner. If there are localized areas of the SCM where the SCM material is not filter-compatible with the subgrade, do not use geotextiles. Rather, place a minimum 6-inch transition filter in these areas. In some cases, a full infiltration section may be constructed with an underdrain that is plugged or controlled with a valve to allow the system to be converted to a partial infiltration if infiltration into the subgrade is not adequate.

- A **partial infiltration section** allows for infiltration into the subgrade but also includes an underdrain to slowly release water that does not infiltrate. This section includes a geotextile filter fabric (Mirafi 180N or equal) along the bottom and the sides of the drainage trench holding the underdrain pipe and drain gravel. The filter fabric is used to prevent finer subgrade soils that are not filter-compatible with the drain gravel from migrating into the gravel and eventually into the pipe. In the unusual condition that the subgrade soil below the base of the SCM consist of coarse gravels and cobbles that are not filter compatible with the overlying SCM materials, place a minimum 6-inch-thick transition filter between the SCM and the underlying layer. For example, in a localized area where the underlying subgrade is composed of gravel, cobbles, and boulders and there is a potential that bioretention growth media could migrate through the voids of the subgrade, consider placement of a 6-inch transition filter that is compatible with both the growth media and the subgrade. Filter sand like that used above the underdrain trench may be used, provided it is filter-compatible with the subgrade. If not, a coarser transition filter material may be needed. Procedures for assessing the filter-compatibility between soils for dams (USDA, 2017) can be used to design a proper transition filter if needed. Using a geotextile filter fabric in place of a minimum 6-inch-thick transition filter is generally not recommended because the fabric could bridge or "tent" over the underlying cobbles and boulders, resulting in voids beneath the fabric. This can cause the unsupported fabric to tear and result in settling of the overlying filter/drainage system and SCM.

- A **no infiltration section** is designed to prevent infiltration into the subgrade and includes a liner and underdrain system designed to gravity-drain water captured by the SCM to an outfall or discharge point. In accordance with criteria below, use a PVC geomembrane with a minimum thickness of 30 mil for the buried liner, and place a protective, non-woven geotextile fabric (Mirafi 180N or equivalent) above the geomembrane to protect the geomembrane from punctures and tears during placement and construction of the overlying filter/drain system and SCM. Consider using a similar geotextile beneath the geomembrane if there are sharp rocks or objects beneath the liner that cannot be removed during subgrade preparation. Other liner systems may be approved by local governments.

4.3.2 SUBGRADE PREPARATION AND COMPACTION

Subgrade preparation and compaction are critical elements of SCM design and construction. Subgrade compaction is needed to prevent settling in no infiltration systems and in load bearing systems, but for partial and full infiltration systems that are not subject to vehicular loads, only limited compaction of the subgrade is recommended to preserve the infiltration characteristics of the subgrade. Different criteria apply depending on the type of filtration and infiltration system and the type of SCM.

For SCMs that require subgrade support (e.g., pavements), scarification and compaction should be provided in accordance with the pavement requirements. Scarification of the upper 6 to 8 inches of subgrade, moisture-conditioning, and recompaction of the subgrade are typically required for subgrade preparation prior to constructing any pavement section, including conventional flexible pavements, or permeable pavements. Scarification is beneficial in providing a more uniformly moisture-conditioned and densified subgrade. It also allows the engineer to observe a proof-roll of the compacted subgrade to identify local soft areas that deflect under compaction that need additional work.

No Infiltration Systems: For a no infiltration system, specify compaction to at least 95 percent of Standard Proctor Compaction (AASHTO T99) at a moisture content within 2 percentage points of the optimum moisture content. Alternatively, specify compaction of the subgrade with several passes of compaction equipment that provides a level of compaction equivalent to at least 95 percent of Standard Proctor. Consult with a qualified geotechnical engineer regarding the compaction equipment and number of passes. These criteria are also applicable for lined basins and ponds.

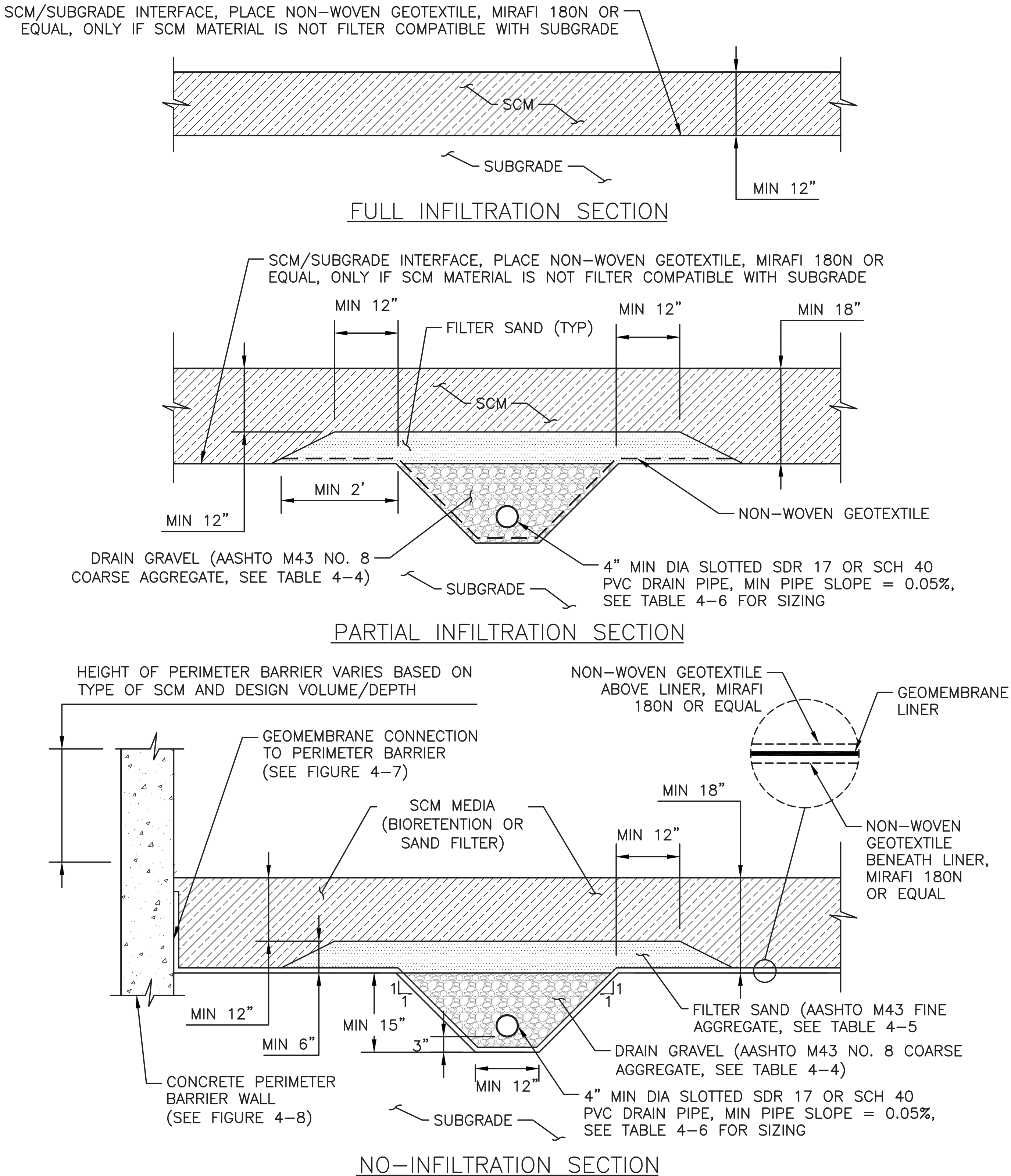


FIGURE 4-2. CONCEPTUAL CROSS SECTIONS FOR FULL, PARTIAL, AND NO INFILTRATION SYSTEMS
SECTION VIEW (NOT TO SCALE)

Partial and Full Infiltration Systems: For partial and full infiltration sections, scarify the subgrade to a minimum depth of 12 inches and level the surface. Provide only limited compaction, where necessary, to limit settlement of the SCM.

For partial and full infiltration sections, place equipment outside limits of the SCM or use low-ground-pressure (LGP) tracked equipment for subgrade grading to limit subgrade compaction.

Refer to the SCM fact sheets in this chapter for specific compaction requirements for different types of SCMs. For SCMs such as permeable pavements that include coarse aggregates, those materials may not be testable for compaction using a method based on specified density (e.g., nuclear density testing). Consider a method specification (e.g., number of passes of a specified vibratory compactor) for those materials. The appropriate number of passes is dependent on the type of equipment and depth of the layer.

4.3.3 UNDERDRAIN SYSTEMS

An underdrain system is required for no infiltration and partial infiltration sections. An underdrain system consists of a slotted PVC pipe placed within a layer of drain gravel consisting of a crushed rock that satisfies gradations requirements for AASHTO M 43 No. 8 aggregate in accordance with Table 4-4. Specify that this be washed or otherwise ensure it contains minimal fines. Do not use rounded or sub-rounded aggregate, sometimes referred to as pea gravel, because it can move under compaction or when stepped on or loaded with construction equipment. Compaction of the drain gravel placed above the underdrain pipe in the confined trench shown on Figure 4-2 typically is not required because that confined material will be adequately densified by compaction of the material placed above it. Place a minimum 6-inch-thick layer of filter sand above the drain gravel and underdrain pipe and extend at least 12 inches beyond the limits of the drain trench. The filter sand must satisfy gradation requirements for AASHTO M 43 fine aggregate material based on the gradation limits in Table 4-5. This table differs from the Class C filter material specified in previous editions of this manual.

TABLE 4-4. GRADATION SPECIFICATIONS FOR AASHTO M 43 NO. 8 COARSE AGGREGATE (DRAIN GRAVEL) (SOURCE: CDOT TABLE 703-1)

SIEVE SIZE	MASS PERCENT PASSING SQUARE MESH SIEVES
12.5 mm (1/2”)	100
9.5 mm (3/8”)	85 – 100
4.75 mm (No. 4)	10 – 30
2.36 mm (No. 8)	0 – 10
1.18 mm (No. 16)	0 - 5

TABLE 4-5. GRADATION SPECIFICATIONS FOR AASHTO M 43 FINE AGGREGATE (FILTER SAND)

SIEVE SIZE	MASS PERCENT PASSING SQUARE MESH SIEVES
9.5 mm (3/8”)	100
4.75 mm (No. 4)	95 – 100
2.36 mm (No. 8)	80 – 100
1.18 mm (No. 16)	50 – 85
600 μm (No. 30)	25 – 60
300 μm (No. 50)	10 – 30
150 μm (No. 100)[1]	0 – 10
75 μm (No. 200)[1]	0 - 3

[1] Slight variation from CDOT Table 703-1

Use factory-slotted pipe consisting of a minimum 4-inch (inside diameter) Schedule 40 or SDR 17 PVC pipe. Do not use perforated pipe or pipe that is hand-slotted. A slotted 6-inch inside diameter Schedule 40 or SDR 26 pipe can be used to allow larger access for video-inspecting the pipe. SDR pipe includes bell-and-spigot joints that provide more joint

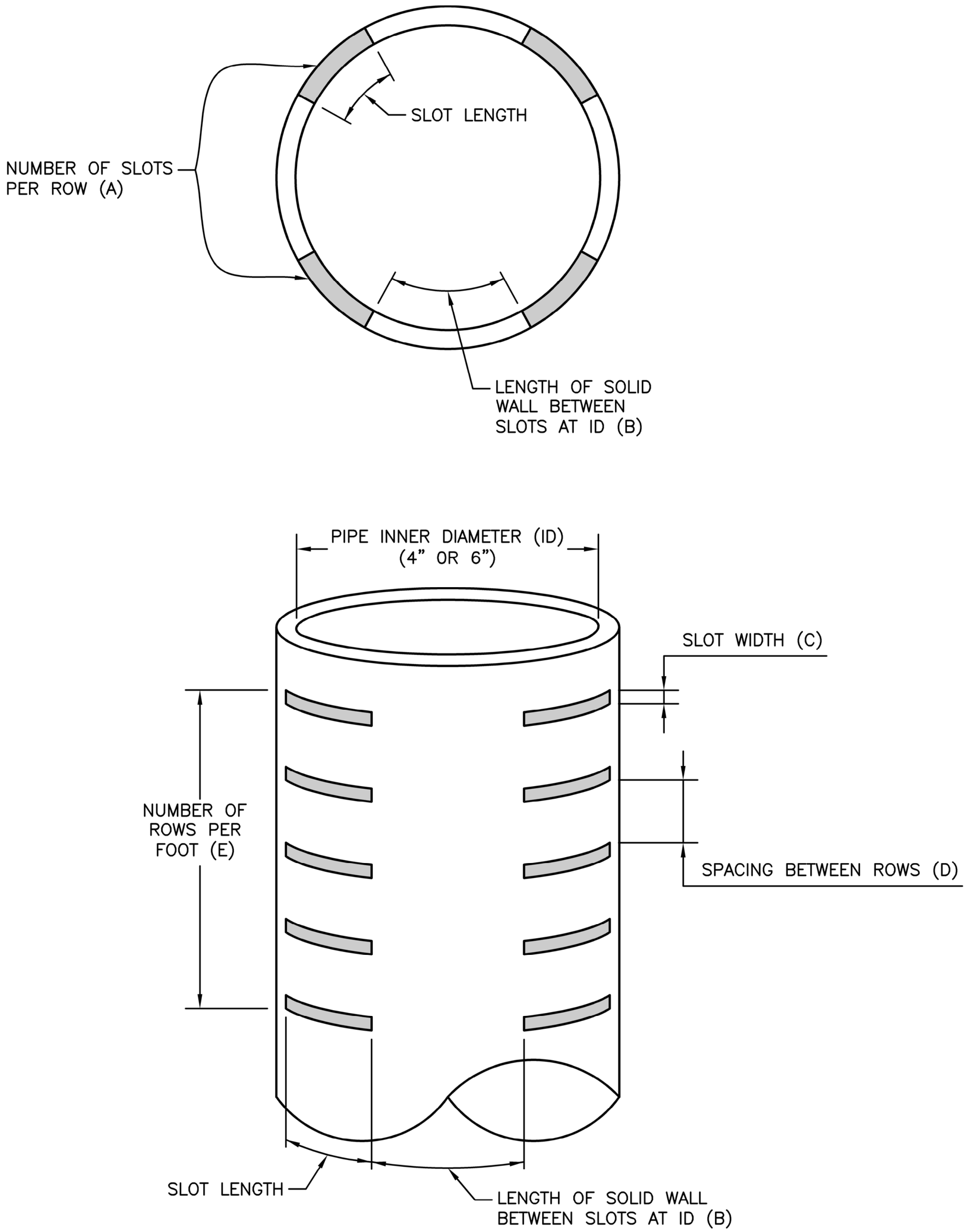


FIGURE 4-3. SLOT CONFIGURATION OF PVC UNDERDRAIN PIPE
(NOT TO SCALE)

flexibility, whereas Schedule 40 pipe requires gluing the couplings, which provides less flexibility at the coupling. This may not be problematic provided that the pipe is well seated in the drain gravel.

Figure 4-3 and Table 4-6 provide recommended configurations of slot rows, widths, lengths, and spacing. Calculate the underdrain open area to verify conformance with the minimum and maximum values provided in Table 4-6. Recommendations aim to provide adequate open area to accept design flow rates while maintaining slot dimensions that retain pipe strength and are compatible with the No. 8 aggregate (USACE, 1984).

Compact the filter sand above the underdrain using a walk-behind vibratory plate compactor in a single, approximately 8-inch-thick loose lift to achieve the minimum compacted thickness of 6 inches measured in place. Compact the filter sand to between 65% and 75% of relative density (ASTM D4253 and ASTM D4254). Do not over-compact the filter sand because this could cause the sand particles to break down, increasing the fines content (percent passing the No. 200 sieve) of the material.

TABLE 4-6. SLOT CONFIGURATION FOR PVC UNDERDRAIN PIPE

GEOMETRY	MINIMUM	MAXIMUM
Number of slots per row (A)	4	6
Length of solid wall between slots at ID (B), inches	1.0	2.0
Slot width (C), inches	0.060	0.100
Spacing between rows (D), inches	0.25	1.0
Rows per lineal foot (E)[1]	11	36
Open area per lineal foot[2] (square inches)	6.0	20.0

[1] Average based on slots over 19' of each 20' length of pipe

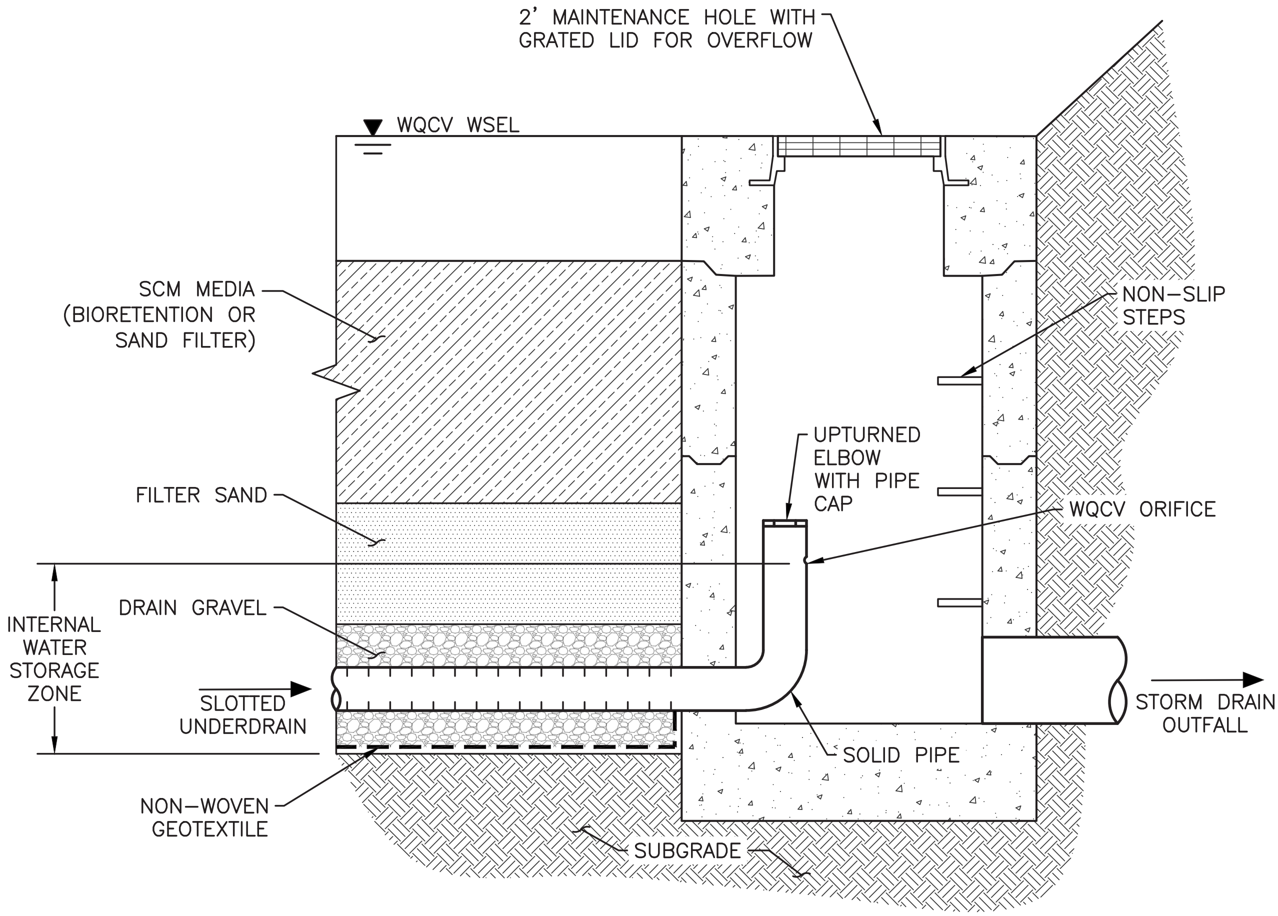
[2] Open area per lineal foot (sq in) = (3.14 * (ID) - (A) * (B)) * (C) * (19/20 * 12/(C+D))

When using an underdrain system, provide a control orifice sized to drain the design volume in 12 hours or more in accordance with the drain time criteria in the SCM fact sheets. Consider a minimum orifice diameter of 3/8-inch to avoid clogging. When drilling orifices into a removable weir plate such as with an Agri Drain Inline Water Control Structure™ outlet, smaller orifice sizes may be used on a case-by-case basis to meet required drain times. The maximum spacing of the underdrain pipes should be determined by the designer based on site-specific considerations but in general, should not exceed a maximum spacing of 30 feet on center.

INTERNAL WATER STORAGE ZONE (IWSZ)

An IWSZ can be created in bioretention systems using partial infiltration systems by adding a 90-degree elbow to the underdrain outlet to raise the elevation of the outlet and increase contact time with the media and infiltration into the subgrade (Brown et al. 2009) as shown in Figure 4-4. The top of the elbow should be at least 12 inches below the lowest elevation of the surface of the SCM in areas with highly permeable soils and 18 to 24 inches below the surface for lower permeability soils (e.g., HSGs B and C). An IWSZ may also be achieved by elevating the orifice in a flow control structure such as an Agri Drain Inline Water Level Control Structure™ (Figure 4-5).

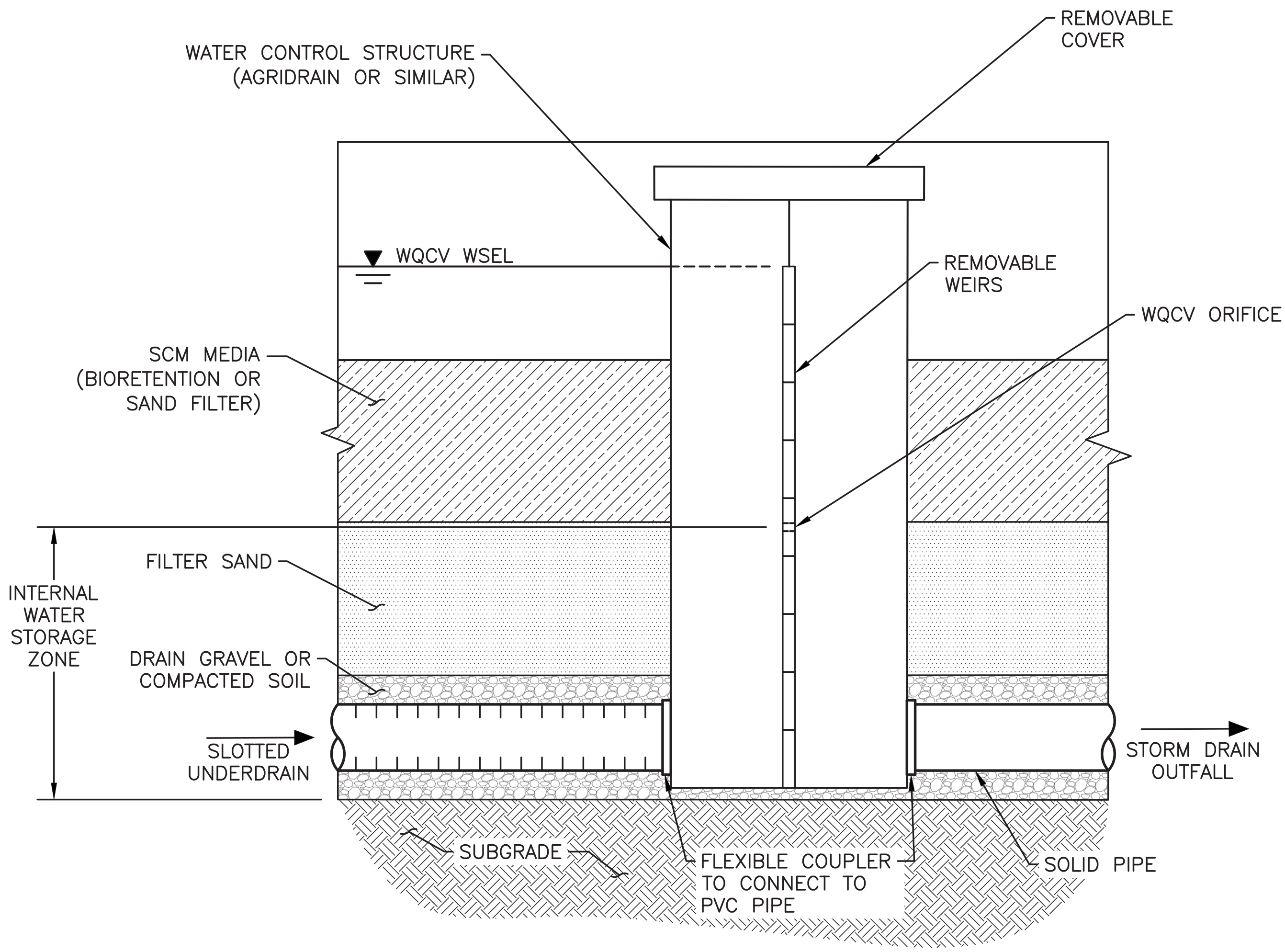
In areas with lower permeability soils, an IWSZ must be carefully evaluated based on the site-specific permeability of the subgrade and the time it will take for water to drain from the IWSZ to avoid creating a permanent (or nearly permanent) saturated condition. The pore storage in the IWSZ may be counted as a part of the WQCV provided by the SCM, assuming effective porosity of 20% for sand and 30% for aggregate. In addition to benefits of increased infiltration and media contact time, the IWSZ promotes denitrification by creating an anoxic zone in the lower layer of the SCM where nitrate removal occurs.



NOTE:

1. PARTIAL INFILTRATION SECTION SHOWN. SEE FIGURE 4-2 FOR MORE INFORMATION.

FIGURE 4-4. CONCEPTUAL CROSS SECTION FOR INTERNAL WATER STORAGE ZONE WITH UPTURNED ELBOW
SECTION VIEW (NOT TO SCALE)



NOTES:

1. PARTIAL INFILTRATION SECTION SHOWN. SEE FIGURE 4-2 FOR MORE INFORMATION.

FIGURE 4-5. CONCEPTUAL CROSS SECTION FOR INTERNAL WATER STORAGE ZONE WITH WATER CONTROL STRUCTURE
SECTION VIEW (NOT TO SCALE)

Provide clean-outs to allow camera inspection of the underdrain pipe system during and after construction to ensure that the pipe was not crushed or disconnected during construction and to allow for maintenance of the underdrain. For small systems, a single cleanout at the upstream end of the underdrain may be needed. For larger systems, multiple cleanouts may be required. Although a slotted 4-inch-diameter underdrain pipe can be video inspected, a slotted 6-inch-diameter Schedule 40 or SDR 26 pipe will allow for easier camera access for inspection and cleaning. The underdrain pipe should include vertical and horizontal bends using long-sweep elbows or elbows angled at 22.5 degrees to allow access for inspection cameras and cleaning equipment. Consider using a protective steel cover with a locking cap to protect the underdrain system from being damaged or vandalized.

4.3.4 LINER SYSTEMS FOR NO INFILTRATION SECTIONS

For no infiltration sections, install a minimum 30 mil PVC geomembrane liner on the bottom and sides of the SCM. Material specifications and physical requirements for the geomembrane liner are presented in Tables 4-7 and 4-8. Bury the geomembrane under at least 12 inches of cover material to protect the geomembrane from UV deterioration. Connect the geomembrane liner to a concrete perimeter wall, structure wall, or building foundation.

The geotextile used as a separator fabric or filter fabric should consist of a non-woven geotextile (Mirafi 180N or equal) satisfying the material specifications presented in Table 4-8.

TABLE 4-7. GEOMEMBRANE PROPERTIES

PROPERTIES	TEST METHOD	SPECIFIED VALUE
Gauge (mils, nominal)		30
Thickness (mils, min.)	ASTM D1593 (Par. 8.1.3)	28.5
Specific Gravity (min.)	ASTM D792 (Method A)	1.20
Minimum Tensile Properties (each direction)	ASTM D882 (Method A or B)	
• Breaking Factor (lbs/in)		73
• Elongation at Break (%)		380
• Modulus at 100% Elongation (lbs/in)		32
Tear Resistance (lbs, min.)	ASTM D1004 (Die C)	8
Low Temperature (deg F)	ASTM D1790	-20
Dimensional Stability (% change, max.)	ASTM D1204 (100 deg. C, 15 min.)	3
Water Extraction (% loss, max.)	ASTM D3083 (NSF 54 Modified)	0.15
Volatile Loss (% loss, max.)	ASTM D1203 (Method A)	0.7
Resistance to Soil Burial (% change, max.)	ASTM D3083 (NSF 54 Modified)	
• Breaking Factor		5%
• Elongation at Break		20%
• Modulus at 100% Elongation		20%
Hydrostatic Water Resistance (psi, min.)	ASTM D751 (Method A)	100
Water Vapor Transmission (cm/sec, max.)	ASTM D814	5.0×10^{-9}
Pinholes (number per 10 sq. yds. Geomembrane)		1
Seam Requirements		
• Bonded Seam Strength (lbs/in width, min.)	ASTM D882	58.4
• Peel Adhesion (lbs/in width, min.)	ASTM D882	15

TABLE 4-8. MATERIAL PROPERTIES FOR NON-WOVEN GEOTEXTILE USED FOR SEPARATOR OR FILTER FABRIC

PROPERTIES	TEST METHOD	SPECIFIED VALUE
Grab Tensile Strength (lbs, min.)	ASTM D4632	200
Grab Tensile Elongation (%)	ASTM D4632	50
Trapezoid Tear Strength (lbs, min.)	ASTM D4533	80
Mullen Burst Strength (psi, min.)	ASTM D3786	375
Puncture Strength (lbs, min.)	ASTM D4833	100
Apparent Opening Size (AOS) (U.S. Sieve)	ASTM D4751	80
Permittivity (sec^{-1})	ASTM D4491	1.4
UV Resistance (at 500 hours) (% strength retained, min.)	ASTM D4355	70
Weight (oz/yd^3, min.)	ASTM D5261	8

Figure 4-6 is a conceptual detail for the underdrain penetration of the liner. A detail for connecting the geomembrane to vertical concrete surfaces such as perimeter barrier walls and/or the concrete facing of buildings or other concrete structures is presented in Figure 4-7, and a detail for an example barrier wall is presented on Figure 4-8. Batten bars used to attach the liner to the concrete structure should consist of a 1/4-inch x 2-inch stainless steel bar with anchor holes at 12 inches on center and should be attached using 3/8-inch x 3-inch stainless steel anchor bolt, nut, and washer.

A perimeter anchor trench for the geomembrane may also be acceptable provided that at least 12 inches of cover material above the anchor trench is provided and that the top of the trench, marking the highest elevation of the geomembrane, provides adequate reservoir capacity for the SCM. Construction recommendations for geomembrane liner installations include:

- Field-seam the geomembrane using a single-track or double-track thermal fusion welder, and in accordance with the geomembrane manufacturer's requirements.
- Provide a 1.5-inch-wide seam for single-track welds and two nominal 0.5-inch-wide seams separated by an air test channel for dual track welds. Provide at least 6 inches of overlap between geomembrane panels for single track and dual track thermal fusion welding (PVC Geomembrane Institute [PGI], 2003).
- Install the geomembrane with some slack to prevent tearing due to backfill, compaction, and settling. Follow manufacturer's specifications related to acceptable weather conditions for installation. Do not install in the presence of standing water, mud, snow and excessive moisture, or frozen subgrade conditions.
- Prepare a smooth-rolled, level subgrade surface that is free of loose fragments greater than 2 inches in size and sharp rocks or objects that could potentially puncture the geomembrane. Both the SCM designer and geomembrane installer should inspect the subgrade for sharp rocks or objects prior to installing the geomembrane.
- Consider placement of a non-woven geotextile (Mirafi 180N or equivalent) beneath the geomembrane, in addition to the geotextile placed above it, if the subgrade surface cannot be prepared to remove sharp materials that could puncture the geomembrane. However, a bottom geotextile should only be when sharp materials are present. This is because geotextile placed under the geomembrane can allow lateral travel of leakage from local pinholes or other small defects to more permeable areas of the subgrade, potentially increasing seepage losses into the subgrade.
- Test all field seams, batten bar connections, pipe penetrations, and patches using a non-destructive air lance test. Perform destructive field seam tests to verify that the seam strength requirements of the specifications are met. Collect random samples at least every 500 linear feet (PGI, 2003) for field seams and conduct at least three tests regardless of the length of seams. Test coupons or samples cut out of the liner at selected seam locations for thickness, bonded seam strength and peel adhesion in accordance with minimum strength requirements presented in Table 4-7. Place and seam geomembrane patches used to repair the liner at each destructive sample location in accordance with the geomembrane supplier's requirements and test each patch with an air lance.

4.3.5 PERIMETER BARRIER

A perimeter barrier is used to contain the subsurface media and aggregate layers of the SCM within the footprint of the SCM. For permeable pavement systems, a perimeter barrier also serves to contain the pavers and helps to reduce the potential for differential settling of the pavement. The perimeter barrier is typically designed to minimize or prevent the subsurface lateral migration of runoff and focus infiltration into the area underlying the SCM. The perimeter barrier also serves to minimize migration of fines from surrounding soils into engineered media and aggregate. Depending on the type of the SCM and the surroundings, a perimeter barrier may range from a geotextile fabric to an impermeable barrier such as a concrete wall or geomembrane. A perimeter barrier can be integrated with landscape edge treatments around the SCM.

Consider the area adjacent to the SCM when evaluating the perimeter design and consult with a geotechnical engineer. Lateral flow can negatively impact adjacent structures and infrastructure. Consider construction of the interface between the permeable pavement and the adjacent materials and how the design will prevent adjacent materials from entering the SCM section. Depending on the soils, depth of SCM, and other factors, this may be achieved with fabric or may require a more formalized barrier. When the SCM section is adjacent to conventional pavement, a vertical liner may be required to separate the aggregate and media or the SCM from the dense-graded aggregates and soils within the conventional pavement. An impermeable liner can be used to provide this vertical barrier and separate the SCM from the adjacent street and utilities.

For a no infiltration section, the perimeter barrier also serves to attach the impermeable membrane. The membrane should extend up to the top of the filter layer and be firmly attached to the concrete perimeter barrier using batten bars to provide a leak-proof seal. A nitrile-based vinyl adhesive can be used when the need for an impermeable liner is less critical. Avoid attaching the liner to the barrier prior to placing aggregate as this often results in tears. See Figures 4-6 and 4-7 for installation details. For ease of construction, including the placement of geotextiles, extend the barrier to the bottom of the filter layer.

For partial and full infiltration sections, the perimeter barrier for these sections restricts lateral flow to adjacent areas of conventional pavement or other structures where excessive moisture and/or hydrostatic pressure can cause damage. When this is of particular concern, extend the perimeter barrier to a depth 12 inches or more below the underdrain; otherwise, extend the barrier to the bottom of the filter layer.

Photograph 4-5. Liner tear after aggregate placement (even with slack provided). To avoid this problem, delay attaching the liner to the perimeter barrier with a batten bar until after placing aggregate by temporarily anchoring the liner.

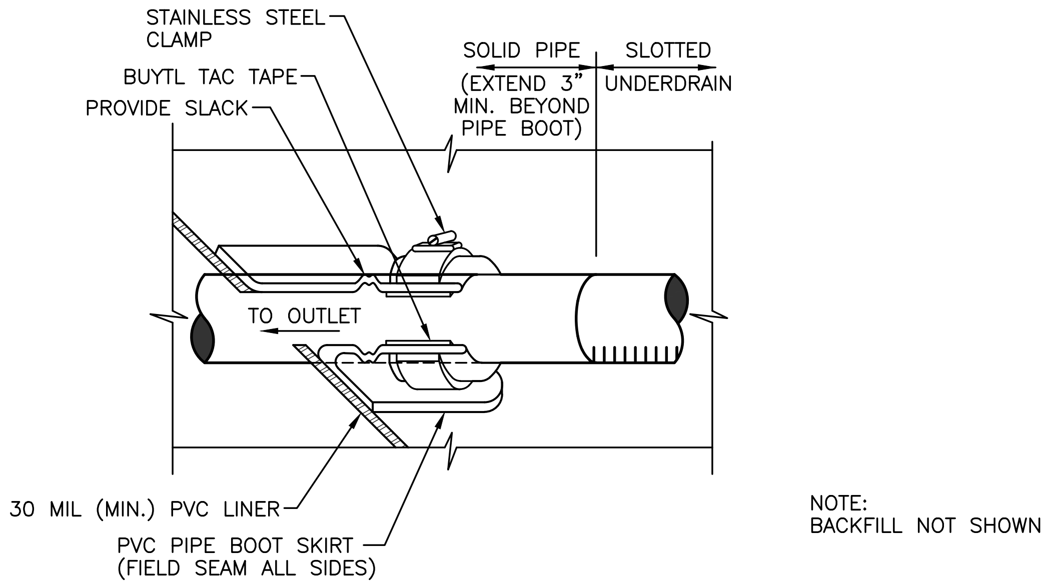


FIGURE 4-6. CONCEPTUAL LINER PENETRATION DETAIL FOR UNDERDRAIN
(NOT TO SCALE)

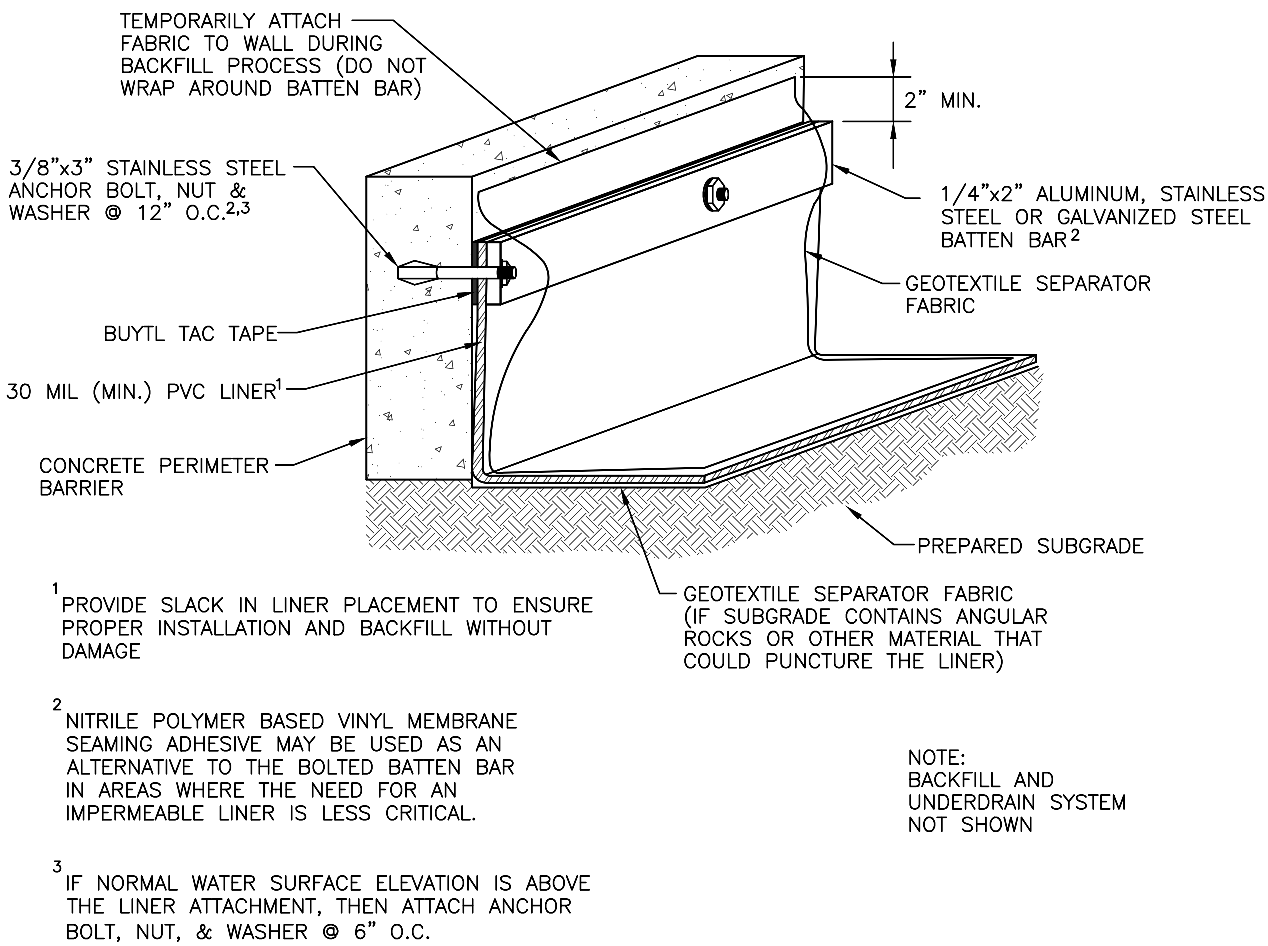
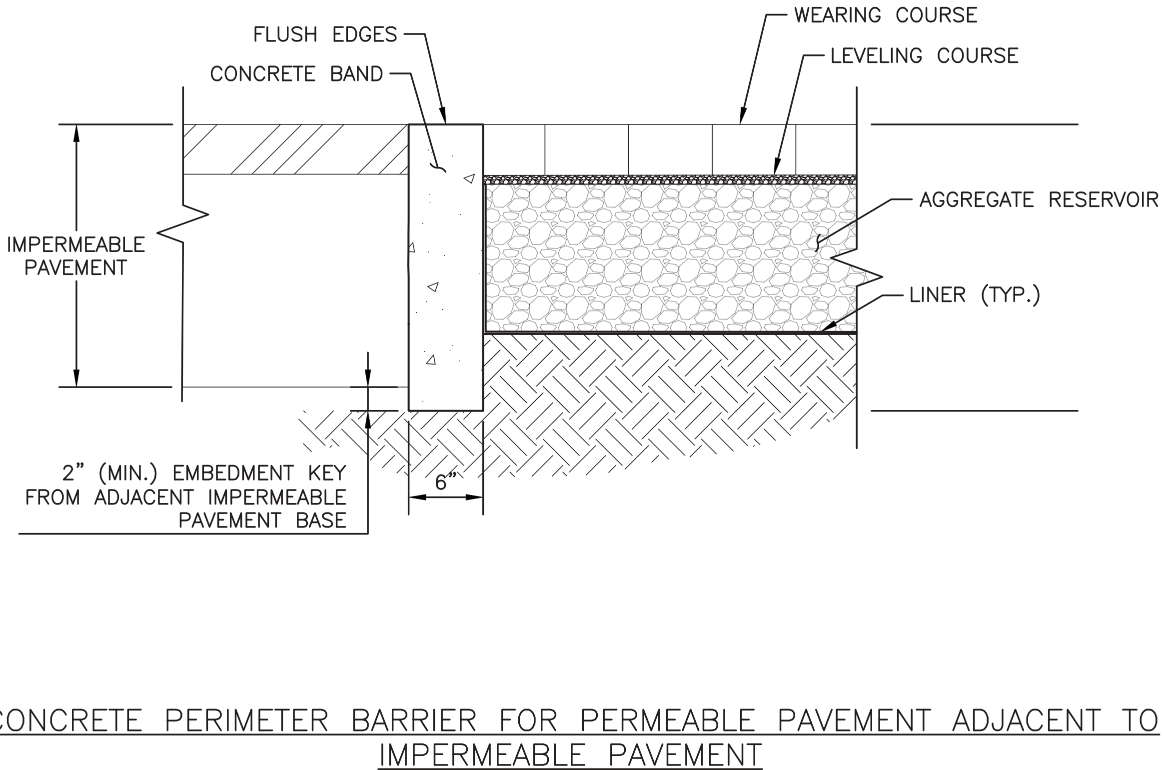


FIGURE 4-7. CONCEPTUAL DETAIL FOR CONNECTING GEOMEMBRANE TO VERTICAL CONCRETE SURFACE
(NOT TO SCALE)



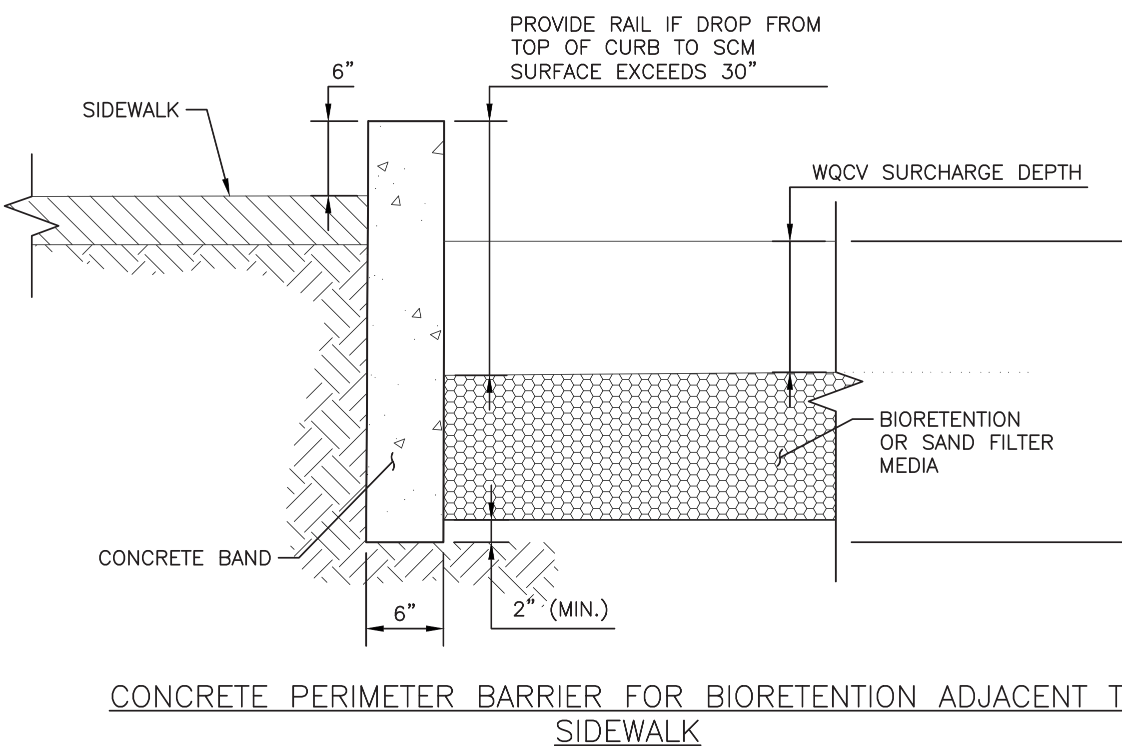


FIGURE 4-8. CONCEPTUAL DETAILS FOR CONCRETE PERIMETER BARRIERS
SECTION VIEW (NOT TO SCALE)

5.0 SCM INFLOW FEATURES

The planning and design of inflow features must consider the flow distribution requirements of the SCM because many types of runoff reduction and filtration- and infiltration-based SCMs require sheet flow conditions to properly function and others can accept concentrated inflows. Once the designer determines whether sheet flow conditions are required or concentrated flows are permitted, evaluate different types of inflow features to select the approach that best fits the treatment objectives of the SCM and the surrounding environment. Sheet flow inflow features must be configured in a way that distributes the flows as intended to benefit vegetation and promote infiltration. For inflow features that convey concentrated flows, a sediment forebay is typically required to dissipate energy and provide an area for sediment and trash accumulation that is accessible for maintenance.

Table 4-9 summarizes a variety of options for inflow features based on the types of flow distribution along with common energy dissipation methods and forebay recommendations. There are many opportunities for creative design of inflow features provided they meet the fundamental objectives of conveying runoff, dissipating energy, allowing for maintenance, and distributing flow in an appropriate manner for the SCM.

MAINTENANCE ACCESS

For sheet flow inflow features, access to the RPA along the downstream edge of curbless pavement, slotted curb, or level spreader is critical to allow for mowing to manage growth of vegetation and/or for sediment removal. Without this type of access and routine maintenance, the RPA can become densely overgrown and block drainage from the impervious area.

5.1 SHEET FLOWS

Sheet flow is uniform shallow surface flow that is evenly distributed, usually with a depth on the order of 0.1 feet of less. This typically occurs in the upper portions of watersheds and transitions to shallow concentrated flow over no more than a few hundred feet unless engineering measures such as level spreaders are used to redistribute the shallow concentrated flow as sheet flow. Some types of SCMs such as grass buffers and permeable pavements require sheet flow conditions to properly function. However, sheet flow conditions are not restricted to these types of SCMs. The banks of SCMs such as grass swales, extended detention basins, or ponds can be designed as vegetated buffers to receive runoff from adjacent impervious areas. Bioretention systems and sand filters can incorporate level spreaders to evenly distribute inflows across the SCM, and level spreaders can be used to transition small, concentrated flows into shallow sheet flows. This section provides guidance and examples of different types of sheet flow inlets including curbless pavement, slotted curbs, and level spreaders.

5.1.1 CURBLESS PAVEMENT

For parking lots, low-speed roads, and similar areas, sheet flow conditions can be created by foregoing a curb and gutter section. As shown in Photograph 4-6, curbless pavement can drain through a grass buffer and into an SCM such as a swale, bioretention system, sand filter, extended detention basin, or pond as a part of a treatment train.

Use a concrete edger to create a stable edge for concrete or asphalt pavements. Provide a minimum 2-inch drop from the edge of the impervious surface to the adjacent RPA to allow for growth of vegetation and accumulation of sediment over time. Some installations include a cobble

TABLE 4-9. SUMMARY OF SCM INFLOW FEATURES

TYPICAL INFLOW FEATURES	ENERGY DISSIPATION	SEDIMENT FOREBAY	TYPICAL APPLICABILITY TO SCMs			
			RPAs, BUFFERS, SWALES	EDBs, RPs, CWPs[2]	PERMEABLE PAVEMENTS	BIORETENTION, SAND FILTERS
Sheet Flows						
Curbless pavement	Vegetation	No	Yes	Yes	Yes	Yes
Slotted Curb	Vegetation	Curb acts as forebay	Yes	Yes		Yes
Curb opening with level spreader	Level Spreader	Blind Swale[1]	Yes			Yes
Pipe outfall with level spreader	Level Spreader	Blind Swale[1]	Yes			Yes
Concentrated Inflows						
Downspout	Vegetation or hardscape	No	Yes		Yes	Yes
Curb opening	Vegetation or rock	Yes	Swale only	Yes		Yes
Pipe outfall	Impact basin	Yes	Swale only	Yes		Yes
Grass swale	Vegetation	No		Yes		Yes
Stable ephemeral channel[3]	Vegetation and bed roughness	Case-by-case		Yes		

Abbreviations: RPA: Receiving Pervious Area; EDB: Extended Detention Basin, RP: Retention Pond, CWP: Constructed Wetland Pond.

[1] A blind swale is a shallow area upstream of the crest of the level spreaders that allows for even distribution of flow across the length of the spreader. Additional information is provided in the Level Spreader section of this chapter.

[2] Level spreader applicable when side slopes act as RPAs.

[3] Locate SCMs offline when feasible, primarily applies to regional facilities, see *Storage* chapter.

shoulder between the pavement and grass buffer. Use cobble rather than fine gravel, which can migrate into the RPA. Because curbless pavement distributes runoff and creates sheet flow conditions, additional energy dissipation features and sediment forebays are typically not necessary. It is very important to include measures to discourage vehicles from driving off the pavement and rutting the SCM. In parking lots, wheel stops may be used. Markers, bollards, or fencing are also options.

5.1.2 SLOTTED CURBS

Slotted curbs create sheet flow conditions in the adjacent RPA while also protecting the area from damage due to vehicles. In addition, slotted curbs provide for some trapping of litter and, in a sump condition, can act as a small sediment forebay. When functioning as a sediment forebay, design the slotted curb with access for a street sweeper for ease of maintenance similar to the City and County of Denver installation shown in Photo 4-7. The typical turning radius for a street sweeper is 25 feet but may be less depending on the specific type of sweeper used.

As shown in Figure 4-9, design slotted curb with a minimum 2-inch vertical drop to the concrete mowing strip. The intent is to allow for the accumulation of sediment over time. The mowing strip facilitates maintenance and removal of sediment and overgrowth using a flat shovel. Space slots 2 feet on center or less to allow runoff to spread and form sheet flow conditions in the grass buffer. Compared to larger openings, sizing the slot openings at 1.5 inches will reduce potential damage from snowplowing. Provide a maintenance plan that specifies plowing of the area with a rubber tipped plow blade to further minimize damage.

Photograph 4-6. Curbless pavement promotes sheet flow in adjacent grass buffers and swales for filtering and infiltration.

Photograph 4-7. Slotted or perforated curbs distribute pavement runoff and can function as a sediment forebay able to be maintained with a street sweeper.

Photograph 4-8. Typical slotted curb showing drop from slot to adjacent pervious area to allow for growth of vegetation and sediment accumulation. This area provides for mowing and maintenance access to keep positive drainage from the parking lot to the RPA.

5.1.3 LEVEL SPREADERS

Level spreaders are features that capture concentrated flows and distribute them evenly over a level surface to create sheet flow conditions. Criteria for determining level spreader geometry are provided in the Receiving Pervious Area fact sheet. As shown in Figure 4-10, the primary components of a level spreader are a "blind swale" upstream of the spreader that distributes the concentrated flow along the upstream edge of the level surface, the level spreader surface (effectively a broad crested horizontal weir), a vertical or sloped drop of at least 2 inches immediately downstream of the spreader surface, and for some designs, a maintenance access mowing strip downstream of the drop along the upper portion of the RPA.

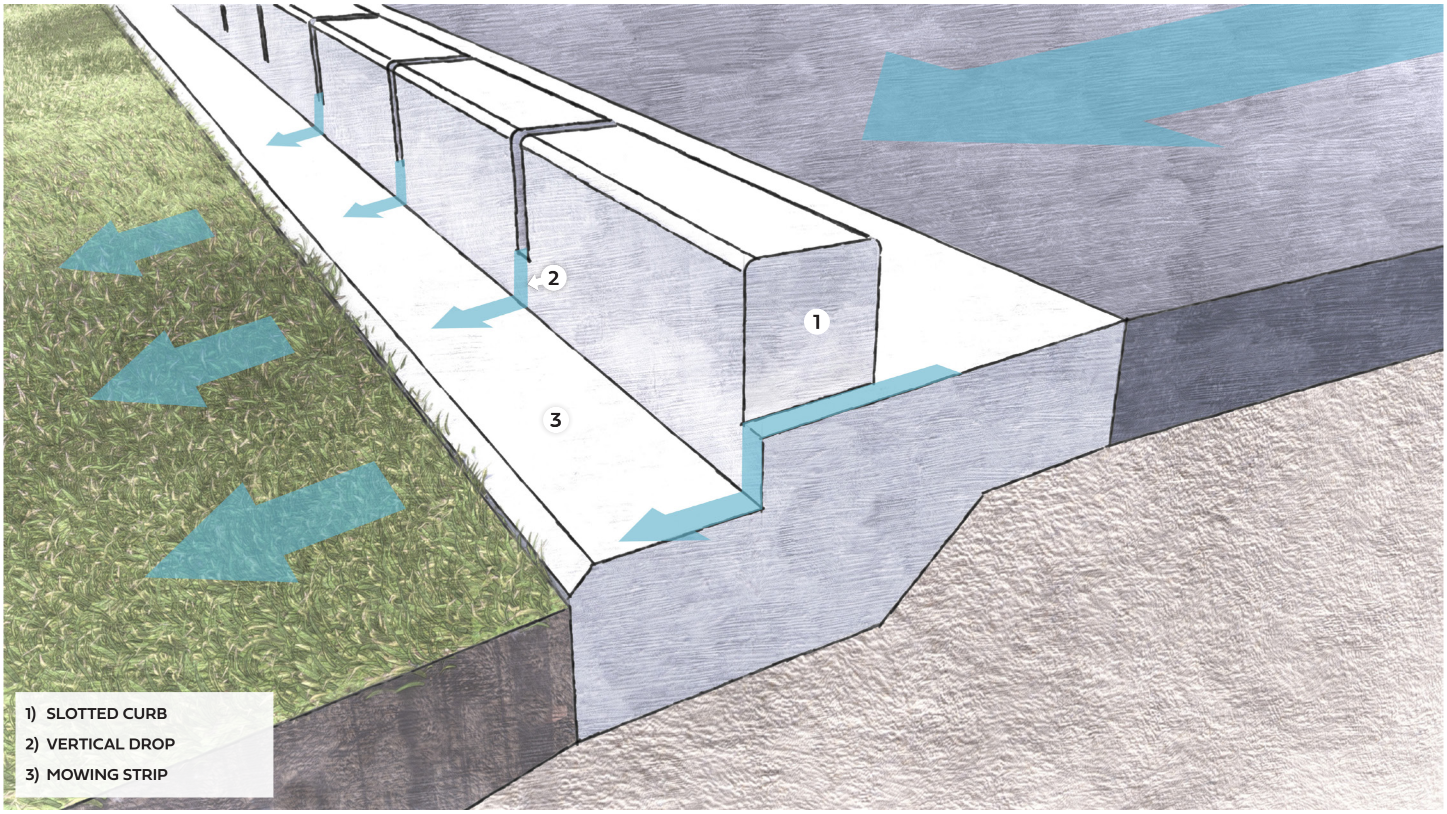


FIGURE 4-9. SLOTTED CURB DESIGN COMPONENTS

For level spreaders designed for shallow concentrated inflows, such as at the edge of a parking lot, the curb and gutter may serve as the blind swale. For larger concentrated inflows from pipes or channels, a vegetated swale with a flat longitudinal slope or depression may be used for the blind swale. When a blind swale is used to distribute flow to a level spreader, evaluate the potential for piping of runoff that infiltrates through the blind swale beneath the level spreader. If underlying soils are erosive, this type of piping can undermine the level spreader. The potential for this occurring can be minimized by providing good compaction beneath the level spreader and extending the foundation of the spreader deep enough to cut off potential piping beneath the level spreader. This is generally only a problem with very sandy soils.

Alternatively, shallow U-shaped concrete channels, rock-lined depressions, and other materials can be used for the blind swale provided that the configuration promotes even distribution of flow along the level spreader and is a surface that can be maintained without undue effort when sediment and trash accumulate in the area. Figure 4-11 illustrates a concept for using a level spreader for a curb opening inflow, and Figure 4-12 presents a concept for a level spreader to diffuse piped inflow. Both show a narrow slot or slots in the level spreader to ensure they remain free draining. The intent is to not create standing water.

The spreader itself consists of a level surface that will not erode over time. Often a concrete sill is used, but other materials can be used to provide more visual interest and integrate the level spreader into the surrounding environment, provided that the surface is level and uniform. For larger drainage areas where the UIA:RPA ratio exceeds 10:1, limit the use of the level spreader to initial (water quality or 2-year event) flows and direct remaining flows to bypass the level spreader to prevent erosion of the receiving pervious area.

The vertical drop on the downgradient side of the level spreader is a critical feature for long-term function. The drop allows room for vegetation to grow and some sediment accumulation without impeding flow over the level surface. A mow strip, as shown in Figure 4-9, will also aid function and provides access for maintenance, specifically with a flat-edge shovel, to ensure the grade immediately downstream of the level spreader can be restored after sediment accumulates.

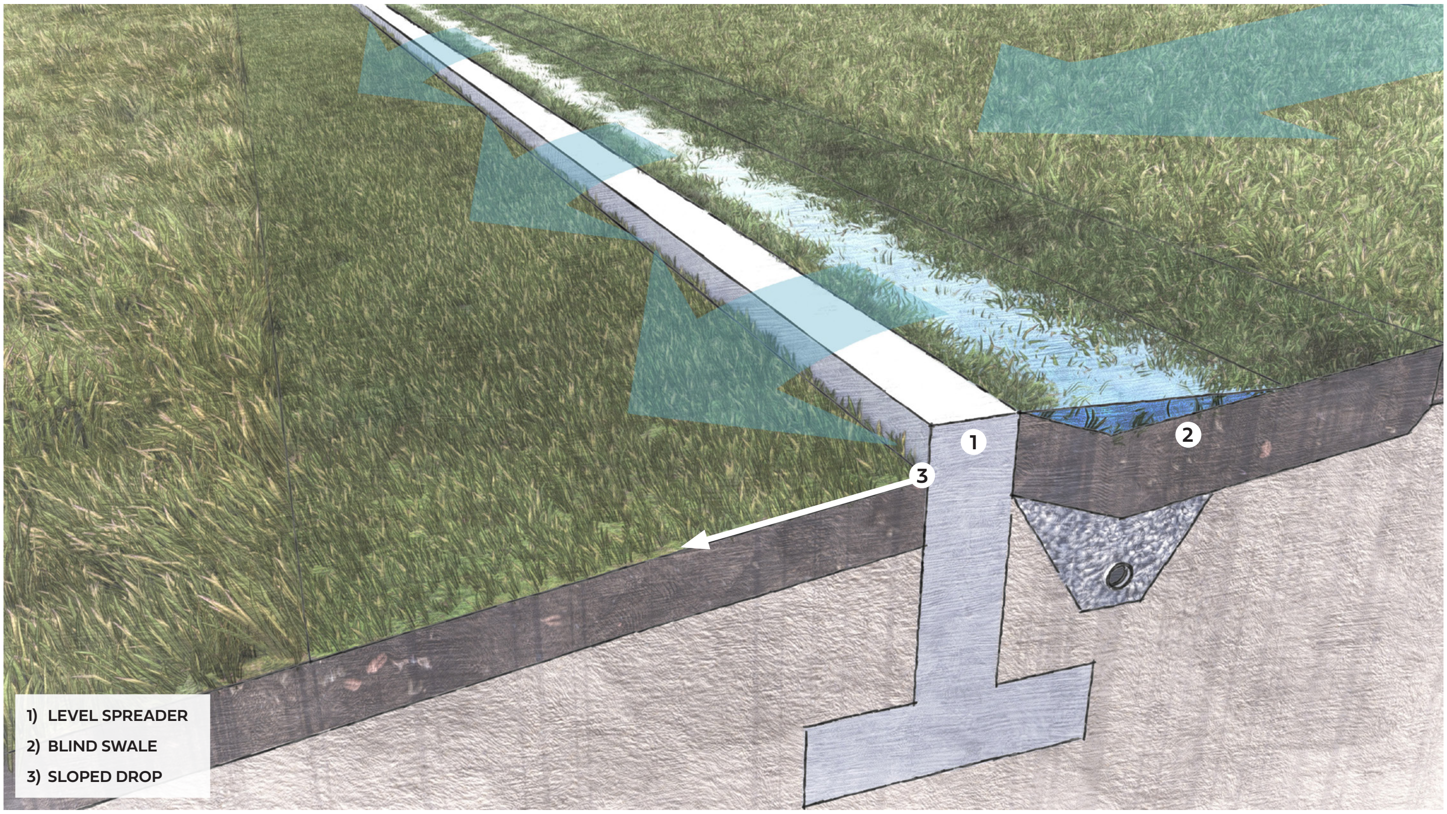


FIGURE 4-10. LEVEL SPREADER COMPONENTS

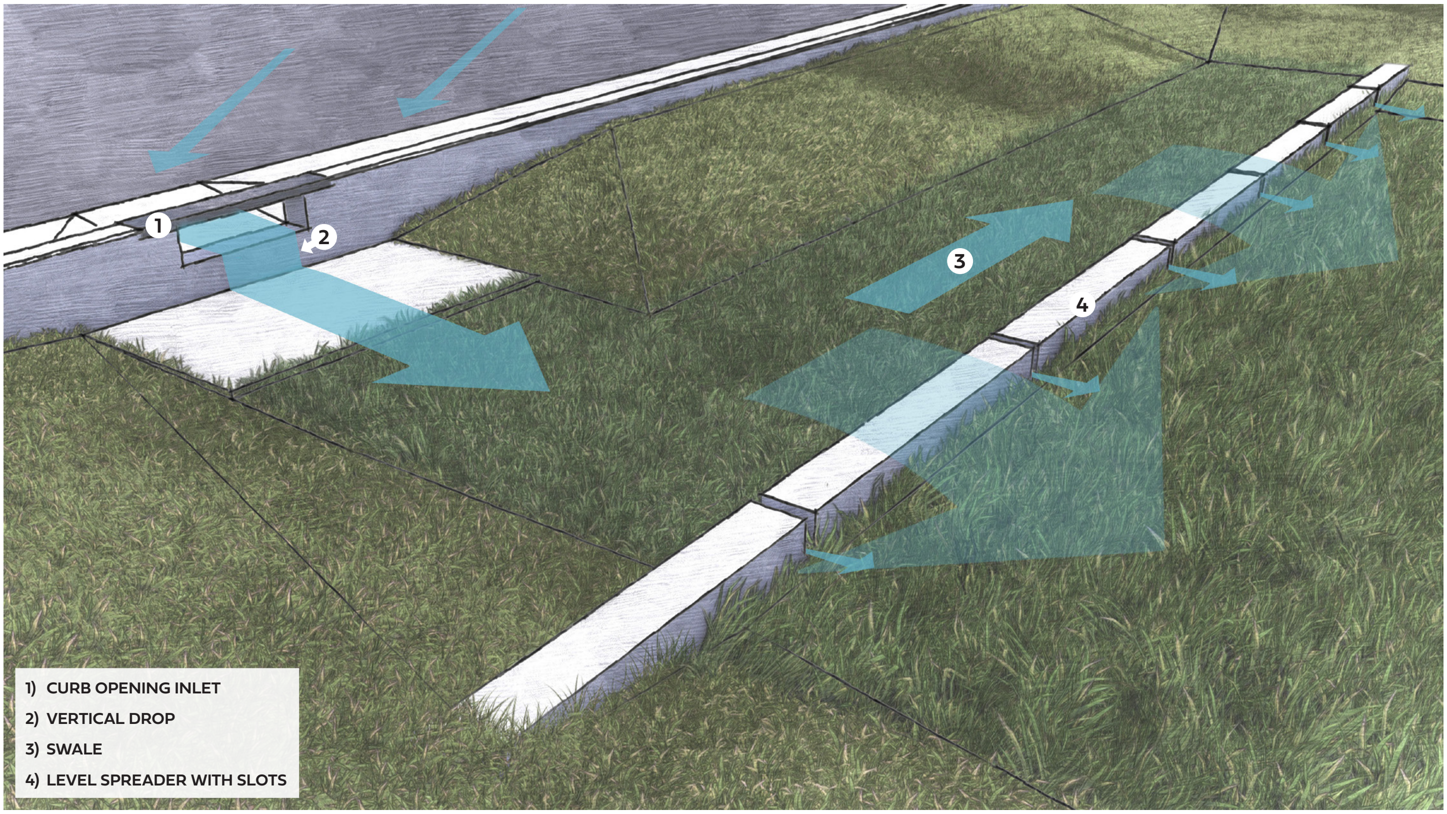


FIGURE 4-11. LEVEL SPREADER FOR CURB OPENING INFLOW

Level spreaders can be effective as inflow features to SCMs including ponds and filtration SCMs. In this case, hydraulic loading rates may be higher than when used to meet criteria in the Receiving Pervious Area fact sheet.

When level spreaders are used to distribute runoff to long vegetated buffers, flow may begin to concentrate as it flows down the buffer. The distance along the buffer where flow begins to concentrate is known as the effective distance, which is a function of the slope and vegetative cover of the buffer. For long buffers, it may be necessary to use level spreaders in series to re-establish sheet flow conditions. Table 4-10 provides typical effective distances for grass buffers based on slope. If the length of the buffer exceeds the effective distance in Table 4-10, use level spreaders in series to maintain sheet flow conditions.

For SCMs that are designed to meet water quality requirements but do not incorporate full spectrum detention, design of a level spreader (or other type of inflow feature) must provide for bypass of larger flows to the receiving conveyance system. For piped systems, a maintenance hole or vault with a weir or orifice can be used to capture and divert design flows to the level spreader, while allowing larger flows to overtop and bypass the treatment system. For channelized conveyances (e.g., swales) a check dam can be used to divert flows up to the design event to a level spreader and the SCM, while bypassing larger flows. In some cases, larger flows can be allowed to flow across the RPA, with collection at the downgradient end of the RPA; however, the designer must ensure that the larger flows will not cause erosion of the RPA.

When using a level spreader for a piped inflow, velocities entering the level spreader will be higher than for shallow concentrated flows. Important design considerations for piped flows include the angle at which the pipe enters the

TABLE 4-10. EFFECTIVE DISTANCE FOR LEVEL SPREADERS IN SERIES (SOURCE: HUNT ET AL., 2001)

GROUND COVER	SLOPE	EFFECTIVE DISTANCE (FEET)
Turfgrass, > 80% density	0-8%	50
	8-25%	25
	>25%	17

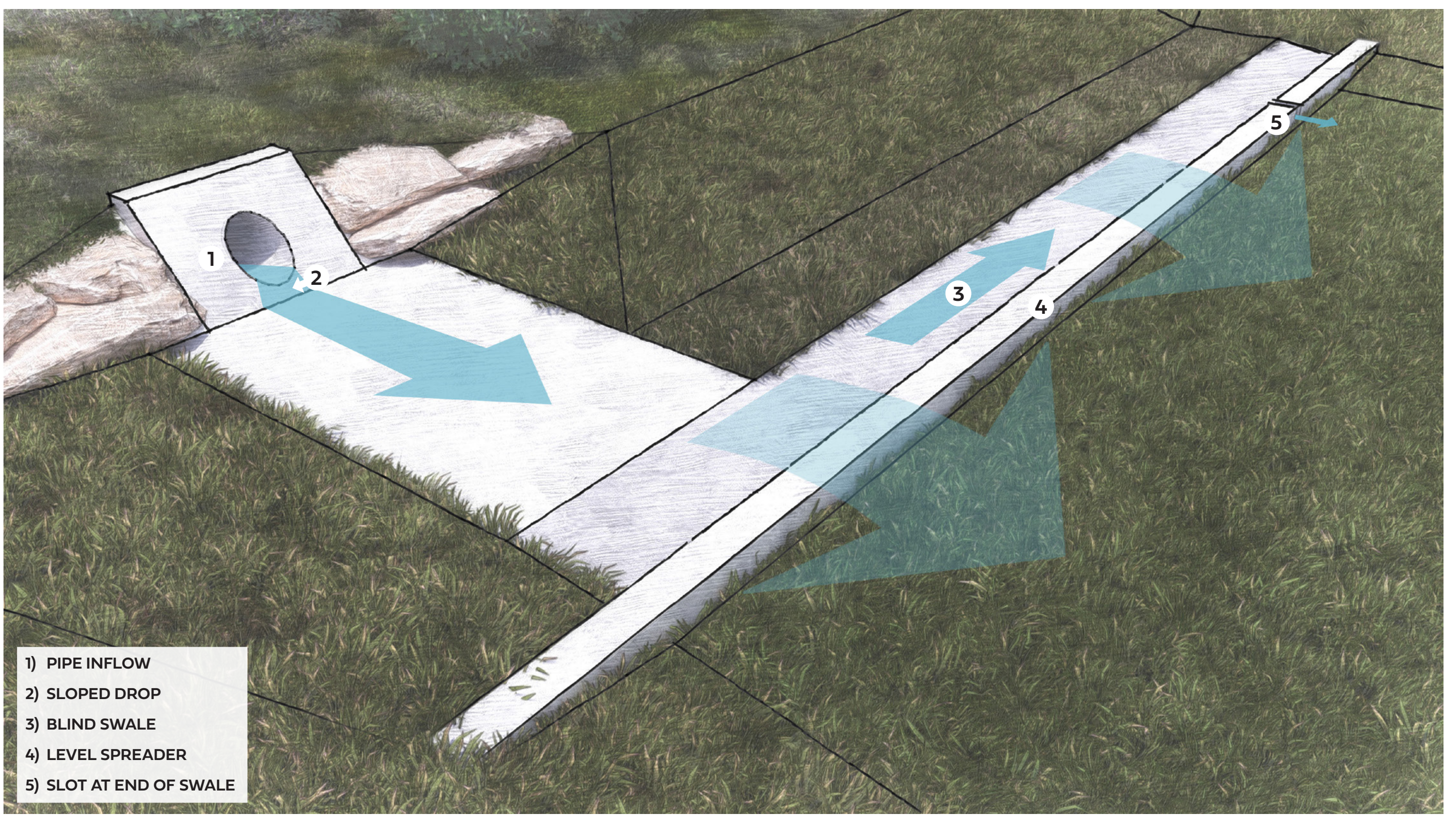


FIGURE 4-12. LEVEL SPREADER FOR PIPE INFLOW

Photograph 4-9. Concrete edge acts as level spreader, distributing flow from parking lot as sheet flow to SCM.

Photograph 4-10. This level spreader distributes concentrated piped inflows from the road to the buffer to the right in the photograph. The concrete sill to the left is the level spreader, and the flat shallow channel with water is the blind swale. Photo: Wenk.

level spreader and the distance from the pipe opening to the level spreader. Piped inflows entering the blind swale perpendicular to the level spreader will not be distributed as effectively along the length of the spreader as flows that enter parallel to the spreader or at an angle that reduces the momentum of the inflow normal to the direction of flow over the level spreader. If enough space or sufficient energy dissipation is not provided between the piped inflow and the level spreader, the flow over the portion of the level spreader in the proximity of the pipe will be greater than portions of the spreader that are further away, resulting in an undesirable, non-uniform flow condition over the spreader. Use energy dissipation measures such as boulders, concrete blocks, or concrete deflection walls at the pipe outfall to dissipate high velocity inflows and create uniform flow conditions on the upstream side of the level spreader in space-limited situations or where the angle of the pipe inflow is not ideal.

A level spreader can also be applied in SCMs such as bioretention or sand filters to achieve more uniform flow across the surface of the SCM. In these cases, a level spreader acts as a horizontal weir to distribute a concentrated inflow across the surface of a filtration- or infiltration-based SCM. The sill of the forebay can be designed as a level spreader.

Photograph 4-11. Concrete ramp provides maintenance access to blind swale. Photo: Wenk.

Photograph 4-12. Aurora Sports Park Level Spreader. This level spreader carries concentrated flows into a slotted pipe encased in concrete to distribute flows evenly to the RPA shown left in the photo. Photo: Wenk.

Photograph 4-13. Level spreader at Aurora Sports Park evenly spreads flow to the wetland area downstream.

The sheet flow criteria in the Receiving Pervious Area fact sheet do not apply in this application because the depths of flow in the SCM will exceed sheet flow depths. In these cases, the intent of the level spreader is to distribute the inflows more evenly across a vegetated surface and/or minimize the visual impact of the forebay.

Level spreaders are also useful features for avoiding rilling and gullying of slopes in areas that may not be designed to provide all the functions of a vegetated RPA, such as a rock mulched areas or landscape areas that may not have the 80% density of turfgrasses required for water quality SCMs. These areas can provide valuable runoff reduction benefits and enhance the aesthetics and community value of a site, even if they are not considered SCMs for purposes of MS4 permit compliance.

5.2 CONCENTRATED FLOWS

Concentrated flows commonly occur in urbanized areas to efficiently route stormwater while minimizing disruptions during frequently occurring runoff events. Concentrated flows include flows in downspouts, gutters, cross pans, curb cuts, pipes, and open channels. In some cases, concentrated flows can be transitioned to sheet flows with a level spreader; however, for larger-diameter pipes and channels, this may not always be feasible. When designing a concentrated inflow feature to an SCM, important objectives include minimizing the potential for erosion and providing an accessible area where sediment and trash conveyed into the SCM can be maintained. These objectives are achieved through implementing energy dissipation measures and the use of forebays. The extent of energy dissipation and forebay requirements depends primarily on the magnitude of the inflow. For example, appropriate energy dissipation for a curb cut draining into a grass swale may consist of only a concrete pad set 3 inches vertically below the edge of the curb cut where sediment and trash can be maintained (essentially a small forebay), as shown in Figure 4-13.

Curb opening inlets like the one illustrated in Figure 4-13 are used to convey runoff into many types of streetside SCMs and are an effective type of inlet for small, highly impervious drainage areas. The curb opening must be located at the upstream end of the SCM, convey runoff from the curb and gutter across the step-out zone, and be sized to convey the water quality event assuming an appropriate amount of debris blockage. The inlet must be designed to function in concert with a forebay (often a concrete pad surrounded by vegetation) that captures coarse sediments, trash, and debris and aids in energy dissipation. The inlet features a 3-inch depression in the flow line of the gutter to help direct runoff into the opening and reduce bypass flow.

DOWNSPOUTS

Downspouts provide excellent opportunities to direct concentrated runoff to RPAs for infiltration. Do not pipe downspouts to underdrains or to the storm drain system where discharge to an RPA is feasible. Energy dissipation is typically provided via a concrete or rock splash pad that directs runoff away from the building's backfill zone. In some cases, downspout extensions are necessary to bridge the backfill zone.

For downspouts draining large roof areas, use a small level spreader to create sheet flow or shallow flow conditions to the RPA.

Decisions related to downspouts are often made by architects without significant input from engineers, so coordination between the engineer and the architect early in the design process is critical to maximize opportunities to disconnect impervious roof area.

The inlet in Figure 4-13 is shown as a chase-type structure with a cover plate. Slope the interior portion of the inlet box (bottom slab of the chase drain) and provide a 1-inch minimum vertical step from the invert of the chase drain to the sediment collection pad or filter surface (for tree trenches), which should be at least 4 inches below the water quality water surface. This allows for some amount of debris and sediment buildup without reducing stormwater conveyance into the SCM.

Table 4-11 provides curb opening lengths required for full capture of the WQE for on-grade inlets. This type of inlet is typically used with streetside stormwater planters or other small SCMs intended for water quality only. Determine the required length based on WQPF or tributary area (assumed to be fully impervious). MHFD-Inlet can also be used to size the inlet length.

For larger inflows, engineered energy dissipation structures and formal forebays are required, as illustrated in Figure 4-14. These features are discussed below and in the *Hydraulic Structures* chapter.

TABLE 4-11. CURB OPENING INLET LENGTH FOR ON-GRADE INLETS BASED ON WQPF OR TRIBUTARY AREA

CURB INLET OPENING LENGTH (FT)	WATER QUALITY PEAK FLOW (WQPF) CAPACITY FOR 100% CAPTURE (CFS)	TRIBUTARY AREA (ACRES)
2 ft	< 0.12	Less than 0.10
3 ft	0.12 - 0.33	0.10 - 0.25
4ft	0.33 - 0.65	0.25 - 0.50

Note: Capacities are based on a curb opening with a 3-inch local depression consistent with CDOT Type R and Denver Type 14 inlets. Inlet sizing assumes a 100% flow capture, a clogging factor of 0.1, and a maximum gutter slope of 5%. Water quality peak flow (WQPF) and estimated tributary area based on CUHP analysis of the water quality event (WQE) with 100% imperviousness and 5% slope.

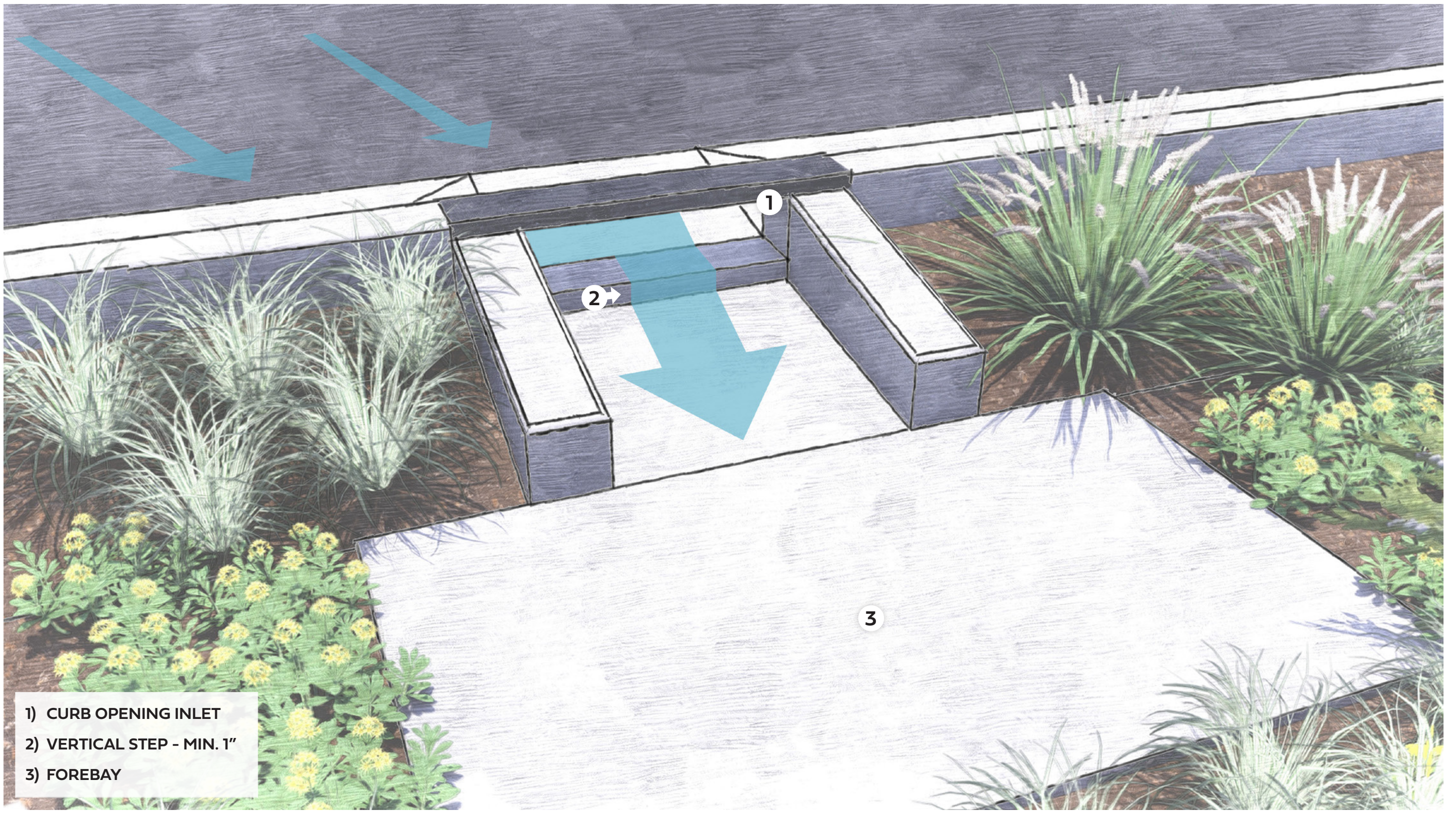


FIGURE 4-13. CURB OPENING INLET INTO STREETSIDE BIORETENTION AREA

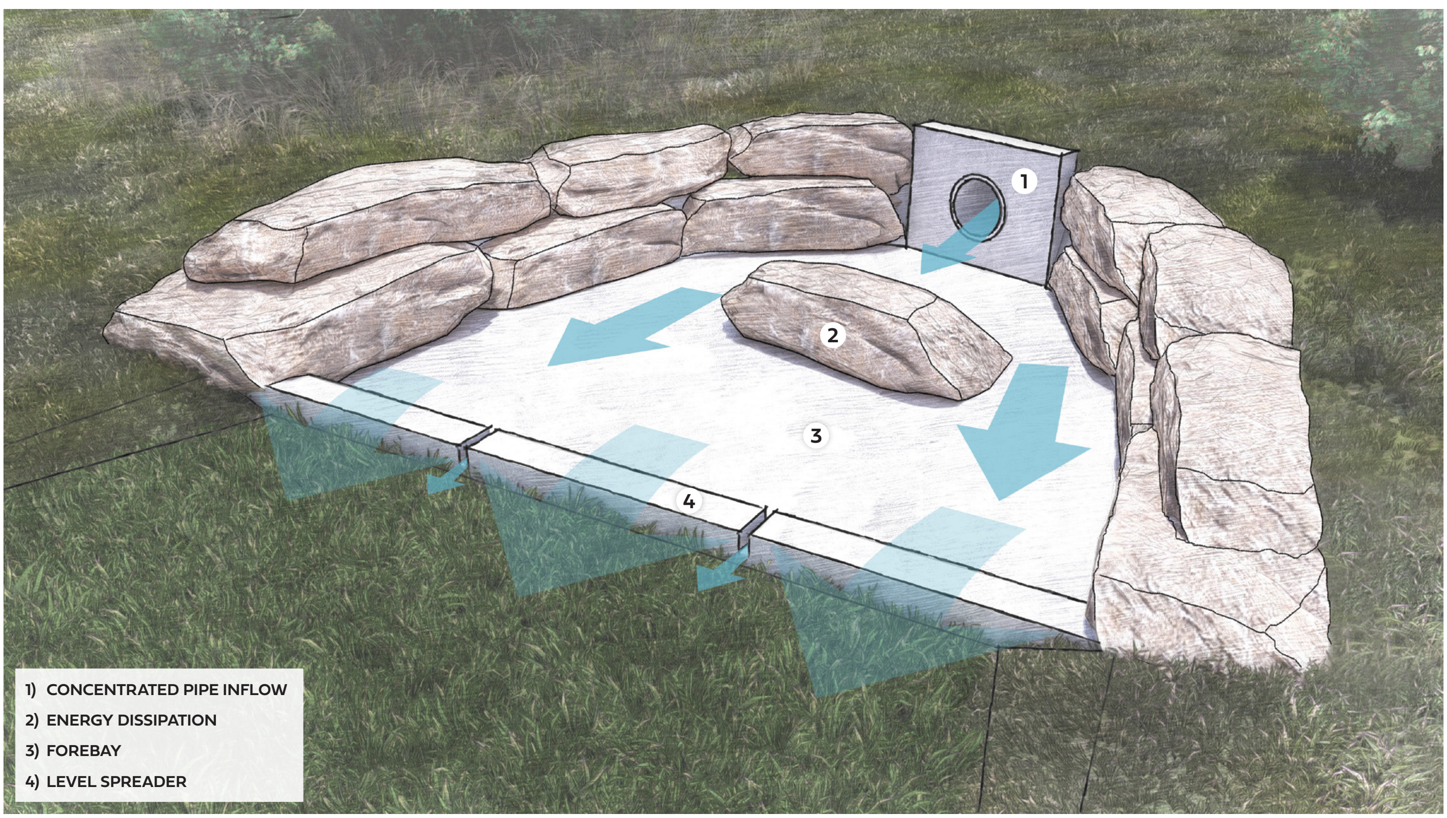


FIGURE 4-14. ENERGY DISSIPATION STRUCTURE AND FOREBAY FOR CONCENTRATED SCM INFLOWS

5.2.1 ENERGY DISSIPATION

Depending on the magnitude and configuration of the design inflow, energy dissipation may be provided through vegetative resistance or structural measures. For concentrated inflow features that are vegetated such as swales and ephemeral channels, the roughness provided by the vegetation and bed may be sufficient for energy dissipation. Perform hydraulic calculations of inflow velocities and tractive forces, considering seasonal variations in roughness coefficients, and compare with permissible velocities of the materials used in the SCM to verify if additional energy dissipation measures are needed.

For impervious conveyances including pipes, velocities are typically much higher, and structural energy dissipation in the form of riprap or an impact basin, sized in accordance with the *Hydraulic Structures* chapter, may be needed to avoid causing erosion in the SCM. Follow the design procedure in the *Hydraulic Structures* chapter to avoid over- or under-sizing energy dissipation structures and take care to install the structures at the appropriate elevation to achieve the intended function.

Photograph 4-14. Disconnected downspouts discharge to grass swale to dissipate concentrated flows and allow for infiltration and filtration. Vegetation provides energy dissipation.

Photograph 4-15. Morse Park forebay provides energy dissipation with placement of a boulder, and the dense vegetation helps encourage sediment to stay in the forebay. This is an easily accessible area to remove sediment and trash, and it provides even distribution of flow to the SCM.

5.2.2 FOREBAYS

A forebay provides an opportunity for coarse sediment and debris to settle out in an area that can be easily maintained. Forebays are recommended for all concentrated SCM inflow locations but vary in size and complexity of design based on the magnitude of the inflows and sediment loads anticipated. For tributary areas with high sediment loads (e.g., road sanding, developing watersheds), forebays are essential for ease of maintenance and to protect infiltrating surfaces. HDSs meet the same intent as forebays and can be used instead of a forebay.

Table 4-12 provides criteria for forebay sizing depending on the impervious area in the contributing watershed. Use this table as a guide as it does not consider the characteristics of the watershed and may not be appropriate for tributaries much larger than 20 acres. For small inflows (up to 2 acres of imperviousness) a concrete sediment pad may be used as a forebay, as illustrated in Figure 4-11 for a curb cut. Dense vegetation along the edge of the pad will help keep sediment on the pad where it can be maintained. When dense vegetation is not planned, another option is a 1-inch-tall metal lip with multiple 1- to 2-inch slots at the edge of the concrete pad, combined with a 1- to 2-inch drop from the pad to the media surface (Denver DOTI 2021). For larger contributing drainage areas, provide a forebay volume of at least 1 percent of the WQCV, and size a notch or weir to drain the volume over approximately 4 to 5 minutes. This will allow time for larger sediment to settle in the forebay.

Concrete forebays are often used in sub-regional and regional SCMs due to the ease of maintenance. While these are effective at their intended function, they are not always attractive. Other alternatives for forebays for larger SCMs include constructing a vegetated berm with a pipe rather than a concrete wall to contain the forebay. For smaller drainage areas, a notch is recommended instead of a pipe to avoid small pipe sizes that cannot be maintained, but even for smaller SCMs, a vegetated berm with a notched concrete section in the middle could be an alternative to a concrete wall.

A primary reason the bottom of the forebay is often concrete is so that there is a well-defined surface to dig to or scrape when sediment removal is required. For a more natural appearance, and when sufficient energy dissipation is provided, the bottom of the forebay can be a reinforced grass pavement such as Grasscrete® or other open-celled concrete. In addition to the bottom of the forebay, also protect the area immediately downstream of the forebay where flows overtop the forebay walls and enter the basin. A vegetated surface such as Grasscrete® also provides greater roughness that slows down runoff and helps with removal of sediment and trash.

Maximize the length of the flow path through the forebay and minimize the forebay bottom slope to encourage settling. When portions of the watershed will remain disturbed for an extended period, increase the forebay size to accommodate the potentially high sediment loads from the disturbed watershed.

Size the forebay area to drain in 4 to 5 minutes using Equation 4-1 to calculate the width of the rectangular notch outlet. The equation is based on the integrated form of a weir equation and enables a designer to calculate the width of a vertical rectangular notch needed to empty the forebay's volume in the desired emptying time (Urbonas 2019). Locate the outlet so that it does not line up with the inflow into the forebay.

Photograph 4-16. Inlet to swale has small riprap forebay to collect trash. Riprap and dense vegetation in swale dissipate energy. However, sediment will be difficult to remove from the riprap.

$$w = 9.23\ (A_{FB} / t)\ (1 / \sqrt{h_{max}})$$ **Equation 4-1**

Where:

w = width of the rectangular vertical notch (inches)

A_{FB} = surface area of the forebay (square feet)

t = emptying time of the brim-full forebay (seconds)

h_{max} = maximum depth of the forebay (feet)

TABLE 4-12. FOREBAY SIZING CRITERIA

FOREBAY SIZING CRITERIA	WATERSHED IMPERVIOUS AREA (IA)				
	IA UP TO 2 ACRES	IA 2 UP TO 5 ACRES	IA 5 UP TO 10 ACRES	IA 10 UP TO 20 ACRES	IA GREATER THAN 20 ACRES
Forebay Release Rate and Configuration	Concrete sediment pad with dense grasses surrounding, concrete pad with slotted metal edge, or similar design	Size to drain in 4 to 5 minutes using Equation 4-1			
Minimum Forebay Volume [1]		1% of WQCV			
Forebay Depth [1]		12 to 15 inches	15 to 18 inches	18 to 24 inches	24 to 30 inches

[1] Appropriate volume and depth should consider maintenance and access needs. The values provided are approximate and provide a starting point for design.

6.0 SCM OUTFLOW FEATURES

SCM outflow features provide two important functions: 1) release the WQCV over the drain time required for the SCM and 2) convey larger flows to the downstream conveyance system. Depending on the type of SCM, outflows may include infiltration into the subgrade, controlled release via an underdrain system, release through an orifice plate, and/or overflow via a weir. In many cases, these features are designed to be part of a single integrated outlet structure.

Often, SCMs that provide the WQCV can be expanded to also incorporate the EURV and 100-year detention storage volumes with relatively simple modifications to the outlet.

The common types of outflow features associated with different types of SCMs are summarized in Table 4-13. Infiltration systems and underdrains are discussed extensively in Section 4.3. Therefore, this section focuses on types of outlets that release the WQCV over the drain times required for different types of SCMs and allow larger flows to pass to the downstream conveyance system. For guidance and criteria on outlet design for Full Spectrum Detention (FSD), see the *Storage* chapter.

Photograph 4-17. Outlet for bioretention system at River Run Park. The WQCV is filtered through media and infiltrates or discharges to the outlet via an underdrain. The outlet is also designed for detention of larger events with a weir control (i.e., top of outlet box) overflow. The spillway for the basin is provided as a low spot above the outlet near the rain gage.

Photograph 4-18. Although each site is different, most sedimentation SCMs have similar outlet structures. Each structure should include a partially submerged orifice plate with a screen (or grate) protecting the orifice plate from clogging, and an overflow weir for flows exceeding the WQCV or EURV when full spectrum detention is used.

TABLE 4-13. SUMMARY OF TYPICAL SCM OUTFLOW FEATURES

TYPICAL OUTFLOW FEATURES	TYPICAL APPLICABILITY TO SCMs			
	RPAs, BUFFERS, AND SWALES	EDBs, RPs, CWPs	PERMEABLE PAVEMENTS	BIORETENTION AND SAND FILTERS
Infiltration (unlined systems only)	Yes	Limited	Yes	Yes
Underdrain (no and partial infiltration systems)	Some swales	Not typical	Yes	Yes
Orifice Plate		Yes	Yes, orifice on underdrain	Yes, orifice on underdrain
Weir		Yes	Yes	Yes
Trash Rack		Yes		When combined with FSD
Safety Grate		Yes		Yes
Spillway		Yes		Yes
Micropool		Yes, EDBs		

Abbreviations: RPA: Receiving Pervious Area; EDB: Extended Detention Basin; RP: Retention Pond; CWP: Constructed Wetland Pond; FSD: Full Spectrum Detention.

Photograph 4-19. Retention pond outlet structure blends with the bank and is easily accessible for maintenance.

6.1 ORIFICE PLATES

Outlets that release the WQCV typically do so with an orifice plate. The fundamental design parameters are the head that the WQCV creates on the orifice, and the required drain time of the SCM. Table 4-14 provides required minimum drain times for different types of SCMs.

TABLE 4-14. REQUIRED WQCV DRAIN TIMES FOR DIFFERENT TYPES OF SCMS

SCMS	MINIMUM WQCV DRAIN TIME (HOURS)
Extended Detention Basins	40
Constructed Wetland Ponds	24
Permeable Pavement Systems, Bioretention, Sand Filters, Retention Ponds	12

To size the outflow orifice(s), use the MHFD-Detention workbook, available at www.mhfd.org, to route flow and calculate the required orifice sizes. For small facilities with 12-hour drain times, the simplified orifice equation (Equation 4-2) can be used for orifice sizing.

$$D_{12\ hour\ drain\ time} = \sqrt{\frac{V}{1414\ y^{0.41}}}$$ **Equation 4-2**

Where:

D = orifice diameter (in)

y = distance from the lowest elevation of the storage volume (e.g., surface of the filter for bioretention) to the center of the orifice (ft)

V = volume (WQCV or the portion of the WQCV in the facility) to drain in 12 hours (ft^3)

For filtration and infiltration-based SCMs such as bioretention, sand filters, and permeable pavement systems that incorporate underdrains, an outlet structure often consists of a shallow structure with an orifice plate separating the underdrain from the downstream conveyance system. The top of the orifice plate may be configured as an overflow weir to limit the buildup of head over the orifice plate to the design depth of the WQCV so that larger events overtop

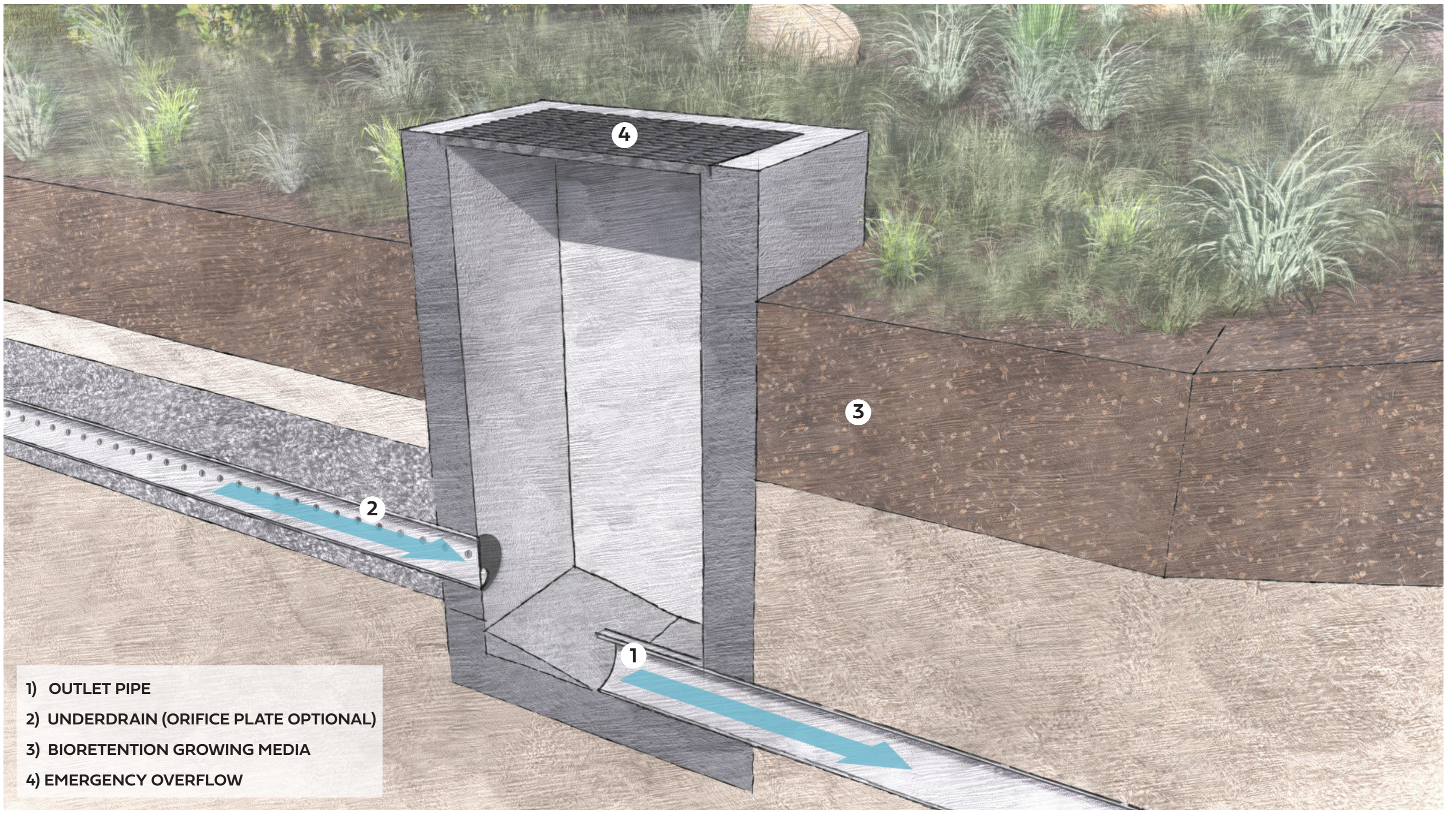


FIGURE 4-15. CONCEPTUAL OUTLET CONFIGURATION FOR SCM THAT RELEASES THE WQCV VIA AN ORIFICE-CONTROLLED UNDERDRAIN

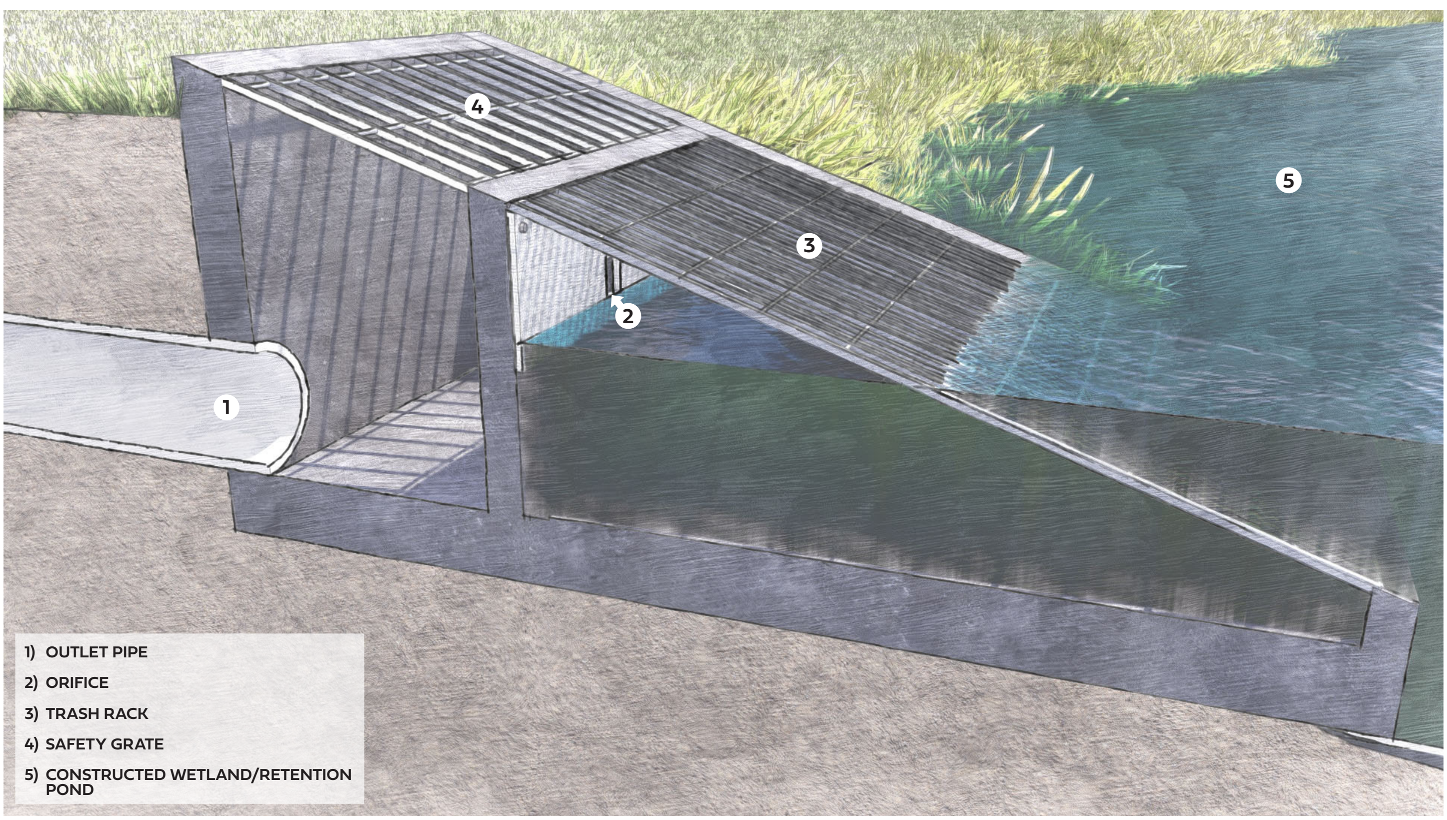
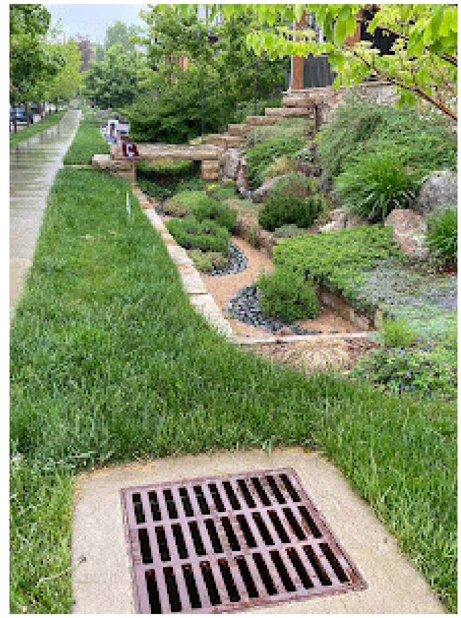


FIGURE 4-16. CONCEPTUAL OUTLET CONFIGURATION FOR RETENTION POND / CONSTRUCTED WETLAND BASIN

and flow downstream. Outlets with removable weir plates such as Agri Drain Inline Water Level Control Structures™ (with or without an orifice drilled into one of the plates) have been successfully used in many applications in the MHFD region as outlets from small to medium-sized filtration and infiltration facilities with underdrains. Figure 4-15 shows a conceptual outlet configuration for an SCM that releases the WQCV via an orifice-controlled underdrain.

For extended detention basins and other basins that function based on surcharge and slow release of the WQCV, orifice plates are commonly used. In most applications, the orifice plate consists of 1/4-inch-thick steel with circular or rectangular orifice openings. The span of the orifice plate should not exceed 2 feet for 1/4-inch-thick steel. Figure 4-16 provides a detail and notes for a typical combination of an orifice plate and trash rack for a retention pond or wetland basin.



Photograph 4-20. Grate acts as overflow weir for bioretention systems located along street frontage. Very large events may spill over the sidewalk to the street with the sidewalk acting as the spillway.

6.2 WEIRS

Weirs come in many different shapes and sizes, depending on the size of the SCM and its overflows. For a bioretention system, the overflow may be an area inlet set at the maximum elevation of the WQCV to allow flows that exceed the WQCV to flow directly into the outlet structure downstream of the orifice plate. For permeable pavement systems, the overflow weirs may be area inlets within the pavement surface that prevent excessive ponding should the runoff rate exceed the pavement infiltration rate. For basins and ponds, the overflow weir is commonly the perimeter of a drop inlet at the top of the outflow structure. Use the MHFD-Detention workbook to size overflow weirs.

6.3 TRASH RACKS AND SAFETY GRATES

Trash racks are intended to keep trash and debris from plugging the orifice openings in the SCM outlet. For orifice openings with a diameter of 1.25 inches or less, use a well screen for the trash rack. When the opening sizes are greater than 2.5 inches, use a bar-grate trash rack, which is less susceptible to plugging than a well screen. For orifices between 1.25 and 2.5 inches, either may be used. Consider the tributary area, expected maintenance practices, and potential clogging of the well screen versus clogging of the orifice when deciding which to specify. See the Extended Detention Basin fact sheet for additional considerations for orifice protection and more information including details.

Safety grates are intended to keep people and animals from inadvertently entering a storm drain. The *Culverts and Bridges* chapter of Volume 2 provides additional information and criteria related to safety grates. The grate on top of the outlet drop box should be designed with safety considerations in mind. These considerations include potential pinning of a person or animal to the grate due to suction force. Although, often the face of the outlet pipe is far enough from the grate and the resulting force on an object on the grate is not

TRASH RACK DESIGN FOR MAINTENANCE

Rather than using the minimum criteria for the trash rack width, maximize the width of the trash rack to match the geometry of the outlet. This will reduce clogging and frequency of maintenance of the SCM. If designing to the minimum criteria, consult with the owner and/or facility maintenance crew to understand how and with what equipment the site will be maintained and how frequently maintenance will occur. These site-specific factors may impact the design.

Hinged safety grates that can be locked provide security and ease of maintenance access.

enough to pin a person or animal. Safety considerations also include potential injury to someone that inadvertently steps on the grate during dry weather and falls through.

The grate over the drop box should consist of standard bar grating or a safety grate and may be flush or raised to provide a vertical opening for additional capacity with lower debris blockage. See the *Storage* chapter for various configurations for the grates over the 100-year drop box and recommendations for preventing debris blockage.

Design grating to satisfy two loading conditions with a deflection of 1/4 inch or less: 1) a uniform load of 100 pounds per square foot and 2) a concentrated load of 200 pounds applied at the center of the span. Designing grates to support the full hydrostatic head is not recommended because this condition is unlikely and will increase the weight of steel members, making removal for maintenance difficult.

The outlet structure design must be completed by a licensed professional engineer and include details for the following components:

1. Steel reinforcement within concrete structure.
2. Orifice plate details, including connection to concrete structure.
3. Well screen details (if used), including connection details or guide channels for removable configuration.
4. Standard bar grating panel dimensions, orientation, connections, and hinges.
5. Coarse safety grating panel dimensions, orientation, and connections.
6. All other metal work and connections required for construction of the outlet structure.
7. Required corrosion protection; all steel members must be hot dip galvanized after fabrication.
8. Outlet pipe bedding and cutoff to reduce the possibility of water piping through the embankment.

TABLE 4-15. PROPERTIES OF TRASH GRATES

TYPE	SPECIFICATION
Well Screen	Stainless steel screen with vertical No. 93 vee-wire and 0.139" openings between wires. Horizontal 0.074" x 0.75" support rods 1" on center spacing. (Johnson well screen or equivalent)
Standard Bar Grating	Aluminum or steel fabricated panels with bearing bars typically 1" or greater (based on span and load) x 3/16" at 1-3/16" on center and cross bars at 4" on center. Steel panels must be hot-dipped galvanized after fabrication.
Safety Grating	Panels fabricated of steel pipes or bars with clear spacing of 5", hot-dipped galvanized after fabrication.

6.4 SPILLWAYS

When designing any type of SCM, consider what will happen when the SCM fills and must overflow. A spillway provides a stable overflow path to discharge runoff to the downstream conveyance system. For SCMs serving small drainage areas, the spillway may be a low spot around the perimeter of the SCM that redirects runoff back to a street or nearby inlet. The spillway can be vegetated or hardscaped depending on the surrounding context of the SCM. If spillway depths are shallow, little armoring other than vegetation is typically needed for SCMs serving drainage areas smaller than one impervious acre.

For SCMs serving larger drainage areas or SCMs that impound water using embankments, a more formal spillway consisting of a broad crested weir is recommended that is sized to pass the undetained 100-year peak flow rate from the drainage area contributing to the SCM. Depending on the size of the peak flows, velocities, and spillway geometry, spillways may consist of vegetated soil riprap, riprap, or concrete. See the *Storage* chapter for additional guidance and criteria for designing spillways.

6.5 MICROPOOLS

Micropools are a unique feature of extended detention basins and are designed in conjunction with the orifice plate and trash rack to allow water to flow through a submerged portion of the trash rack and reach the openings in the orifice plate even when floating vegetation and debris is matted against the portion of the trash rack that is above the water surface. The same effect can be achieved in retention ponds and constructed wetland ponds, which are designed to have open water in front of the outlet, by extending the trash rack below the water surface in front of the orifice plate. Because micropools are specific features of extended detention basins, guidance and criteria for micropool sizing and concepts for integrating the micropool with the extended detention basin outlet design are provided in the Extended Detention Basin fact sheet.

7.0 SOILS, VEGETATION, AND IRRIGATION FOR SCMS

Vegetation is a key component of many types of SCMs and provides important functions that enhance treatment processes, aesthetics, ecology, and overall sustainability of the SCM. These functions include:

- Filtering (straining) of trash and sediment.
- Increasing surface roughness to reduce runoff velocity, broaden runoff hydrographs, and attenuate peak flows.
- Providing pathways into the soil through shoots and roots to promote and sustain infiltration over time.
- Enhancing soil ecology and biochemical processes in the SCM soils.
- Providing habitat and ecosystem services.
- Stabilizing the ground to reduce erosion in the watershed surfaces and along streams.
- Reducing weed growth by providing dense desirable vegetation.
- Mitigating urban heat island effects.
- Reducing heat gain and providing aesthetic value for green roof installations.

Vegetation transforms SCMs into multi-functional infrastructure that improves public acceptance and adds value to communities and the environment by enhancing the wildlife habitat, aesthetics, and user experience. Appropriately selected and well-established vegetation is fundamental to expanding the benefits of SCM functionality; in addition, vegetation is central to water quality treatment processes.

Because favorable topsoil conditions are critical for the successful establishment of vegetation, an essential resource to support development of revegetation plans is *MHFD's Topsoil Management Guidance*, which provides guidance for assessing and developing a plan for healthy topsoil to support newly planted or seeded vegetation in SCMs. Another important resource is the *Revegetation* chapter of this manual, which provides revegetation guidance for SCMs and water resource-related project sites in the MHFD region. However, the *Revegetation* chapter is largely geared to the revegetation of natural areas, particularly stream corridors, which can present different hydrologic regimes and growing conditions than those found within SCMs. SCMs often occur in and around urban development, which ranges in character from ultra-urbanized sites with little or no natural context to suburban open space tracts that include relatively natural landscapes. The landscape plan for the SCM should reflect the specific characteristics and context of surrounding land use, as each situation presents different opportunities and constraints. The *MHFD Topsoil Management Guidance* and the *Revegetation* chapter provide information that can be applied to many different types of SCMs, and these documents are intended to be used in conjunction with the SCM-specific guidance provided in the fact sheets.

SOURCES OF VEGETATION GUIDANCE AND CRITERIA FOR SCMS

- RPAs – Fact Sheet and *Revegetation* Chapter
- Green Roofs – Fact Sheet
- EDBs, RPs, CWPs – *Revegetation* Chapter
- Bioretention – Fact Sheet

In addition to these resources, the Colorado Natural Heritage Program and the Colorado State University Extension Service have extensive guidance on plants suitable for Colorado's climate.

The primary objectives to address in SCM landscape plans include:

- **Create vegetation plans that support SCM water quality functions.** The specific roles that vegetation plays in the function/performance of each SCM vary. Vegetation design and establishment is especially critical to achieving sustained infiltration in SCMs such as bioretention and grass buffers, swales, and other RPAs. Refer to the SCM fact sheets for specific guidance for selection of vegetation appropriate to the type of SCM.
- **Develop landscape plans that stabilize SCMs and create sustainable facilities**. Landscape plans should address SCM stability issues such as steep slopes, spillway areas, problematic soils, and other areas with high erosion potential. Plans should include specific measures to establish resilient vegetation that will protect the SCM from erosion. Deep-rooted vegetation can out-compete weeds, providing a stable and attractive SCM. Drought-tolerant native plants are preferred over types of vegetation that require more irrigation. Landscape plans should address proper soil assessment/placement/preparation, seeding, plantings, erosion control measures, and weed control, among other items.
- **Create landscape plans that enhance the SCM's surrounding context and provide multiple benefits to the community.** SCM locations and contexts vary a great deal, from highly visible ultra-urban locations to remote suburban or rural sites surrounded by open space. In each case, the designer should consider the context and site-specific opportunities and constraints to develop an overall vision and strategy for what the vegetation should accomplish for the site. These strategies may range from "creating a functional landscape feature" in the case of a very visible and urban site to "maximizing habitat and plant diversity and integrating the SCM into the surrounding landscape" in remote open space sites. Objectives of landscape plans for SCMs should include:
  - Enhancing community benefits by employing a "place-making" approach (providing shade, reducing heat island effects, visual interest, etc.).
  - Improving biodiversity of the site with use of appropriate native species and including pollinator species in the plant palette.
  - Practicing environmental stewardship through conservation of water and other resources.
- **Develop landscape plans that are adapted to the ecology and environmental characteristics of the site and the conditions created by the SCM.** Consider site characteristics including solar aspect, soils, and water regime in developing a landscape plan for an SCM. Inundation frequencies and depths associated with temporary storage and/or infiltration of runoff affect planting conditions and potential for plant growth. Many SCMs have modified hydrologic regimes compared to streams and other natural areas. Consider the hydroperiod of the SCM, as well as the potential for extended periods of drought and how healthy vegetation will be maintained during very dry periods. In many settings, drought-tolerant native plants are preferred over types of vegetation that require more irrigation. Designers must evaluate the specific characteristics of each SCM and site and specify plant material that can survive and thrive under those specific conditions. "One-size-fits-all" vegetation design is not an acceptable approach for successful vegetation establishment for an SCM.
- **Consider maintenance requirements.** Maintenance of vegetation is necessary for all types of vegetated SCMs to maintain healthy vegetation, manage weeds, and prevent overgrowth of vegetation from interfering with the functions of the SCM. The level of maintenance required for vegetation is dictated by the conditions in the SCM and by plant selection and density. The planning and design of vegetation for an SCM that will be maintained frequently will be different than for an SCM that is intended to have low, infrequent maintenance requirements. In addition to the level of service anticipated for maintenance, understanding specific maintenance practices, such as how mowing and weed control will be performed, may influence plants that are selected and how plants are grouped and spaced. As part of the landscape plan, the designer must provide instructions on how the landscape is to be maintained over time and ideally who is responsible for various types of maintenance. Incorporate this information into the overall operations and maintenance plan for the SCM.
- **Determine SCM irrigation requirements.** Develop an irrigation plan in conjunction with the vegetation plan for the SCM, including irrigation system operation and maintenance requirements. Establishing vegetation, even drought-tolerant native species, in the semi-arid rainfall zone prevalent in the MHFD is difficult and may not be successful with natural rainfall alone, especially if optimum seeding periods are missed. In some cases, the natural hydrology

may be sufficient for establishment of vegetation (for example, native seeding in an average or wetter-than-average spring); however, there is an equal chance that hydrologic conditions will be drier than average. Because of hydrologic variability, irrigation is necessary for all vegetated SCMs during vegetation establishment, including native plantings.

For native species, irrigation may not be necessary once the vegetation becomes established, except in periods of extended drought. Given the potential for future climate variability with longer periods of drought, providing irrigation is prudent, even when using native species. The need for and extent of the permanent irrigation system will be dictated by plant selection. Once native, drought-tolerant species are established in an SCM, the long-term irrigation requirements may be eliminated or significantly reduced (with supplemental irrigation during periods of drought only). Given the need for irrigation during the establishment period for native species, installing an irrigation system that can be used during establishment and then intermittently during extended dry periods may be more cost-effective than installing and removing a temporary irrigation system and then having to secure another form of irrigation during a drought.

For non-native vegetation and many ornamental species and trees, permanent irrigation is necessary for healthy vegetation. The irrigation plan should include guidance for water-efficient irrigation according to the needs of the established plants.

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T-1 RECEIVING PERVIOUS AREAS INCLUDING GRASS BUFFERS & SWALES

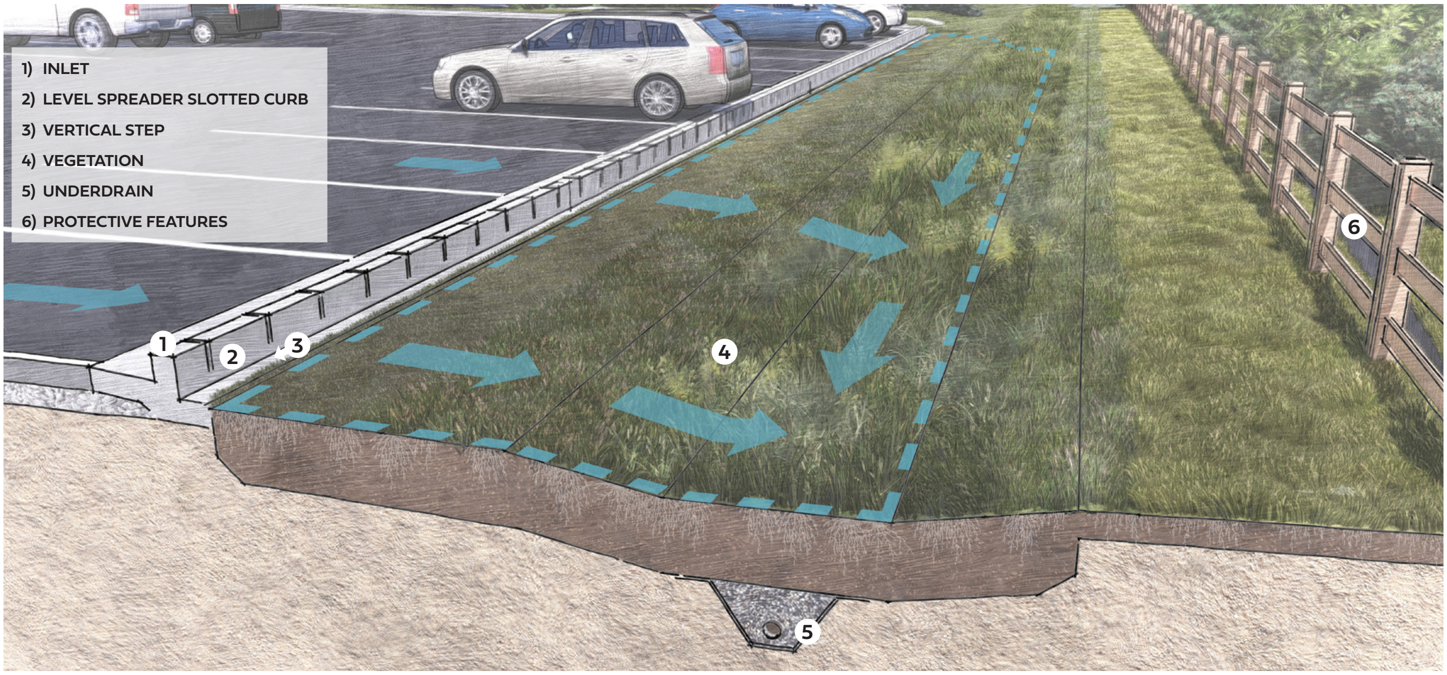

Figure RPA-1. Grass Buffer and Grass Swale Components

DESCRIPTION

Receiving pervious areas (RPAs) reduce the volume of runoff through infiltration and wetting of soils/media with subsequent evapotranspiration. RPAs are commonly used as the first step in MHFD's Four Step Process to disconnect impervious area and provide opportunities for filtration and infiltration of runoff, while conveying runoff to other SCMs. RPAs are integral to Low Impact Development and Green Infrastructure approaches. When properly sized, RPAs including grass buffers and swales can partially (as part of a treatment train) or fully satisfy the Runoff Reduction Standard in MS4 permits. These types of SCMs are not generally capable of meeting the WQCV or Pollutant Removal Standards in the MS4 permits due to the transient storage volumes and generally low hydraulic residence times of runoff in these SCMs.

While all of these practices rely on vegetation and soils to infiltrate runoff, design procedures vary depending on whether the SCM is a buffer or swale.

RPAs include grass buffers, swales and other small landscaped areas receiving runoff from roof or hardscape areas that promote infiltration of runoff and are wetted in the water quality design event.

Grass buffers are densely vegetated strips of grass designed to accept sheet flow from upgradient developed areas. Properly designed grass buffers enable infiltration and play a key role in slowing runoff. Grass buffers provide filtration (straining) of sediment. Buffers differ from swales in that they are designed to accommodate overland sheet flow rather than concentrated or channelized flow.

TABLE RPA-1. RPA OVERVIEW

RECEIVING PERVIOUS AREAS	
MS4 Permit Applicability (Dependent on design and level of treatment)	
Meets Runoff Reduction Standard	Potential
Meets WQCV Capture Standard	No
Meets Pollutant Removal Standard	No
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	High
Total Phosphorus	Low-Medium[1]
Total Nitrogen	Low
Total Metals	Medium
Bacteria	Low
Common Applications	
Runoff Reduction (General)	Yes
Used for Pretreatment	Yes
Integrated with Flood Control	No

[1] Concentration reduction is typically low, but load reduction can be more significant due to volume reduction.

Grass swales have dense vegetation and broad cross-sections that convey concentrated flow in a slow and shallow manner, facilitating infiltration, sedimentation, and filtering (straining) while limiting erosion. Check dams may be incorporated into grass swales to flatten steep slopes and reduce velocities to encourage settling and infiltration. Although swales carry concentrated flows, they are included in this fact sheet as RPAs because of infiltration that occurs in the swale bottom during conveyance and embankments that can act as lateral flow grass buffers.

SCM COMPONENTS

The primary components of RPAs are the inflow distribution feature and the vegetated pervious area. Components of grass buffers and grass swales are illustrated in Figure RPA-1. Other RPAs are simply adaptations of buffers or swales and share the same general components.

Because RPAs are based on infiltration of runoff, distribution of the runoff from the upgradient watershed evenly across the vegetated surface is critical. Runoff must be able to flow freely into the SCM from the tributary impervious area; therefore, the inflow distribution system must be designed to avoid excessive accumulation of sediment and allow for maintenance that includes removal of accumulated sediment. Level spreaders are commonly used to achieve uniform distribution of runoff to these types of SCMs and are discussed in detail in Section 5.0 *SCM Inflow Features* of this chapter.

The vegetated RPA must be planned and designed to allow for infiltration of runoff (in some cases, a significant fraction of the WQCV), while avoiding standing water for prolonged periods. A minimum vegetation density of 80% is required for RPAs to function as intended. Guidance on selecting vegetation is provided in Section 7.0 of this chapter. Healthy topsoil is critical for the dense vegetation needed for RPAs to properly function. See MHFD's *Topsoil Management Guidance* for information on soil management, testing, and amendments. In some cases, an underdrain may be needed to avoid prolonged standing water, depending on soils, depth to groundwater, and topography of the RPA.

TABLE RPA-2. RPA COMPONENTS

COMPONENT	INTENT	GRASS SWALE	GRASS BUFFER	OTHER RPAS
Inlet	Allows stormwater to enter the SCM.	Yes	Yes	Yes
Level Spreader (Sheet Flow Inlet)	Spreads flow and maximizes infiltration and pollutant removal.	Yes (some cases)	Yes	Yes (or similar function)
Vertical Drop	Provides a small drop to ensure that flow can enter the SCM, even when a buildup of sediment or vegetation is present. This is also the primary location for sediment removal.	Yes	Yes	Yes
Vegetation	Slows runoff and provides pollutant removal through volume reduction, pollutant uptake and straining.	Yes	Yes	Yes
Underdrain	Minimizes prolonged standing water. Ensures desired vegetation is not stressed due to excessive moisture. Supports maintenance.	Yes (with very mild slopes such as <2%)	Not typical	Not typical
Protective Features	Minimizes compaction and disturbance over time.	Yes	Yes	Yes

Photograph RPA-1. Grass buffers are often used in conjunction with grass swales as a treatment train. These pervious areas also help reduce heat island effects in urban areas. Photo: Muller Engineering.

SITE CONSIDERATIONS

Grass buffers, grass swales, and other types of RPA can be integrated on many sites across the spectrum from low density to urban development. These SCMs are generally best suited for sites with low to moderate slopes but can be used on steeper sites when grade control measures are implemented such as terracing for buffers or check dams for swales. RPAs can be incorporated on almost any site by directing runoff to landscaped areas. For lower density sites, this could include directing downspouts to lawn areas, sloping hardscape areas to sheet flow to vegetated areas, and using buffers and swales. For more urban sites, RPAs may include vegetated planters. Permeable pavements can also function as RPAs but are more commonly designed to store the WQCV.

Grass swales can serve as an important part of the conveyance network for a development, while also promoting infiltration and filtration of runoff.

Photograph RPA-2. RPAs including grass buffers and swales treat runoff by filtering and infiltration. For treatment to be effective, grass buffers must receive runoff as sheet flow. Photo: WWE.

BENEFITS OF RECEIVING PERVIOUS AREAS

- Reduction in runoff rate and volume.
- Delay in time to peak.
- Potential reduction of the storm drain systems in upper portions of a watershed.
- Easily integrated into treatment train with other SCMs.
- Stormwater features are integrated with landscaping.
- Maintenance is straightforward and consistent with routine landscape practices.

LIMITATIONS OF RECEIVING PERVIOUS AREAS

- Irrigation is typically required, although may be reduced for native grasses once established.
- May not be appropriate in areas with high sediment, trash, or debris loading.
- Space may not be available to fully meet the MS4 Runoff Reduction Standard.
- Damage from adjacent vehicular traffic may occur if protection is not provided.

Photograph RPA-3. This grass swale provides treatment of runoff from a parking lot, portions of the building, and sidewalks at a healthcare facility. Photo: WWE.

Photograph RPA-4. Grass buffers can be used to manage runoff from parking lots, multi-use paths, roadways, or roof areas, provided the flow is distributed in a uniform manner over the width of the buffer. Native grasses provide a more natural appearance. Photo: WWE.

Incorporating the existing ephemeral stream network of an undeveloped watershed into a development as a system of shallow stabilized swales can have significant runoff reduction benefits. In other cases where impacts to the low-order stream network cannot be avoided, the natural system can be mimicked by using swales rather than pipes for the minor drainage collection system.

COMMUNITY VALUES

RPAs including grass buffers and swales are adaptable SCMs that can be integrated into many different landscapes in a distributed manner to provide runoff reduction benefits while also providing attractive, enjoyable, usable, and sustainable green space for the community. Key considerations for creating RPAs that provide value to the surrounding community include:

- **Design RPAs to complement the other functions of the site.** Consider how RPAs relate to viewsheds, pedestrian and bike circulation, social gathering areas, and other site uses and design RPAs to complement these uses. For example, a vegetated buffer strip on the downgradient side of a bike path can be designed as a linear RPA to infiltrate much of the runoff from the path from frequently occurring events.
- **Integrate drainage and landscape design to distribute RPAs across a site.** RPAs are distributed SCMs and are most effective when implemented throughout a site as a part of integrated drainage and landscaping plans. Many types of RPAs can be designed to be indiscernible from the surrounding landscape, except during shallow, short-term ponding during rainfall events. Add interest to RPAs by creating dynamic landforms through the use of curves and variations in side slopes. Even slopes intended to drain by sheet flow can have subtle variations to create visual interest.
- **Consider native vegetation for water conservation.** The selection of native versus non-native turf grasses for a RPA should be a conscious decision based on which type best meets objectives for the site usage and surroundings as well as runoff reduction and water quality objectives for the site. Irrigated turf, such as Kentucky bluegrass, is a more durable surface for areas where there is foot traffic or in recreational areas. Irrigated turf grass provides a manicured appearance that complements certain urban and suburban aesthetics. However, non-native, irrigated turf grasses require more water, frequent mowing, fertilizing, and weed control.

  Native grass turf areas provide wildlife habitat and create a 'regional' natural aesthetic. Pollinator plants can be seeded in with the native grasses to provide additional environmental benefit. Compared to irrigated bluegrass, native grasses and pollinator plants require much less water and have fewer maintenance, fertilizer, and weed control needs once established. During establishment, irrigation is required to achieve required vegetation density in a timely manner. In many settings, native turf grasses are a more sustainable option than non-native, irrigated turf grasses. Sod-forming native grasses are preferred over bunch grasses. See Section 7.0 of this chapter for additional considerations related to vegetation selection.

MAINTENANCE

RPAs including grass buffers and swales require maintenance of vegetation and periodic removal of sediment. During design, identify where and how sediment will be removed. See Chapter 6 for detailed maintenance requirements for all SCMs. During design, consider the following to facilitate maintenance over the long-term:

- Incorporate a "blind swale," which can be a gutter section or a pervious linear depression running along the upgradient side of the level spreader, to distribute flow along the spreader and facilitate sediment deposition. This can enable collection and removal of sediment without impeding the ability of the level spreader to function between maintenance cycles. (See Figure 4-10 in Section 5.1.3 of this chapter for an example.)
- Consider an underdrain system if there are concerns about excessively wet areas that could cause rutting and damage to the vegetation during mowing operations. See Section 4.3.3 *Underdrain Systems* in this chapter for guidance and criteria on underdrains.
- Provide suitable topsoil based on recommendations in MHFD's *Topsoil Management Guidance*. Good topsoil and healthy vegetation will reduce the extent of maintenance required for weed control and will avoid having areas with unhealthy vegetation susceptible to erosion.
- Design and adjust the irrigation system (temporary or permanent) to provide water in amounts appropriate for the selected vegetation at the appropriate irrigation frequencies. Irrigation needs will change from month to month and year to year. For RPAs with native vegetation, temporary irrigation is typically required to establish suitable vegetation density. Avoid over-irrigation, which can result in ponding and limit infiltration capacity. See Section 7.0 of this chapter for more information on irrigation requirements.
- Provide access for mowing equipment and design side-slopes flat enough for the safe operation of equipment.
- Consider the use and function of other site features so that the SCM fits into the landscape in a natural way. This can encourage upkeep of the area, which is particularly important in residential areas where a loss of aesthetics and/or function can lead to homeowners modifying SCMs.
- Protect pervious areas from vehicular traffic when implemented adjacent to roadways. This can be done with a slotted curb (or other type of barrier) or by constructing a reinforced grass shoulder as discussed in Section 5.0 *SCM Inflow Features* in this chapter. Signage can also be provided in lieu of a physical barrier.

Photograph RPA-5. Grass buffers are well suited for use in riparian zones to assist in stabilizing channel banks adjacent to major drainageways and receiving waters.

Photograph RPA-6. Dense vegetation in this 5% sloping swale provides the roughness to resist erosion and slow, filter, and infiltrate runoff. Photo: Muller Engineering.

Photograph RPA-7. RPA in multi-family residential neighborhood. Sign warns of periodic flooding which helps establish expectations for periodic temporary ponding, while providing a safety warning. Photo: WWE.

Photograph RPA-8. Post signage to protect RPAs from vehicular traffic if there is not a barrier between the parking or roadway and the RPA. Photo: Nancy Styles.

- Consider impacts of snow storage on vegetation and designate an area for snow storage outside of the RPA. Additional maintenance of vegetation is often required when vegetation receives runoff from snowmelt containing salt and sand in the winter.
- Consider providing pet waste disposal stations and signage in areas frequented by dog owners.
- If the RPA is used to meet post-construction MS4 permit requirements, local governments may have specific requirements for RPAs to be covered by drainage easements or other legal agreements so that these areas are not modified over time.

DESIGN PROCEDURES & CRITERIA

Table RPA-3 provides a summary of design criteria, and the following steps outline the procedure for quantifying stormwater runoff reduction associated with RPAs. The criteria in Table RPA-3 and the steps below are applicable to all types of RPAs including grass buffers and swales. Additional criteria specific to buffers and swales are provided following the criteria applicable to all types of RPAs. The SCM Design workbook available on the MHFD website can be used to quantify runoff reduction for RPAs and can help with sizing grass buffers and swales to achieve specific runoff reduction objectives.

DESIGN PROCEDURE AND CRITERIA FOR ALL RPAS

The following steps provide design criteria and procedures applicable to *all* RPAs:

1. **Apply Four-cover Land Use Model to Site Layout:** Identify areas of directly connected impervious area (DCIA), unconnected impervious area (UIA), RPA, and separate pervious area (SPA) as stormwater management plans are developed for a site in accordance with Chapter 3. Look for opportunities to direct impervious areas to vegetation and to integrate RPAs with landscaping. For grass buffers, define a UIA:RPA pair where the pervious area receives stormwater from the UIA in a distributed manner that wets the entire width of the RPA. For grass swales, the RPA should only include the bottom area of the swale which receives concentrated flow from multiple upstream areas (DCIA, UIA:RPA pairs, and SPA). Grass swale embankments should be defined as SPA unless there is lateral inflow from an impervious surface in which case they can be treated as a grass buffer and defined as a UIA:RPA pair.
2. **Protect the RPA from Traffic**: The RPA must be protected from vehicular traffic. A slotted curb can be used for this purpose. See Section 5.0 *SCM Inflow Features* in this chapter for guidance and criteria on inflow configurations for RPAs.

3. **Characterize On-site Topsoil and Determine Suitability for the RPA**: The NRCS Web Soil Survey is a good resource for an initial investigation of site soils. However, only soil sampling and testing will confirm the actual NRCS Hydrologic Soil Group (HSG). Inexpensive laboratory tests quantify particle size based on sieve and hydrometer analyses to determine sand gradation and percent sand, silt, and clay for texture determination, and include agronomic tests for organic content, pH, salinity, and nutrients. MHFD recommends onsite topsoil sampling and testing as a standard of practice on every project. It is essential to characterize soil conditions to identify locations

TABLE RPA-3. DESIGN PARAMETERS FOR RPAS INCLUDING GRASS BUFFERS AND SWALES

DESIGN PARAMETERS	DESCRIPTION, GUIDANCE, AND CRITERIA
Area of UIA	UIA should be approximately 1 acre or smaller for grass buffers, although larger areas may be applicable with proper grading and flow distribution to the RPA. Flow bypass and/or multiple level spreaders may be needed for larger areas. Grass swales can convey runoff from larger areas, but runoff reduction is limited by the saturated hydraulic conductivity of the swale bottom. Therefore, runoff reduction in swales decreases with increasing tributary area.
Wetted Area of the RPA and Flow Characteristics	Grass buffers must receive evenly distributed flow (sheet flow) from the UIA. Consider only the wetted area directly within the flow path when delineating the RPA. For swales, only the bottom width is considered RPA when evaluating concentrated flow through the swale. The embankments of grass swales should be defined as SPA unless there is lateral inflow from an impervious surface in which case it can be treated as a grass buffer and defined as a UIA:RPA pair. See the design procedure for additional criteria and considerations for swales and buffers.
Vegetation of RPA	RPA vegetation (from seed, sod, or plugs) should form a turf with a uniform density of at least 80%. Non-native turf grasses such as Kentucky bluegrass are often used in manicured areas but require more irrigation than native turf grasses. Where a more natural look is desired, use dense native turf-forming grasses. Depending on anticipated flows, consider erosion control measures until vegetation is established. Mulch, gravel, and any materials that can be washed away easily should not be used for the RPA.
Interface between UIA and RPA	The RPA must be protected from vehicle traffic, and the interface between the UIA and the RPA must provide a vertical drop to allow runoff to flow freely from UIA to RPA as sediment and grasses build up over time.
Length-to-Width Ratio of UIA:RPA pair	SWMM modeling for evaluating grass buffer runoff reduction was limited to a length-to-width ratio of the UIA:RPA pair between 0.06 and 16.0. When evaluating grass buffers outside of these limits, results may vary. There are no length-to-width ratio criteria for grass swales although shallower flow increases infiltration capacity.
Slope of RPA	The slope of a grass buffer should be no greater than 3:1 (H:V). Grass swale slopes must maintain positive drainage while limiting velocities to non-erosive levels. For native turf grass RPAs, consider using milder slopes to reduce the potential for erosion while the native grasses are becoming established.
UIA:RPA ratio	The recommended maximum UIA:RPA ratio is 10:1. Ratios greater than this may be appropriate if pretreatment and level spreaders in series are provided. Consider pretreatment as the ratio of UIA:RPA increases.
Soil Type and Preparation	The topsoil and underlying soils of the RPA affect infiltration characteristics and the density and health of vegetation. Perform a gradation test to ensure assumptions are accurate, especially when quantifying runoff reduction in HSG A and B soils. See MHFD's *Topsoil Management Guidance* for information on soil types, soil management, testing, and preparation.
Irrigation	Provide temporary or permanent irrigation systems, depending on the type of vegetation selected. Adjust irrigation application rates and schedules throughout the establishment and growing season as appropriate to meet the needs of the selected plant species. Initially, native grasses have similar irrigation requirements to bluegrass. After the grass is established, irrigation requirements for native grasses can be reduced.

that are well suited to serve as RPA and to determine appropriate amendments where RPA is planned (some local governments may also require proof of soil conditions/amendment in landscaped areas for water conservation reasons).

Soil characterization is also required to ensure runoff reduction calculations discussed in subsequent sections use appropriate soil type parameters and coefficients. Plot the percent sand, silt, and clay of each sample on a USDA soil triangle and use this to confirm soil texture and HSG. Table RPA-4 indicates HSG based on percent sand, silt, and clay according to the NRCS National Engineering Handbook (USDA 2009). Based on the results of on-site soil sampling and testing, refer to Table RPA-4 to select the most suitable soil from the site for use in the RPA. See MHFD's *Topsoil Management Guidance* for additional information on preserving topsoil and providing amendments as needed to create a healthy medium for vegetation to grow.

4. **Select Appropriate Vegetation**: Modeling supporting the calculations in this fact sheet assume all RPA is vegetated. RPA vegetation should be turf grass with a uniform density of at least 80%. Seed or sod is acceptable and plugs may provide quicker establishment compared to seed. When selecting a seed mix, consider using all turf grasses or a combination of turf and bunch-forming grass to produce uniform density of 80%. Grass buffers can be dryer than grass swales so selecting the appropriate seed mix is important. See the *Revegetation* chapter in Volume 2 for guidance and consult with a qualified landscape architect or ecologist to confirm the appropriate mixes and seeding locations of the mixes in natives areas. Irrigation is required for establishment of vegetation, and supplemental irrigation may be necessary during extended dry periods once vegetation is established and to maintain a healthy turf.

GRASS BUFFER ADDITIONAL DESIGN PROCEDURE AND CRITERIA

Previously described criteria outlined above for *all* RPAs are required for grass buffers. Additional procedures and criteria specific to designing grass buffers include:

1. **Define the UIA:RPA pair, Ratio, and Interface Width:** When delineating UIA:RPA pairs only include pervious area directly receiving stormwater that wets the entire width of the RPA. Do not include areas receiving concentrated flow as RPA since these criteria assume uniform sheet flow across the wetted portion of the RPA. Use a level spreader at the UIA:RPA interface when flows from the UIA are concentrated. Section 5.0 *SCM Inflow Features* in this chapter provides guidance and criteria for design of level spreaders.

TABLE RPA-4. PERCENT SAND, SILT, AND CLAY FOR HSG A THROUGH D[1]

HSG	% SAND	% CLAY	% SILT
A	> 90	< 10	0 – 10
B	50 – 90	10 – 20	10 – 50
C	< 50	20 – 40	0 – 100
D	< 50	> 40	0 – 60

[1] Consider these values approximate as hydrologic soil groups are not exclusively determined by gradation.

FLEXIBILITY TO FIT SITE CONSTRAINTS

Grass buffers, swales, and other types of RPAs provide some benefit in volume reduction and pollutant removal even when the geometry of the SCM does not meet the criteria provided in this Fact Sheet. These criteria provide a design procedure that should be used when possible; however, when site constraints are limiting, grass buffers, swales, and RPAs designed for stability are still encouraged.

Photograph RPA-9. Grass buffer provides an opportunity for filtration and infiltration of roof runoff and disconnects impervious area of roof from inlet to storm drainage system.

UIAs should be approximately 1 acre or smaller for grass buffers, although larger areas may be applicable with proper grading and flow distribution to the RPA. The recommended maximum UIA:RPA ratio is 10:1. If a level spreader and grass buffer system are used to treat concentrated discharge from a larger drainage area, provide a bypass system for flood flows to avoid creating erosive velocities within the buffer.

Measure the interface width, where uniform sheet flow passes from the UIA onto the RPA. Divide the total area (UIA+RPA) by the interface width to determine the total flow path length. The resulting length-to-width ratio (L:W ratio, flow path length divided by interface width) is used to evaluate runoff reduction with respect to travel time across the RPA. The SWMM modeling supporting these criteria was limited to a L:W ratio of the UIA:RPA pair between 0.06 and 16.0. Therefore, MHFD's SCM Design workbook is constrained to length-to-width ratios within this range.

2. **Buffer Length:** The length of the buffer is the measure of the vegetated surface in the direction parallel to flow. While there are no minimum length requirements for buffers, the runoff reduction and pollutant removal benefits of buffers increase as the total wetted area increases. For very long buffers and/or for buffers on steep slopes, additional level spreaders may be needed along the buffer length to avoid concentration of flow. *Design of Level Spreaders to Treat Stormwater Runoff* (Hunt et al. 2001) provides guidance on calculations for evaluating buffer length limitations and the number of level spreaders needed for longer buffers or those on steeper slopes.

3. **Buffer Slope**: The design slope of a grass buffer in the direction of flow must be mild enough to avoid erosion and to allow for infiltration, while still allowing for positive drainage to avoid problems with standing water. Generally, a minimum slope of 2% or more is adequate to facilitate positive drainage for turf grasses. Grass buffers should not exceed a 3:1 slope. For native turf grass RPAs, consider using milder slopes to reduce the potential for erosion while the native grasses are becoming established. For buffers with higher UIA:RPA ratios and steeper slopes,

TIERED LEVEL SPREADER-BUFFER SYSTEMS

If the calculated buffer width is more than 100 feet, tiered level spreader-buffer systems can be used to design wider buffers, while still providing for even sheet-flow distribution across the width of the buffer.

calculations may be needed to evaluate buffer stability. *Design of Level Spreaders to Treat Stormwater Runoff* (Hunt et al. 2001) provides guidance on permissible velocity calculations for evaluating potential for erosion.

4. **Provide a Vertical Drop:** Provide a minimum vertical separation of 3 inches between the UIA and RPA at their interface. Where pedestrian or vehicular traffic is of concern, the drop can be sloped from the edge of the impervious surface to the buffer using #57 stone underlain with geotextile separator fabric. Limit the drop to no more than 6 inches. The drop is required to ensure positive drainage from the UIA to RPA as vegetation becomes established

5. **Calculate Runoff for the UIA and RPA Pair**: In the MHFD region, the precipitation depth associated with the WQCV event is 0.6 inches. For areas outside of the Denver Metro region, the precipitation depth for the WQCV event may differ. The Runoff Reduction calculations in MHFD's SCM Design workbook are not applicable for precipitation depths less than 0.25 inches or greater than 0.95 inches. For evaluating greater rainfall depths, CUHP and SWMM should be applied. Calculate the total runoff from each UIA:RPA pair using Equation RPA-1 (Piza and Rapp 2018):

$$Q = C_0 + C_1(0.95 - P_2) + C_2(A) + C_3(L{:}W) + C_4(S) + C_5(I) + C_6(I^2)$$ **Equation RPA-1**

Where:

Q = Runoff from the UIA:RPA pair (watershed inches)

P_2 = Precipitation for the Water Quality Event (WQE) over 2 hours (inches)

A = Total Area of UIA:RPA pair = Area of UIA + Area of RPA (ft^2)

$L{:}W$ = Ratio of total flow length to interface width

S = Average overland slope (ft/ft)

I = Imperviousness of UIA:RPA pair = UIA/(UIA + RPA), expressed as a decimal

C_x = Regression coefficients, see Table RPA-5.

TABLE RPA-5. COEFFICIENTS FOR QUANTIFYING RUNOFF FROM UIA:RPA PAIR FOR RUNOFF REDUCTION ANALYSIS (PIZA AND RAPP 2018)

HYDROLOGIC SOIL GROUP	CONSTANT C_0	PRECIP, P_2 (IN), C_1	AREA (AC), C_2	L:W, C_3	SLOPE (FT/FT), C_4	IMPERV., C_5	IMPERV., C_6
A	0.581	-0.779	-3.34×10^{-07}	-0.00193	0.0703	-2.49	2.64
B	-0.0777	-0.925	-2.45×10^{-07}	-0.00145	0.0502	-0.0136	0.924
C/D	-0.0113	-0.899	-2.68×10^{-07}	-0.00157	0.0545	0.355	0.464

Calculate the volume of runoff from the UIA:RPA pair by multiplying the watershed inches determined in Equation RPA-1 by the total area of the UIA:RPA pair as shown in Equation RPA-2:

$$V_{UIA:RPA} = \left[\frac{Q}{12}\right] A_{UIA:RPA}$$ **Equation RPA-2**

Where:

$V_{UIA:RPA}$ = Volume of runoff from UIA:RPA pair (ft^3)

$A_{UIA:RPA}$ = Area of UIA:RPA pair (ft^2)

6. **Compare Runoff from UIA:RPA Pair to Runoff from UIA Only**: Calculate the runoff from the UIA by assuming impervious area depression storage of 0.1 inches.

$$V_{UIA} = \left[\frac{P_2 - d_{store}}{12}\right] A_{UIA}$$ **Equation RPA-3**

Where:

V_{UIA} = Volume of runoff from UIA (ft^3)

P_2 = Precipitation for WQE over 2 hours (in)

d_{store} = Impervious area depression storage (in), assume 0.1 for most impervious surfaces

A_{UIA} = Area of UIA:RPA (ft^2)

The difference between this value (V_{UIA}) and $V_{UIA+RPA}$ from Equation RPA-2 is the runoff reduction associated with the UIA:RPA configuration. The percentage reduction in runoff can be calculated as:

$$\%Runoff\ Reduction = \left[\frac{V_{UIA} - V_{UIA:RPA}}{V_{UIA}} \right] \qquad \textbf{Equation RPA-4}$$

TABLE RPA-6. QUICK REFERENCE SIZING FOR RPAS, INCLUDING GRASS BUFFERS

HSG	REQUIRED UIA:RPA RATIO[1]	
	60% WQCV REDUCTION	100% WQCV REDUCTION
A	7.2:1	3.7:1
B	3.4:1	1.9:1
C/D	2:1	1:1

[1] Based on WQCV precipitation of 0.6 inches and slopes up to 33%.

HOW MUCH IS ENOUGH?

When using RPA as stand-alone treatment for the WQCV, some MS4 permits require a certain percent runoff reduction (e.g., 60%) of what the calculated WQCV would be if all impervious area for the applicable development site discharged without infiltration. Some municipalities may have more stringent requirements. Regardless, downstream SCMs may still be required to meet permit conditions and MHFD's SCM Design workbook can help size those while accounting for volume reduction utilizing this method. Use Table RPA-6 for a quick reference when initially sizing RPAs to reduce 60% or 100% of the WQCV.

GRASS SWALE ADDITIONAL DESIGN PROCEDURE AND CRITERIA

Grass swales are important SCMs for conveying runoff from a site through a vegetated, pervious flow path. Swales slow down runoff, promote infiltration, and extend the time of concentration of the watershed, thereby reducing the rate, volume, and frequency of runoff produced by a watershed. When designed for shallow depths with dense vegetation, grass swales may aid in achieving the MS4 Permit Runoff Reduction Standard for a site. Even when designed primarily for conveyance purposes (e.g., somewhat higher velocities and depths), swales help to dampen the runoff response and filter and infiltrate runoff. Swales provide the types of benefits envisioned by Step 1 of MHFD's Four Step Process.

Criteria outlined above that apply to *all* RPAs are required for grass swales. Additional procedures and criteria specific to designing grass swales for runoff reduction and swale stability include:

1. **Delineate Areas Tributary to Swale:** Identify the area tributary to the swale during the water quality event. This may include any combination of upstream DCIA, UIA:RPA pairs, and SPA. The swale RPA should only include the bottom area of the swale which receives concentrated flow from multiple upstream areas. This bottom area will be used to calculate the runoff reduction in the swale. Swale embankments should be defined as SPA unless there is lateral inflow from an impervious surface in which case they can be treated as a grass buffer and defined as a UIA:RPA pair tributary to the swale.
2. **Swale Inflows**: Provide a sediment pad or forebay at the entrance to the swale to facilitate maintenance as shown in Figure 4-10 of Section 5.1.3.

Photograph RPA-10. Sediment forebay at the entrance to a grass swale leading to an EDB concentrates maintenance needs at entrance of swale. This is an example of a three-step treatment train: forebay, swale, pond.

Locating a vertical drop where inflow meets the sediment pad allows for sediment accumulation where it is intended without impeding inflow. See Section 5.0 *SCM Inflow Features* for more ideas at the inlet.

3. **Swale Cross Section**: The swale cross section should be trapezoidal with side slopes not exceeding 4:1 (horizontal: vertical), preferably flatter. Fit the swale into the site by varying the swale alignment and side slopes and avoid linear, prismatic designs to the extent practical unless the application is in a highway environment. Trapezoidal swales with wide bottoms maximize the wetted perimeter. Per Table RPA-3, it is only the bottom area of the trapezoid that is considered RPA in quantifying volume reduction.

4. **Longitudinal Slope**: Establish a longitudinal slope that will maintain positive drainage while limiting velocities in the swale to non-erosive levels. Typically, positive drainage for a swale can be achieved with a minimum longitudinal slope of 2%. MHFD recommends using an underdrain when swales have longitudinal slopes less than 2% to minimize the potential for standing water and nuisance conditions. See Section 4.3.3 *Underdrain Systems* of this chapter for additional information on underdrains for grass swales. Flow discharged from underdrains cannot be considered in runoff reduction calculations. Therefore, MHFD's SCM Design workbook is not appropriate for quantifying runoff reductions for swales using underdrains. Use check dams as needed to accommodate steeper site constraints. Commonly used check dam materials include rock, riprap, concrete, and vegetated earth (MPCA 2023; Davis, Hunt and Traver 2022). Provide energy dissipation downstream of each check dam when using these grade control structures.

5. **Calculate Runoff from Tributary Area**: In the MHFD region, the precipitation depth associated with the WQCV event is 0.6 inches. For areas outside of the Denver Metro region, the precipitation depth for the WQCV event may differ. The Runoff Reduction calculations in MHFD's

BIOSWALES

In some cases, engineers may design "bioswales" that incorporate more diverse, often hydrophytic, vegetation and enhanced landscaping features. These types of swales can provide an enhanced level of water quality treatment and in many applications serve as a hybrid of a swale and a bioretention facility. These types of swales are encouraged when they can be incorporated into the landscaping and provide benefits beyond water quality treatment. The same fundamental procedures apply for designing a bioswale; however, the vegetative retardance coefficient must be adjusted to reflect the mature state of planned vegetation for evaluation of depth. The "E" curve (very low vegetal retardance) should be used to evaluate velocities, representing conditions prior to establishment of dense vegetation.

SCM Design workbook are not applicable for precipitation depths less than 0.25 inches or greater than 0.95 inches. For evaluating greater rainfall depths, CUHP and SWMM should be applied. Calculate the total runoff from all areas tributary to the swale by assuming upstream pervious areas don't produce runoff during the WQCV event, the upstream impervious area depression storage is 0.1 inches, and account for direct precipitation on the swale bottom.

$$V_{Swale} = \left[\frac{P_2 - d_{store}}{12}\right] A_{TIA} + \left[\frac{P_2}{12}\right] A_{RPA}$$ **Equation RPA-5**

Where:

V_{Swale} = Volume of runoff applied to swale bottom (ft^3)

P_2 = Precipitation for WQE over 2 hours (in)

d_{store} = Impervious area depression storage (in), assume 0.1 for most impervious surfaces

A_{TIA} = Tributary Impervious Area contributing runoff to swale (ft^2)

A_{RPA} = Bottom Area of swale receiving direct precipitation (ft^2)

6. **Calculate Runoff Reduction through Swale Bottom**: The bottom of the swale is assumed to infiltrate runoff at a rate equal to the saturated hydraulic conductivity of the soil. Due to the potential for decay of infiltration rates over the life of a facility, the HSG-based final infiltration rates in the *Runoff* chapter are used for estimating runoff reduction in the SCM Design workbook.

$$V_{Infil} = \left[\frac{2f_o}{12}\right] A_{RPA}$$ **Equation RPA-6**

Where:

V_{Infil} = Volume of runoff infiltrated for WQE over 2 hours (ft^3)

A_{RPA} = Bottom Area of swale infiltrating runoff (ft^2)

f_o = Final Infiltration Rate based on HSG from *Runoff* chapter (in/hr)

The ratio of the volume infiltrated (V_{Infil}) divided by the volume of runoff applied to the swale (V_{Swale}) from Equation RPA-5 is the runoff reduction associated with the grass swale. The percentage reduction in runoff can be calculated as:

$$\%Runoff\ Reduction = \frac{V_{Infil}}{V_{Swale}}$$ **Equation RPA-7**

7. **Design Discharge**: Calculate peak flows for the swale using the methods in the *Runoff* chapter. For swale stability design, use a 2-year event to evaluate velocity and flow depth. Larger events such as the minor storm event also may be conveyed in swales; see the *Open Channels* chapter for design of conveyance swales.

8. **Design Velocity**: The maximum flow velocity in the swale should not exceed 1 foot per second. Higher velocities up to 3 to 5 feet per second (depending on the soil type and swale lining) for the 2-year event are permissible for swales that are intended primarily for conveyance rather than infiltration, provided that the Froude number does not exceed 0.5. Even if velocities exceed 1 foot per second, swales can still play an important role in disconnecting impervious area and will provide some infiltration benefits. Use the Natural Resource Conservation Service (formerly the Soil Conservation Service) vegetal retardance curves for the Manning coefficient (Chow 1959). Determining the retardance coefficient is an iterative process that the MHFD SCM Design workbook automates. When starting the swale vegetation from sod, use curve "D" (low retardance). When starting vegetation from seed, use the "E" curve (very low vegetal retardance) to evaluate potential for erosion during initial establishment and the "D" curve for evaluating depths and velocities for the established condition.

9. **Design Flow Depth**: The maximum flow depth should not exceed 1 foot at the 2-year peak flow rate if the swale will provide runoff reduction benefits as a part of a system intended to satisfy a MS4 permit treatment standard. Depths up to 3 feet may be allowed in the 2-year event for swales that are intended only to satisfy Step 1 of the Four Step Process, provided that the Froude number does not exceed 0.5. Check the conditions for the 100-year peak discharge to ensure that drainage is being handled without flooding critical areas, structures, or adjacent streets.

10. **Swale Outflows**: Provide a means for downstream conveyance for the range of flows that may be conveyed through the swale. For swales that drain to inlets or culverts, perform analysis of headwater depth for the 2-year design flow rate to be sure that the headwater depth is contained within the swale with an allowance for a minimum of 6 inches of freeboard. Greater freeboard requirements may apply depending on road classifications adjacent to swales.

CONSTRUCTION CONSIDERATIONS

Success of RPAs, including buffers and swales, depends not only on a good design and long-term maintenance but also on proper construction so that the RPA functions as designed. Construction considerations include:

Photograph RPA-11. Signage and construction fencing can help protect the RPA as vegetation becomes established.

1. Fence off areas to avoid over-compaction of soils to preserve infiltration capacities.

2. When using an underdrain, ensure no filter sock is placed on the pipe. This is unnecessary and can cause the slots or perforations in the pipe to clog.

3. Perform fine grading, soil amendment, and seeding only after upgradient surfaces have been stabilized and utility work crossing the SCM has been completed. The final grade of the RPA, once sod has been placed or seeded vegetation has become established, must accept sheet flow from adjacent impervious surfaces without impeding flow.

4. Inspect the RPA prior to placement of seed or sod to check that inflows are not concentrated and that the final grade, including the vegetation, will not impede sheet flow onto the vegetated pervious area.

5. When using sod tiles, stagger the ends of the tiles to prevent the formation of channels along the joints. Use a roller on the sod to ensure there are no air pockets between the sod and soil.

6. If the area where the SCM will ultimately be constructed will be used as an SCM during construction (e.g., sediment trap, drainage ditch), the area must be restored prior to constructing the permanent SCM by removing all accumulated sediments and ripping the soils to a depth of 12 inches. Do not install underdrains or place topsoil in the SCM until the watershed is stabilized and the SCM is no longer acting as a sediment trap.

7. Erosion and sediment control measures on upgradient disturbed areas must be maintained to prevent excessive sediment loading to the SCM. Implement final grading, soil amendments, seeding, and related activities once the contributing watershed has been effectively stabilized.

8. Provide irrigation appropriate to the type of vegetation. Note that irrigation will be needed for native grasses to establish the root system (typically one or two growing seasons).
9. Weed the area during the establishment of vegetation by hand or mowing. Mechanical weed control is preferred over chemical application.
10. Consider signage and barriers to prevent use of the RPA while the vegetation becomes established.

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T-2 ROOFTOP SYSTEMS

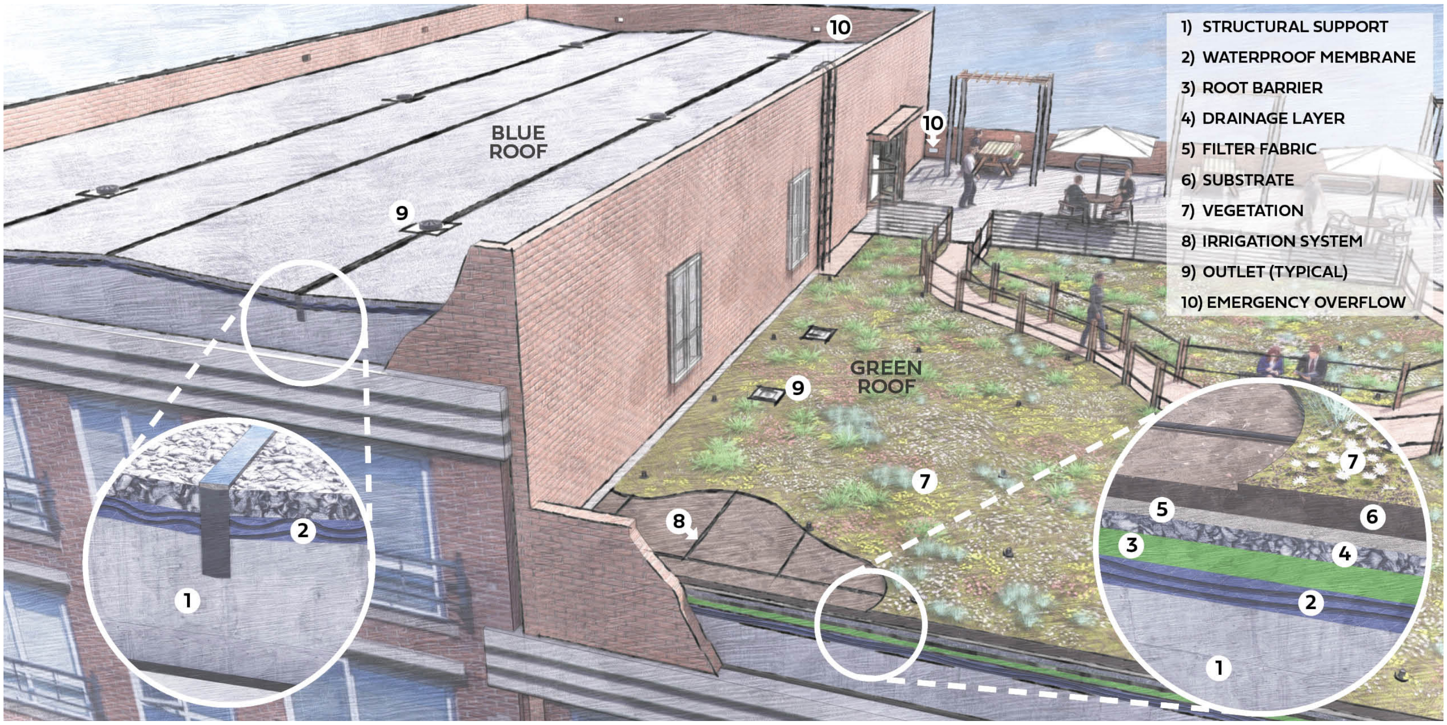

Figure GR-1. Green Roof and Blue Roof Components

DESCRIPTION

Rooftop systems for stormwater management include green roofs and blue roofs. Green roofs are vegetated systems grown in substrate that helps to reduce runoff volumes and rates. Blue roofs are unvegetated rooftop stormwater detention areas. Blue-green roofs combine these two systems.

There are two main types of green roofs: extensive and intensive. Extensive green roofs are shallow, usually with up to 6 inches of substrate, and do not typically support a large diversity of plant species because of root zone limitations. Intensive green roofs are more like rooftop gardens with deep substrate (from 6 inches to several feet) and a wide variety of plants. Most buildings are not designed to withstand the additional weight loading for intensive roofs unless accounted for in the original design of the building. For this reason, intensive green roofs are typically limited to new construction. Extensive green roofs are shallower, less expensive and generally much better suited to the structural capabilities of existing buildings and therefore, are installed more often.

Blue roofs are a rooftop system that provides rooftop detention without vegetation or substrate. Roof drain orifices regulate the rate of runoff from the roof to release the WQCV. Combining blue roof and green roof systems on the same rooftop is increasingly becoming more common.

TABLE GR-1. GR OVERVIEW

ROOFTOP SYSTEMS (GREEN AND BLUE ROOF)	
MS4 Permit Applicability (Dependent on design and level of treatment)	
Meets Runoff Reduction Standard	Green Roofs Only
Meets WQCV Capture Standard	Yes
Meets Pollutant Removal Standard	No
Typical Effectiveness for Targeted Pollutants[1]	
Sediment/Solids	Low
Total Phosphorus	Low
Total Nitrogen	Low
Total Metals	Low
Bacteria	Low
Common Applications	
Runoff Reduction (General)	Yes
Used for Pretreatment	Yes
Integrated with Flood Control	No[2]

[1] Primary benefit is volume reduction.
[2] May vary by jurisdiction for blue roofs.

SCM COMPONENTS

The primary components of green roofs include structural support, a waterproof membrane, a root barrier, drainage layer, filter fabric, the substrate (growing media), vegetation, an irrigation system and outlets to drain the roof (Table GR-2). In the case of blue roofs, components include structural support, a waterproof membrane, and orifice-controlled outlet(s). Before installing a green roof or blue roof on an existing structure, a structural engineer must verify that the roof structure can support the load associated with the rooftop system.

Some systems may also incorporate a water retention layer if Colorado water rights constraints are addressed. Insulation layers may also be incorporated into the design based on building heating/cooling objectives. For new buildings, the building design should include the rooftop system load.

TABLE GR-2. GR COMPONENTS

COMPONENT	INTENT
Structural Support	Roof structure that supports the substrate, vegetation, and live loads associated with rainfall, snow, people, and equipment.
Waterproof Membrane	Prevents water from entering the building.
Root Barrier	Protects the waterproof membrane by preventing roots from reaching the membrane. (Note: In some proprietary products, root barriers may be integrated into the product with the drainage layer.)
Drainage Layer	Drains the rooftop system to the outlet. This is sometimes an aggregate layer or a proprietary product.
Filter Fabric	This prevents fine soil and substrate from being washed out into the drainage layer.
Substrate (Growing Media)	Provides a growing media for the rooftop vegetation. Although the substrate is typically not "soil," the terms *soil matrix, soil media* and *growth substrate* are sometimes used.
Vegetation	Provides evapotranspiration to reduce runoff volumes, aesthetic appeal, ecosystem services and a cooling effect for the building. Native/adapted, drought-tolerant grasses, perennials, and shrubs with relatively shallow root depths are possibilities for roof plantings.
Irrigation System	Supports vegetative health of green roofs. Even vegetation with low water requirements will require supplemental irrigation in the metro Denver area.
Outlet(s)	Provides outlet for detained flows to drain from the rooftop. Orifice controls are not required for green roofs designed to treat the WQCV but could be used to detain larger volumes. Orifice controls are required for blue roofs.

SITE CONSIDERATIONS

Green roofs can be installed on commercial or residential buildings as well as on underground structures such as a parking garage (Photo GR-2). Green roofs may be particularly well suited for ultra-urban areas where development is typically lot-line-to-lot-line and garden space is at a premium.

BENEFITS OF GREEN ROOFS

- Reduces runoff rates and volumes.[1]
- Reduces heat island effect in urban areas.
- May qualify for multiple green building credits and/or help satisfy local green building codes.
- May extend roof lifespan by reducing daily temperature fluctuations and providing shading from ultraviolet light.
- May provide energy savings from additional insulation and cooling from evapotranspiration.
- Provides an additional protective layer over the rooftop that may extend the lifespan of traditional roof membranes relative to impacts from hail and UV degradation.
- Provides aesthetically pleasing open space in ultra-urban areas.
- Provides habitat for pollinators and birds.
- Reduces (or eliminates) stormwater quality management footprint on the ground surface.[1]

LIMITATIONS OF GREEN ROOFS

- Initial installation costs are greater than conventional roof (although life cycle costs are lower).[1]
- Supplemental irrigation is required in semi-arid climate.
- Maintenance during vegetation establishment (first two years) may be significant.

[1]*Also applies to blue roofs.*

Photograph GR-1. Extensive Green Roof. Photo: Jennifer Bousselot.

Photograph GR-2. Denver Botanic Gardens intensive green roof over parking garage. Photo: Michael Guidi.

Green roofs are particularly valuable when their use extends to a place of enjoyment with visual or physical access for those that inhabit the building.

For existing buildings, verify the structural integrity of the building prior to consideration of retrofitting the building with a green roof. For both existing and new construction, a multi-disciplinary design team is essential. This team may include a structural engineer, stormwater engineer, architect, landscape architect, and horticulturist. Involve all members of the design team early in the process to ensure the building and site conditions are appropriate for green roof installation (Tolderlund, 2010).

Several factors contribute to the success of green roofs in a semi-arid environment. Access to permanent irrigation is required, even if it is only used in drought conditions once the green roof is established. Wind scour is a major concern for rooftop systems (particularly taller buildings), so it is important to keep the slope consistent throughout the green roof and avoid vegetating high wind areas at building corners. In a dry climate, the aspect of the green roof is important: south or west-facing sloped applications may require more irrigation and maintenance; therefore, north and east-facing installations are preferred when feasible. Scale is also important – it is challenging to maintain a thriving green roof in a small space or disconnected pattern.

Blue roofs have similar site considerations to green roofs, but without vegetation and irrigation-related factors. Blue roofs are not typically designed for public access or to serve as multi-purpose amenities.

COMMUNITY VALUES

Green roofs, blue roofs, and blue-green roofs improve the quality of the urban environment by using an underutilized space for stormwater management. In the case of green roofs and blue-green roofs, this SCM also provides valuable green space in an urban environment. To decide between a green roof or blue roof, assess the overall objectives of the project and the opportunities and constraints presented by the roof area and surroundings. Green roofs and blue roofs have distinct characteristics that must factor into this choice, as described below.

GREEN ROOFS: Even in the semi-arid climate of the Denver metro area, green roofs can be a good choice for an SCM, particularly in ultra-urban environments. When evaluating applicability of this SCM, consider whether the community benefits (beyond the stormwater management objectives) merit the higher construction costs, irrigation system, and water required to sustain the plants, and evaluate costs of maintenance required to establish the green roof and sustain the plants for the long term. The value of green roofs to the community can be significant, particularly when safe, public and semi-public access to the green space is allowed. These “gardens in the sky” can provide valuable outdoor spaces that might otherwise not be available in dense urban environments. These spaces benefit not only those who have direct access to the space, but also people in upper building floors and in adjacent buildings who are able to look down at the green roof. Other benefits provided by green roofs include enhanced habitat for pollinators and birds, improved air quality, building energy efficiency, and reduction in the urban heat island effect. In some cities, green roofs are also used for rooftop vegetable and herb gardens, supporting restaurants in the building.

Key design objectives to consider in efforts to maximize the community value of green roofs include:

- Take design cues from the architectural and landscape architectural design and materials of the building on which the green roof is located. The green roof should either blend with the architecture's forms and materials or be intentionally designed to contrast and stand out as a special feature.
- Create spaces for people. Ensure that the rooftop area open to public use is universally accessible (refer to ADA Standards for Accessible Design) by providing adequate doorways, walkways, ramps and seating. Provide shaded areas if possible, and lighting if evening/night use is a possibility.
- Design for safety. Green roofs that provide physical access will need appropriate safety features to ensure that visitors cannot endanger themselves.
- Design the green roof for viewing from all possible vantage points (including upper floor windows and adjacent buildings).
- Provide diverse plant material that can withstand harsh rooftop growing conditions and that enhances the urban ecosystem, including flowering plants for pollinators. (Follow the plant selection guidance provided later in this Fact Sheet.)
- Create more favorable environments for plants and people by siting planting and use areas away from prevailing winds and harsh southwestern sun exposures. Use wind screen panels or solar panels to deflect the wind if the green roof must be located in windier areas. Also be aware of the potential for the sun to reflect off of upper story building windows and other reflective surfaces, intensifying heat (i.e., magnifying glass effect) that can kill plants.

BLUE ROOFS: Blue roofs have lower construction and maintenance costs than green roofs, have no irrigation requirements (relative to green roofs), and are well suited for rooftop areas when the potential for community benefits is low (e.g., the building rooftop has limited physical or visual access). In these cases, blue roofs may be more economical choices for rooftop SCMs, making use of an otherwise underutilized area. Blue roofs benefit the community by eliminating or reducing the need for SCMs elsewhere on the site, allowing more of the site to be dedicated to community-oriented uses, thereby enhancing the urban environment.

MAINTENANCE

Recommended ongoing maintenance practices for all SCMs are provided in Chapter 6. When designing a rooftop system, the designer and owner must understand both the initial establishment and long-term maintenance requirements for rooftop systems. Prepare a written maintenance plan at the time of design that clearly describes the legal means of access, types of equipment required for maintenance and maintenance requirements, including the various components of the rooftop system. Rooftops are a challenging location to grow vegetation, so maintenance is essential, especially during establishment. Address the unique characteristics of the green roof including: irrigation system, shading, microclimates (shade, temperature, and wind), nutrient/fertilizer management, plant debris removal, maintenance access, and vegetation design (i.e., keeping plants in specific areas). During design, consider the following to ensure ease of maintenance for green roofs over the long-term:

- Provide access for equipment and inspections following construction.
- Carefully design and install the irrigation system, substrate, and appropriately selected plants because these are critical factors determining long-term maintenance requirements and survival of the green roof vegetation under hot, dry conditions. Otherwise, vegetation may have to be repeatedly replanted and/or the irrigation system replaced.
- If an underdrain system is used, provide cleanouts for inspection and maintenance. There is potential over the long term for the roof underdrain system to become clogged with substrate that migrates down beneath the

Photograph GR-3. Intensive green roof over parking garage is readily accessible for maintenance.

plant root zone. The ability to access the underdrain system for cleanout is important. See Section 4.3.3 *Underdrain Systems* of this chapter for guidance and criteria on underdrains.

- Provide signage for orifice-controlled outlets to prevent modification of the orifice.
- Consider winter maintenance access requirements such as breaking up ice formation around outlets and overflows (particularly for blue roofs).

DESIGN PROCEDURES & CRITERIA

Design considerations include:

1. **Structural Integrity:** For green roofs, blue roofs and combination green-blue roofs, a structural engineer must ensure the load-bearing capacity of the roof is adequate for the system to be installed. Account for the load of the green roof plus any ponded water below the overflow weir or scupper. For new buildings, green roofs require a multi-disciplinary team and coordination throughout all phases of design.
2. **Water Quality Capture Volume:** Green roofs with a substrate of 4 inches or more typically meet MS4 permit design standards for the green roof area (not including run-on) without orifice-controlled flow-release. The WQCV is temporarily detained within the pore space of the green roof's substrate and drainage layer.

   In Colorado, green roofs are allowed without a water right provided they intercept only precipitation that falls within the perimeter of the vegetated area of the green roof and do not intercept or consume concentrated flow or store water below the root zone (DWR 2016). In cases where a portion of the roof is a green roof and a portion of the roof is a traditional roof, the WQCV for the green roof area can be deducted from the stormwater quality treatment requirement for the overall site.

   For blue roofs, a 12-hour drain time is used to calculate the WQCV. The 12-hour drain time differs from the 40-hour extended detention basin drain time due to the lower pollutant loads of roof runoff compared to

GREEN ROOFS AND THE WQCV

Stormwater performance monitoring data collected by EPA from the Region 8 office green roof in Denver, Colorado demonstrated that green roofs can be effective at detaining and reducing runoff volume. This is especially true for snowmelt events and for smaller precipitation events (generally <1" rainfall in a 24-hour period). EPA's monitoring showed that the green roof retains and evapotranspires 98 to 100% of the WQCV, even without a restriction on the outlet for drain time control. This is largely due to wetting and subsequent evapotranspiration in the substrate. The data showed few exceptions to this finding, which were attributed to successive rain events.

Based on these findings, MHFD recognizes green roofs as a volume-based SCM, able to capture the WQCV for the area of the green roof, without constructing a controlled release at the outlet. This finding applies to green roofs that meet or exceed the EPA building's green roof section, which is a modular system using trays with a minimum of 4 inches of substrate. An intensive roof, which typically has greater substrate depth, also meets the WQCV Capture Standard in the MS4 permit.

runoff from roads, landscaped areas, and other ground-level land uses. The 12-hour drain time also is intended to allow the SCM to drain fully before another storm occurs to avoid storing excessive runoff for structural reasons. Determine the required WQCV using Figure 3-2 of Chapter 3 of this manual. Design the orifice controls for blue roofs (or other roof conditions requiring orifice control) to release the WQCV over the required drain time.

3. **Impermeable Membrane and Waterproofing:** For green and blue roofs, an impermeable membrane is required. Install roof membranes in accordance with the manufacturer's specifications to provide proper waterproofing. The system must have a waterproof seal along all seams in the roof membrane and in areas where mechanical devices, equipment, or other structures are affixed to the roof surface. Attach the waterproofing system to the roof surface using adhesives or other methods approved by the system manufacturer. Adhesives that may corrode or otherwise compromise the performance of the membrane or roof system should be avoided. If a green roof will be used as ballast for the membrane, provide temporary ballast until the green roof is installed (NYDEP 2012).

   For existing buildings, check waterproofing warranty and consult the warranty company to ensure the policy will not be voided by a green roof application. A leak test is required following installation of the impermeable membrane, and a leak detection system is recommended for long-term operations, especially in systems with permanent irrigation.

4. **Root Barrier System:** All green roofs require protection against root penetration. The waterproofing system should be able to resist even the most aggressive plant roots. Only plastic or rubber membranes are acceptable as root barriers. If waterproofing is used without a supplemental root barrier, obtain and evaluate test data for root resistance of the waterproofing materials. Seams should provide the same level of root resistance as the root barrier membrane. Acceptable seaming methods are hot-air welding (thermoplastic membranes) or overlaps of at least 5 feet combined with an adhered seam. Sealing the root barrier seams also provides additional waterproofing for the system and may extend the life of the roof (NYDEP 2012).

5. **Granular Drainage Layer and Drainage System:** For green roofs, granular mineral drainage media can be used to provide a drainage layer that slows flow toward roof drains and lengthens the time of concentration. Granular drainage layers may be as thin as 1 inch but are typically 2 to 4 inches thick. This type of drainage layer can be used to supplement assemblies that include reservoir sheets and fill in some void space to reduce shock to the root system. Layers that incorporate drainage media become part of the root zone of the plants, and the materials should be chosen accordingly. Granular drainage layers should contain as little silt and clay as possible and should have high permeability and porosity. See FLL Guidelines for recommended granular drainage layer recommendations (NYDEP 2012).

   Provide a filter fabric above the drainage layer to keep the substrate from clogging the drainage media. Although roots may pass through the filter fabric, roots should not pass through the waterproof membrane below the

Photograph GR-4. The metal edging has perforations near the bottom to allow flow into the drain.

Photograph GR-5. Metal edging separates substrate from rock that surrounds the roof drain. It also serves to facilitate regular maintenance by limiting plant and root growth near the drain.

drainage layer. Roof outlets, interior gutters, and emergency overflows must be kept free from of debris and plant material in order to convey drainage properly (NYDEP 2012).

Provide vegetation-free zones such as gravel with stainless steel edging between the green roof and outlets and at the roof border with the parapet wall and for any joints where the roof is penetrated or joins with vertical structures. Vegetation free zones serve as both material separation and root barrier.

6. **Substrate:** The substrate serving as the growing media for green roof plants is a key component for plant health, irrigation needs, proper drainage, and stormwater benefits. The substrate is not the same thing as "soil." Most extensive green roof substrates consist primarily of expanded slate, expanded shale, expanded clay, or another lightweight aggregate such as pumice. Such lightweight aggregates have some limitations such as draining very quickly and leaving little water or nutrients available to plants. To prevent filter fabric clogging and loss of permeability, substrate should not contain more than 15% particles in the silt-size fraction, nor should it contain more than 3% in the clay-size fraction (NYDEP 2012). Substrate criteria are not explicitly defined in this Fact Sheet; see the FLL Guidelines for recommendations. Additional research is ongoing related to substrate mixes appropriate for use on extensive green roofs in Colorado. For intensive green roof applications where weight is explicitly factored into the structural design, the substrate can include materials with higher water retention characteristics such as organic matter (e.g., compost), provided the structural design accounts for the saturated load. The substrate is the most critical element to the success of a green roof system and should therefore be purchased from reputable suppliers or specified by green roof experts.

7. **Planting Method:** In general, the planting method will be either "continuous" (planted *in situ*) or "modular" (tray approach):

   - Continuous systems are "built in place" on the roof with layers designed to work together to provide a healthy environment for plants. Examples of continuous roof approaches range from rolled sedum mats to hand-planted buffalograss plugs. Due to the variations in green roof designs, it is important to consult with a multi-disciplinary team to determine the type of roof design most appropriate for the short-term and long-term conditions expected at the site.

   - Modular systems are self-contained trays, which can vary in size, and have relatively shallow depth (2 to 8 inches deep). When modular trays are planted with groundcover and placed close together, the roof often has the appearance of a continuous system once the vegetation is established. Modular systems, without substrate or vegetation, are also used for blue roofs in some retrofit situations.

8. **Plant Selection:** While there are several species that could potentially adapt to extensive green roof systems along the Colorado Front Range, the most used species are stonecrops or sedums because of desirable characteristics such as prostrate growth form, shallow root systems, and drought tolerance. Another favorable attribute of sedums is that the

SUBSTRATE AND DRAINAGE SYSTEM TECHNOLOGY AND RESEARCH

In Colorado and nationally, research continues on various types of substrate and drainage technology for green roofs. Green roof substrate characteristics that are lightweight, drain well, and provide nutrients for plants without exporting nutrients are ideal. Additionally, some vendors have developed technologies that use water retention mats or wicking technologies to access water stored below the root zone or to retain water in the root zone. When evaluating emerging technologies, factors to consider include treatment of the WQCV and compliance with Colorado water law, which does not currently allow storage of water below the root zone (without a water right).

TABLE GR-3. EXTENSIVE GREEN ROOF PLANS SPECIES SUGGESTIONS

Common Name	Scientific Name	Requirements/ Conditions	Notes
Stonecrops	*Sedum spp.*	Dry, full sun, spreading	Most common genus of plants on green roofs
Buffalograss	*Buchloe dactyloides*	Full sun, spreading	Native grass
Blue grama	*Bouteloua gracilis*	Upright, spreading	Native grass
Pineleaf penstemon	*Penstemon pinifolius*	Full sun, good for pollinators	Also many other Penstemon relatives
Prickly pear	*Opuntia sp.*	Dry, full sun, spreading	Colorful flowers, fruit
Pussytoes	*Antennaria spp.*	Spreading	Silvery; some reseeding
Wormwood	*Artemesia spp.*	Spreading	Silvery; sage-like scent

foliage tends to remain greener than grasses throughout the entire year, even in northern climates. However, drawbacks to a monoculture for green roofs are the same as for a monoculture in agricultural applications – risk of widespread vegetation loss if conditions (e.g., drought, disease, temperature, etc.) change from the anticipated range.

Characteristics of plants that tend to work well on green roofs in a semi-arid climate include:

- Self-seeding.
- Perennial.
- Low or compact growth format.
- Diffuse or fibrous root system.
- Low water use.
- Cold hardiness. For rooftops, two zones lower than the assigned U.S. Department of Agriculture (USDA) Plant Hardiness zone is recommended (e.g., Denver is in Zone 5b, so select plants suitable for Zone 3b or 4a).
- Cressulacean Acid Metabolism (CAM), which is common in sedums (stonecrops) where plant stomata are closed during the day to conserve water.

Extensive green roof plant species suggestions are provided in Table GR-3. Intensive green roof species can be as diverse as gardens at grade. Research findings from a mixed extensive and intensive green roof at Denver Botanic Gardens (Schneider et al. 2021) is a good source of information on plants to consider or avoid for green roofs.

9. **Irrigation:** Irrigation is required for successful green roofs in Colorado. Colorado State University green roof research has shown that shallow green roofs in Colorado can survive on a minimum of 5 inches of irrigation over the growing season (about ¼ inch of irrigation per week spread across 3-4 small irrigation events). The decision to use drip or overhead spray irrigation is determined based on substrate characteristics and plant needs. Overhead irrigation, particularly large droplet rotor systems, is recommended for shallow depth applications rather than drip irrigation, which may not spread laterally when applied over a rapidly

CONSIDERATIONS FOR PLANT SELECTION FOR COLORADO GREEN ROOFS

General categories of potentially viable plants for Colorado green roofs include native, alpine (grows in shallow rocky soils), and xeric plants (e.g., sedum). Plants must meet certain criteria to optimize their chance of survival on a green roof. Due to the shallow, well-drained materials in extensive green roof systems, plants must be drought resistant. However, not all drought resistant plants are well-suited for green roofs. For example, some plants avoid drought by rooting deeply to access a more stable supply of water. Such plants are not suitable for a shallow green roof. Grasses with strong rhizome growth such as bamboo and varieties of Chinese reeds should be avoided because these have the potential to compromise the roof membrane.

draining substrate. Drip irrigation may be considered for intensive roof applications. Where drip irrigation is used, it is more efficient when installed below the vegetation layer to avoid heating of the drip line and to transfer water more effectively to the roots. When overhead spray systems are used, exposed mainline and distribution pipe should be UV-stabilized and rated for sun exposure. Additionally, winter watering is required in the relatively warm and dry winter days if precipitation has not occurred in three weeks. Typically, winter watering is done by using the irrigation system and blown out the same day (ideally with an inline air compressor) or through use of a temporary/mobile irrigation product.

10. **Site-Specific Design Considerations:** When designing a green roof, various site-specific factors must be considered. Examples include:

    - **Wind:** Select substrate and install material layers in a manner to withstand expected average and storm wind conditions, especially for taller buildings (e.g., greater than four stories). Maintaining a consistent slope throughout the green roof will prevent excessive wind scour in steeply sloped areas. When designing for wind, make sure that high wind areas at the corners of buildings are fully vegetated at the time of installation or otherwise screened for wind protection. In some cases, solar panels can serve as wind screens.
    - **Roof Microclimates:** Consider the effect of roof microclimates on the vegetation, including factors such as shading, temperature fluctuations, localized strong winds, and reflected solar radiation from surrounding buildings. Solar panels can provide partial shade to vegetation that may not perform well when exposed to full sun.
    - **Sloped Roof Applications:** Green roofs may be installed on flat, low slope, or steep roofs. For flat roofs (e.g., roof slopes less than 2%) a deeper drainage course is recommended to avoid water logging. For steep roofs (e.g., slopes greater than 30%), structural anti-shear protection will normally be needed to prevent sloughing of materials. There are many products available for substrate stabilization on slopes, which may include baffles, cells, meshes, or fabrics.

11. **Outlets (for Blue Roofs):** Controlled-flow roof drains for blue roofs are designed based on a 12-hour release rate of the WQCV. Provide these design parameters to a specialized drain manufacturer to design the roof drain(s) to achieve the desired release rates in place of conventional roof drains. Settings on the drains must be fixed prior to installation to prevent future modification. Flood tests should be conducted after installation of the controlled flow drains to verify that they function as intended. To prevent clogging of the drains, each orifice should be equipped with a screen or strainer that completely encloses the inlet. Attach screens to the roof with tamper-proof screws or bolts (NYDEP 2012).

12. **Emergency Overflow/Bypass:** Both green and blue roof designs must include a bypass/overflow mechanism to allow rapid discharge when the storage volume of a blue roof system is exceeded and to ensure green roofs remain free draining. The overflow structure determines the maximum ponding depth for a blue roof.

SOLAR ENERGY CONSIDERATIONS

Combining solar panels with green roofs is mutually beneficial (Irga et al. 2021). Solar panels stay cooler, and vegetation receives partial shade, reducing irrigation requirements.

13. **Signage (for Blue Roofs):** Post signs on doors that provide access to the roof and near drainage inlets to inform building owners, maintenance staff, and others that the roof is designed for storing stormwater. Signs should indicate that several inches of water may pond after storm events and that roof drains require specific maintenance procedures and should not be altered. Signage increases awareness of the rooftop system and is intended to prevent future modifications, which may be incompatible with the roof design (NYDEP 2012).

CONSTRUCTION CONSIDERATIONS

Success of green roofs depends not only on a good design and maintenance, but also on construction practices that enable the SCM to function as designed. Construction considerations include:

- **Load-bearing Inspection:** Before any construction for the rooftop system begins, construction of all major components of the building's structural system must be complete, and a construction inspection by a licensed professional must be conducted to verify that the building, as constructed, has the capacity to support roof loads from the rooftop system (NYDEP 2012).
- **Permit Requirements, General Coordination, and Warranties:** Investigate permitting requirements for green roofs in the local jurisdiction. Significant coordination between architects, engineers, roofers, and landscapers is needed. Contractually, it is common to have the roofer warranty the impermeable membrane, whereas the landscaper is typically responsible for the growing media, vegetation, and other landscaping. Typically, irrigation systems have warranties, but plants do not, with the exception of situations where a maintenance contract is in place. Where a maintenance contract is in place, some landscapers or greenhouses will provide plant warranties.
- **Roof Membrane:** Inspect the roof membrane (the most crucial element of both green roofs and blue roofs) and conduct a leak test prior to installing the remaining layers of the roof. Leak testing involves closing the roof drains and filling the roof with water (flood testing) to determine if there are leaks present following the membrane installation process. Flood testing requires at least 24 hours (ASTM D5957-98).
- **Plant Protection During Establishment:** Where wind scour is a concern, protect plants during establishment using fabrics (secured mesh wind blanket) or other techniques.
- **Installation Safety:** Most landscapers are accustomed to working on the ground, so safety training is important. If the green roof will be accessible to the public, safety at roof edges must be a paramount objective and are required per OSHA standards.

ADDITIONAL DESIGN RESOURCES

Because green roofs are an emerging practice area in the Denver metropolitan area relative to other commonly used SCMs, designers should consider additional resources for green roof designs in addition to the guidance provided in this Fact Sheet. Examples include:

- **FLL Guidelines:** The FLL Guidelines are green roof standards developed by the German Research Society for Landscape Development and Landscape Design. (FLL is derived from the German title: "Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.") These guidelines include the planning, execution and upkeep of green roof sites. The 2008 edition of these widely consulted guidelines is available for purchase in English through http://www.greenrooftechnology.com/fll-green-roof-guideline.
- **ASTM Book of Standards, v. 04-12, 2005:**
  - » ASTM E2396-E2777: ASTM has developed a set of standards for green roofs; however, it is important to recognize these standards were developed outside of Colorado.
  - » ASTM E2396-05: Standard test method for saturated water permeability of granulated drainage media (falling-head method) for green roof systems.

  - ASTM E2397-05: Standard practice for determination of dead loads and live loads associated with green roof systems.
  - ASTN E2777-20: Standard guide for vegetative (green) roof systems.

- **BOCA Codes, International Code Council (ICC):** Building Officials and Code Administrators International Inc. (BOCA), now known as the International Code Council (ICC), publish codes that establish minimum performance requirements for all aspects of the construction industry. BOCA codes at the Library of Congress are located in the Law Library Reading Room. Some state codes are available at no cost through the eCodes sections of the ICC Website, while others must be purchased http://www.iccsafe.org/.
- **Various Green Building and Sustainable Infrastructure Programs:** Over the past few decades, a variety of green building and sustainable infrastructure programs have emerged that provide credit for green roofs and rooftop stormwater management systems. Credit may be available in areas such as runoff reduction, stormwater treatment, reduced heat island effects, and energy efficiency.
- **City and County of Denver Green Building Ordinance:** The City and County of Denver City Council passed a Green Building Ordinance in October 2018 after a public vote in 2017. Green roofs are one of the options for compliance for 5+ story commercial and residential buildings larger than 25,000 square feet indoors: https://www.denvergov.org/content/denvergov/en/denver-development-services/commercial-projects/green-roof-initiative.html
- **Green Roofs for Healthy Cities:** Green Roofs for Healthy Cities website (www.greenroofs.org) provides a variety of resources related to green roof design. Green Roofs for Healthy Cities - North America Inc. is a non-profit 501(c)(6) professional industry association. Their mission is to develop and protect the green roof market by increasing the awareness of the economic, social, and environmental benefits of green roofs, green walls, and other forms of living architecture through education, advocacy, professional development, and celebrations of excellence.
- **New York City Guidelines for the Design and Construction of Stormwater Management Systems:** This guidance provides detailed design, construction and maintenance information on both green and blue roofs, as well as combining rooftop systems with other treatment systems. Although climate and vegetation recommendations in New York differ from Colorado, the remainder of the guidelines may be useful for designers in Colorado.

Photograph GR-6. A green roof installed on a maintenance and restroom building at Red Rocks Park and Amphitheatre promotes sustainable design and adds aesthetic value.

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T-3 BIORETENTION SYSTEMS

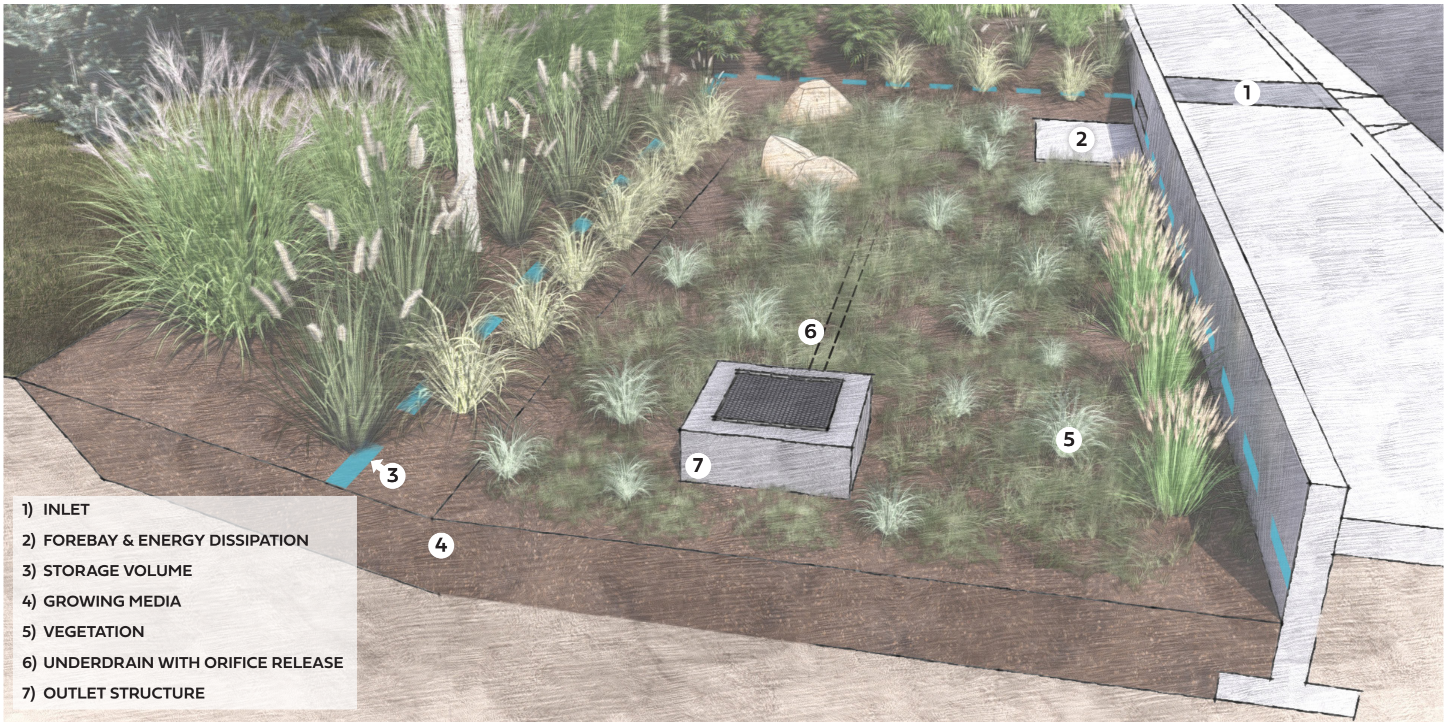


Figure BR-1. Bioretention System Components

DESCRIPTION

Bioretention systems are vegetated, engineered, depressed landscape areas designed to capture and filter and/or infiltrate the water quality capture volume (WQCV). Engineered media and vegetation facilitate filtration, adsorption, absorption, and biological processes that retain stormwater pollutants and enhance infiltration capabilities. The terms porous landscape detention (PLD), rain garden, and bioretention are often used interchangeably in the MHFD region. The term rain garden is sometimes used to describe smaller engineered bioretention systems or non-engineered installations and when describing this SCM to the public. Bioretention can be configured in several ways in urban areas and may be described as streetside planters, curbside bioretention, bump-out stormwater planters. Ultra-urban adaptations of bioretention can also include tree trenches and tree pits (although not described in this fact sheet). Local jurisdictions may have additional or different requirements for various types of bioretention systems.

MHFD strongly encourages use of bioretention as a stormwater control measure (SCM) because properly designed, constructed and maintained bioretention systems provide effective stormwater treatment, reduce runoff volume and erosive flow rates, and provide community connection benefits and green space in the urban environment.

Bioretention systems can be designed to provide detention for events exceeding the WQCV by incorporating storage of the Excess Urban Runoff Volume (EURV) and 100-year detention storage volumes above the WQCV, with drain times and release rates in accordance with the *Storage* chapter.

TABLE BR-1. BR OVERVIEW

BIORETENTION SYSTEMS	
MS4 Permit Applicability (Dependent on design and level of treatment)	
Meets Runoff Reduction Standard	Potential[1]
Meets WQCV Capture Standard	Yes
Meets Pollutant Removal Standard	Yes
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	High
Total Phosphorus	Low-Medium[1]
Total Nitrogen	Low-Medium[1]
Total Metals	High
Bacteria	Medium
Common Applications	
Runoff Reduction (General)	Potential[1]
Used for Pretreatment	No
Integrated with Flood Control	Yes

[1] Depends on design including full-infiltration, partial infiltration or no-infiltration section.

SCM COMPONENTS

The primary components of bioretention include inlet(s), energy dissipation and forebay(s), a surcharge volume, engineered media, vegetation, an underdrain (for no- or partial-infiltration designs), and an outlet structure (Figure BR-1). The primary outflow for the WQCV is typically an underdrain or infiltration into the underlying soil. When bioretention is designed to provide full spectrum detention, design the outlet to release the EURV and 100-year volumes in accordance with the EURV drain time and 100-year release rates. Even if the bioretention system is only designed to treat the WQCV, an emergency overflow (outlet or spillway) is necessary to safely convey flows from larger events.

See Section 3.0 *Site Assessment* and Section 4.0 *Filtration and Infiltration Systems* of this chapter for guidance and criteria on determining the appropriate type of bioretention system and designing underdrain and liner systems as needed based on site-specific conditions. Section 5.0 *SCM Inflow Features* and Section 6.0 *SCM Outflow Features* of this chapter provide guidance on creative ways to drain runoff into the SCM and release the treated runoff.

Check bioretention media sourcing and composition is important. MHFD recommends confirming the gradation and nutrient content in the field. The engineered media and vegetation are the core water quality treatment

TABLE BR-2. BR COMPONENTS

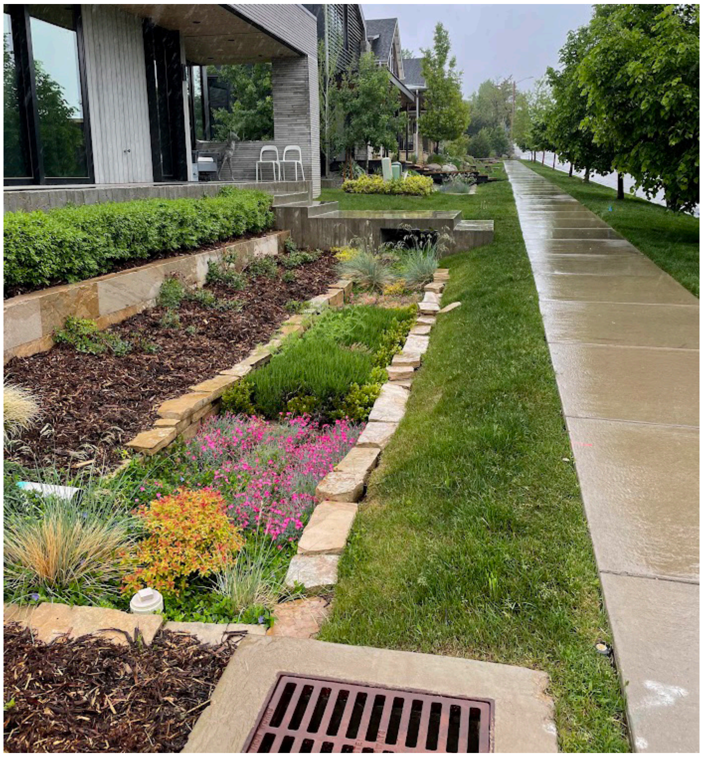
COMPONENT	INTENT
Inlet	Allows stormwater to enter the SCM.
Forebay	Facilitates removal of trash and coarse sediments, providing pretreatment for the SCM.
Energy Dissipation	Minimizes potential for erosion of media surface.
Storage Volume	Provides temporary storage needed to attenuate design flows.
Engineered Media	Supports plant growth and reduces pollutants by filtering and through other biological treatment processes.
Vegetation	Helps maintain infiltration over time through root penetration of media, increases evapotranspiration and biological uptake of pollutants, aerates media, catalyzes soil ecology, and creates an attractive SCM.
Underdrain with Orifice Release	For partial and no infiltration systems, collects and slowly releases the WQCV over 12 hours to reduce erosion in the receiving stream and enhance treatment by increasing contact time with the media.
Outlet Structure	Safely conveys stormwater flows that exceed the design volume. For bioretention systems that detain the EURV and/or 100-year flow, surface outlet structures will have additional orifice controls for surface discharge rather than infiltration through the media.

BENEFITS OF BIORETENTION

- When designed and constructed correctly, routine maintenance is straightforward consisting of sediment/debris removal from the forebay and vegetation management.
- Incorporates multiple treatment processes including sedimentation, filtering, adsorption, evapotranspiration, and biological uptake of constituents.
- Stormwater features are integrated with landscaping.
- Decreases urban heat island effects.
- Can be integrated into space-constrained urban areas in a variety of shapes and sizes.
- Avoids problems with clogging of small orifices common with some EDBs.

LIMITATIONS OF BIORETENTION

- Vegetation requires management.
- Requires additional steps when near a building foundation or when expansive soils exist.
- In a developing or otherwise erosive watershed, sediment loads can clog the system.
- Trash and sediment can block inlets and cause bypass of flows, if not maintained.



Photograph BR-1. This bioretention area treats runoff from the roof and lot, while serving as an aesthetically pleasing landscape feature. Photo: Wright Water Engineers.

Photograph BR-2. Bioretention system treating urban stormwater during runoff event. Photo: Wright Water Engineers.

elements of bioretention. The media must balance good infiltration capabilities with properties needed to support vegetation. MHFD has conducted significant testing of different mixes for bioretention media to develop the recommended specifications in this fact sheet. Additionally, national research has included media amendments targeting specific pollutants (Tirpak et al. 2021, Pitt and Clark 2010, Clark and Pitt 2012, Erickson et al. 2012 & 2021, Hunt et al. 2012, Chandrasena 2014, Mohanty and Boehm 2015, O'Neil and Davis 2012a&b, Mohanty et al. 2018, Herrera 2020, among many others). This fact sheet focuses on a basic engineered media design suitable for broad use in the MHFD jurisdiction, but does not preclude consideration of media amendments designed to target specific pollutants, provided that they maintain the intended functions of MHFD's media.

Other bioretention design variations in the underdrain configuration, such as use of an upturned underdrain elbow to create an internal water storage zone (Brown et al. 2009) to reduce nitrogen, are discussed further in Section 4.3.3 of this chapter.

SITE CONSIDERATIONS

Bioretention is an excellent choice for small sites because it treats the WQCV and serves as a landscape feature. It is typically a much better choice for small sites than an extended detention basin (EDB) because EDBs treating small drainage areas have outlet structures with small orifices that are prone to clogging. Bioretention can also be incorporated into larger sites and can be designed to provide full spectrum detention.

Bioretention systems typically are installed in locations such as:

- Plazas
- Parks
- Parking lot islands
- Street medians

Photograph BR-3. Terraced bioretention SCM in recreation center parking lot. Photo: MHFD

- Landscape areas between the road and a detached walk
- Planter boxes that collect roof drain flows

To avoid clogging of media, bioretention requires a stable watershed. When the watershed includes phased construction, sparsely vegetated areas, or steep slopes, consider another SCM that is less susceptible to clogging or provide pretreatment to facilitate sedimentation before runoff from these areas reaches the bioretention media surface. Additionally, bioretention is intended to dry out between runoff events; therefore, it should not be used when a baseflow is anticipated.

The surface of the bioretention media should be flat or at a mild slope. For this reason, bioretention can be more difficult to incorporate into steeply sloping terrain; however, terracing can be used to create flat areas suitable for bioretention even with sloped topography.

When bioretention areas are located adjacent to structures or infrastructure that could be adversely affected by infiltrating runoff or in areas with expansive soils, consult with a geotechnical engineer. A geotechnical engineer can evaluate the suitability of soils, identify potential impacts, and establish minimum distances or other physical barriers to implement between the bioretention system and structures. See Section 3.0 *Site Assessment* and Section 4.0 *Filtration and Infiltration Systems* for guidance and criteria on geotechnical considerations and testing requirements, underdrain and filter layers, perimeter barriers, and other aspects common to infiltration-based SCMs including bioretention.

COMMUNITY VALUES

Bioretention provides opportunities to provide a high level of treatment for stormwater while also creating landscape features that add value to a site by enhancing the landscape aesthetics and experience. Bioretention areas that are an integral part of the site's landscape provide far more benefits than areas dedicated solely to stormwater treatment, such as small EDBs, because bioretention areas are multifunctional and can serve other purposes including meeting landscape area requirements, providing attractive pockets of interesting plants, aesthetic screening of parking lots, and others.

It is important to establish pre-design planning objectives to facilitate a successful design. At an early stage, determine the aesthetic design approach that best meets the overall project objectives. There are many opportunities for creativity in grading, plant selection, and design of inflow and outflow features for bioretention. Design approaches typically endeavor either to integrate the SCM into its surroundings with a "contextual design," or consciously contrast with the surroundings to highlight the SCM as a "stand-alone element," providing a counterpoint to the context of the site.

In a contextual design, the design responds to and builds on the character of the surroundings. Forms and shapes are related to and harmonious with surrounding structures and site improvements and fit into their environment through use of similar or complementary materials, scale, and design detailing. Materials used in this approach may directly reflect materials used in the surrounding architectural and engineering improvements. Coordinate design details for the bioretention area, such as concrete or stone edgers and retaining walls, with the surrounding site improvements to provide a unifying effect with the surroundings. Plant materials should also relate to surrounding landscape in overall character, massing, and degree of formal or naturalistic arrangement, while selecting drought-tolerant plants that will also thrive in the periodically wet environment.

A "stand-alone" or counterpoint design aims to create a feature that contrasts with its surroundings through uses of form, scale, materials, color, and other features. A counterpoint design can create a strong dramatic effect, but to be successful, it must be done in a way that creates an overall balanced site design.

Of these two approaches, contextual design is more common and is generally easier to accomplish. With either approach, the emphasis should be on creating a feature that adds value to the site while effectively treating the WQCV. Maintenance is critical for ensuring long-term function of bioretention and community acceptance, so planning for maintenance and selecting plants that are suitable for the hydrologic conditions in the SCM are important design aspects to avoid burdensome maintenance.

Appropriate plant selection enhances the community value of bioretention systems. Considerations for plant selection from a community-values perspective include:

- Select plants that thrive and perform over the long-term without excessive maintenance. For bioretention to be accepted by the community, it should be attractive (Davis, Traver and Hunt 2022), which requires healthy plants and routine maintenance.
- Select plants appropriate for the site's unique micro-climatic conditions and bioretention design features, construction techniques, and expected maintenance levels of service. Microclimate, including solar aspect, exposure to wind, and shading or sun reflections from adjacent buildings, can have a significant effect on the conditions that plants must tolerate. Visiting the site during different times of the day in summer months prior to design is very informative for understanding sun and shading as well as urban heat island effects.
- Small trees can provide significant added value to bioretention areas, including runoff reduction and mitigation of urban heat island effects. When considering trees for bioretention systems, assess the compatibility of different species with the hydrologic, soil, and solar aspect of the SCM. Healthy trees also require adequate above and belowground space (Davis et al. 2022). (See additional considerations for trees in the Design section of this fact sheet.)
- Use natives plant species when feasible. Native species tend to tolerate the region's hot summers and cold winters better than most non-natives. Native grasses have deep roots that can reach residual moisture in the bioretention media during times of drought.
- Select plants that are drought tolerant but that can also tolerate prolonged periods of inundation or media saturation, particularly during sequential storms.
- Consider planting vegetation in groupings or masses of single or similar species. Generally, large masses of plants grouped relatively close together create dense stands of vegetation that grow together to out-compete weed growth, while enhancing infiltration through root penetration that creates macropores as roots die and decay.

MAINTENANCE

Routine maintenance of bioretention is similar to landscape maintenance, consisting of trash and sediment removal from the forebay and care for vegetation. Chapter 6 of this manual provides recommended maintenance practices for all SCMs. During design, consider the following during design to ensure ease of maintenance over the long-term:

- Consider how the SCM will be accessed for routine and restorative maintenance, what equipment will be required, and how routine maintenance activities can be performed in a way that minimizes impacts to vegetation.
- Understand the level of maintenance that will be needed over the long term. Bioretention features designed as aesthetic amenities in public areas may require more frequent maintenance than those with more naturalized designs in suburban settings. Do not select plantings that require frequent maintenance if the owner does not have the resources to perform such maintenance. Poorly maintained bioretention areas can become weedy eye sores that contribute to poor public acceptance.
- Make the bioretention surface area (bowl) as shallow as needed. Increasing the depth unnecessarily can create erosive side slopes and complicate maintenance. Shallow bioretention areas are also more attractive.
- The best surface cover for bioretention is full vegetation, in part because it reduces weeding and various mulch-related maintenance issues. Use rock mulch sparingly because it limits infiltration, is more difficult to maintain and can also increase urban heat island effects. Wood mulch handles sediment build-up better than rock mulch; however, wood mulch floats and can settle unevenly or clog the overflow depending on the configuration of the outlet. Some municipalities may not allow wood mulch for this reason. When specifying mulch, look for shredded varieties. Also, increase density of grasses at the interface of the forebay and vegetation to slow flows entering the basin.
- Provide pretreatment when it will reduce the extent and frequency of maintenance necessary to maintain function over the life of the SCM. Provide a forebay for any concentrated inflows. For small inflows, the forebay may consist of a pad for sediment accumulation and removal surrounded by grasses to help keep sediment from migrating onto the filter area.
- Note that research shows that deicers can cause reduced infiltration rates in media and soils with clay content (Sileshi, Pitt and Clark 2017). Understand the composition of the media and the underlying soils in this respect and develop the planting plan accordingly. Deicers in runoff can stress vegetation, which may result in increased maintenance and vegetation replacement requirements. Conifers are particularly sensitive to salt.
- Establishing healthy vegetation is critical for this SCM to properly function. Design and adjust the irrigation system (temporary or permanent) to provide appropriate water for the establishment and maintenance of selected vegetation.
- Consider maintenance access and requirements for tree pruning and frequency of raking, if trees are included in bioretention systems. Do not operate heavy equipment on the media surface (e.g., cherry picker lifts) for tree pruning.
- Do not put a filter sock on the underdrain. This is not necessary and can cause the underdrain to clog.
- Never use bioretention systems for snow storage. Designate a location for snow storage elsewhere.

DESIGN PROCEDURES & CRITERIA

Criteria and guidance for bioretention components including inlets, forebays, underdrains, liners, and outlets are provided in the front section of this chapter. Reference this section for design of these specific features.

The SCM Design workbook, available at www.mhfd.org, is an Excel-based workbook that steps through the criteria listed below and performs design calculations for bioretention. Use this workbook to ensure designs meet criteria for treating the WQCV. Use a separate tool, MHFD-Detention, to develop and route storm hydrographs for a range of events through bioretention systems.

The following steps outline the design procedures and criteria for designing bioretention for water quality:

1. **Subsurface Exploration and Determination of a Full Infiltration, Partial Infiltration or No-Infiltration Section**: See Section 3.0 *Site Assessment* and Section 4.0 *Filtration and Infiltration Systems* of this chapter to determine the most appropriate type of filtration and/or infiltration system for the bioretention area based on site conditions.

2. **Inlet Design and Pretreatment**: See Section 5.0 *SCM Inflow Features* of this chapter for guidance and criteria for inlets, energy dissipation, and forebays. Provide pretreatment with a properly designed forebay or other device designed to remove coarse sediment, trash, and debris. Pretreatment of roadway runoff to remove sediment is especially critical for bioretention systems receiving roadway runoff.

   Where feasible, inlets set above the WQCV elevation will reduce maintenance requirements related to sediment deposition in the inflow pipe due to backwater conditions.

3. **Design Storage Volume**: Provide a storage volume equal to the WQCV[1] based on a 12-hour drain time, after accounting for runoff-reduction SCMs in the contributing watershed. Determine the required WQCV (watershed inches of runoff) using Equation 3-2 of Chapter 3 of this manual (for WQCV). Always size SCMs based on their tributary area. When sizing the basin for EURV or larger detention volumes, see the *Storage* chapter of Volume 2. Where needed to meet the required volume, also consider the available void storage capacity of the media at 15 percent.

4. **Bioretention System Basin Geometry**: Basin geometry considerations include surface area, filter surface slopes and ponding depth.

   - **Media Surface Area**: Equation BR-1 provides a minimum media surface area for the WQCV allowing for some of the volume to be stored beyond the flat area of the media (i.e., above the side slopes of the bioretention basin). Additional surface area beyond this minimum may be necessary to meet the maximum recommended ponding depth.

     $$A_F = 0.02 \cdot A \cdot I$$ **Equation BR-1**

     Where:

     A_F = minimum filter area (ft^2)

     A = area tributary to the SCM (ft^2)

     I = imperviousness of tributary area draining to the SCM (percent expressed as a decimal)

     Use vertical walls or slope the sides of the basin to achieve the required volume. Side slopes should be no steeper than 4:1.

   - **Ponding Depths**: Maximum ponding depths vary depending on the bioretention design, with a maximum recommended WQCV ponding depth of 12 inches stored above the surface to minimize stress to vegetation for frequent inundation and to manage the hydraulic loading. When the bioretention basin is designed for the WQCV only, locate the overflow spillway crest at or above the elevation associated with the maximum ponding depth for the WQCV measured vertically from the flat filter media surface.

   - **Media Surface Slopes**: The media surface of the bioretention area typically should be flat. The exception to this is when a mild slope (e.g., < 1%) from the inlet to the outlet will help distribute runoff to the vegetation and reduce sediment deposited at the inlet. Linear systems, such as streetside stormwater planters, may benefit from a mild slope from inlet to outlet. When the flow path is long, consider level grade beams to maintain sheet flow. The intent is to fully use the filter area to avoid higher sediment deposition in lower areas of the basin.

[1] MHFD's standard design procedure is based on treatment of the WQCV, which corresponds to the Colorado's MS4 WQCV design standard. In some cases, bioretention systems may be designed to meet a volume reduction target, particularly where underlying soils allow for infiltration. In this case, conduct site-specific analysis to determine whether the volume reduction target can be met for site conditions.

TABLE BR-3. BIORETENTION MEDIA PROPERTIES

SOIL PARAMETERS	TEST NAME	BIORETENTION MEDIA PROPERTIES
Texture/Gradation	ASTM D7928 Sedimentation (Hydrometer) Method	<u>Particle Size Distribution:</u> 70-80% Sand (0.05-2.0 mm diameter) 5-25% Silt (0.002-0.05 mm diameter) 5-15% Clay (<0.002 mm diameter) <u>Notes:</u> Sand, silt and clay percentages are by dry weight. Particle sizes are based on the USDA soil classification system. Distribution is measured after gravel > 2 mm is removed from sample. Media should have no more than 25% material > 2 mm. Equivalent sieve sizes for the upper and lower limit of sand are #10 and #240, respectively.
Organic Matter	ASTM D2974	1-5% by dry weight
pH	ASA/AASHTO	6.0 - 8.5
Salinity/Salts (EC) dS/m or mmhos/cm	Saturated Paste	<3
Nitrate Nitrogen (ppm)	ASA2 33-3	<30
Phosphorus (ppm)	Use Olsen when pH>6.2, otherwise use Mehlich-3	Olsen: <20 or Mehlich-3: <30

5. **Underdrain System, Impermeable Liner, and Geotextile Separator Fabric**: See Section 4.0 *Filtration and Infiltration Systems* of this chapter for guidance and criteria based on the type of filtration and infiltration system selected. Underdrain systems in bioretention basins consist of a slotted PVC pipe placed within a layer of drain gravel beneath the bioretention media. A 6-inch layer of sand is also specified above the drain gravel in Section 4.0. Research (Herrera 2020) indicates that a sand layer below the media can serve as a polishing layer for the effluent.

6. **Bioretention Media**: Provide a minimum of 18 inches of bioretention media to enable establishment of the roots of the vegetation. If trees are planted, increase the media depth to 36 inches.

   MHFD's bioretention media is intended to balance high infiltration capacity with properties needed to support healthy vegetation. Table BR-1 outlines recommended parameters for bioretention media. MHFD's media recommendation begins with topsoil that can be amended as needed, typically with sand, until it meets the specifications in Table BR-1. See Availability of Bioretention Media in the MHFD Region (MHFD 2023) for more information. It is important that the media contain organic material with living soil organisms such as earthworms, bacteria, and fungi to enhance agronomic and infiltration properties and create a healthy, living media. Do not add compost to the bioretention media; instead, other forms of organic matter such as mulch, peat or woodchips should be used if needed because they have lower nitrogen and phosphorus content and are more resistant to microbial degradation (Davis, Hunt and Traver 2022).

   The media texture in Table BR-1 has a slightly higher proportion of silts and clays and a lower sand percentage compared to prior MHFD media specifications. The purpose of this change is to increase moisture and nutrient holding capacity to aid in the establishment of a dense vegetation cover, which ultimately helps to sustain infiltration capacity.

   A high level of quality control for the media is critical. Quality control measures include reviewing media particle size distribution data, media chemistry data, and results of nutrient analysis to ensure that the media meets specifications. The media can either be sampled after delivery and prior to placement, or sampled by the supplier just prior to site delivery. In any case, the samples should be collected within several days of placement of the media so that the results are representative of the media placed.

7. **Vegetation**: The media must be vegetated. MHFD recommends drought-tolerant species that thrive in sandy soils. Approaches to vegetating bioretention areas can include planting sod-forming native grasses from seed, installing sand-grown sod, and/or planting container-grown plants or small trees. Consult with a vegetation specialist to understand which types of vegetation will be successful in a given location, considering shade, heat island effects, application of deicers in the watershed, and other site-specific factors. Recommendations for vegetation established from seed, planted in containers or plugs, and trees follow. While establishment from seed typically costs less than container-grown plants, container-grown plants establish more quickly and are less susceptible to being washed away during establishment. A mixture of container-grown plants and seed may help with initial vegetation cover and media stabilization.

   Table BR-4 provides a suggested seed mix for sites that typically will not need to be irrigated after the grass has been established, except for periods of extended drought. Guidelines for establishing vegetation from seed include:

   - Mix seed well and broadcast, followed by hand raking to cover seed .
   - Immediately after seeding, install a biodegradable 100-percent coconut erosion control blanket over the media to keep seed and media in place during runoff and irrigation events during establishment.
   - Consider seasonality when planting to ensure establishment. Both frequent storms and extended hot, dry periods can affect seed establishment.
   - Do not place seed when standing water or snow is present or if the ground is frozen.
   - Weed control is critical in the first two to three years, especially when starting with seed.

   When using sod, specify sand-grown sod which is available in Colorado, although not as common as conventional sod. Do not use conventional sod. Conventional sod is grown in clay soil that can seal the filter area, greatly reducing overall function of the SCM. Be aware that local jurisdictions may restrict use of turf varieties with high irrigation requirements (e.g., Kentucky bluegrass) and may require native grasses for water conservation reasons.

TABLE BR-4. NATIVE SEED MIX FOR BIORETENTION

COMMON NAME	SCIENTIFIC NAME	VARIETY	PURE LIVE SEED (PLS)	
			POUNDS/ACRE	OUNCES/ACRE
Sand bluestem	*Andropogon hallii*	Garden	3.5	
Sideoats grama	*Bouteloua curtipendula*	Butte	3	
Prairie sandreed	*Calamovilfa longifolia*	Goshen	3	
Indian ricegrass	*Oryzopsis hymenoides*	Paloma	3	
Switchgrass	*Panicum virgatum*	Blackwell	4	
Western wheatgrass	*Pascopyrum smithii*	Ariba	3	
Little bluestem	*Schizachyrium scoparium*	Patura	3	
Alkali sacaton	*Sporobolus airoides*		3	
Sand dropseed	*Sporobolus cryptandrus*		3	
Pasture sage[1]	*Artemisia frigida*			2
Blue aster[1]	*Aster laevis*			4
Blanket flower[1]	*Gaillardia aristata*			8
Prairie coneflower[1]	*Ratibida columnifera*			4
Purple Prairie Clover[1]	*Dalea (Petalostemum) purpurea*			4
Sub-Totals:			27.5	22
Total pounds/acre			**28.9**	

[1] Wildflower seed (optional) for a more diverse and natural look.

TABLE BR-5. CONTAINER-GROWN PLANTS AND PLUGS FOR BIORETENTION (SOURCE: CITY & COUNTY OF DENVER 2016)

COMMON NAME	SCIENTIFIC NAME
Grasses	
Dancing Wind Big Bluestem	*Andropogon gerardii* 'Dancing Wind'
Windwalker Big Bluestem	Winter *Andropogon gerardii* 'P003S'
Feather Reed Grass	Winter *Calamagrostis x acutiflora* 'Karl Forester'
Tufted Hair Grass	*Deschampsia caespitosa*
Blonde Ambition Grama Grass	*Bouteloua gracilis* 'Blonde Ambition'
Hot Rod Switchgrass	*Panicum virgatum* 'Hot Rod'
Northwind Switchgrass	*Panicum virgatum* 'Northwind'
Prairie Sky	*Panicum virgatum* 'Prairie Sky'
Prairie Blues Little Bluestem	*Schizachirium scoparium* 'Prairie Blues'
Undaunted Ruby Muhly	*Muhlenbergia reverchoni* 'Undaunted'
Prairie dropseed	*Sporobolus heterolepis*
Herbaceous Perennials	
Pearly Everlasting	*Anaphalis margaritacea*
Prairie Bluebell	*Mertensia lanceolata*
Dakota Sunshine Sunflower	*Helianthus maximiliani* 'Dakota Sunshine'
Western Blue Flag Iris	*Iris missouriensis*
Rocky Mountain Gayfeather	*Liatris ligulistylis*
Wild Bergamont	*Monarda fistulosa*
Eastern Bergamont	*Monarda bradburiana*
Evening Primrose	*Oenothera fruticose* 'Fireworks' / Fyrveckeri
Husker Red Penstamon	*Penstemon digitalis* 'Husker Red'
Garden Phlox	*Phlox paniculate* 'Blue Paradise'
Border Phlox	*Phlox paniculate* 'David'
Prairie coneflower	*Ratibida pinnata*
Bluebird smooth aster	*Symphiotrichum laeve* 'Bluebird' smooth aster
Bulbs	
Blue Danube Wild Hyacinth	*Camassia leichtlinii* 'Blue Danube'
Shrubs	
Leadplant	*Amorpha canescens*
Prairie Snow White Cinquefoil	*Dasiphora* (Potentilla) *fruticosa* var. *dahurica* 'Prairie Snow'
Apache Plume	*Fallugia paradoxa*
Pawnee Buttes Sand Cherry	*Prunus besseyi* 'Pawnee Buttes'
Autumn Amber Skunkbush Sumac	*Rhus trilobata* 'Autumn Amber'
Glow Girl Spirea	*Spirea betulufolia* 'Tor Gold'

When selecting a container-grown plant palette, consider water needs, exposure (sun/shade), plant height and spread, recommended container sizes, plant spacing and future maintenance requirements. Common container-grown plants or plugs suitable for bioretention systems in urban areas are listed in Table BR-3 (City and County of Denver 2016). Other drought-tolerant plants may also be considered.

When using an impermeable liner, select plants with diffuse (or fibrous) root systems, not taproots. Taproots can damage the liner and/or underdrain pipe.

Small trees may be considered in bioretention areas, provided that adequate media, irrigation, and space are available. Trees are generally better suited for larger bioretention areas. Recommendations for planting trees in bioretention areas include:

- Do not install trees in bioretention systems with an impermeable liner.
- Provide irrigation for trees.
- Consider planting trees on side slopes, above the more frequently inundated areas.
- Select trees that can withstand periods of inundation.
- Avoid conifers in areas exposed to deicing chemicals.
- Provide access for tree maintenance, which may include pruning, removal of bioretention media removal and replacement, tree removal and replacement, and incidental removal of other vegetation.
- Install trees at least 5 feet away from inlets, outlets, and underdrains because tree roots may obstruct inlets and outlets or damage the underdrain. Consider limiting the length of the underdrain to allow for placement of trees where desired.
- For deciduous trees, plan for additional seasonal maintenance to remove leaf litter and avoid media clogging.
- Avoid trees with fruit litter.
- Select shade-tolerant species for tree understory plants.
- When considering trees for bioretention systems located in easements, check local requirements regarding allowed vegetation types and replacement requirements.
- Be aware that some jurisdictions may not allow trees in bioretention.
- See Denver's Ultra-Urban Guidelines (Denver 2016) for tree pit/trench bioretention variations.

8. **Irrigation**: Irrigation is required for vegetation establishment, for supplemental water during extended dry periods, and may be needed on a routine basis depending on plant selection. During establishment, all plants should receive approximately 1 inch of moisture (combined rain and irrigation) per week for the first growing season to promote establishment. Some plants may require more than one growing season to become fully established. Providing a permanent irrigation system at the time of SCM installation provides greater flexibility in plant selection and aesthetics, even if regular irrigation is not routinely required after plant establishment.

   Install spray irrigation at or above the WQCV elevation when permanent irrigation is provided or place temporary irrigation on top of the bioretention media surface. Do not place sprinkler heads on the flat media surface as they can become buried over time. Remove temporary irrigation pipes that are laid on the surface once vegetation is established.

VEGETATION ESTABLISHMENT AND INFILTRATION RATES

During vegetation establishment, water applied to bare media can mobilize and rearrange fine silt and clay particles on the surface to create a lower permeability layer. For this reason, vegetation is a critical component in maintaining infiltration in the bioretention system over time. When establishing vegetation from seed, install seed and blanket immediately after media is placed to reduce the mobilization of fines and facilitate germination of the seed.

If left in place, temporary irrigation will become buried over time and will be damaged during maintenance operations.

Adjust irrigation schedules during the growing season to provide the minimum amount of water necessary to maintain plant health, while maintaining free pore space for infiltration.

9. **Outlet**: For partial and no-infiltration configurations, drain the underdrain to the outlet structure and use an orifice plate to drain the WQCV over approximately 12 hours. Section 6.0 *SCM Outflow Features* of this chapter includes conceptual details for the underdrain and orifice outlet both for attenuating the WQCV and larger volumes. When designing for EURV and/or 100-year attenuation, flows greater than the WQCV are controlled and released at the outlet structure, rather than forced through the filter area of the bioretention basin. Provide a spillway for larger events that will convey overflows to the receiving drainage system without adversely affecting adjacent structures or infrastructure. Use the simplified equation in Section 6.1 of this chapter or the MHFD-Detention workbook to size the orifice. MHFD-Detention also aids with design of outlet controls for larger runoff events.

CONSTRUCTION CONSIDERATIONS

Proper construction of bioretention areas involves careful attention to material specifications, final grades, and construction details. For a successful project, implement the following practices:

- Protect the bioretention area from excessive sediment loading during construction. This is the most common cause of clogging of bioretention systems. The portion of the site draining to the SCM must be stabilized before allowing flow into the bioretention area. This includes completion of paving operations.
- Avoid over-compaction of the bioretention area to preserve infiltration rates (for partial and full infiltration sections).
- Provide construction observation to ensure compliance with design specifications. It is important to avoid improper installation, particularly related to elevations of the inlet, underdrain and outlet. Observation/oversight is recommended for the following:
  - Conformance of subgrade with design assumptions.
  - Installation of impermeable liner (for no infiltration sections).
  - Construction of underdrain and installation of media layer.
  - Review of bioretention media test data to verify conformance with specifications prior to installation.
- Provide adequate construction staking to ensure that the site properly drains into the SCM, particularly with respect to surface drainage away from adjacent buildings.

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T-4 SAND FILTERS

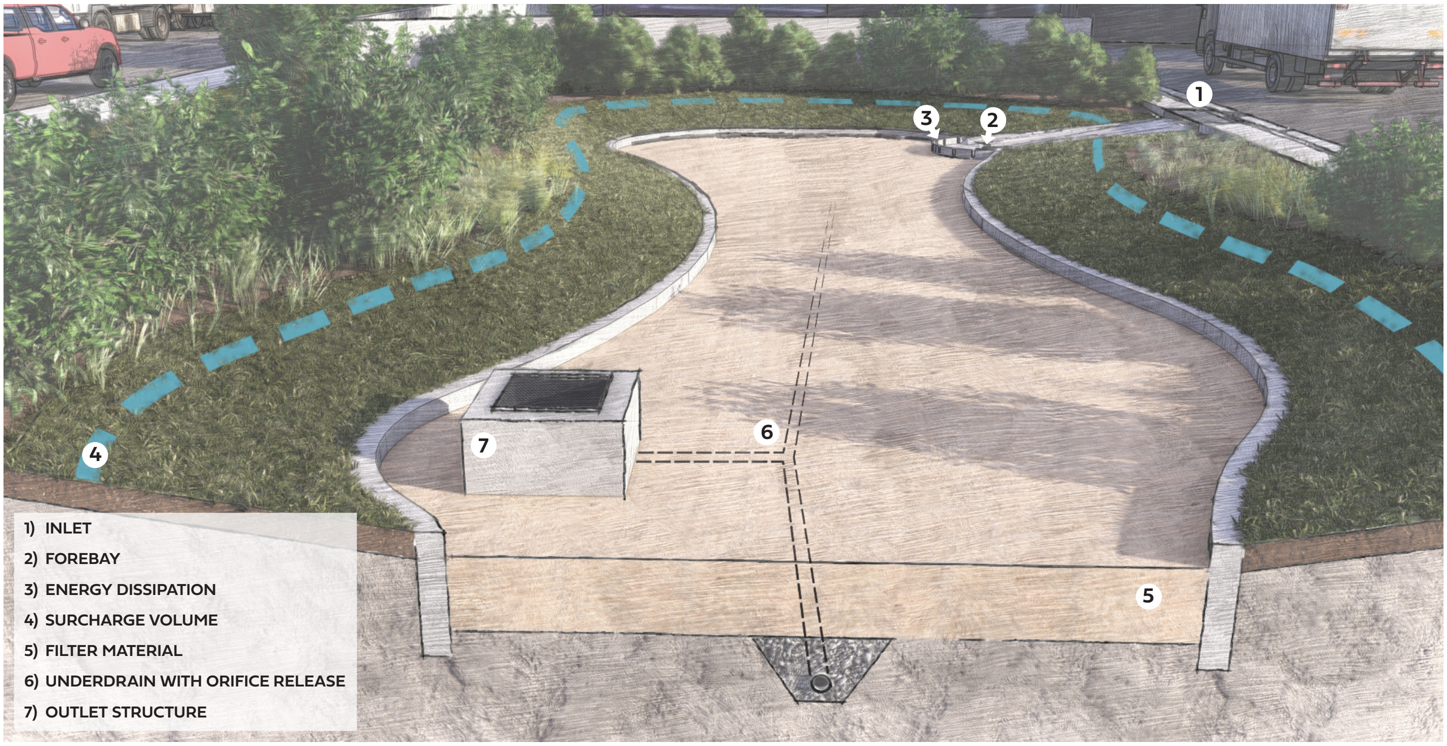

Figure SF-1. Sand Filter Components

DESCRIPTION

A sand filter treats runoff by filtration and also provides infiltration when unlined systems are used. A sand filter consists of a surcharge zone underlain by a sand bed, often with an underdrain system (Urbonas 1999). During a storm, runoff collects in the surcharge zone and gradually infiltrates into the underlying sand bed, filling the void spaces of the sand. The underdrain gradually releases the runoff that is filtered through the sand bed and discharges the runoff to a nearby channel, swale, or storm drain. When suitable based on site conditions, a partial or full infiltration section can be used to infiltrate some or all of the runoff from the water quality design event.

A sand filter is similar to bioretention in terms of filtration and infiltration treatment mechanisms but differs in that it is not specifically designed for vegetative growth. The absence of vegetation in a sand filter allows for active maintenance of the surface of the filter (i.e., raking to loosen the surface layer or to remove accumulated sediments). For this reason, sand filter criteria allow for a larger contributing area and greater depth of storage than bioretention but will also require more frequent maintenance at the surface of the filter to ensure adequate infiltration. A sand filter can be designed to include the Excess Urban Runoff Volume (EURV) and 100-year flood storage volume, released through a surface-release outlet structure. Sand filters can be placed in a vault for subsurface applications. However, these types of installations are more difficult to inspect and maintain and should only be used if surface treatment is infeasible.

TABLE SF-1. SF OVERVIEW

SAND FILTERS	
MS4 Permit Applicability (Dependent on design and level of treatment)	
Meets Runoff Reduction Standard	Potential[1]
Meets WQCV Capture Standard	Yes
Meets Pollutant Removal Standard	Yes
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	High
Total Phosphorus	Medium
Total Nitrogen	Low
Total Metals	High
Bacteria	Medium
Common Applications	
Runoff Reduction (General)	Potential[1]
Used for Pretreatment	No
Integrated with Flood Control	Yes

[1] Depends on design including full-infiltration, partial infiltration or no-infiltration section.

Photograph SF-1. This sand filter, constructed on two sides of a parking garage, is accessible for maintenance, yet screened from public view by a landscape buffer.

SCM COMPONENTS

The primary components of a sand filter include inlet(s), energy dissipation and forebay(s), the surcharge volume, filter material, an underdrain (for no- and partial-infiltration sections), and an outlet structure (Figure SF-1 and Table SF-2). The primary outlet for the Water Quality Capture Volume (WQCV) is typically an underdrain or infiltration into the underlying soil. Surface outlet structures are provided to convey flows that exceed the WQCV design volume and for facilities designed to manage the EURV and 100-year design events.

TABLE SF-2. SF COMPONENTS

COMPONENT	INTENT
Inlet	Allows stormwater to enter the SCM.
Forebay	Facilitates removal of trash and coarse sediments.
Energy Dissipation	Minimizes potential for erosion of sand filter surface. Often incorporated into forebay.
Surcharge Volume	Provides temporary storage volume needed for attenuation of design flows.
Filter Material	Removes pollutants in runoff by filtration through porous media (sand).
Underdrain with Orifice Release	Collects and slowly releases the WQCV over 12 hours to reduce erosion in the receiving stream and enhance treatment by increasing contact time with the media.
Outlet Structure	Conveys stormwater flows that exceed the design volume.

BENEFITS OF SAND FILTERS

- Filtration processes effectively remove a range of pollutants, including phosphorus.
- Filter surface area does not require irrigation.
- Straightforward maintenance procedures.

LIMITATIONS OF SAND FILTERS

- Less attractive than vegetated bioretention systems unless additional aesthetic or vegetative screening is provided.
- Not suitable for installation while construction or major landscaping activities are taking place in the watershed.
- Susceptible to clogging if not properly equipped with a forebay and regularly maintained.
- Typical lined installations do not provide significant volume reduction.
- Ammonification and nitrification of organic nitrogen may occur in the media, resulting in nitrate export (Barrett 2003; Clary et al. 2020).

SITE CONSIDERATIONS

When the tributary watershed includes ongoing phased construction, sparsely vegetated areas, or steep slopes in sandy soils, consider another stormwater control measure (SCM) or provide robust pretreatment before runoff from these areas reach the sand filter. Sand filters are susceptible to clogging and are better suited to stable watersheds without excessive sediment loading.

See Section 3.0 *Site Assessment* and Section 4.3 *Filtration and Infiltration Section Development* of this chapter to determine the section of the sand filter based on site-specific conditions.

Sand filters are often used in industrial settings, where pollutants may be present that warrant use of a lined system to prevent subsurface pollutant mobilization.

COMMUNITY VALUES

Sand filters are highly functional SCMs that are well suited for industrial and large-scale commercial land uses that have generally lower aesthetic expectations. With an exposed sand bed and lack of vegetation, a sand filter is not the best SCM option for highly visible sites such as boutique commercial or mixed-use development, where aesthetics are important to business owners and property managers. Sand filters are also not generally ideal options for low-density residential or park and open space-type sites, where a more naturalistic aesthetic is generally expected. However, if properly screened with shrubs or other site elements (e.g., site walls, raised planters), a sand filter can be made inconspicuous and may be successfully integrated into almost any type of land use. When located in a visible area, frequent inspection and maintenance are critical to public acceptance because an unmaintained sand filter can become an unattractive weed patch with sediment and trash deposits.

While successfully integrating a sand filter into certain types of sites may be aesthetically challenging, their straightforward design and function provides some distinct advantages over other SCMs that require vegetation, including water conservation and a simplified maintenance regime. If creatively located and designed and well maintained, sand filters can be an appropriate and effective stormwater quality treatment solution for a wide variety of sites.

MAINTENANCE

Periodic maintenance for sand filters includes removing sediment, scarifying the filter surface, and removal and/or replacement of the top layer of the media. More detailed maintenance recommendations for sand filters are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term:

- Provide forebays for inlets to remove coarse sediments and trash in a manner that can be easily accessed for maintenance.
- Provide energy dissipation to minimize erosion of the filter bed.
- Do not put a filter sock on the underdrain. This is not necessary and can cause the sand filter to clog, resulting in ponded water for extended periods.
- Install cleanouts to enable camera inspection immediately following construction to ensure the underdrain pipe was not crushed during construction. Cleanouts also facilitate maintenance over the life of the facility. Consider locating cleanouts in the side slopes of the basin and above the depth of ponding to prevent short circuiting of flow through the cleanouts to the underdrain.
- For facilities with side slopes, consider vegetated side slopes to pre-treat runoff by filtering (straining). This will reduce the frequency of maintenance. Use native vegetation to limit the need for irrigation of side slopes to the initial establishment period, with supplemental irrigation as needed during prolonged drought periods. Side slopes also may be stabilized with alternative permeable, non-erosive cover such as appropriately sized aggregate,

provided that the material is designed to stay in place under design conditions up to and including the 100-year event.

- If a sand filter is located in an underground vault, design the vault in a way that allows for routine scarification of the filter surface and eventual media replacement. Multiple access manholes are typically required, and vaults must be designed with adequate clearance for access by equipment and maintenance personnel (an underground sand filter is a confined space). In some installations, grates can be used instead of solid covers, allowing for easier inspection and maintenance. Design of sand filter vaults is not addressed in detail in this fact sheet and requires additional design considerations to address issues such as biofouling, multi-chamber pretreatment considerations and other factors (DC DOEE 2020, Davis et al. 2022).
- When screening is provided for aesthetic reasons, maintenance access must still be provided.

DESIGN PROCEDURES AND CRITERIA

The following steps outline the design procedure and criteria for a sand filter:

1. **Subsurface Exploration and Determination of a No-Infiltration, Partial Infiltration or Full Infiltration Section***:* See Section 3.0 *Site Assessment* and Section 4.0 *Filtration and Infiltration Systems* of this chapter to determine the most appropriate section design for the sand filter based on site conditions. Given that sand filters are often used in industrial settings where subsurface pollutant mobilization should be avoided, lined systems (no-infiltration sections) should be considered based on site conditions.

2. **Inlets, Energy Dissipation, Forebays and Pretreatment**: Use inflow features that create sheet flow or shallow flow conditions to evenly distribute flow. Provide energy dissipation and a forebay at all locations where concentrated flows enter the sand filter. The only inflows that do not require energy dissipation and a forebay are sheet flow inflows to the sand filter. All piped or channelized inflows to sand filters require energy dissipation and forebays, ranging from concrete pads for smaller facilities to more formal structures for larger installations. See Section 5.0 *SCM Inflow Features* of this chapter for additional guidance. In addition to properly sized forebay(s), other types of pretreatment such as grass buffers, hydrodynamic separators, and trash collection devices may also be considered. Underground sand filters in vaults must have a separate pretreatment sedimentation chamber or pretreatment device.

3. **Design Storage Volume**: Calculate the storage volume provided above the sand bed of the basin equal to the WQCV based on a 12-hour drain time, after accounting for runoff-reduction SCMs in the contributing watershed. Determine the required WQCV or EURV (watershed inches of runoff) using Figure 3-2 of Chapter 3 of this manual (for WQCV) or equations provided in the *Storage* chapter of Volume 2 (for EURV).

Photograph SF-2. Underground sand filter at Denver Botanic Gardens has a grated top, which enables inspection and maintenance.

Photograph SF-3. Sand filter with incorporation of minor event flood attenuation provides water quality and detention for a substation.

4. **Sand Filter Geometry**: Sand filter geometry considerations include minimum surface area, side slope conditions and maximum ponding depth:

- **Minimum Filter Surface Area**: Use equation SF-1 to calculate the minimum filter area for the WQCV, which is the flat surface of the sand filter. Sediment will deposit on the filter area of the sand filter. Therefore, if the filter area is too small, the filter may clog prematurely. If clogging of the filter is of particular concern, increasing the filter area will decrease the frequency of maintenance. Equation SF-1 provides the minimum filter area, allowing for some of the volume to be stored beyond the area of the filter. Note that the total volume must also equal or exceed the design volume.

$$A_F = 0.0125 \cdot A \cdot I$$ **Equation SF-1**

Where:

A_F = minimum filter area (flat surface area) (ft^2)

A = area tributary to the sand filter (ft^2)

I = imperviousness of area tributary to the sand filter (percent expressed as a decimal)

- **Side Slopes**: The side slopes of the basin should be stable and maintainable. For vegetated side slopes, a slope no steeper than 4:1 (horizontal: vertical) is recommended. Use vertical walls where side slopes are steeper than 3:1. Using milder side slopes is an effective way to manage the maximum ponding depth of the WQCV in the SCM when space constraints allow.

  When side slopes use alternative permeable, non-erosive cover such as the aggregate shown in Photograph SF-3, the engineer must perform analysis to demonstrate the cover material placed on the slope will resist movement from tractive forces under design conditions. This analysis should consider the condition when the sand filter is filling and the side slopes may be exposed to overland runoff, as well as the condition when the facility is full and the spillway is operating.

- **Maximum Ponding Depth**: The maximum recommended ponding depth is governed by the minimum filter area and basin geometry. For Full Spectrum Detention (FSD) facilities, limiting the WQCV depth to 18 inches will generally help to avoid excessive depths for the EURV and 100-year storage volume. Greater WQCV depths will require more frequent maintenance and may drive the depths of the EURV and 100-year storage volumes to undesirable levels for FSD facilities. Particularly in publicly accessible urban areas, consider surrounding land use and public safety when greater ponding depths are included in the design.

5. **Underdrain System, Impermeable Liner, and Geotextile Separator Fabric**: See Section 4.0 *Filtration and Infiltration Systems* of this chapter for guidance and criteria based on the type of filtration and infiltration

SAND FILTER MEDIA AMENDMENTS

An area of evolving research for sand filter media includes various amendments that enhance performance for specific pollutants (e.g., bacteria, metals, nutrients). For example, iron-enhanced sand filter designs target phosphorus removal (MPCA 2022; Erickson and Gulliver 2010). Other examples include calcite/limestone, zeolite, aluminum-based media, manganese-based media, fly ash, olivine and various proprietary media (Davis et al. 2022). Research has also included layering of various media types to target specific pollutants (Prabhukumar et al. 2015).

Designers may consider use of novel amendments to improve water quality performance, provided that the functions and performance of media are maintained or improved. For example, novel amendments should not cause increases in nutrient or metals export or decrease the infiltration rate relative to MHFD's recommended media.

system selected. Underdrain systems in sand filter basins consist of a slotted PVC pipe placed within a layer of drain gravel beneath the filter sand.

6. **Filter Material**: Provide, at a minimum, an 18-inch layer of AASHTO M43 fine aggregate (filter sand), as shown in Table 4-5 in Section 4.3.3 of this chapter. Maintain a flat surface on the top of the sand bed.

7. **Outlet**: Drain the underdrain to the outlet structure and use an orifice plate to drain the WQCV over approximately 12 hours. Section 6.0 *SCM Outflow Features* of this chapter includes conceptual details for the underdrain and orifice outlet for attenuating both the WQCV and larger volumes via full spectrum detention. For facilities that are designed to treat the EURV and/or 100-year flood, flows greater than the WQCV are orifice-controlled and released to the surface, rather than forced through the sand filter. Provide a spillway for larger events that will convey overflows to the receiving drainage system without adversely affecting adjacent structures or infrastructure. Use the simplified orifice equation in Section 6.1 of this chapter or the MHFD-Detention workbook to size the orifice. MHFD-Detention also aids with the design of outlet controls for larger runoff events.

CONSTRUCTION CONSIDERATIONS

Proper construction of sand filters involves careful attention to material specifications and construction details. During construction, implement these practices:

- Protect area from excessive sediment loading during construction. The portion of the site draining to the sand filter must be stabilized before allowing flow into the sand filter.
- When using an impermeable liner, ensure enough slack in the liner to allow for backfill, compaction, and settling without tearing the liner as described in Section 4.0 *Filtration and Infiltration Systems* of this chapter. Concrete spray-on liners may also be used.
- Avoid application of herbicides for weed control within the sand filter and areas draining directly into the sand filter (e.g., embankments).

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T-5 PERMEABLE PAVEMENT SYSTEMS

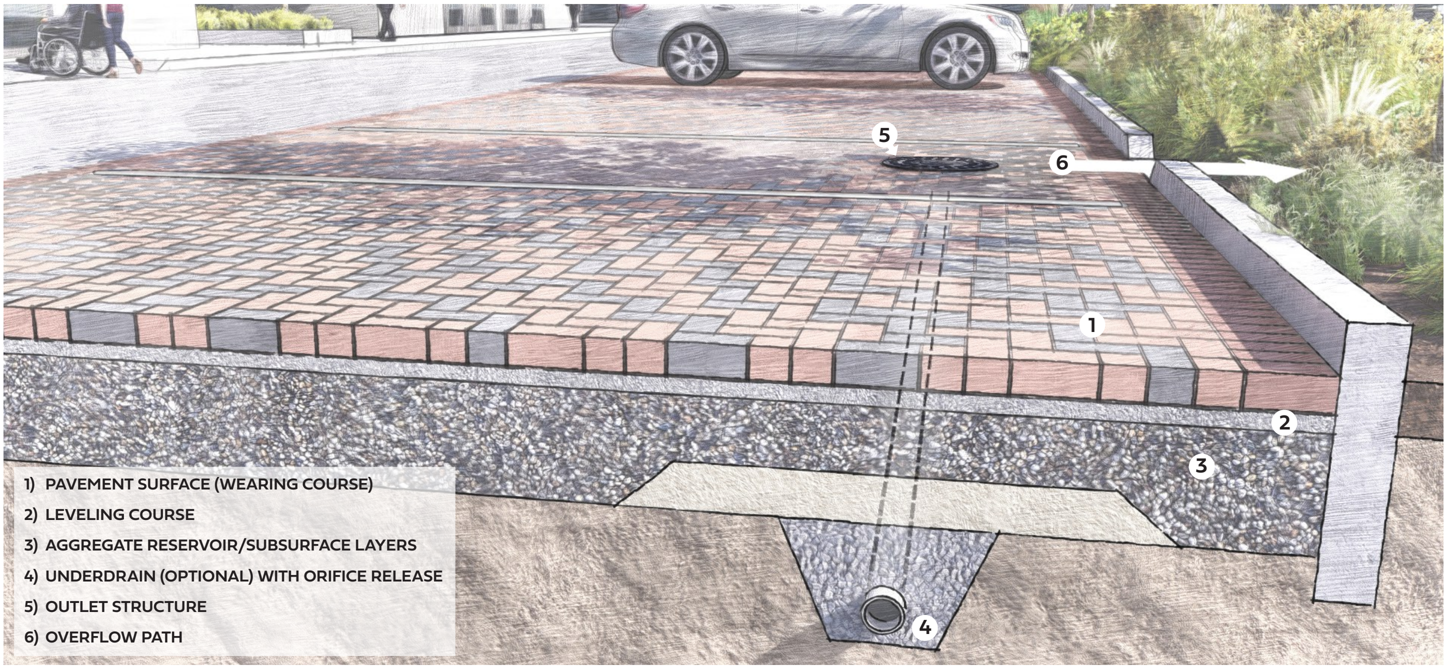


Figure PPS-1. Permeable Pavement System Components

DESCRIPTION

Permeable pavement systems include several types of pavements that allow stormwater to infiltrate through engineered surface layers below the pavement surface. Permeable interlocking concrete pavement (PICP), concrete grid pavement (CGP), and porous gravel pavement (PGP) are included in this fact sheet. Reinforced grass pavement (RGP) is also included, although this type of permeable pavement is most commonly used for fire lanes or to reduce impervious area and does not always provide treatment of the water quality capture volume (WQCV) from surrounding areas.

Permeable pavement systems provide filtration of runoff through aggregate layers and store the WQCV in the aggregate reservoir with slow release via an orifice-controlled underdrain and/or infiltration into the subgrade. Permeable pavement systems provide runoff reduction via wetting and drying of the aggregate and infiltration in unlined systems. When designed to provide the WQCV, both lined and unlined permeable pavement systems are capable of providing effective water quality treatment. A permeable pavement system can be designed with an increased depth of aggregate to provide storage exceeding the WQCV, including the excess urban runoff volume (EURV) and the 100-year detention storage volume.

SCM COMPONENTS

A permeable pavement system functions by filtering, storing, and infiltrating runoff. Filtration occurs as the water infiltrates through the pavement surface or between pavers through a leveling course into an aggregate reservoir.

TABLE PPS-1. PPS OVERVIEW

PERMEABLE PAVEMENT SYSTEMS	
MS4 Permit Applicability (Dependent on design and level of treatment)	
Meets Runoff Reduction Standard	Potential
Meets WQCV Capture Standard	Yes[2]
Meets Pollutant Removal Standard	Yes[1,2]
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	High
Total Phosphorus	Medium
Total Nitrogen	Medium
Total Metals	Medium
Bacteria	Medium
Common Applications	
Runoff Reduction (General)	Yes
Used for Pretreatment	No
Integrated with Flood Control	Yes

[1] When designed in accordance with WQCV criteria.
[2] Reinforced grass pavement excluded.

The aggregate reservoir stores the WQCV (or larger design volume such as the EURV or 100-year storage volume) and allows for infiltration into the subgrade for full and partial infiltration designs. The subsurface drainage system for a permeable pavement system, including use of underdrains, is site-specific, and guidance and criteria are provided in Section 4.0 *Filtration and Infiltration Systems* of this chapter.

TABLE PPS-2. PPS COMPONENTS

COMPONENT	INTENT
Pavement Surface (Wearing Course)	Provides the wearing course for the permeable pavement, allows infiltration into pavement section, and provides filtration.
Leveling Course	Provides bedding for the pavement surface (PICP and CGP) as well as filtration.
Aggregate Reservoir/ Subsurface Layers	Provides structural stability and storage for design storm events. Allows for quiescent settling of fine particulates not filtered by wearing or leveling courses.
Underdrain with orifice release (for partial and no infiltration sections)	Collects and slowly releases the WQCV over 12 hours to reduce erosion in the receiving waters and enhance water quality. Full infiltration designs infiltrate the WQCV into the subgrade.
Lateral Flow Barriers	Separate permeable pavement cells in stepped or sloped installations to prevent all runoff entering system from draining to lowest area. Also used to provide separation between permeable pavement section and adjacent structures or infrastructure.
Outlet Structure	Releases flows in accordance with required drain times and release rates for design events. For multi-cell systems, each cell must have an outlet to avoid flow between cells that overwhelms lower-elevation cells and can lead to washout and differential settlement.
Overflow Inlet	Provides route for runoff to reach the aggregate reservoir if pavement surface is clogged. Required for detention applications.
Overflow Path	Conveys runoff to street or storm drain system via surface flow if pavement surface or outlet is clogged or for events exceeding design flows.

TYPES OF PERMEABLE PAVEMENT SYSTEM SURFACES

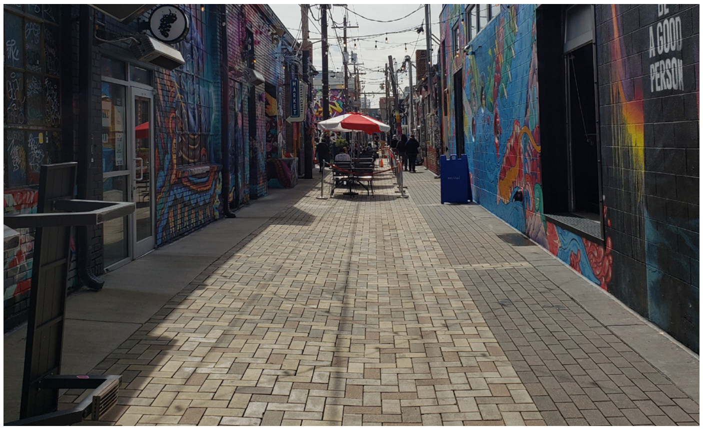
There are several options for permeable pavement system surfaces including PICP, CGP, PGP, and RGP. Porous concrete and porous asphalt are not included in this fact sheet and MHFD does not recommend them due to past issues with durability and performance over time (UDFCD 2013a&b).

BENEFITS OF PERMEABLE PAVEMENT SYSTEMS

- Provides stormwater treatment in a multi-use area.
- Increases air and water to nearby trees.
- Less likely than conventional pavements to form ice on the surface because as snow melts, it infiltrates before it can freeze.
- Green/sustainable building certification credits may be available.
- Provides traffic calming.
- Pavers can be removed and re-used after utility repairs or restorative maintenance.
- Can manage runoff when surrounding storm drain infrastructure is shallow, potentially avoiding underground storage and pumps.

LIMITATIONS OF PERMEABLE PAVEMENT SYSTEMS

- Must be protected from high sediment loads during construction and is not well-suited for areas contributing significant sediment loads.
- Must be designed to allow for repair and replacement of underlying utilities.
- Maintenance requires specialized equipment.
- Lack of routine maintenance may result in costly repairs.



Photograph PPS-1. PICP in alley provides stormwater treatment in a retrofit setting while also providing outdoor seating and an attractive pedestrian area.

Photograph PPS-2. PICP in alley treats runoff from roof drains and adjacent parking spaces. A surface overflow path to the street provides drainage if the system is clogged or overwhelmed by runoff.

PERMEABLE INTERLOCKING CONCRETE PAVEMENT (PICP): PICP has a wearing course consisting of precast concrete blocks that, when placed together, create spaces between the blocks where runoff enters the pavement. The blocks contain ridges along the sides that both create these spaces and help ensure that the blocks are installed correctly. The joint spaces between the blocks must be filled with aggregate that allows runoff on the surface to migrate down into the aggregate reservoir. Depending on the manufacturer, these joints should provide an open surface between 5 and 15% of the pavement surface. Figure PPS-2 provides a typical full infiltration pavement section for PICP, and Figure PPS-3 shows a typical no infiltration section. The Interlocking Concrete Pavement Institute (ICPI) published a manual on PICP that includes detailed design, construction, and maintenance information (ICPI 2017) along with various technical specifications (e.g., ICPI 2015; ICPI 2020a,b&c).

PICP has many design options including various shapes, colors, and sizes that can be arranged in creative patterns and color schemes. Light-colored pavers can be used to mark pavements, thereby eliminating the need for painting. Properly designed and maintained PICP systems sustain infiltration rates well over time and can be removed and replaced if utility work is needed below the surface. Most PICP systems can be constructed as an Americans with Disabilities Act (ADA)-compliant pavement.

PICP may have a more expensive upfront cost than other types of permeable pavements, but it generally offers greater benefits. PICP's durable, high-strength concrete wearing surface offers more longevity than some other types of permeable pavements. PICP installation costs can also be offset by reductions in stormwater infrastructure requirements and increased land utilization. ICPI Tech Spec 18 provides additional information on the benefits of PICP (ICPI 2019).

Photograph PPS-3. PICP in downtown Ft. Morgan, CO. Note soldier course of light-colored pavers where PICP meets conventional pavement. Photo: SEH and the City of Ft. Morgan.

Photograph PPS-4. CGP installation allows for infiltration into subsurface via permeable infill material. Photo: True Grid.

CONCRETE GRID PAVEMENT (CGP): CGP consists of concrete block units with large openings (at least 20% of the total surface area) that are typically filled with free-draining aggregate. CGP has many of the same benefits of PICP in terms of flexibility with removal and replacement of blocks and maintaining good infiltration rates over time, but CGP is generally not ADA-compliant because of the extent of the open areas in the grid. Figure PPS-4 shows a typical section for CGP. CGP installation costs may be offset by reductions in stormwater infrastructure requirements. Detailed information on CGP is available in ICPI Tech Spec 8 (ICPI 2020c).

POROUS GRAVEL PAVEMENT (PGP): PGP is a lower-cost alternative to PICP or CGP that is most applicable to parking areas, materials storage areas (without potential to introduce pollutants), driveways, and maintenance access paths.[1] PGP is not ADA-compliant. Ruts typically will develop unless the surface is stabilized. Use a cellular grid confinement system to stabilize the PGP and prevent excessive rutting. Figure PPS-5 shows a typical section for PGP pavement.

REINFORCED GRASS PAVEMENT (RGP): RGP has the appearance of grass turf while providing the stability of pavement. Several types of reinforced grass products are available and provide various levels of turf protection and pavement stability. RGP is frequently used to provide emergency vehicle access, maintenance access to SCMs, parking in infrequently used areas, and stabilization of roadway shoulders. Irrigation will typically be needed to establish and maintain grass cover for RGP. Maintaining grass in more heavily used areas requires more irrigation. Figure PPS-6 shows a typical RGP section.

RGP should be treated similarly to other vegetated areas of a site. It reduces the site imperviousness and allows for reduction of runoff for impervious areas that drain to it, but it is not designed to capture and slowly release the WQCV like PICP, CGP, and PGP. It can be used as receiving pervious area; however, other SCMs will be likely be needed to meet water quality requirements.

Photograph PPS-5. PGP with grid for containment of surface material to minimize potential for rutting. Photo: True Grid.

Photograph PPS-6. Reinforced grass pavement using concrete grid for maintenance access to a stormwater pond.

SITE CONSIDERATIONS

Permeable pavement systems provide unique opportunities for unseen stormwater storage and treatment beneath areas that often occupy highly visible and functional portions of a site. For a permeable pavement system to perform effectively, careful evaluation of underlying soils, and surrounding structures and infrastructure is critical. Section 4.0 *Filtration and Infiltration Systems* of this chapter describes site evaluations required for designing infiltration-based SCMs, including permeable pavement systems. Key considerations include:

- PICP and aggregate-filled CGP are well suited for situations where stormwater storage and treatment are required and the surrounding storm drainage infrastructure is shallow. PICP and aggregate-filled CGP installation costs may be offset by the costs of avoiding underground vaults, pumps, mechanical water quality treatment devices, and their associated long-term maintenance costs.

[1] If PGP is used in a roadway subjected to vehicular traffic, refer to Gravel Roads – Maintenance and Design Manual, Appendix A: Gravel Road Thickness Design Methods (Skorseth and Selim 2000).

- Permeable pavement systems are generally not suitable in areas where heavy vehicles will be frequently loading/unloading or turning, areas with concentrated pollutant sources (e.g., trash or loose material storage areas, gas stations, fast food drive-throughs, near grease interceptors, and similar areas), sites with high sediment in runoff, and/or sites that use deicers or sanding for snow and ice management (ICPI 2019). See Section 4.0 *Filtration and Infiltration Systems* of this chapter for additional considerations that apply to all infiltration and filtration based SCMs.
- Permeable pavement systems are not appropriate near sediment source areas, including near loose material storage areas or areas with steep slopes and/or sparse vegetation. During construction, protect the permeable pavement system area from runoff with excessive sediment to preserve the infiltration capabilities of the area. Ideally, construct the permeable pavement system as a final step in construction after the contributing drainage area is stabilized. While this is not always feasible, installation of a permeable pavement system before the watershed is stabilized risks the facility failing to function as designed (ICPI 2019).
- When used in or adjacent to streets (e.g., in streetside parking spaces or bike lanes), consider underlying utilities that may require maintenance, repair, or replacement. Due to increased particulate loading in vehicular environments and increased potential for clogging, the ratio of unconnected to receiving pervious area may need to be lower than the maximum limits stated in this fact sheet for sustainable performance without excessive maintenance. Many local governments restrict the use of permeable pavement systems within the public right-of-way, especially when there are underlying utilities.
- Traffic loads must be considered for a permeable pavement system that will have vehicular traffic. Consult a geotechnical engineer for structural design of permeable pavements subject to vehicular traffic. Such applications may require a thicker and/or stabilized aggregate base/subbase. For PICP, review the structural design method in ASCE 68-18 Permeable Interlocking Concrete Pavement (ASCE 2018).
- Trees and plantings that seasonally drop leaves on permeable pavements will require regular maintenance to remove leaves to ensure that the systems remain functional.
- For sites with land uses or activities that can cause infiltrating stormwater to contaminate groundwater, special design requirements such as impermeable liners are required to ensure no exfiltration from the permeable pavement system into underlying soils and groundwater. In these cases, a permeable pavement system may not be the most appropriate SCM.
- Setbacks may be required between permeable pavement systems and nearby domestic wells, septic systems, or shallow groundwater tables. Check local requirements for required setbacks.
- When utilities are located beneath permeable pavement systems, provide access for the types of equipment that may be needed to repair or replace the utilities. Avoid utility installations below permeable pavement systems when practical, and sleeve utilities when they must be located

SELECTION CONSIDERATIONS FOR REINFORCED GRASS PAVEMENT

- **Frequency of Use**: For more frequently used areas, it is important to select a system that protects the root system of the turf from compaction.
- **Appearance**: Concrete and plastic systems differ aesthetically.
- **Vehicle Loading**: Emergency vehicle access roads may need to be designed for high loads but will be used infrequently.
- **Irrigation Expectations**: Some pavements rely, in part, on the turf for stability.
- **Drainage Capability**: Where soils allow for infiltration, select a product that will bridge the subgrade, providing better protection from over-compaction.

Photograph PPS-7. Perimeter barrier and trench with underdrain to protect street subgrade with adjacent PPS installation. Photo: Beck Group.

within the pavement area. For utilities that are sleeved within a permeable pavement section, provide a cutoff wall against the soil/aggregate interface using an impermeable liner or concrete where the utility enters or exits the pavement section to prevent water exfiltration (piping) along the utility line bedding.

COMMUNITY VALUES

Permeable pavement, particularly PICP, is a highly flexible and useful option for providing water quality, runoff reduction, and potentially Full Spectrum Detention (FSD) for very urban or constrained sites. Permeable pavement systems can be a particularly good option in urban areas where high levels of use, high land value, and visual sensitivity do not favor the use of other SCMs that require more dedicated space. The ability of permeable pavement systems to filter, capture, store, infiltrate, and convey stormwater below ground allows sites to be used to their maximum potential, which can justify higher installation costs compared to many other SCMs. PICP should be considered for areas such as urban plazas and courtyards, hotels, multi-family developments, conference venues, access drives and access roads, and high visibility parking lots that periodically function as event venues or gathering spaces. PICP can be aesthetically pleasing in areas of historic designation. It is also a good choice for visitor facilities and parking for sensitive natural and historic areas where minimizing disturbance from site development and associated infrastructure is a primary design objective.

PICP is also an excellent way to manage surface drainage on highly constrained sites, and it can replace the need for curb and gutter, extensive inlets, and drainage piping to convey runoff through high use areas such as plazas and other high use/high visibility areas. PICP is useful for social gathering areas, where it can provide a hardscape environment that is truly barrier-free in terms of accessibility, visually pleasing, and designed to complement other site structures and improvements. Most PICP systems are ADA accessible. Verify ADA compliance with the manufacturer.

Other types of permeable pavement systems, such as CGP, PGP, and RGP, while less expensive than PICP, are less ideal for community uses, primarily due to their lack of ADA accessibility in many typical configurations, and in the case of RGP/CGP, their need for either irrigation (if soil and plant material are used to infill voids), or frequent weed control (if aggregate is used as infill). These types of permeable pavement systems may be suited for overflow parking areas or commercial/industrial areas where community value is a lower priority (i.e., areas not typically used by the public).

Photograph PPS-8. PICP with striped ADA parking and tree planter. Photo: Creative Civil.

MAINTENANCE

Recommended maintenance practices are specific to the type of permeable pavement system and are detailed in Chapter 6 of this manual. During design, consider the following to facilitate maintenance over the long-term:

- Develop an operations and maintenance plan (O&M Plan) that identifies the type(s) of equipment needed to maintain the permeable pavement system (e.g., the availability of a regenerative vacuum sweeper) and communicate expectations of this plan with the owner.
- Consider how the permeable pavement system will be accessed by maintenance equipment and allow space for maneuvering of equipment to access the full surface (ICPI 2019).
- Specify how snow will be removed from the permeable pavement system in the O&M Plan. Permeable pavement systems are not well suited in areas where deicers or sand are applied, so alternative means of managing snow and ice are necessary. In general, permeable pavement systems facilitate melting by infiltrating melting water instead of allowing it to refreeze (ICPI 2019). Plowing is the recommended snow removal process. Use plows with rubber tips on the blades to reduce the potential for damaging pavement.
- When utilities are located beneath the permeable pavement system, provide access and clearance for the types of equipment that may be needed to repair or replace the utilities.
- Include observation well(s) as needed to monitor the drain time of the permeable pavement system over time and assist with determining the required maintenance needs over time. See Figure PPS-7 for a typical observation well configuration. Include observation wells for detention applications and for WQCV applications that include an internal water storage zone below the underdrain. Observation wells are not needed for installations that are just intended to reduce impervious cover but that do not provide the WQCV (e.g., RGP for a maintenance access ramp).
- Periodic testing of the infiltration capabilities of the pavement surface is useful for assessing the need for maintenance. The simple infiltration test (SIT) is a method that can be used to assess the pavement infiltration rate in a relatively short period of time using a standardized method that has been correlated with the ASTM method for determining surface infiltration rates (Winston et al. 2016).

DESIGN PROCEDURES AND CRITERIA

The following procedures are common to all types of permeable pavement systems in this fact sheet. Details specific to each pavement type are presented following the general procedure. MHFD recommends using ICPI standard details as a resource for developing a site-specific design. Conceptual design details are located at the end of this fact sheet.

1. **Subsurface Exploration and Determination of a Full Infiltration, Partial Infiltration or No-Infiltration Section**: Conduct subsurface investigations and determine infiltration section type. Follow the guidance and criteria in Section 4.0 *Filtration and Infiltration Systems* of this chapter to evaluate subsurface characteristics and select a full infiltration, partial infiltration, or no infiltration section. Guidance and criteria are also provided for full, partial, and no infiltration sections including underdrain systems, filter sections, perimeter barriers, and impermeable liners.
2. **Inflows and Run-on Ratio**: Identify unconnected impervious area (UIA) that will drain to the permeable pavement system. The ratio of UIA to the permeable pavement area, which acts as receiving pervious area (RPA), is a critical design parameter that affects the sizing of the SCM, the treatment and runoff reduction effectiveness, and maintenance requirements. Limit the amount of impervious area run-on to the permeable pavement to keep hydraulic and pollutant loading at levels that will not require frequent maintenance over time. Permeable pavement systems are most effective when the ratio of UIA:RPA is low. For PICP, restrict the UIA:RPA ratio to 3:1 to minimize clogging. A maximum ratio of 5:1 is permitted where needed (ICPI 2019); however, at such a ratio, very frequent maintenance will be required. For other types of permeable pavements, the maximum recommended ratio of UIA:RPA is 2:1. If the permeable pavement will serve vehicular traffic, use lower ratios (e.g., 1:1) to account for the higher loading of particulate material.

Photograph PPS-9. The reservoir layer of a permeable pavement provides storage volume for the WQCV. Photo: Muller Engineering and Jefferson County Open Space.

The ratio of UIA:RPA is directly proportional to the hydraulic and pollutant loading that the SCM will receive, with higher ratios requiring more frequent maintenance. With other parameters being similar, a permeable pavement designed with a 5:1 ratio would require maintenance more than twice as often as a permeable pavement designed with a 2:1 ratio, and a permeable pavement with a 2:1 ratio would require maintenance twice as often as one designed with a 1:1 ratio. Therefore, it is important to design permeable pavements with UIA:RPA ratios that will provide for sustainable infiltration given the resources and capabilities of the entity responsible for maintaining the pavement.

For a permeable pavement system to be effective, run-on from adjacent areas must be distributed uniformly across the permeable pavement surface. Designs that direct run on to only a portion of the permeable pavement system effectively overload one part of the system and underutilize others. A level spreader, as discussed in Section 5.0 *SCM Inflow Features* of this chapter, may be needed to achieve uniform flow distribution for larger run-on areas.

Because permeable pavement systems are often located near buildings, there are opportunities to treat and detain roof runoff in permeable pavement systems. Downspouts from the roof may discharge onto the surface of the pavement as long as the vertical distance between the pavement surface and downspout outlet is less than 6 inches. This is necessary to avoid wash out of aggregate in joints. Roof downspouts also may discharge to a permeable pavement system via a sub-surface connection to the aggregate layer as showing in Figure PPS-8. When this approach is used, pretreatment is needed using a baffle box and screen to filter out particulates in runoff, as shown in Figure PPS-8.

3. **Design Storage Volume**: Determine the WQCV and other design volumes the system is intended to control. Account for all areas draining to the permeable pavement system and determine imperviousness calculated from the site plan. Use a 12-hour drain time for the WQCV. Calculate the required storage volume, accounting for runoff reduction SCMs in the contributing watershed. Determine the required WQCV or EURV

DESIGNING FOR FLOOD CONTROL

When designing for flood control volumes, provide an overflow inlet that will allow runoff to flow directly into the aggregate reservoir when the hydraulic loading rate exceeds the surface infiltration capacity or in the event the surface is clogged.

(watershed inches of runoff) using guidance in Chapter 3 of this manual (for WQCV), or equations provided in the *Storage* chapter of Volume 2 for the EURV and 100-year storage volume. For permeable pavement systems, also add the precipitation that falls directly on the permeable pavement area to the total design volume for each event.

4. **Depth and Volume of the Aggregate Reservoir**: The aggregate reservoir consists of the layers of aggregate below the bedding course:

   - For PICP, the aggregate layers beneath the bedding course consist of a minimum of 4 inches of AASHTO No. 57 or No. 67 coarse aggregate underlain by a minimum 6-inch-thick subbase of AASHTO No. 2 stone.
   - For CGP, the aggregate layers beneath the bedding course consist of a minimum of 4 to 8 inches of AASHTO No. 57 or No. 67 coarse aggregate depending on the anticipated traffic load. When designing deeper sections for increased storage, use a minimum 6-inch layer of AASHTO No. 2 stone beneath the layer of No. 57 or No. 67 coarse aggregate.
   - For PGP, provide a minimum of 8 inches of AASHTO No. 57 or No. 67 coarse aggregate beneath the containment grid, given the typical 2-inch depth of the overlying 1/2” to 3/4” clean (< 2% passing No. 200 sieve), angular stone for the gravel surface. When designing deeper sections for increased storage, use a minimum 6-inch layer of AASHTO No. 2 stone beneath the layer of No. 57 or No. 67 coarse aggregate.
   - For RGP, the subsurface layer consists of a mixture of aggregate and sandy soil. Consult with a geotechnical engineer on aggregate-soil mixture gradation in areas of vehicular loading.

   Additional depth may be required to support anticipated loads or to provide additional storage (i.e., for flood control). This is usually achieved by deepening the subbase layer of AASHTO No. 2 stone. Size the void storage of the aggregate to accommodate the design volume. Assume a porosity of 40% for the aggregate reservoir. Specify fractured faces for reservoir aggregate.

   When a permeable pavement system is installed on a slope, a stepped or sloped subgrade installation may be used to provide storage. Figures PPS-9 and PPS-10 depict stepped and sloped subgrade installations.

   For preliminary sizing, calculate the storage volume using Equation PPS-1 for a flat or stepped subgrade installation. Use Equations PPS-2 and PPS-3 for a sloped subgrade installation. These equations allow for a minimum of 1 inch of freeboard. Flat installations are preferred because the design spreads infiltration more evenly over the subgrade.

   For flat or stepped installations (0% slope at the reservoir/subgrade interface), calculate the volume using Equation PPS-1:

$$V = P\left[\frac{D-1}{12}\right]A_{Pavement}$$ **Equation PPS-1**

PAVEMENT DESIGN FOR VEHICULAR TRAFFIC

When used for vehicular traffic, a qualified engineer experienced in the design of permeable pavements and conventional asphalt and concrete pavements should design the pavement section. The permeable pavement must be adequately supported by a properly prepared subgrade, properly compacted filter material, and aggregate reservoir material designed for traffic loads.

For sloped installations (slope of the reservoir/subgrade interface > 0%), use Equations PPS-2 and PPS-3:

$$V = P\left[\frac{D - 6SL - 1}{12}\right]A_{Pavement}$$ **Equation PPS-2**

$$L < \frac{(D - 1)}{(12S)}$$ **Equation PPS-3**

Where:

V = volume available in the reservoir (ft^3)

P = porosity, ≤0.4 for AASHTO No. 57 or No. 67 coarse aggregate and AASHTO No. 2 stone layers

S = slope of the reservoir/subgrade interface (ft/ft)

D = depth of reservoir (in), 1 inch is subtracted from D in the numerator of Equation PPS-3 to provide a small amount of freeboard to reduce potential for washout of infill material

L = length between lateral flow barriers (see step 5)(ft)

$A_{Pavement}$ = area of the permeable pavement (ft^2)

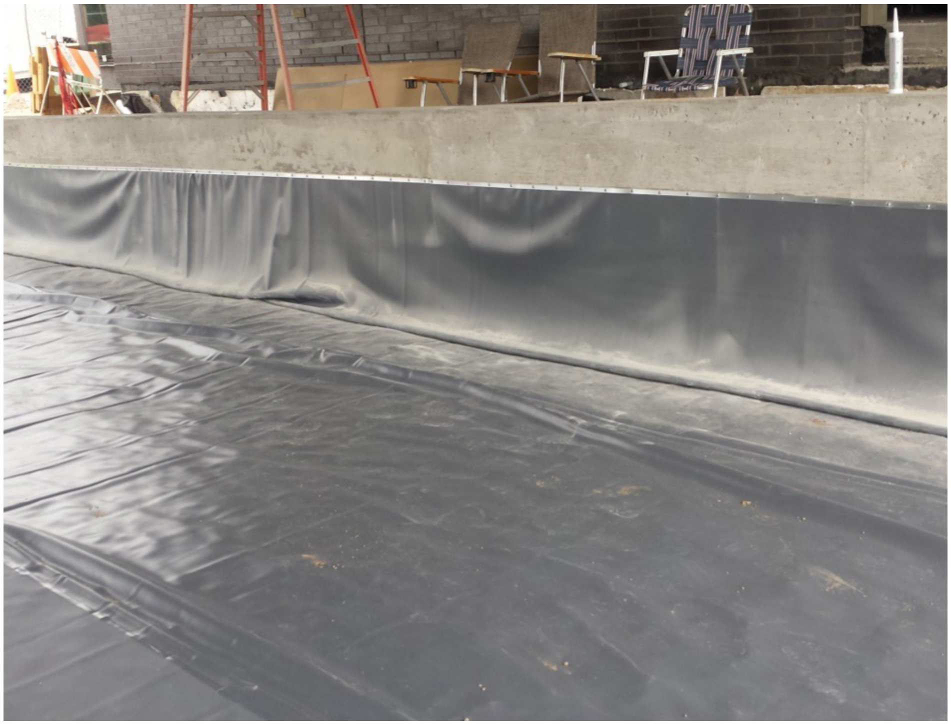
Note that these are idealized equations for simple geometric situations and are not intended for final design. For sloped bottoms, it is not uncommon for the bottom to be sloped longitudinally along the underdrain and transversely toward the underdrain. For these cases, the volume provided by the permeable pavement system can be calculated based on the average cross-sectional area of the reservoir, adjusted for 1 inch of freeboard below the pavement surface. Multiply this average cross-sectional area by the porosity, P, and the pavement area, $A_{pavement}$, to calculate volumes for irregular geometry. Where lateral flow barriers or irregular shapes exist, break the storage reservoir into several storage cells to be calculated separately and summed for total volume.

5. **Lateral Flow Barriers**: Lateral flow barriers help maximize storage volumes in stepped and steeply sloped systems. Lateral flow barriers also help use the full infiltration surface and ensure that water doesn't resurface in the lowest areas of the permeable pavement system. For installations with lateral flow barriers, each individual subsurface cell must be able to drain independently. For partial infiltration systems on steeper slopes, this may require lateral flow barriers that are several feet deep to prevent water that infiltrates in one cell from reemerging in another downgradient cell.

   Construct lateral flow barriers using concrete walls or a 30 mil (minimum) PVC geomembrane. Figures PPS-9 and PPS-10 illustrate concrete lateral flow barriers in stepped and sloped systems, and Figure PPS-11 shows a typical plan view of a multi-celled system with lateral flow barriers. For lateral flow barriers constructed of PVC, see Section 4.0 *Filtration and Infiltration Systems* of this chapter for geomembrane and geotextile fabric criteria. Place lateral flow barriers parallel to the contours of the subgrade (normal to flow). This maximizes the volume available for storage and avoids issues with stormwater resurfacing and washing out infill material.

LATERAL FLOW

Consider subsurface areas adjacent to the permeable pavement system when evaluating the perimeter design. Lateral flow can negatively impact the adjacent conventional pavement section, structures, or other infrastructure (especially when the subgrade is sloped).



Photograph PPS-10. Geomembrane attached to concrete perimeter barrier. Photo: Creative Civil.

Photograph PPS-11. Geomembrane attachment to horizontal footing for light pole. Photo: Creative Civil.

Lateral flow barriers are recommended for all permeable pavement system installations that have a sloped reservoir/subgrade interface. Space lateral flow barriers as needed to maintain at least 6 inches of AASHTO No. 57 or No. 67 coarse aggregate in the reservoir.

6. **Perimeter Barriers**: Perimeter barriers are required for all PICP and CGP systems to confine the permeable pavement system and prevent horizontal spreading and differential settlement under the weight of the layers of materials and loads on the permeable pavement system surface. Figure PPS-12 shows several typical configurations of perimeter barriers. Perimeter barriers may not be necessary for shallow PGP or RGP installations. Precast, cast-in-place concrete, or cut-stone barriers are required. Precast barriers must be interlocked or attached so that they do not separate. In urban areas, foundations and site walls can also be structurally designed as perimeter barriers.

   When a permeable pavement system is adjacent to conventional pavements, a vertical impermeable liner or concrete perimeter barrier with an underdrain may be required to separate the two pavement systems and prevent saturation of the subgrade below the conventional pavement. Consult with the geotechnical engineer on protection required adjacent to conventional pavements. Municipalities may have additional regulations on subgrade protection adjacent to public streets. Section 4.0 *Filtration and Infiltration Systems* of this chapter provides additional guidance related to perimeter barriers.

7. **Features in Permeable Pavement Installations**: Light poles and trees are common features within many permeable pavement installations. Parking lot lighting or trees installed within a permeable pavement system typically are deeper than the permeable pavement system cross section. Design post bases with a horizontal breakaway footing (attach the liner to the footing when lined).

   There are a number of ways that trees can be incorporated within permeable pavement areas including soil planting vaults separated from the aggregate layer by an impermeable liner or aggregate-filled plastic crates to provide air and water with drainage to prevent prolonged saturation of roots. Regardless of the method, providing effective drainage is critical as prolonged saturation of roots will stunt or kill trees. Consult with an arborist or landscape architect knowledgeable of trees when planning trees within a permeable pavement area. See Figure

Photograph PPS-12. Tree planter vault for PICP installation. Photo: Creative Civil.

PPS-13 for a tree planting concept with PICP over structural soil. It is important to avoid prolonged inundation of tree roots, so the base of the root ball is elevated above the bottom of the aggregate reservoir, and underdrains are provided to help drain the area around the tree's root ball.

8. **Underdrain System, Impermeable Liner, and Geotextile Separator Fabric:** See Section 4.0 *Filtration and Infiltration Systems* of this chapter for guidance and criteria based on the type of filtration and infiltration system selected. Underdrain systems for permeable pavements are slightly different than those shown in Figure 4-2 for other filtration SCMs and consist of a slotted PVC pipe placed within a layer of No. 57 drain gravel beneath the subbase layer (or beneath the aggregate layer when a subbase layer is not used). Figure PPS-3 illustrates an underdrain for a no infiltration PICP system.

9. **Outlets**: SCM outlets are customized around overall design constraints and design-storm events included in the reservoir layer. Sites can vary greatly in shape, size, elevations of reservoir cells and ultimately the depth of the connecting outfall system. In multi-cell installations, each cell must drain independently to avoid overflow between cells and washout. This requires the designer to know the depths of design events including the WQCV and larger design storage volumes within each cell to design an outlet for each cell that satisfies release criteria. A well-designed outlet will provide for ease of maintenance and cleaning. The entire system should be designed with consideration of the 100-year storm conveyance through the reservoir layers to the outlet to prevent backwashing paver joints, resulting in paver movement and settlement. The outlet structure should be capable of conveying all storm events and maintaining the reservoir storage volumes per the design.

   Outflows from permeable pavement systems are controlled using orifices and weirs designed as part of the outlet riser pipe. Figure PPS-14 shows a concept for an outlet structure designed to control the WQCV. In this application, a restrictor plate or cap with an orifice can be placed on the end of the underdrain where it enters the outlet structure. Larger events are conveyed into the outlet structure via a grated area inlet, bypassing the permeable pavement system. Figure PPS-15 provides an example of a conceptual permeable pavement outlet configuration for FSD design. In this case, the outlet structure consists of a riser with multi-level controls, and the WQCV, EURV, and 100-year design event are filtered through and stored in the aggregate reservoir levels before they are released by the multi-level control riser. All designs must implement properly sized overflow paths that do not result in paver displacement or settlement during events exceeding design storms for which the reservoir layers are sized.

Section 6.0 SCM *Outflow Features* of this chapter provides guidance, including a simple orifice restriction equation, to design subsurface outlets to release the WQCV. The outlet sizing is based on the depth of the WQCV or other design storage volume in the aggregate reservoir. The aggregate reservoir can also be sized for the EURV and 100-year storage volume based on guidance in the *Storage* chapter of Volume 2. See Section 6.0 SCM *Outflow Features* of this chapter for conceptual outlet structures with single and multiple orifice-controlled release rates. It is important to know the depth of each volume stored to properly control release via the outlet structure.

For calculating depth of the WQCV using a flat/stepped installation (Figure PPS-9), use Equation PPS-4:

$$D = \frac{12WQCV}{PA_{Pavement}}$$ **Equation PPS-4**

For calculating depth of the WQCV using a sloped installation (Figure PPS-10), use Equation PPS-5:

$$D = \frac{12WQCV}{PA_{Pavement}} + 6SL$$ **Equation PPS-5**

Where:

$WQCV$ = water quality capture volume (ft^3)

D = depth of storage in the reservoir (in)

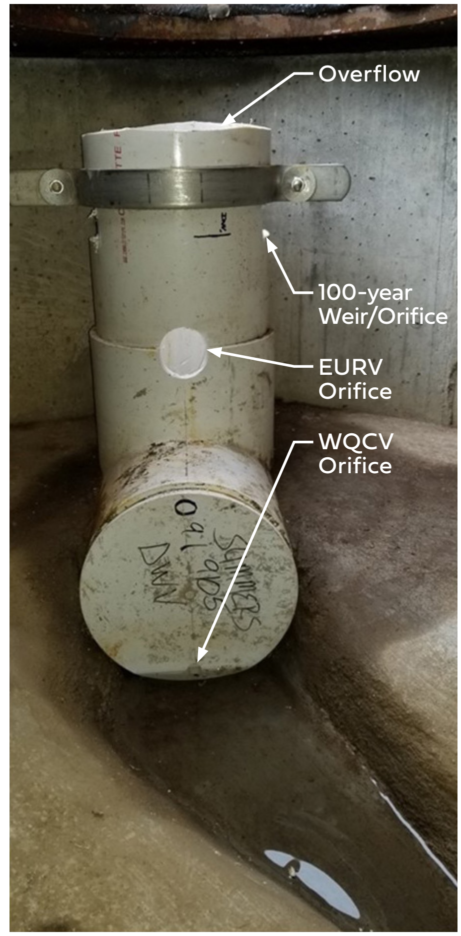
P = porosity, ≤0.4 for AASHTO No. 57 or No. 67 coarse aggregate and AASHTO No. 2 stone layers

$A_{Pavement}$ = area of the permeable pavement system (ft^2)

S = slope of the reservoir/subgrade interface (ft/ft)

L = length between lateral flow barriers (ft)

As with Equations PPS-1 through PPS-3, Equations PPS-4 and PPS-5 are applicable for permeable pavement designs with simple geometry. For irregularly shaped installations or those with laterally and transversely sloping subgrade, calculate the average cross-sectional area of the pavement section corresponding to the design volume (WQCV, EURV, and/or 100-year), and determine the depth for each design volume based on the porosity and area of overlying pavement and use this depth to calculate the head used in orifice and weir equations for outlet orifice and weir sizing.



Photograph PPS-13. FSD outlet for PICP system. WQCV orifice is drilled in front of cap at bottom. EURV is controlled by the circular orifice midway up the riser. The 100-year event is released via rectangular orifices on the sides of the riser just below the band. The open top of the riser provides an emergency overflow. Photo: Creative Civil.

MHFD-Detention (available at www.mhfd.org) can be used to size FSD for permeable pavement systems, including the WQCV, EURV, and 100-year detention storage volumes. Consult with a geotechnical engineer on restrictions on reservoir depth related to pavement stability, traffic loading, and other geotechnical constraints. Aggregate reservoir depths up to 6 feet have been implemented successfully along the Front Range of Colorado.

The following sections provide additional criteria that are specific to each permeable pavement type.

PERMEABLE INTERLOCKING CONCRETE PAVEMENT (PICP): Design of a PICP system follows the procedures outlined above in combination with guidance and criteria in Section 4.0 *Filtration and Infiltration Systems* of this chapter. The following additional criteria and considerations apply:

- Provide a 2-inch bedding course of AASHTO No. 8, 89, or 9 aggregate above a 4-inch thick open-graded base of AASHTO No. 57 or No. 67 aggregate to set the pavers. Provide a minimum 6-inch-thick subbase of ASSHTO No. 2 stone beneath the open-graded base. Increase the depth of the No. 2 stone layer as needed to achieve the design volume. See Figures PPS-2 and PPS-3 for illustrations of these aggregate layers.
- For vehicular applications, use herringbone patterns as demonstrated in Photograph PPS-15 and pavers with an overall length to thickness (aspect) ratio of 3:1.
- A continuous perimeter barrier is required for all PICP installations.
- Provide a line of uncut blocks adjacent to the concrete border. This will ensure that cut edges are not placed directly against the concrete border, which can cause damage to the paver at the interface with the concrete. This is often accomplished by specifying a sailor course or soldier course adjacent to the concrete edge.
- All cut pavers must be at least 50% of the full uncut paver size when subject to vehicular use.
- PICP pavers must not exceed a 101-square-inch surface area per ASTM C936 if subject to vehicular traffic. Specific paver thickness recommendations include:
  - Residential and pedestrian areas: 2-3/8” minimum thickness.
  - Vehicular areas: 3-1/8” minimum thickness with maximum aspect or overall length/thickness ratio of 3:1.
- Where cutting pavers can be avoided, there is often a savings of time and cost. Additionally, the integrity of the paver is preserved.
- Avoid installation of circular inlets, valve boxes, bollards, light poles, and other similar features within PICP installations when practical. When used, install a square cast-in-place, reinforced concrete collar. It is helpful for the installer to provide framed box-outs where collars are needed within the PICP layout to avoid small paver cuts.

Photograph PPS-14. The very small cut paver shown in this photo could have been eliminated by rotating the paver above it 90 degrees.

Photograph PPS-15. Concrete collar helps avoid small-cut pavers around edges of inset features and can be colored to match surrounding pavers. Photo: Creative Civil.

CONCRETE GRID PAVEMENT (CGP): The design of CGP follows the procedures outlined above in combination with guidance and criteria in Section 4.0 *Filtration and Infiltration Systems* of this chapter. The following additional criteria and considerations apply:

- For CGP, there are two options for infill and bedding course material:
  - For vegetated installations with openings filled with topsoil, use a 1/2- to 1-inch layer of sand bedding to set the concrete blocks.
  - For xeric installations that will not be vegetated, fill the openings with AASHTO No. 8, 89, or 9 aggregate and use the same material to provide a 2-inch bedding layer.

  Note that Figure PPS-4 shows a configuration with topsoil filling the openings and a sand layer for the bedding course. The option using No. 8, 89, or 9 aggregate is the same as what is shown for PICP in Figures PPS-2 and PPS-3.
- For vegetated installations, plant the grid with grass plugs or seed with native grasses. Irrigation will be required for establishment of vegetation and may be required episodically in the future due to severe drought periods.
- The aggregate layer beneath the bedding course consist of a minimum of 4 to 8 inches of AASHTO No. 57 or No. 67 coarse aggregate depending on the anticipated traffic load. When designing deeper sections for increased storage, use a minimum 6-inch layer of AASHTO No. 2 stone beneath the layer of No. 57 or No. 67 coarse aggregate.
- A continuous perimeter barrier is required for all CGP installations.

Photograph PPS-16. Forms for concrete grid for reinforced grass pavement to access pond outlet structure.

Photograph PPS-17. PGP parking area with markers to delineate parking spaces. Photo: True Grid

POROUS GRAVEL PAVEMENT (PGP): The design of PGP follows the procedures outlined above in combination with guidance and criteria in Section 4.0 *Filtration and Infiltration Systems* of this chapter. The following additional criteria and considerations apply:

- The gravel surface consists of 1/2" to 3/4" clean, angular stone (5/8" typical) with less than 2% passing the No. 200 sieve. This material is filled flush to the top of the containment grid. The containment grid, typically 2 inches deep but variable depending on the manufacturer, sits on a permeable subbase layer consisting of at least 8 inches of AASHTO No. 57 or No. 67 aggregate that is capable of storing the WQCV in the aggregate pore space beneath the containment grid. AASHTO No. 2 stone may be placed beneath the layer of No. 57 or No. 67 stone as needed for additional storage or structural stability.
- Use an interlocking plastic cellular paving product (or similar containment system) to stabilize the wearing course and avoid rutting in loose gravel. Without some type of containment system, rutting is likely to occur in driving or parking areas.

Photograph PPS-18. Concrete cellular paving grid for RGP provides maintenance access to the forebay. Photo: Creative Civil.

- If the PGP will experience vehicular traffic, refer to Gravel Roads – Maintenance and Design Manual, Appendix A: Gravel Road Thickness Design Methods (Skorseth and Selim 2000).

REINFORCED GRASS PAVEMENT (RGP): Figure PPS-6 shows a non-proprietary RGP section adapted from the Federal Aviation Administration (FAA) for aggregate turf pavement that can be used as a conceptual start for developing a site-specific design. In addition to this non-proprietary section, various products are available under the name of reinforced grass or turf pavement systems. The most common systems include:

- **Plastic Cellular Paving**: This category includes interlocking plastic pavers typically designed to be filled with turf. This system allows for a high percentage of grass surface within the pavement area. Plastic cellular paving is not recommended for areas that will have traffic loads due to potential for compaction and loss of infiltration capacity, unless a properly engineered permeable base layer is provided with adequate depth. Consult with a geotechnical engineer on how to meet structural needs (heavy loads), while retaining porosity to grow grass.
- **Concrete Cellular Paving**: This type of pavement consists either of interlocking pavers that have openings for the placement of grass or a similar cast-in-place system. Some systems include a reinforcement system that ties the pavers together, providing greater protection from over-compaction and greater resistance to differential movement. Although some systems confine the grass area to the openings in the concrete, others are designed to provide the appearance of a fully vegetated landscape.

CONSTRUCTION CONSIDERATIONS

Proper construction of permeable pavement systems requires measures to preserve natural infiltration rates (for full and partial infiltration sections) prior to placement of the pavement, as well as measures to protect the system from the time that pavement construction is complete to the end of site construction. The following recommendations apply to all permeable pavement systems and should be noted on plans as applicable:

1. On the plans, require a construction fence around pervious areas where infiltration rates need to be preserved and are vulnerable to compaction from construction traffic or storage of materials.
2. Hold a pre-construction meeting to ensure that the contractor understands how the permeable pavement system is intended to function.

Photograph PPS-19. Underdrain penetration of geomembrane with boot. Photo: Creative Civil.

Photograph PPS-20. Mechanical placement in larger areas can reduce the unit cost of the pavement. Photo: Muller Engineering Company and Jefferson County Open Space.

3. When using an impermeable liner, ensure enough slack in the liner to allow for backfill, compaction, and settling without tearing the liner. Provide necessary quality assurance and quality control (QA/QC) overseen by a professional engineer when constructing an impermeable geomembrane liner system, including, but not limited to, fabrication testing, destructive and non-destructive testing of field seams, observation of geomembrane material for tears or other defects, and air lance testing for leaks in all field seams and penetrations. Consider requiring field reports or other documentation from the engineer. Avoid use of heavy equipment over the liners.

4. Follow subgrade and filter layer compaction criteria in Section 4.0 *Filtration and Infiltration Systems* of this chapter. Filter material placed above the prepared subgrade should be compacted to a relative density between 70% and 75% (ASTM D4253 and ASTM D4254) using a walk-behind vibratory roller, vibratory plate compactor, or other light compaction equipment. Do not over-compact because it will limit infiltration into the underlying subgrade. The reservoir layer may not be testable for compaction using a method based on specified density (e.g., nuclear density testing). The designer should consider a method specification (e.g., number of passes of a specified vibratory compactor) for those materials. The number of passes appropriate is dependent on the type of equipment and depth of the layer. For unlined systems, place the aggregate in 6-inch (maximum) lifts, compacting each lift by using a 10-ton or heavier, vibrating steel drum roller. Make at least four passes with the roller, with the initial passes made while vibrating the roller and the final one to two passes without vibration.

5. For lined installations, providing protection fabric on top of the liner is essential for protecting the liner from tears due to compaction of angular aggregates used in backfill. Install the lower 16 inches of aggregate in 4-inch maximum lifts using lightweight compaction equipment such as a walk-behind vibratory plate compactor or a walk-behind vibratory roller. Heavier grade compaction equipment can be utilized for upper layers only.

6. To reduce sediment within the pavement section, specify all aggregate outside of the filter layer to be washed and have no more than 2% passing the No. 200 sieve per ASTM C136. Observe aggregate on-site prior to placement to ensure it is free of excess sediment.

7. Discuss the contractor's proposed sequence of construction and look for activities that may require protection of the permeable pavement system. Ensure that the permeable pavement system is protected from construction activities following pavement construction (e.g., landscaping operations). Protective measures may include covering areas of the pavement, providing alternative construction vehicle access, and providing education to all parties working on-site. Keep mud and sediment-laden runoff away from the pavement area. Temporarily divert runoff around the permeable pavement system or install sediment control measures as necessary to reduce the amount of sediment run-on to the pavement. Cover surfaces with a heavy impermeable membrane when construction activities threaten to deposit sediment onto the pavement area. Sequence construction of the permeable pavement system later in the construction process to avoid contamination of the permeable pavement system aggregates and joints with eroded sediments from construction disturbances. Aggregate contaminated with sediment should be removed and replaced with aggregate conforming to the recommendations herein.

8. It is important for the designer to observe construction of the permeable pavement system at key points during construction. At a minimum, the engineer should observe the construction for conformance to the design at the following milestones:
   i) Subgrade inspection – The engineer should review subgrade surveyed elevations to ensure design volumes can be obtained. Many local jurisdictions require record drawings (as-builts) to prove storage volumes were achieved. In these cases, a subgrade survey will be required by licensed surveyor.
   ii) Impermeable liner and underdrain installation and seams (if applicable).
   iii) Placement of underdrain and completion of filter layer.
   iv) Placement of aggregate reservoir material.
   v) Placement of leveling course and pavement surface.
   vi) For PICP, verify that the specified types of pavers are used and that they meet the requirements in ASTM C936. Some pavers are designed to be used in permeable applications, and others are not. Do not allow design substitutions for pavers that do not comply with original design specifications.
9. Where cutting pavers can be avoided, there is often a savings of time and cost. Additionally, the integrity of the paver is preserved. The designer must provide clear examples for incorporating markings into the pavement without cutting paver blocks. Around inlets and curbs, a colored concrete band or specialty pattern should be considered to avoid small paver cuts that will be unstable. Consider using squared-off gutters for curb and gutter with radii smaller than 10 feet.
10. For landscaped areas adjacent to PICP and CGP, do not apply mulches that float or could potentially wash into and clog the paver joints.

Because proper installation of permeable pavement systems is critical for long-term function and structural stability, MHFD has developed example construction drawing notes for permeable pavement installations. The MHFD *Permeable Pavement Example Construction Drawing Notes* are available on the MHFD website and are intended as a starting point for designers to develop their own project-specific notes. Some of the *Permeable Pavement Example Construction Drawing Notes* may not be applicable in all situations, additional notes may be necessary, or notes may require alteration for site-specific installations. The MHFD *Permeable Pavement Construction Example Drawing Notes* are intended to convey to contractor, owner, and installers the basic functions, installation details, and cautions that must be followed for installation of a permeable pavement system that functions as intended. These notes <u>must not</u> be used without the design engineer editing the notes to reflect site-specific conditions.

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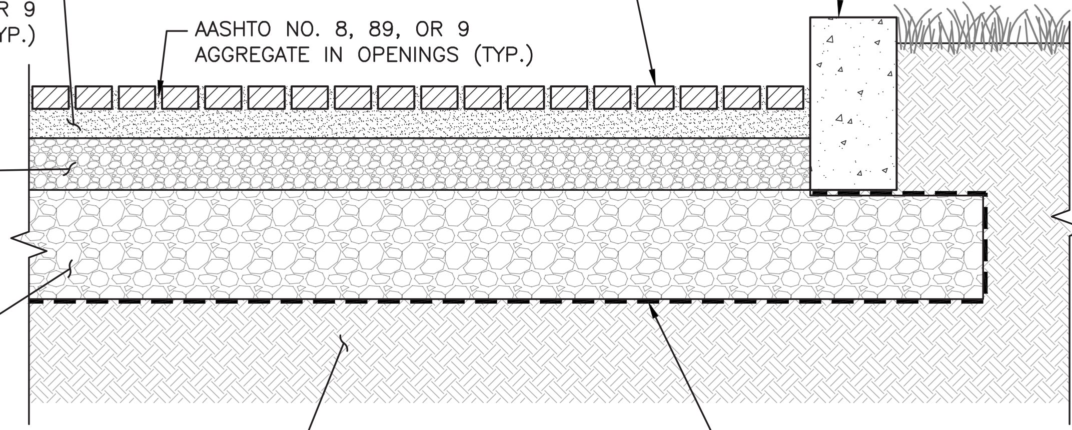
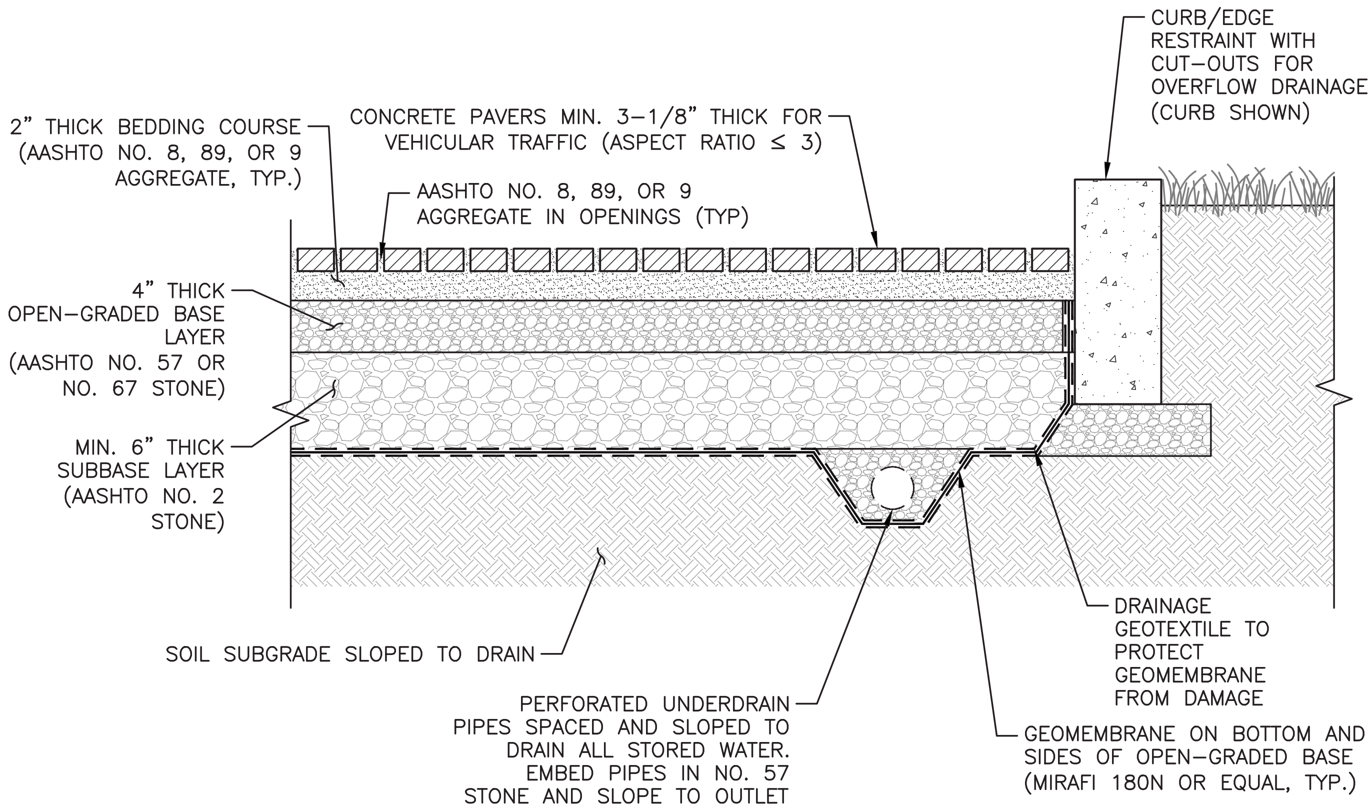


NOTES:

1. 2–3/8" THICK PAVERS MAY BE USED IN PEDESTRIAN AND RESIDENTIAL APPLICATIONS.
2. NO. 2 STONE SUBBASE THICKNESS VARIES WITH DESIGN. CONSULT INTERLOCKING CONCRETE PAVEMENT INSTITUTE (ICPI) PERMEABLE INTERLOCKING CONCRETE PAVEMENT MANUAL.
3. AASHTO NO. 2 STONE MAY BE SUBSTITUTED WITH AASHTO NO. 3 OR NO. 4 STONE.
4. SELECT GEOTEXTILE PER AASHTO M 288.
5. BASED ON ICPI DRAWING NO. ICPI–68. SEE OTHER ICPI DETAILS AVAILABLE ONLINE FOR VARIOUS CONFIGURATIONS AND EDGE TREATMENTS FOR PICP.
6. PAVEMENT DESIGN FOR TRAFFIC LOADING REQUIRED IN AREAS WITH VEHICULAR USE.

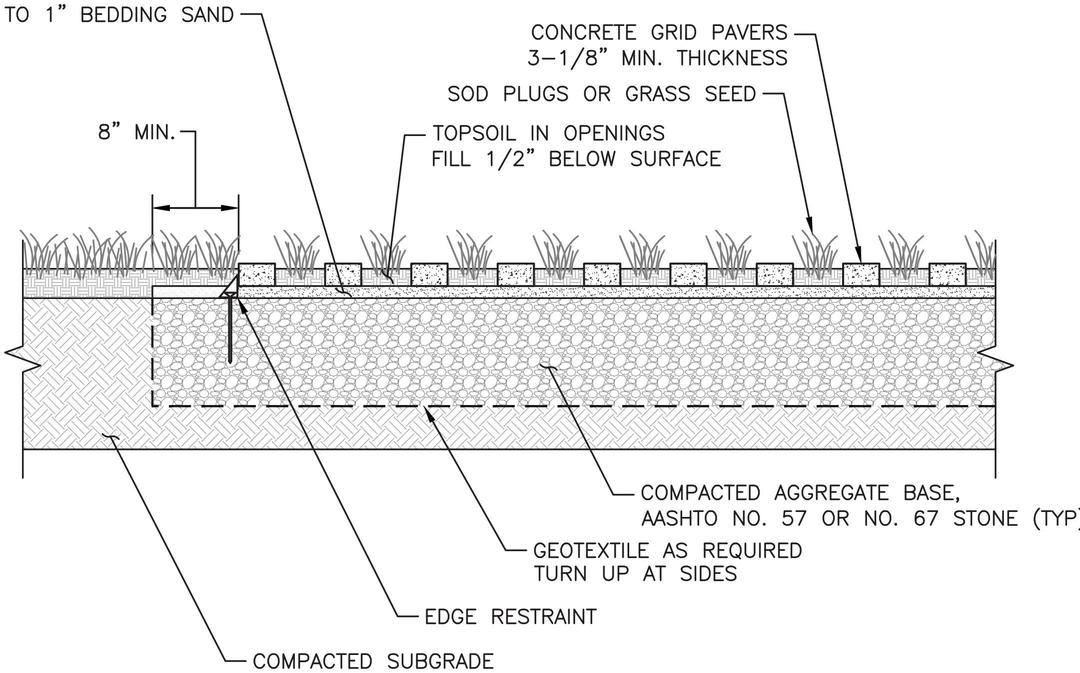
FIGURE PPS-2. PERMEABLE INTERLOCKING CONCRETE PAVEMENT WITH FULL INFILTRATION
SECTION VIEW (NOT TO SCALE)



NOTES:

1. 2-3/8" THICK PAVERS MAY BE USED IN PEDESTRIAN AND RESIDENTIAL APPLICATIONS.
2. AASHTO NO. 2 STONE SUBBASE THICKNESS VARIES WITH DESIGN. AASHTO NO. 3 OR NO. 4 IS ACCEPTABLE. CONSULT INTERLOCKING CONCRETE PAVEMENT INSTITUTE (ICPI) PERMEABLE INTERLOCKING CONCRETE PAVEMENT MANUAL.
3. PERFORATED PIPES MAY BE RAISED FOR WATER STORAGE FROM LARGE RAIN EVENTS WITH OUTLET(S) AT LINER BOTTOM TO DRAIN SMALL RAIN EVENTS.
4. SELECT GEOTEXTILE PER AASHTO M288.
5. BASED ON ICPI DRAWING NO. ICPI-70. SEE OTHER ICPI DETAILS AVAILABLE ONLINE FOR VARIOUS CONFIGURATIONS AND EDGE TREATMENTS FOR PICP.
6. PAVEMENT DESIGN FOR TRAFFIC LOADING REQUIRED IN AREAS WITH VEHICULAR USE.

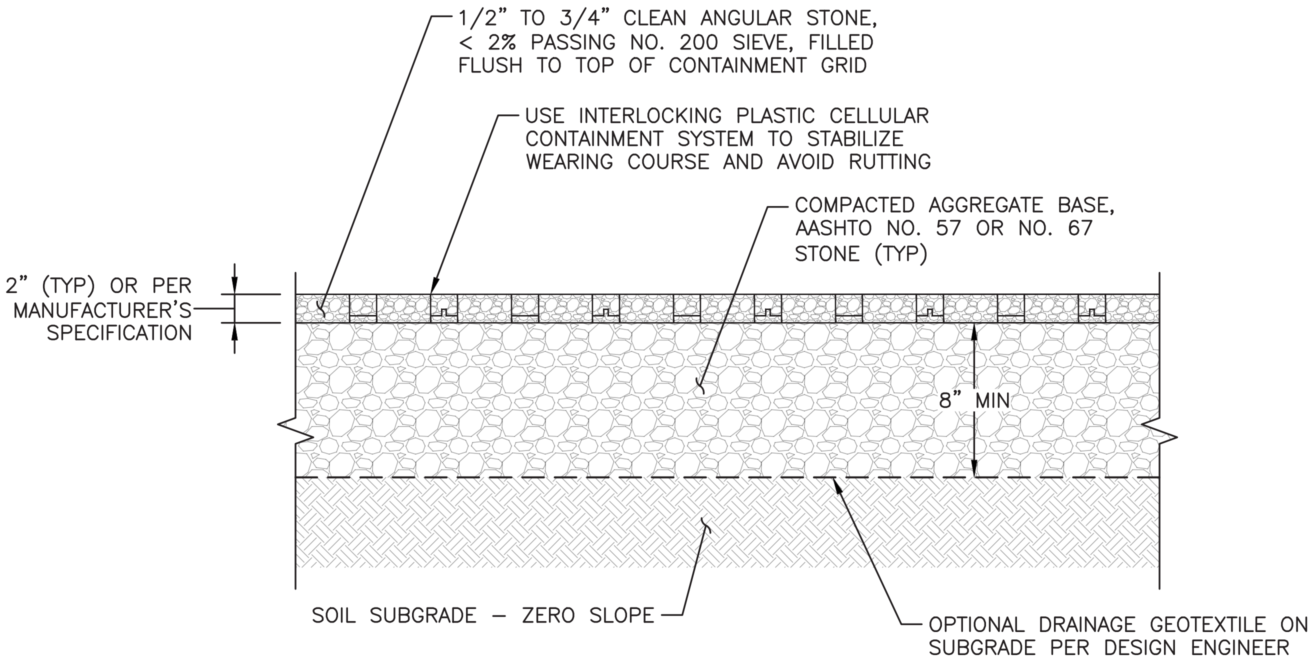
FIGURE PPS-3. PERMEABLE INTERLOCKING CONCRETE PAVEMENT WITH NO INFILTRATION
SECTION VIEW (NOT TO SCALE)



NOTES:

1. BASE THICKNESS VARIES WITH TRAFFIC, CLIMATE, AND SUBGRADE.
2. MINIMUM BASE THICKNESS: 6" RESIDENTIAL DRIVEWAYS, 8" FIRELANES AND PARKING LOTS.
3. IF OPENINGS ARE FILLED WITH TOPSOIL, USE A 1/2" TO 1" LAYER OF SAND BEDDING. IF THE OPENINGS ARE FILLED WITH OPEN-GRADED NO 8, 89, OR 9 AGGREGATE, USE THE SAME MATERIAL TO PROVIDE A 2-INCH BEDDING LAYER.
4. BASED ON INTERLOCKING CONCRETE PAVEMENT INSTITUTE (ICPI) DRAWING NO. ICPI-08. SEE OTHER ICPI DETAILS AVAILABLE ONLINE FOR TYPICAL CONFIGURATIONS OF CONCRETE GRID PAVEMENT.
5. PAVEMENT DESIGN FOR TRAFFIC LOADING REQUIRED IN AREAS WITH VEHICULAR USE.

FIGURE PPS-4. CONCRETE GRID PAVEMENT
SECTION VIEW (NOT TO SCALE)



NOTES:

1. PAVEMENT SECTION SHOWN IS FOR FULL INFILTRATION SECTION, SEE FIGURE PPS–3 FOR TYPICAL UNDERDRAIN DETAIL IF A PARTIAL OR NO INFILTRATION SECTION IS USED.
2. PAVEMENT DESIGN FOR TRAFFIC LOADING REQUIRED IN AREAS WITH VEHICULAR USE.
3. WHEN DESIGNING DEEPER SECTIONS FOR INCREASED STORAGE, USE A MINIMUM 6–INCH LAYER OF AASHTO NO. 2 STONE BENEATH THE LAYER OF NO. 57 OR NO. 67 COARSE AGGREGATE.

FIGURE PPS-5. POROUS GRAVEL PAVEMENT
SECTION VIEW (NOT TO SCALE)

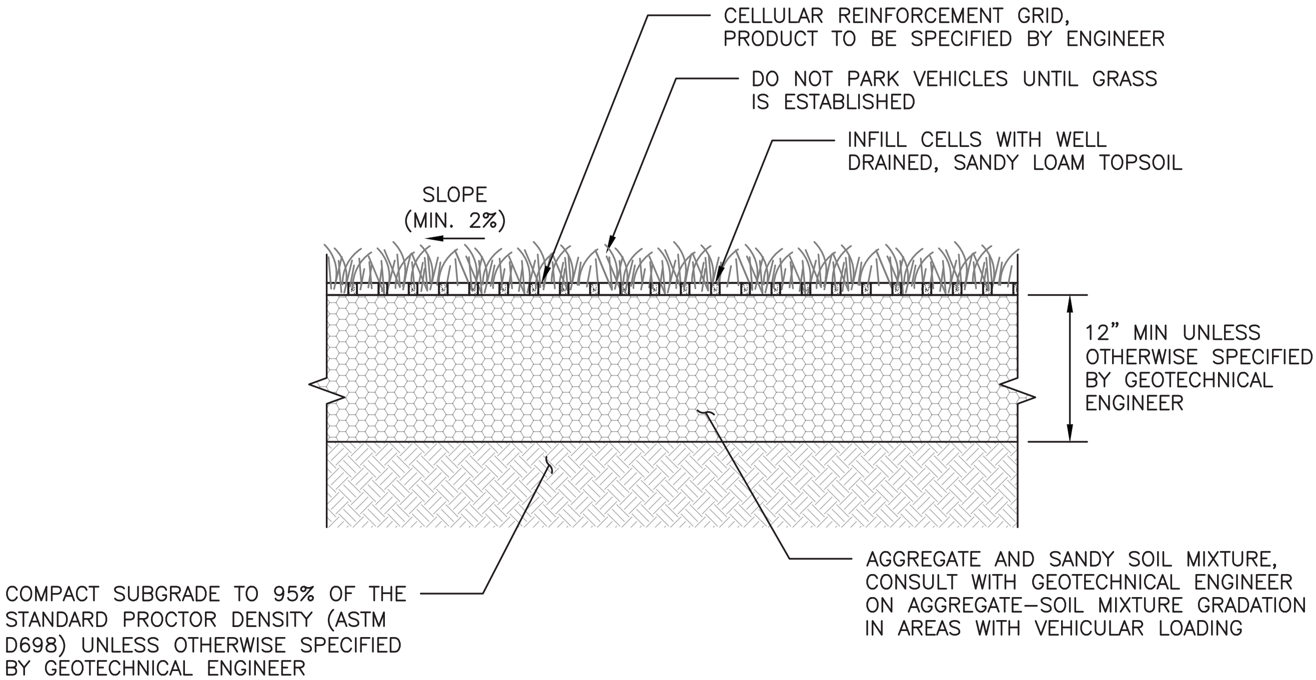
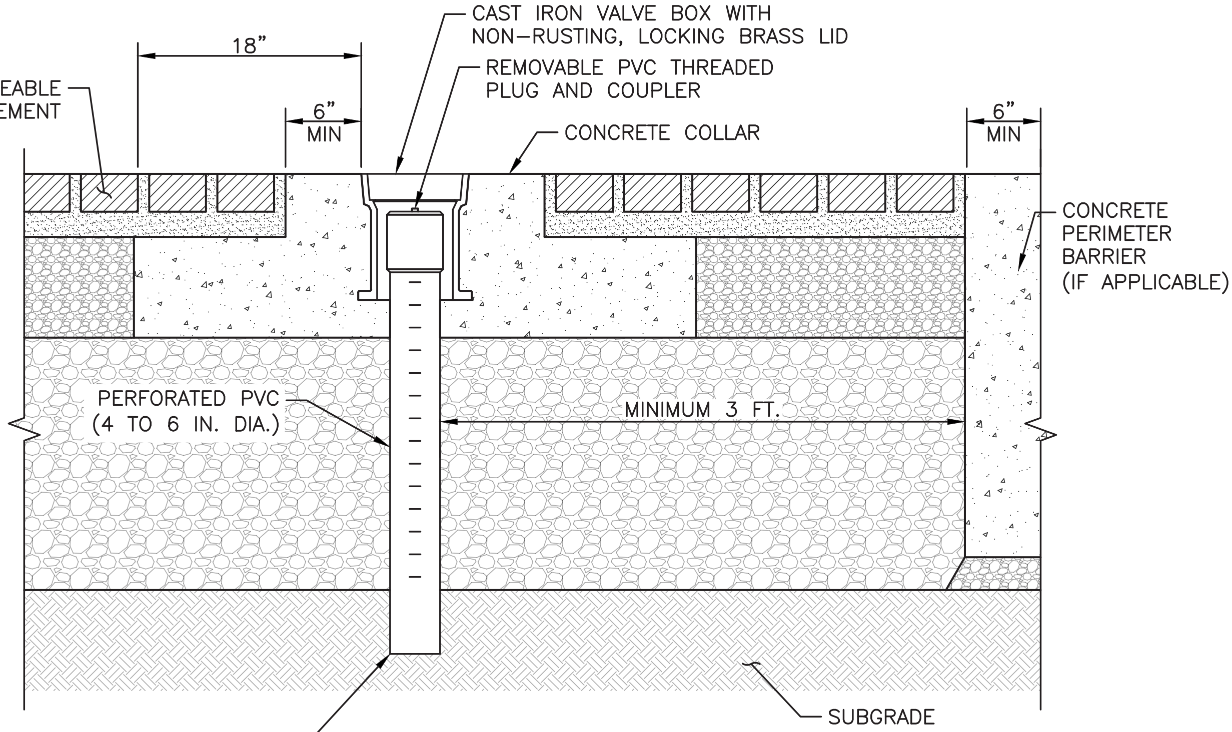
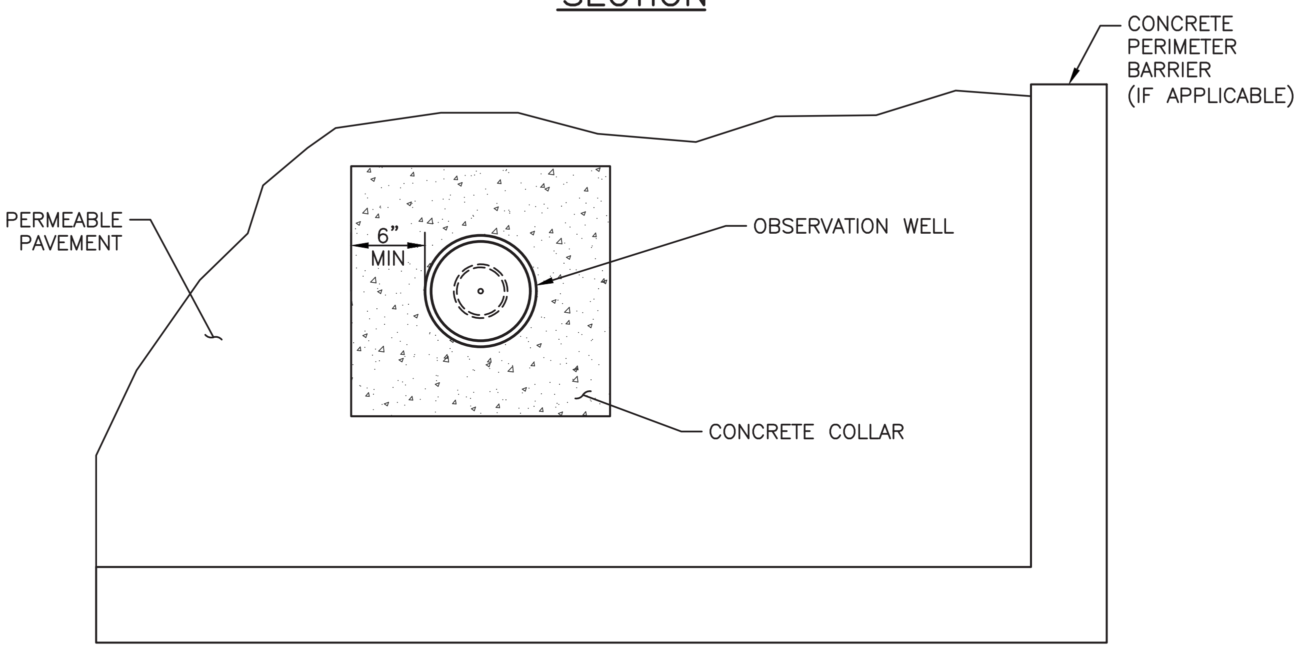


FIGURE PPS-6. REINFORCED GRASS PAVEMENT
SECTION VIEW (NOT TO SCALE)



SECTION

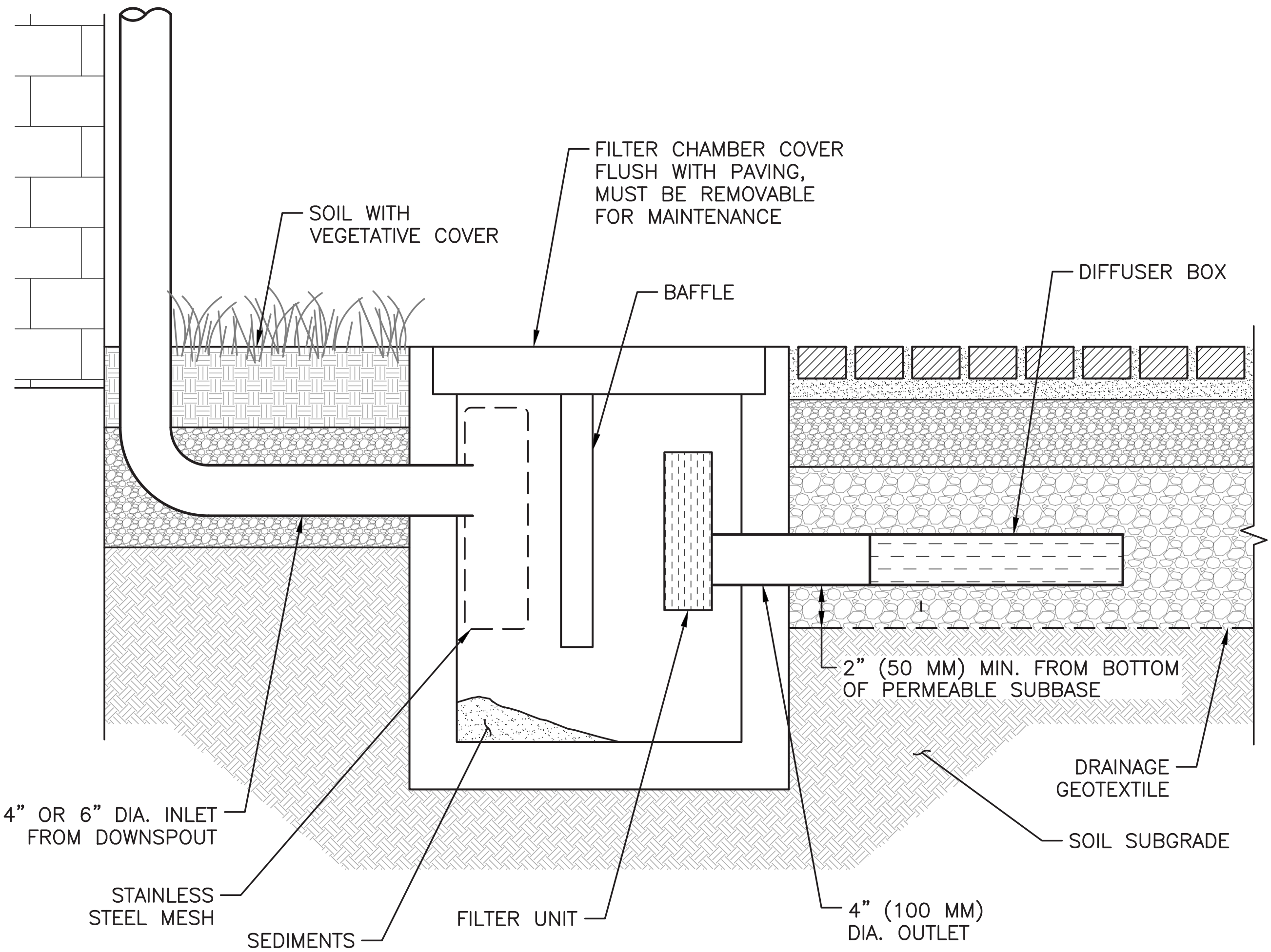


PLAN

NOTES:

1. REFER TO INTERLOCKING CONCRETE PAVEMENT INSTITUTE (ICPI) DETAILS FOR ALTERNATIVE CONFIGURATIONS OF OBSERVATION WELLS LOCATED WITHIN AND OUTSIDE PERMEABLE INTERLOCKING CONCRETE PAVEMENT.

FIGURE PPS-7. OBSERVATION WELL WITHIN PERMEABLE INTERLOCKING CONCRETE PAVEMENT
PLAN & SECTION VIEW (NOT TO SCALE)



NOTES:

1. SELECT GEOTEXTILE PER AASHTO M 288.
2. DETAIL BASED ON INTERLOCKING CONCRETE PAVEMENT INSTITUTE (ICPI) DRAWING NO. ICPI–90.

FIGURE PPS-8. ROOF DRAIN CONNECTION TO PERMEABLE INTERLOCKING CONCRETE PAVEMENT
SECTION VIEW (NOT TO SCALE)

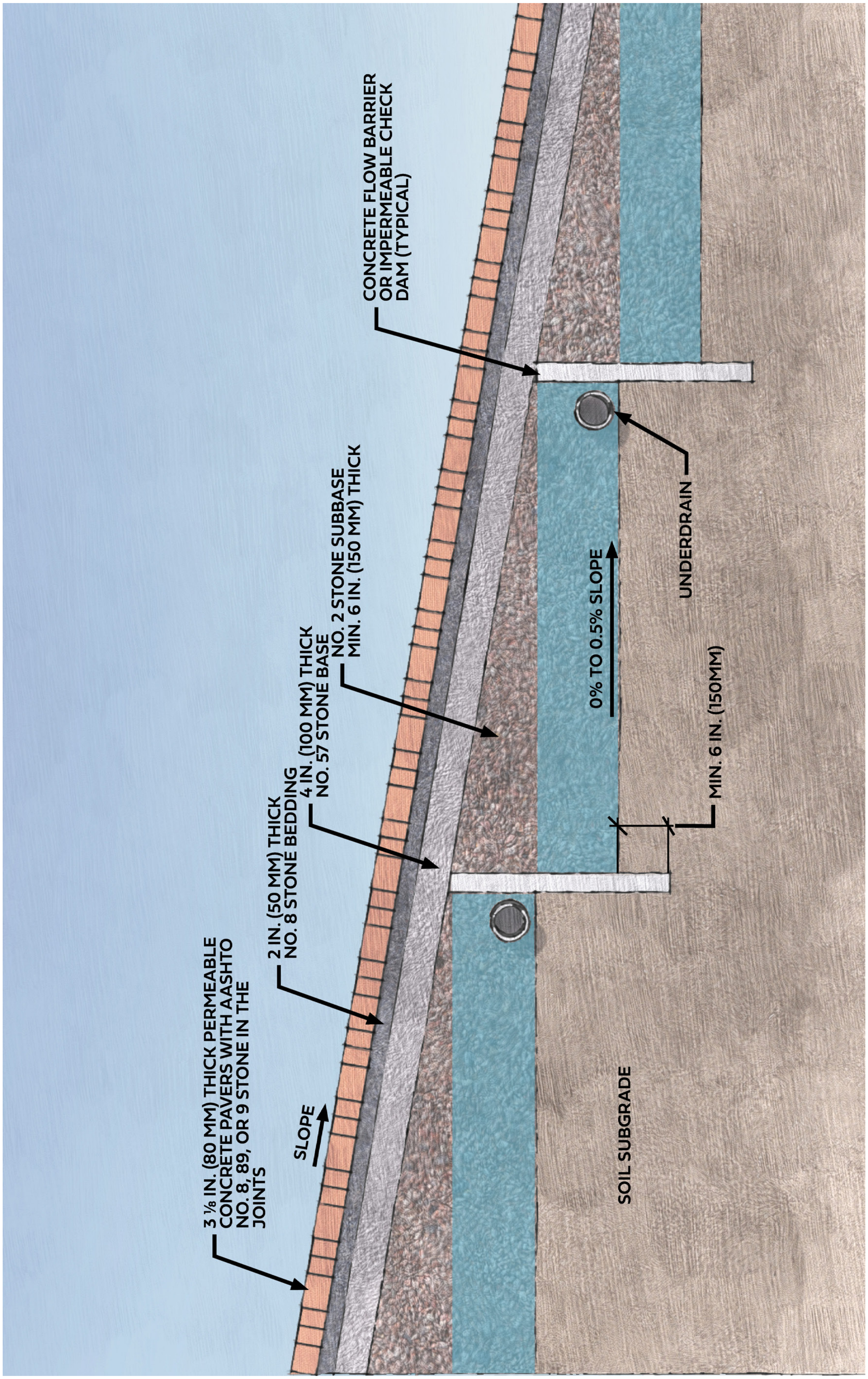


FIGURE PPS-9. STEPPED PERMEABLE PAVEMENT SYSTEM INSTALLATION
SECTION VIEW (NOT TO SCALE)

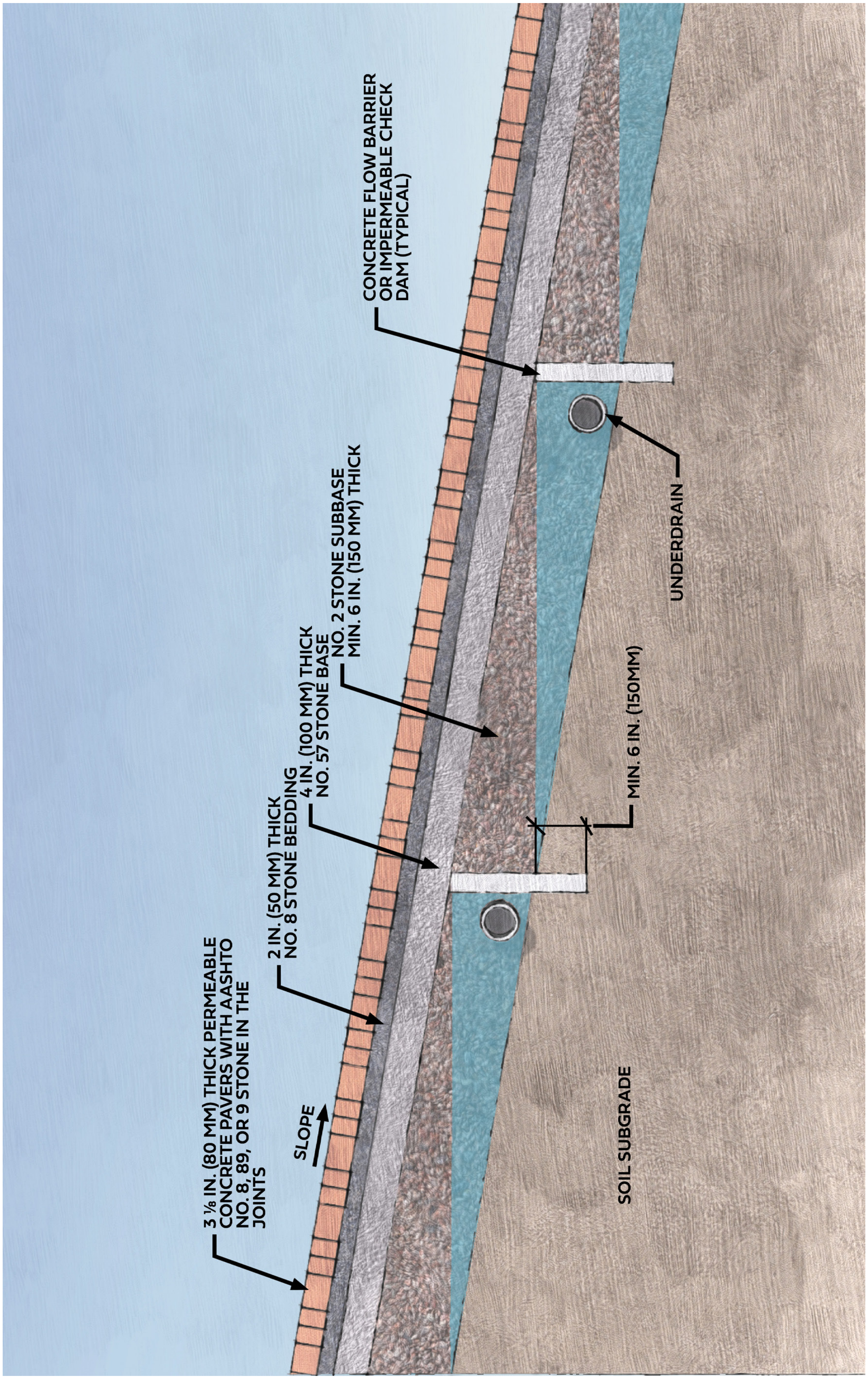


FIGURE PPS-10. SLOPED PERMEABLE PAVEMENT SYSTEM INSTALLATION
SECTION VIEW (NOT TO SCALE)

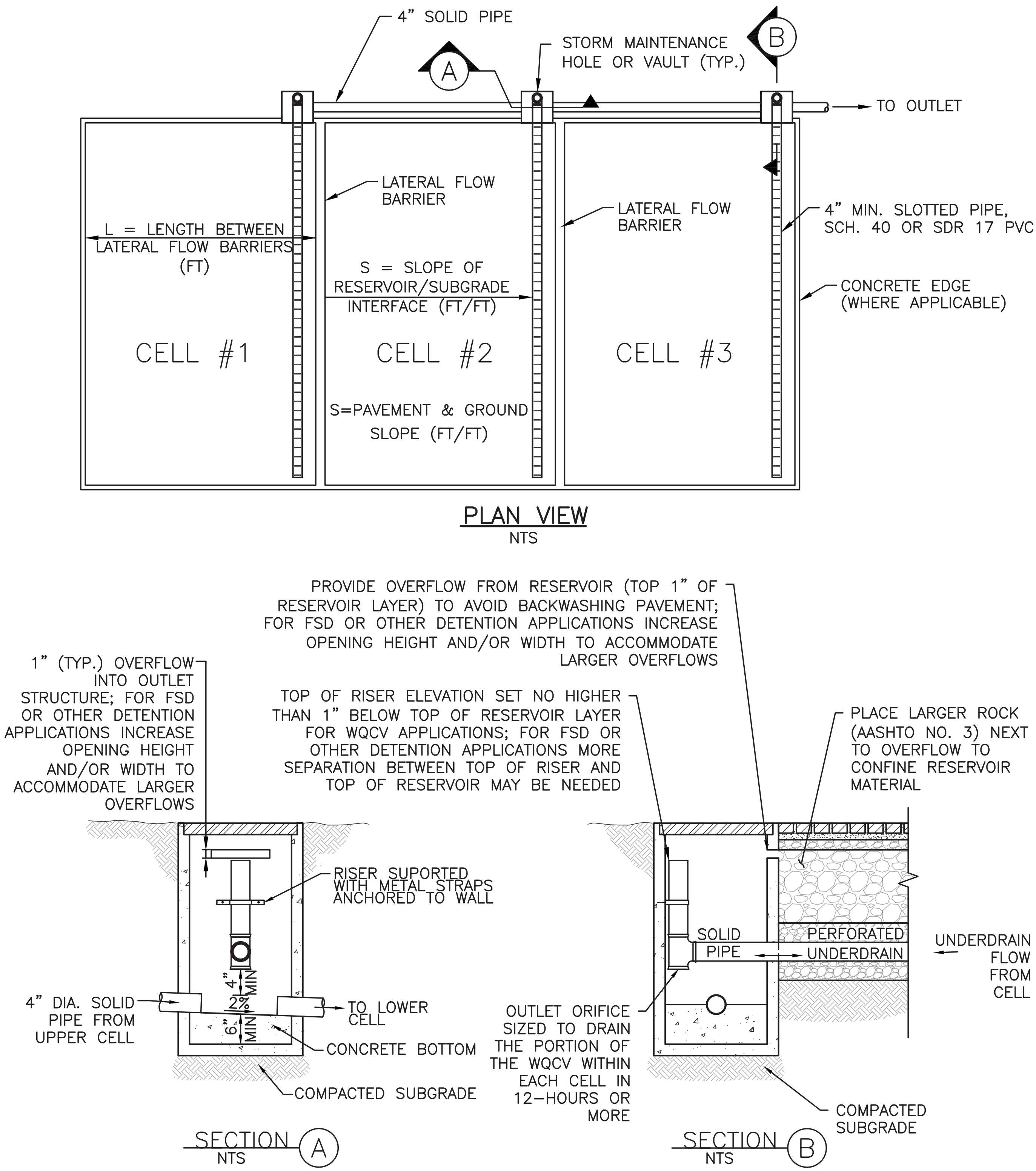


FIGURE PPS-11. MULTI-CELL PERMEABLE PAVEMENT INSTALLATION WITH LATERAL FLOW BARRIERS
PLAN & SECTION VIEWS (NOT TO SCALE)

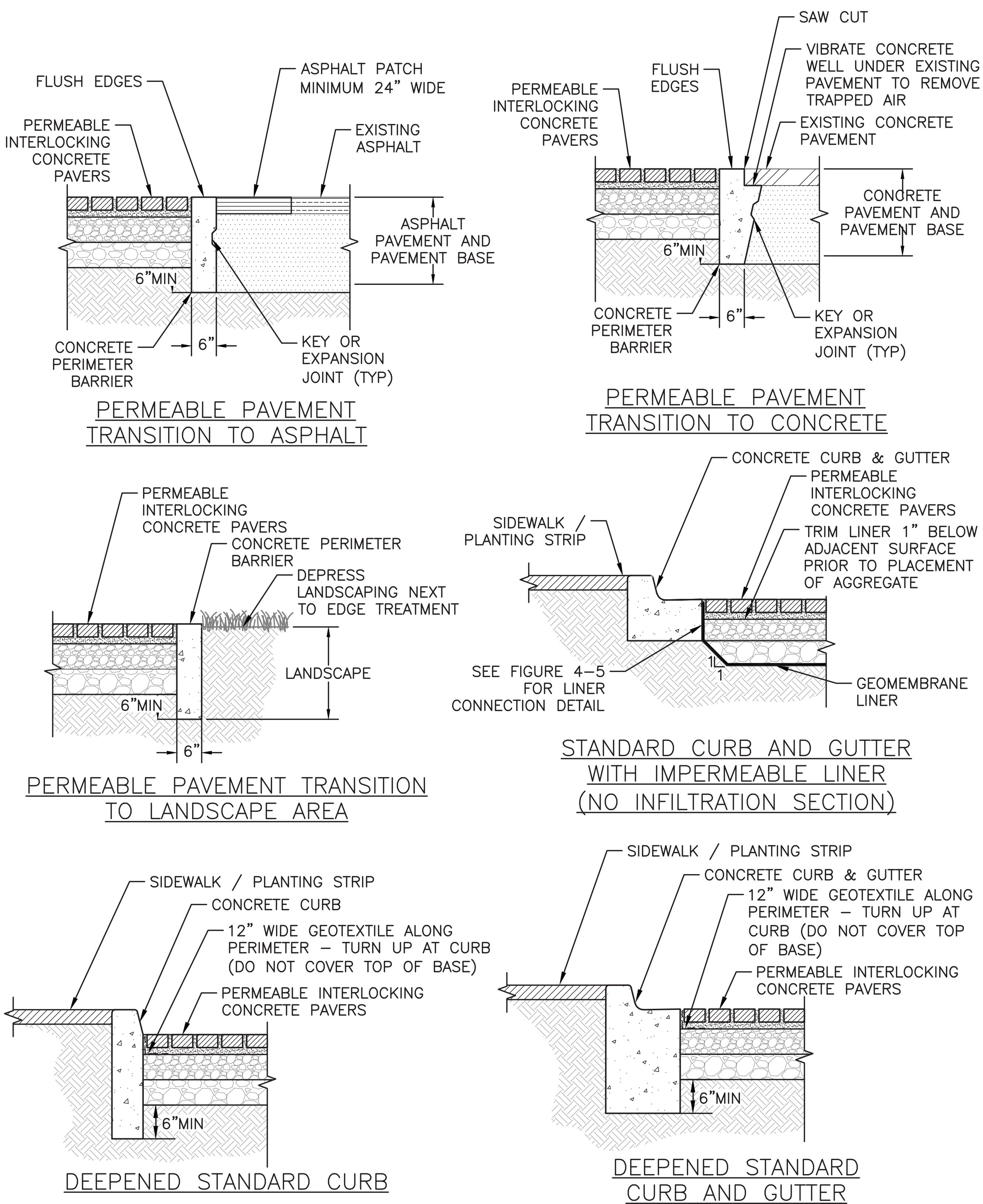
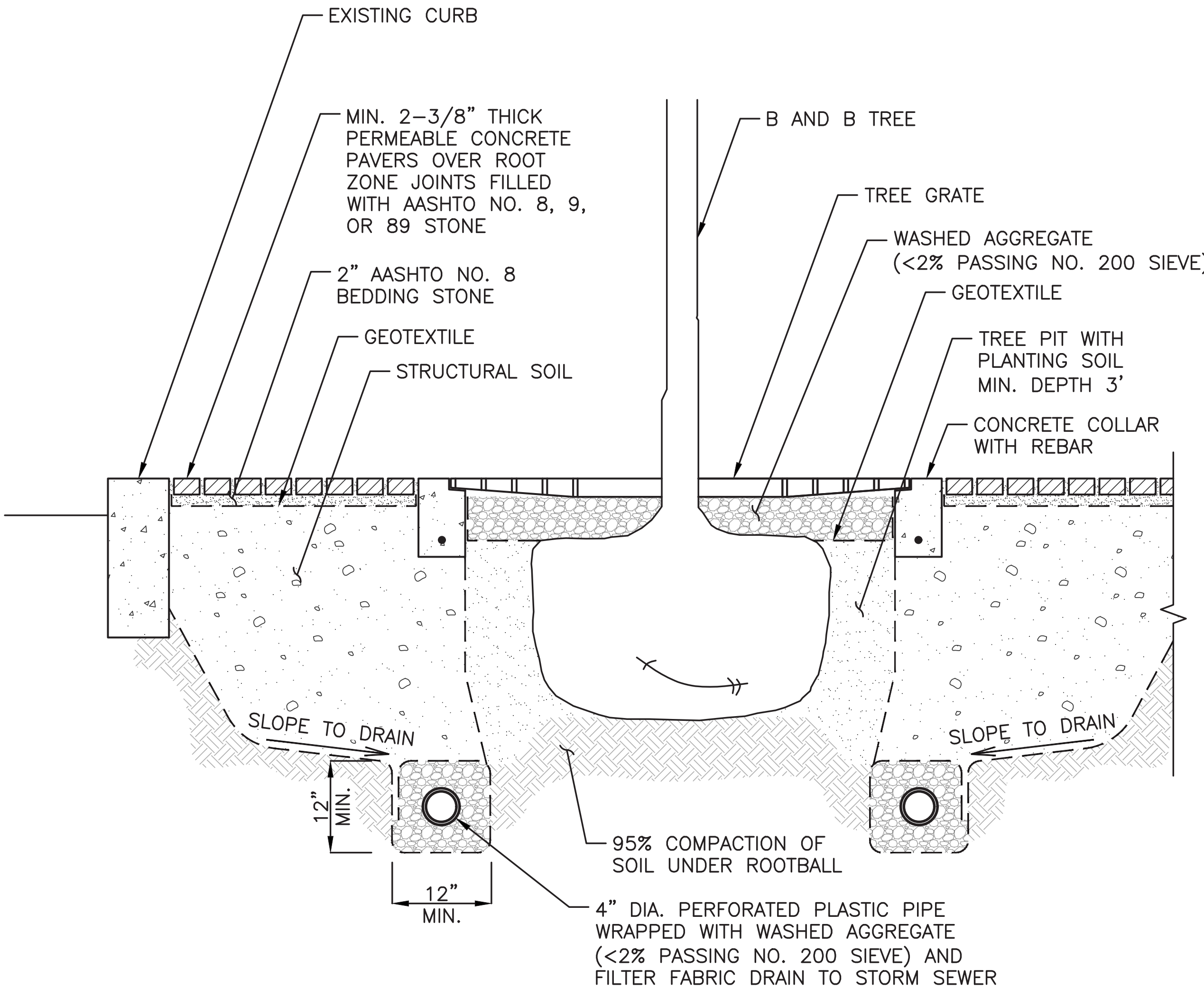


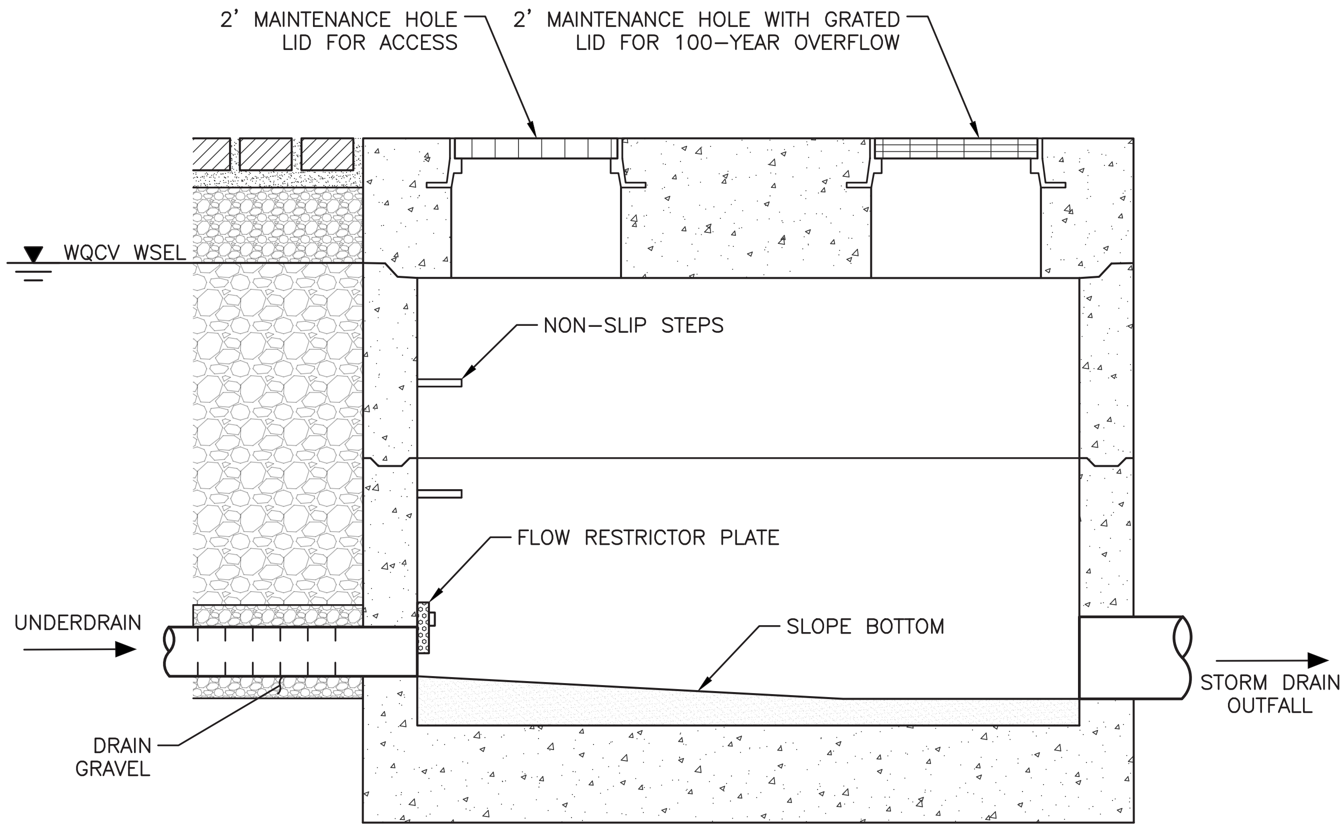
FIGURE PPS-12. CONCEPTUAL DETAILS FOR PERIMETER BARRIER WALLS
SECTION VIEWS (NOT TO SCALE)



NOTES:

1. ROOT BARRIER MAY BE REQUIRED INSIDE OF CONCRETE COLLAR DEPENDING ON TREE SPECIES. CONSULT ARBORIST FOR THIS APPLICATION.
2. NON–VEHICULAR APPLICATIONS ONLY.
3. BASED ON INTERLOCKING CONCRETE PAVEMENT INSTITUTE (ICPI) DRAWING NO. ICPI–83.

FIGURE PPS-13. CONCEPTUAL TREE PIT WITH PERMEABLE INTERLOCKING CONCRETE PAVEMENT OVER STRUCTURAL SOIL
SECTION VIEW (NOT TO SCALE)

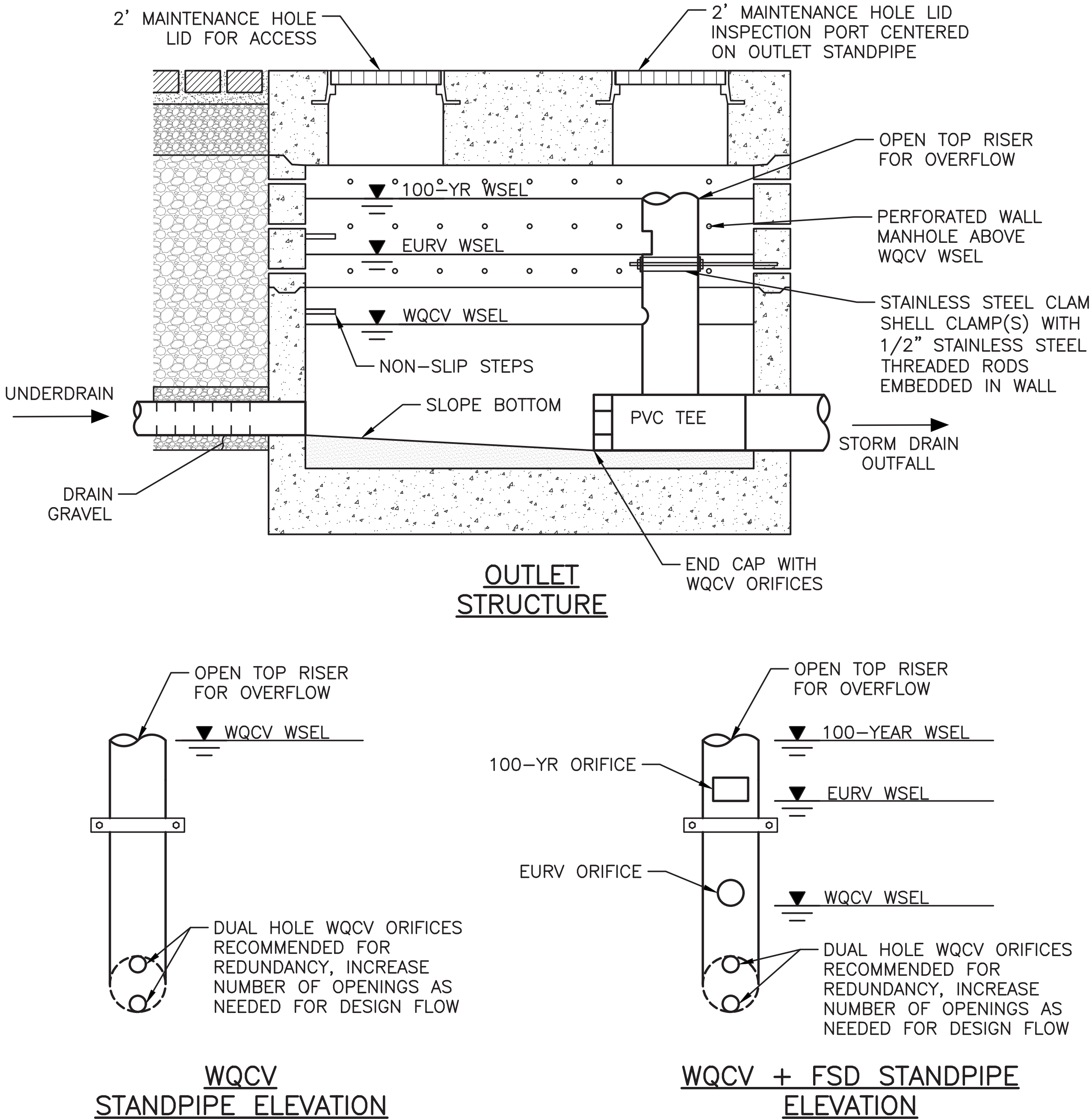


NOTES:

1. THE SECTION SHOWN REPRESENTS A CONCEPTUAL DESIGN OF A PERMEABLE PAVEMENT OUTLET STRUCTURE FOR BOTH WQCV ONLY USING A FLOW RESTRICTOR PLATE. SEE FIGURE PPS-15 FOR CONCEPTUAL DESIGNS OF A PERMEABLE PAVEMENT OUTLET STRUCTURE FOR BOTH WQCV ONLY AND A FULL-SPECTRUM DETENTION AND WQCV SCENARIO USING A STAND-PIPE.

2. REFER TO INTERLOCKING CONCRETE PAVEMENT INSTITUTE (ICPI) DETAIL ICPI-89 FOR ALTERNATIVE DETAIL FOR CONFIGURATION OF PERMEABLE PAVEMENT SYSTEM OUTLET STRUCTURE.

FIGURE PPS-14. CONCEPTUAL PERMEABLE PAVEMENT OUTLET STRUCTURE WITH FLOW RESTRICTOR PLATE
SECTION VIEW (NOT TO SCALE)



NOTES:

1. THE SECTION(S) SHOWN REPRESENT CONCEPTUAL DESIGN OF A PERMEABLE PAVEMENT OUTLET STRUCTURE FOR BOTH WQCV ONLY AND A FULL-SPECTRUM DETENTION AND WQCV SCENARIO USING A STAND-PIPE. SEE FIGURE PPS-14 FOR CONCEPTUAL DESIGN OF A PERMEABLE PAVEMENT SYSTEM OUTLET STRUCTURE WITH A FLOW RESTRICTOR PLATE.

2. REFER TO INTERLOCKING CONCRETE PAVEMENT INSTITUTE (ICPI) DETAIL ICPI-89 FOR ALTERNATIVE DETAIL FOR CONFIGURATION OF PERMEABLE PAVEMENT SYSTEM OUTLET STRUCTURE.

FIGURE PPS-15. CONCEPTUAL PERMEABLE PAVEMENT OUTLET STRUCTURE WITH FULL-SPECTRUM DETENTION
SECTION VIEW (NOT TO SCALE)

T-6 EXTENDED DETENTION BASINS

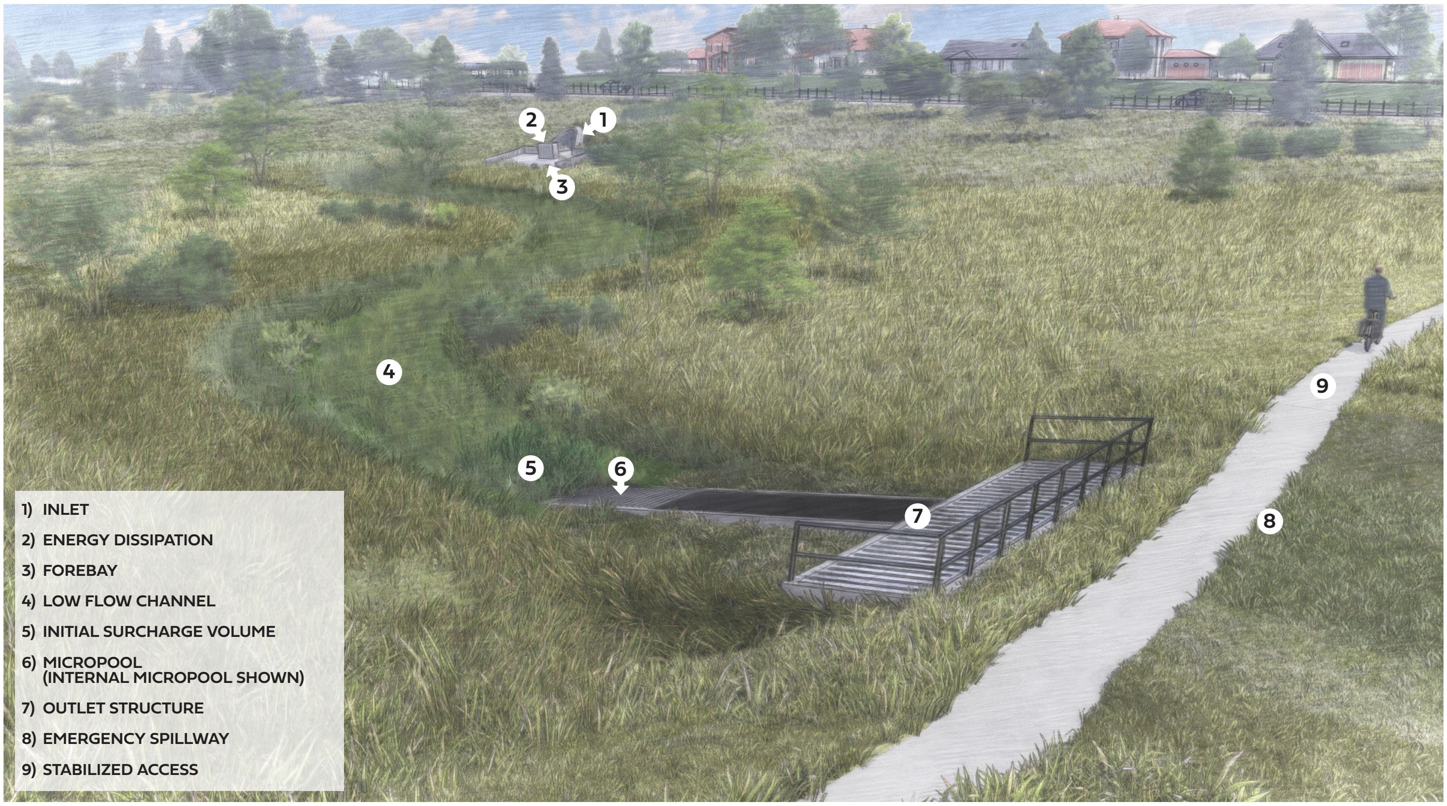


Figure EDB-1. Extended Detention Basin Components

DESCRIPTION

An extended detention basin (EDB) detains and slowly releases stormwater runoff, providing time for sediments and particulate pollutants to settle to the bottom. EDBs are designed to release the water quality capture volume (WQCV) over a 40-hour drain time to allow time for sedimentation processes to occur. An EDB can be combined with full spectrum detention (FSD) to provide flood control as described in the *Storage* chapter.

EDBs are sometimes called "dry ponds" because they are designed not to have a significant permanent pool of water remaining between storm runoff events. EDBs can serve as a component in a treatment train downstream of distributed, infiltration-based stormwater control measures (SCMs) that provide runoff reduction and pre-treatment throughout the contributing watershed prior to treatment by the EDB.

TABLE EDB-1. EDB OVERVIEW

EXTENDED DETENTION BASINS	
MS4 Permit Applicability (Dependent on design and level of treatment)	
Meets Runoff Reduction Standard	No
Meets WQCV Capture Standard	Yes
Meets Pollutant Removal Standard	Yes
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	Medium-High
Total Phosphorus	Medium
Total Nitrogen	Low
Total Metals	Medium
Bacteria	Low
Common Applications	
Runoff Reduction (General)	No
Used for Pretreatment	No
Integrated with Flood Control	Yes

SCM COMPONENTS

Primary EDB components include inlet(s), energy dissipation measures and forebay(s) or other pretreatment practices, low flow channel(s), the initial surcharge volume, micropool, outlet structure, emergency spillway, and stabilized access as shown in Figure EDB-1 and Table EDB-2. All of these components provide important functions in an EDB and omitting one or more of these components will put additional stress and importance on other components, requiring additional and sometimes more costly types of maintenance. Providing pretreatment with runoff reduction measures in the watershed can reduce the volume of runoff that must be managed by the EDB. Other pretreatment SCMs can also be used to capture and retain trash that may otherwise clog outlet structure orifices.

TABLE EDB-2. EDB COMPONENTS

COMPONENT	INTENT
Inlet	Allows stormwater to enter the SCM. Maximize distance between inlet(s) and outlet to minimize short-circuiting and increase hydraulic residence time.
Energy Dissipation	Reduces the velocity and energy of runoff entering the SCM through roughness and/or structural measures to promote sedimentation in the forebay.
Forebay	Facilitates removal of trash and coarse sediments in an accessible location to reduce the frequency of sediment removal in the main body of the EDB.
Low Flow Channel	Conveys low flows from the inlets to the outlet structure, limiting the inundation area of frequent flows to facilitate maintenance operations.
Initial Surcharge Volume	Stores runoff from frequently occurring events in an area with hydrophytic vegetation adapted to frequent and prolonged inundation.
Micropool	Reduces potential clogging at the outlet by providing a flow path below the permanent water surface elevation to the orifice plate even when the trash rack becomes clogged above the water surface.
Outlet Structure	Releases the WQCV through control orifices over a 40-hour drain time and conveys runoff from larger events to downstream conveyance system.
Emergency Spillway	Discharges flows exceeding design events or flows during plugged outlet conditions to downstream conveyance system while protecting embankment stability.
Stabilized Access	Provides maintenance access to components of the EDB.

SITE CONSIDERATIONS

EDBs can be located as regional, sub-regional, or onsite facilities as discussed in the *Storage* chapter in the context of FSD. One of the most important factors for assessing suitability of an EDB for a site is the contributing drainage area and imperviousness. EDBs are not appropriate for tributary areas with less than 2 acres of impervious area because the size of the orifice needed to release the WQCV over 40 hours becomes very small and cannot practically be protected from clogging. EDBs in large watersheds must account for additional factors such as baseflow and impact to stream stability. Table EDB-3 summarizes considerations for various contributing impervious areas (Wulliman and Bolger 2022).

Although there are many considerations and constraints that may dictate the location of EDBs, these SCMs function best when designed for contributing impervious areas of approximately 20 to 50 acres. This range provides the following benefits:

- At 20 acres of impervious tributary area, the orifices are typically large enough to use standard bar grating for the trash rack rather than a well screen. This will reduce required maintenance at the outlet structure.
- These EDBs are large enough to achieve meaningful flow attenuation especially when combined with FSD.
- EDBs in this size range generally will not have baseflows large enough to complicate the design and function of outlet structures.

For watersheds with 2 to 20 impervious acres, consider filtration or infiltration SCMs instead of EDBs to avoid small orifices prone to clogging. To function properly, the orifices for EDBs in this size range require protection by a well screen, which requires frequent inspection and maintenance to ensure that the orifices and well screen do not become clogged.

Watersheds larger than 50 acres and watersheds with baseflows complicate EDB design, pose sedimentation issues, and may reduce the level of treatment provided. In these situations, the most effective water quality treatment can be achieved by distributed detention with the watershed subdivided into smaller areas where subregional EDBs or other practices can be used in an offline configuration. Additionally, providing distributed EDBs that treat smaller areas throughout the watershed, as opposed to a single large EDB at the watershed outfall, helps to protect the lower order streams in the watershed from degradation due to conveyance of undetained developed flows. This may help to reduce the required size of storm drain infrastructure.

The *Storage* chapter of Volume 2 provides guidance on locating EDBs and combining EDBs with FSD. The *Storage* chapter provides extensive discussion of siting considerations for onsite, subregional, and regional detention facilities that is applicable to planning and design of EDBs.

TABLE EDB-3. CONTRIBUTING IMPERVIOUS AREA CONSIDERATIONS FOR EDBS

CONTRIBUTING IMPERVIOUS AREA (ACRES)	EDB CONSIDERATIONS
0-2	Not recommended - use filtration-based SCM.
2-20	Consider sand filter, bioretention, or other filtration or infiltration SCM as alternative. Limit EDB outlet to two WQCV orifices to maximize orifice size while still providing redundancy in case one orifice clogs. Protect orifices less than 1.25 inches with well screen and consider additional measures such as standard bar grating upstream of well screen to reduce the frequency of maintenance of the well screen.
20-50	Limit EDB outlet to two WQCV orifices to maximize orifice size while still providing redundancy in case one orifice clogs. Protect orifices with standard bar grating unless orifice dimensions are less than 1.25 inches, in which case use a well screen.
>50	Evaluate baseflow under current and fully developed conditions considering irrigation return flows and design outlet to pass baseflows without affecting the storage provided by the WQCV. Baseflows may change seasonally and year to year, so if observed baseflows are used in design, be sure to consider recent climate. Consider using multiple sub-regional EDBs throughout the watershed instead of designing the EDB for this size tributary. Not suitable for drainage areas exceeding one square mile. Must still provide WQCV for entire upgradient watershed.

COMMUNITY VALUES

EDBs are important features in the urban landscape, and when designed thoughtfully, can provide significant value to the community above and beyond their water quality functions. There are generally two aesthetics for EDBs: 1) graded, landform-type basins with vegetated sides and bottoms and 2) architectural-type basins, using walls and other structures instead of earth for containment of the WQCV. Whether planning an architectural or a graded landform EDB, consider how the SCM contributes to or impacts its site, visitors, and the surrounding community, as well as how access is provided for maintenance operations. Since the graded landform type EDBs are most common, the following discussion focuses on this type of facility. Recommendations for architectural EDBs follow at the end of this section.

In addition to performing water quality treatment, EDBs should enhance the site's landscape, provide diverse vegetation for aesthetics and wildlife habitat, and incorporate visitor amenities such as walkways and seating. Key considerations for EDBs to integrate community values include:

- Create EDBs with interesting and attractive landforms. A simple but effective approach is to design landforms that appear to have been created by fluvial processes, with sinuous low flow channels, curving transitions between the EDB bottom and side slopes, and a more curvilinear, stream-like form versus a rectangular basin shape. Side slopes of the basin should be varied and may include intermediate terraces or benches to reinforce the idea of a water-sculpted landform. When shaping the basin, consider requirements for access and vegetation management.
- Consider designing EDBs with terraces of different elevations in the pond bottom (potentially stepping up from the lowest parts of the pond by 1 foot +/- elevation increments) to vary the inundation periods and depth of ponding for each terrace, and as a result, creating different water regimes and soil saturation levels for each. These different terraces can then be vegetated with specific vegetation types (emergent wetland, wetland fringe, riparian, upland, etc.) corresponding to their anticipated water regimes, resulting in a diverse and more resilient vegetative habitat within the EDB. Photograph EDB-1 illustrates an EDB with varied basin grading and vegetation. The variation in bottom surface elevation will also make it easier to maintain the vegetation of the pond, as the consistently wet areas will be limited and clearly defined so that the remainder of the pond will be less soggy and easier to maintain. Avoid flat-bottomed ponds with little or no variation in elevation in the bottom surface.
- Don't place active uses and/or substantial visitor amenities within the area that will be inundated by the WQCV. Any uses, amenities, or enhancements included as part of the EDB design should either be resilient to frequent inundation or placed out of prolonged inundation zones. Active uses within the facility, such as sports fields and walking trails, may either have very limited use due to flooding or soggy conditions or may require high levels of

Photograph EDB-1. This EDB illustrates the use of a soft, meandering low flow channel and varied bottom grading with vegetation selected for the associated hydrologic conditions.

maintenance due to saturated soils and sediment deposition. MHFD discourages the use of irrigated bluegrass and other high maintenance turfgrasses in EDBs due to the wet conditions and accumulation of sediment expected in these facilities.

- Minimize negative impacts of required structural elements (i.e., outfalls, energy dissipation, and retaining walls) on the EDB's surroundings. Pay special attention to those elements visible from prominent viewing points. Techniques include positioning wall faces and culvert openings away from view areas, screening structures with vegetation, using natural materials such as boulders, using soil riprap in lieu of exposed riprap, using an upstream trash vault or hydrodynamic separator (HDS) for pretreatment (acting as a forebay), or custom-designing structural components to be attractive design elements that enhance the setting. Prominently placed standard drainage infrastructure elements such as precast flared end sections, "dragon's teeth" energy dissipators, and exposed riprap embankments communicate a message that a place is not intended for community use.
- Consider planting appropriate vegetation in addition to native grass. EDBs can sustain a wide variety of plant material, including trees, shrubs, and herbaceous plants. Plant diversity is beneficial for wildlife, pollinators, aesthetics, and people. Plant selection and placement should reflect the water regimes that will be created within the pond bottom (and any terraces, if employed) and should be appropriate for the anticipated level of maintenance that property managers are committed to providing for the long term. Avoid planting trees in locations where roots can damage structures and where sediment will accumulate. As with many other SCMs, an irrigation system is recommended, at a minimum for establishment of vegetation, but ideally for supplemental use during extended periods of drought.

Walls are generally discouraged due to concerns with safety, access, maintenance, and long-term replacement costs. Where walls are needed, install railing for safety and consider the following design approaches:

- Limit wall heights to a maximum of 3 to 4 feet for safety and to improve accessibility. If additional pond depth is necessary, use multiple walls with landscaped intermediate terraces. If internal landscaped terraces are not possible, consider screening the perimeter of the EDB with shrub plantings or hedges, prioritizing primary viewing areas to the facility.
- Use materials for structures and walls with aesthetic qualities that fit the context of the site, such as natural stone, colored and/or stamped concrete, or concrete textured by use of a form-liner. Provide thoughtful detailing to reduce apparent mass of walls and structures and add refinement. Potential techniques include visually breaking up large panels of concrete with reveals, chamfers or stone veneer, and by adding stone or pre-cast concrete capstones to walls.

MAINTENANCE

Recommended maintenance practices for all SCMs are provided in Chapter 6 of Volume 3. Routine maintenance for EDBs includes cleaning sediment and debris from forebays, clearing debris from outlet structure orifices and trash racks as necessary, vegetation management, and cleaning accumulated sediment from low flow channels.

During design, consider the following to ensure ease of maintenance over the long-term:

- Route foundation drains and other groundwater drains to bypass the water quality plate, directing these drains to a conveyance element downstream of the EDB. This will reduce potential for excessively wet areas for prolonged periods of time within the EDB.
- A micropool, or alternative measures that provide equivalent function, is recommended to reduce clogging of the orifices. If a micropool is not used, the low flow channel, initial surcharge volume, and outlet configuration become even more critical, and more frequent maintenance may be required.
- Provide an initial surcharge volume and follow criteria for the low flow channel. Whether the low flow channel is vegetated or concrete, follow design criteria for low flow section depth and width to limit the spreading of frequent inundation across the whole bottom of the EDB. Ensure that areas adjacent to the low flow channel have adequate slope to drain into the low flow channel.

- When available, use sandier-textured soils (loamy sand, sandy loam) in the bottom of an EDB to promote infiltration, quicker dewatering, and improved stability compared to clayey soils. For watersheds with low sediment loading, consider installing an underdrain and sand or bioretention media in the lowest portions of the EDB to help the basin bottom dry out after storm events.
- Provide a stable bottom for the forebay that can be scraped with maintenance equipment to remove sediment (e.g., concrete or a cast reinforced concrete system with open cells for vegetation).
- Identify what maintenance equipment will be used and provide stabilized access to the forebay and outlet for maintenance. Consider what flow management techniques such as temporary diversion or dewatering may be required in order to maintain the EDB.
- Limit walls to areas above the WQCV because failures are more likely in frequently inundated areas.
- Ensure walls do not impact access for maintenance equipment.
- During vegetation establishment, adjust irrigation systems (if present) on a monthly basis. Following establishment of vegetation, inspect plant material on a bi-monthly basis to determine if supplemental irrigation is needed for plant health.

DESIGN PROCEDURES & CRITERIA

The following steps outline the design procedure and criteria for an EDB, and Figure EDB-1 shows a typical EDB plan view. SCM Design is an Excel-based workbook that performs many of the design calculations below and checks for conformance to these criteria. Designers can use the *MHFD-Detention* workbook (MHFD 2021) to develop and route storm hydrographs through an EDB, either stand-alone or with FSD, and to design the outlet structure. Design details in Figures EDB-2 through EDB-13 are located at the end of this fact sheet.

1. **Inlet and Forebay**: Design the inlet(s) and forebay(s) to satisfy criteria in Section 5.0 *SCM Inflow Features* of this chapter.
2. **Design Storage Volume**: Determine the WQCV and other design volumes that the EDB is intended to control such as the EURV and/or the 100-year detention volume. Calculate the required storage volume, accounting for runoff reduction SCMs in the contributing watershed. Determine the required WQCV using guidance in Chapter 3 or use equations provided in the *Storage* chapter of Volume 2 for the EURV and larger design storms.
3. **EDB Shape**: Always maximize the distance between the inlet and the outlet. When feasible, shape the EDB so that the ratio of basin length (measured along the low flow channel from inlet to outlet) to average basin width is at least 1.5:1 (EPA 2021) and preferably greater than 2:1. A longer flow path from inlet to outlet reduces short circuiting and provides more residence time for sedimentation to occur. Meander the alignment of the low flow channel to increase the length while still maintaining a bench on one or both sides for equipment access. See the *Storage*

DESIGNING TO ATTAIN THE REQUIRED STORAGE VOLUME

It is good practice to design an EDB to provide slightly more volume than the minimum required. Most jurisdictions require a survey to confirm that the design volume is achieved. Given construction grading tolerances, providing slightly more volume reduces the chance that rework will be necessary to achieve the required volume. Designing with additional volume also allows for some accumulation of sediment while still maintaining the design volume. This may reduce the frequency of cleanout in some instances.

Photograph EDB-2. This EDB depicts a meandering low flow channel with adjacent benches that remain drier to allow equipment access for maintenance.

chapter of Volume 2 for additional guidance on basin shape for multiuse facilities.

4. **Side Slopes**: EDB side slopes should be 4:1 or flatter for maintenance and aesthetics. In general, the use of walls is discouraged due to concerns with access, maintenance, and long-term replacement costs.

5. **Low Flow Channels and Basin Bottom Grading**: Design a low flow channel to convey concentrated runoff from inlets to the initial surcharge zone near the outlet. Low flow channels should be 18 inches deep to limit migration over time and reduce inundation of adjacent benches so that they remain stable to allow equipment access for maintenance. Side slopes for the low flow channel may be as steep as 2:1 (horizontal:vertical) provided that the side slopes are designed with appropriate soils and groundcover to resist erosion from anticipated design flows.

   Grade the bottom of the basin outside the limits of the low flow channel to slope at 2% or more to encourage drainage. Consider shaping the basin bottom to create zones of varied depths and hydrology. Provide at least 6 inches of suitable topsoil in the basin bottom and side slopes. See MHFD's *Topsoil Management Guidance* for information on texture and nutrients for suitable topsoil. Consider using sandier-textured soils (loamy sand, sandy loam) from onsite or imported sources in the low flow channel and bottom benches to promote higher infiltration capacity, quicker dewatering, and improved stability compared to clayey soils.

   Low flow channel options include:

   - **Vegetated Low Flow Channels**: Sedimentation is the primary pollutant removal mechanism for EDBs; however, when designed and maintained properly, vegetated low flow channels enhance treatment by slowing and filtering stormwater runoff and promoting infiltration and wetland treatment processes. Design vegetated low flow channels with sinuosity and varied grading to emulate a natural stream channel. Select riparian grasses, sedges, and rushes that thrive with frequent and prolonged inundation. Design vegetated low flow channels with a consistent longitudinal slope between 0.5 to 2% from the forebay to micropool with a minimum depth as shown in Figure

EDB GRADING AND SHAPING

EDBs can provide significant value to the community when thoughtfully designed. As discussed in the Community Values section, consider variation in basin shape, grading that provides terraces of mixed elevations and appropriate vegetation for varying hydrologic conditions.

EDB-2. Provide concrete or boulder sills to demarcate the design grade and facilitate restorative maintenance when sediment removal in the low flow channel is necessary. Provide a bottom width of at least 6 feet for maintenance equipment.

Consider vegetated low flow channels for enhancement of stormwater quality via filtering and infiltration and to promote natural materials when compatible with the context of the site and the maintenance capabilities of the owner. MHFD recommends vegetated low flow channels on a case-by-case basis, with the approval of the local jurisdiction.

- **Low Flow Channels with Concrete Pan**: A low flow channel with a concrete pan establishes the bottom of the basin for routine maintenance. The concrete pan should have a 6-inch curb and additional depth created by side slopes adjacent to the concrete pan as shown in Figure EDB-2. The total depth of 18 inches will limit the area of the basin bottom inundated by frequent flows and reduce maintenance over time. See Figure EDB-2 for geometry. Design a concrete pan with a longitudinal slope between 0.4% and 1%; the flatter slopes reduce flow velocities, and the steeper slopes help avoid low points due to construction tolerances. Riprap and soil-riprap-lined low flow channels are not recommended due to past maintenance experiences where the riprap was inadvertently removed along with sediment during maintenance.

6. **Initial Surcharge Volume**: Provide a surcharge volume above the micropool to manage frequently occurring runoff and sedimentation. This helps to minimize prolonged standing water and sediment deposition in turf grass portions of the EDB, which is critical to turf maintenance and mosquito control. The initial surcharge volume has a minimum depth of 4 inches and extends from the water surface elevation of the micropool up to the lowest elevation of the low flow channel. When no micropool is provided, increase the depth of the initial surcharge volume to 12 inches to accommodate the additional clogging anticipated with this option. Plant hydrophytic vegetation in or hardscape the initial surcharge area. The initial surcharge volume is a part of the WQCV and does not need to be provided in addition to the WQCV. Clearly show the initial surcharge area on the grading plan and in profile/section.

DESIGNING FOR BASEFLOWS

Large tributary areas will generate baseflows that can be accommodated in a variety of ways. Consider the following:

- If water rights can be obtained, consider alternate SCMs such as a constructed wetland pond or retention pond.
- Anticipate and build in the ability to make future adjustments to the size of the lowest orifice. Following construction, monitor periodically. Intermittent flows can become perennial and perennial flows can increase over time. If baseflows increase over time, orifice adjustments may be necessary long after construction of the SCM is complete.
- When feasible, design foundation drains and other groundwater drains to bypass the water quality plate, directing these drains to a conveyance element downstream of the EDB. This will reduce baseflows and help preserve storage for the WQCV.
- When the watershed is fully developed and baseflow can be approximated prior to design, the water quality orifices should be increased to drain the WQCV in 40 hours while also conveying the baseflow. This requires reservoir routing using an inflow hydrograph that includes the baseflow, which can be accomplished using the *MHFD-Detention* workbook available at www.mhfd.org.
- Increase the initial surcharge volume of the pond to provide some flexibility when baseflows are known or anticipated. Baseflows are difficult to approximate and will continue to increase as the watershed develops. Increasing the initial surcharge volume will accommodate a broader range of flows.

7. **Outlet Structure**: Use criteria in this fact sheet and Section 6.0 *SCM Outflow Features* to design the outlet. Locate the outlet structure in the downstream embankment at the low point of the EDB. As described in Section 6.0 *SCM Outflow Features* of this chapter and the *Storage* chapter, the outlet may be designed for release of the WQCV as well as other design volumes including the EURV and 100-year storage volume. Use the *MHFD-Detention* workbook to size the outlet geometry. Outlet structures can be designed in a variety of configurations including external or internal micropools, vertical or sloping trash grates, and different sized grating depending on the size of the orifices. Several example outlet configurations are summarized in Table EDB-4 and illustrated in Figures EDB-3 through EDB-7.

TABLE EDB-4. EXAMPLE OUTLET STRUCTURE CONFIGURATIONS

FIGURE	WQ OR FULL SPECTRUM	MICROPOOL TYPE	TRASH RACK CONFIGURATION
EDB-3	WQ	External	Vertical
EDB-4	FSD	External	Vertical
EDB-5	FSD	External	Flush sloping
EDB-6	FSD	Internal	Flush sloping
EDB-7	FSD	None	Flush sloping

Photograph EDB-3. Outlet structure with coarse safety grating covering the micropool in the foreground, standard bar grating flush with the top of parallel concrete wingwalls and extending down through the micropool, and coarse safety grating covering the 100-year drop box in the background.

REDUCING CLOGGING OF ORIFICES

One of the key design considerations for EDBs is reducing the risk that the orifices clog with debris. A variety of techniques are used to reduce the likelihood of clogging, including:

- Protecting small orifices with well screen; however, well screen is so efficient at trapping debris that the screen itself is susceptible to clogging and requires frequent inspection and maintenance.
- Providing bar grating upstream of well screen to capture larger debris and reduce the amount of debris approaching the well screen.
- Eliminating well screen if orifices are large enough to be protected by standard bar grating. Orifice dimensions greater than 1.25 inches are generally large enough to eliminate the well screen in favor of standard bar grating. Do not eliminate the well screen if the smallest orifice dimension is less than 1.25 inches.
- Reducing the number of orifices draining the WQCV to increase the size of the orifices. Using two orifices instead of three will increase orifice size while providing redundancy in case one orifice clogs.
- Locating EDBs to serve larger impervious areas with corresponding larger WQCV orifices.
- Designing trash deflectors to cover orifices that are not protected by well screen. Trash deflectors, shown Photograph EDB-4, consist of a vertical V-shaped plate projecting in front of the orifice to reduce the likelihood that debris can lay flat against the plate and block the orifice.

Wingwalls extending upstream of the orifices may be parallel or angled. Parallel wingwalls provide a consistent, reduced span length for flush-sloping grating configurations. In turn, flush-sloping grating provides increased trash rack area compared with vertical grating, facilitates trash removal, and may reduce the length of handrail required. Photograph EDB-3 shows an outlet structure with parallel wingwalls and flush-sloping grating similar to that depicted in Figure EDB-6.

Each of the example outlets shown in Figures EDB-3 through EDB-7 are based on water quality orifices large enough to be protected with standard bar grating, omitting the well screen. Figures EDB-8 through EDB-10 provide plan and section views for standard bar grating. For smaller orifices where a well screen is used, an example configuration of WQCV and EURV orifice plates (for full spectrum detention) is shown in plan and section views in Figures EDB-11 through EDB-13.

Consider site context and public safety during design of outlet structure. Install handrails where needed to prevent the public from injury associated with vertical falls off of a structure or between the bars of a grate.

Key components of EDB outlets include:

- **Orifice Plate**: The water quality orifice plate releases the WQCV over 40 hours. As highlighted in Table EDB-4 and in order to maximize the orifice size and the allowable opening in the trash grates, MHFD recommends two orifices arranged vertically to drain the WQCV and a third orifice when designing for FSD. For most applications, an orifice plate consists of a 1/4-inch-thick steel plate with circular or rectangular openings spanning a concrete block-out. Figure EDB-12 provides a detail for a typical orifice plate for an EDB protected by a well screen. Orifices large enough to be protected with standard bar grating as opposed to a well screen may benefit from a trash deflector, shown in Photograph EDB-4, to reduce the likelihood that debris can lay flat against the plate and block the orifice.
- **Trash Racks and Safety Grates:** Protect the orifice plate with either a well screen or bar grate depending on the size of the orifices. See criteria in Section 6.0 *SCM Outflow Features* for when to use a well screen versus a bar grate. Design trash racks to be at least 2 feet wide to provide adequate net open area, regardless of orifice size.

Photograph EDB-4. Where orifices are large enough to omit well screen, trash deflectors can be used in combination with standard bar grating to reduce the likelihood that debris will plug one or more orifice.

Photograph EDB-5. Well screen is intended to protect small orifices from clogging; however, the fine screen is itself subject to clogging and requires frequent inspection and maintenance to keep clear.

As shown in Photograph EDB-5, the openings in the specified well screens are small and almost all trash and debris are filtered by the screen, making well screens efficient at protecting smaller orifices but susceptible to clogging and requiring frequent maintenance. Consider designing the well screen to be removable during maintenance and adding an upstream trash rack constructed of standard bar grating to reduce the amount of debris impacting the well screen and to facilitate maintenance.

See additional information in Section 6.0 *SCM Outflow Features* including safety grate design and sizing information for well screen, standard bar grating, and safety grating.

- **Micropool:** Design the micropool in conjunction with the orifice plate and trash rack to allow water to flow through a submerged portion of the trash rack, shown in Photograph EDB-6, and reach the openings in the orifice plate, even when floating vegetation and debris are matted against the portion of the trash rack that is above the water surface. Micropools should be 2.5 feet deep and at least 15 square feet in area to facilitate maintenance.

8. **Emergency Spillway and Overflow Embankment:** At a minimum, design the emergency spillway to convey the fully developed, undetained peak discharge for the 100-year design storm event. Design spillway structures in accordance with the *Storage* chapter, applicable Colorado dam safety regulations, and any local drainage criteria.

   Design the embankment to be stable during the 100-year storm. If the embankment falls under the jurisdiction of the State Engineer's Office (SEO), also meet SEO requirements for dam safety. Design embankment slopes to be no steeper than 4:1, preferably flatter, and planted with turf grasses. Excavate and replace poorly compacted native soils. Compact embankment soils to 95% of maximum dry density for ASTM D698 (Standard Proctor) or 90% for ASTM D1557 (Modified Proctor). Consider the use of stabilizing materials such as buried soil riprap or turf reinforcement mats installed per manufacturer's recommendations rather than exposed riprap.

9. **Vegetation**: A dense, healthy stand of vegetation reduces erosion, helps trap fine sediment, and enhances infiltration. Primary vegetative ground cover should be native grasses and other herbaceous vegetation and should be dominated by rhizomatous sod-forming grass species (rather than bunch grasses) to establish full cover. In addition to its functional role, vegetation adds aesthetic and habitat value. Designers may create a range of planting zone types by creating terraces with varying elevations within the pond bottom, and thereby varying the water regimes of each. Higher terraces will have less depth of ponding and less time of inundation and will therefore support different plant species than lower terraces. Each terrace should be seeded/planted with appropriate multi-species seed mixes and plant materials that reflect the anticipated water regime for each location (e.g., wetland, wetland fringe, riparian, upland). Trees can be incorporated in EDB designs to provide shade, aesthetic values, and other benefits. Plant trees in areas that do not require frequent sediment removal (i.e., avoid the initial surcharge area) and consider the mature size of the tree as well as its root structure to avoid potential

ALTERNATIVES TO MICROPOOLS

Outlet structures without micropools will require more frequent maintenance to remove debris than outlets with properly designed micropools. If an outlet is designed without a micropool, it is essential to maximize orifice size, provide a deeper initial surcharge zone, and provide a low flow channel meeting MHFD's criteria. Figure EDB-7 shows an outlet structure alternative without a micropool.

To compensate in part for the increased maintenance issues associated with an outlet that does not have a micropool, consider incorporating these features:

1. **Deeper initial storage zone.** Because of the increased likelihood of debris blockage at the lowest portions of an outlet structure without a micropool, provide a deeper initial storage zone to contain water that may back up upstream of the outlet.
2. **Sand filter upstream of outlet.** As depicted in Photograph EDB-8, a sand filter section in the low flow channel upstream of the outlet structure can aid in dewatering the EDB. This requires an upstream watershed with low sediment loading to avoid rapid clogging of the filtration feature. When using a sand filter, size the surface area of the sand filter to be at least as large as the footprint of the forebays for the EDB. Provide a media depth of 1.5 feet and an underdrain. See the Sand Filter fact sheet for criteria for filter media and Section 4.3.3 *Underdrain Systems* of this chapter for criteria for underdrains.
3. **Increased sediment trapping efficiency.** Consider incorporating a larger forebay that exceeds minimum recommendations to increase sediment trapping efficiency. Consider ways to provide open-cell concrete in the bottom of the forebay to establish dense vegetation to slow flows and improve sediment trapping. Use a vegetated low flow channel for increased sediment trapping.
4. **Additional trash capture at inflow points.** Integrate trash collection features into the inflow conveyances entering the EDB. These may take the form of specially designed grating, debris "fences" at the downstream perimeter of the forebay, trash/debris nets, or manufactured treatment devices.

damage to structures and future maintenance access issues. Irrigation is recommended to aid in vegetation establishment. Where possible, place irrigation heads outside the basin bottom to prevent damage from pond sediment and damage during maintenance.

10. **Maintenance Access**: Provide maintenance access into the forebay and the area next to the outlet structure. Consider the type of maintenance equipment that will be used and provide stabilized access for maintenance vehicles and excavation equipment where needed. The maintenance plan developed as a part of the design must provide details on required maintenance equipment and how sediment and trash will be removed from the outlet structure and micropool. Some review agencies may require vehicle access to the bottom of the EDB and into the low flow channel regardless of the size of the watershed. Use a minimum path width of 10 feet when designing for vehicle access. Do not exceed grades of 10% for haul road surfaces and 20% for skid-loader and backhoe access. Stabilized access includes concrete, articulated concrete block, concrete grid pavement, reinforced turf pavement, and other surfacing as accepted by the municipality. Provide a cross-slope for the access path of 2%.

CONSTRUCTION CONSIDERATIONS

Successful construction of an EDB requires careful attention to proposed grades, construction details, and vegetation establishment. For project success, implement the following practices:

- If an area identified as an EDB is used as a sedimentation basin during construction, the area must be fully rehabilitated after construction by removing sediment and other materials accumulated during construction, placing topsoil, and establishing vegetation.

Photograph EDB-6. In this outlet, runoff flows through safety grating (5-inch clear bars) to separate floating debris before continuing through standard bar grating that extends to the bottom of the micropool The grating extending down into the micropool can be raked through the gap in coarse safety grate to clear debris.

Photograph EDB-7. This EDB was originally constructed without a micropool and was retrofitted with a sand filter with underdrain to reduce the potential for clogging the outlet and water backing up in the basin.

- Verify the subgrade elevations of the EDB prior to placement of topsoil. Adjusting pond grades after topsoil placement can be costly.
- Avoid over-compaction of the initial storage area and other areas that will be frequently inundated to promote improved infiltration within the EDB.
- Provide construction observation to help the contractor comply with design specifications and elevations. Improper construction of the forebay, outlet structure, and other features will result in a poorly functioning and difficult to maintain facility.

REFERENCES

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United States Environmental Protection Agency (EPA). 2021. *Stormwater Best Management Practice, Dry Detention Ponds.* EPA-832-F-21-031A.

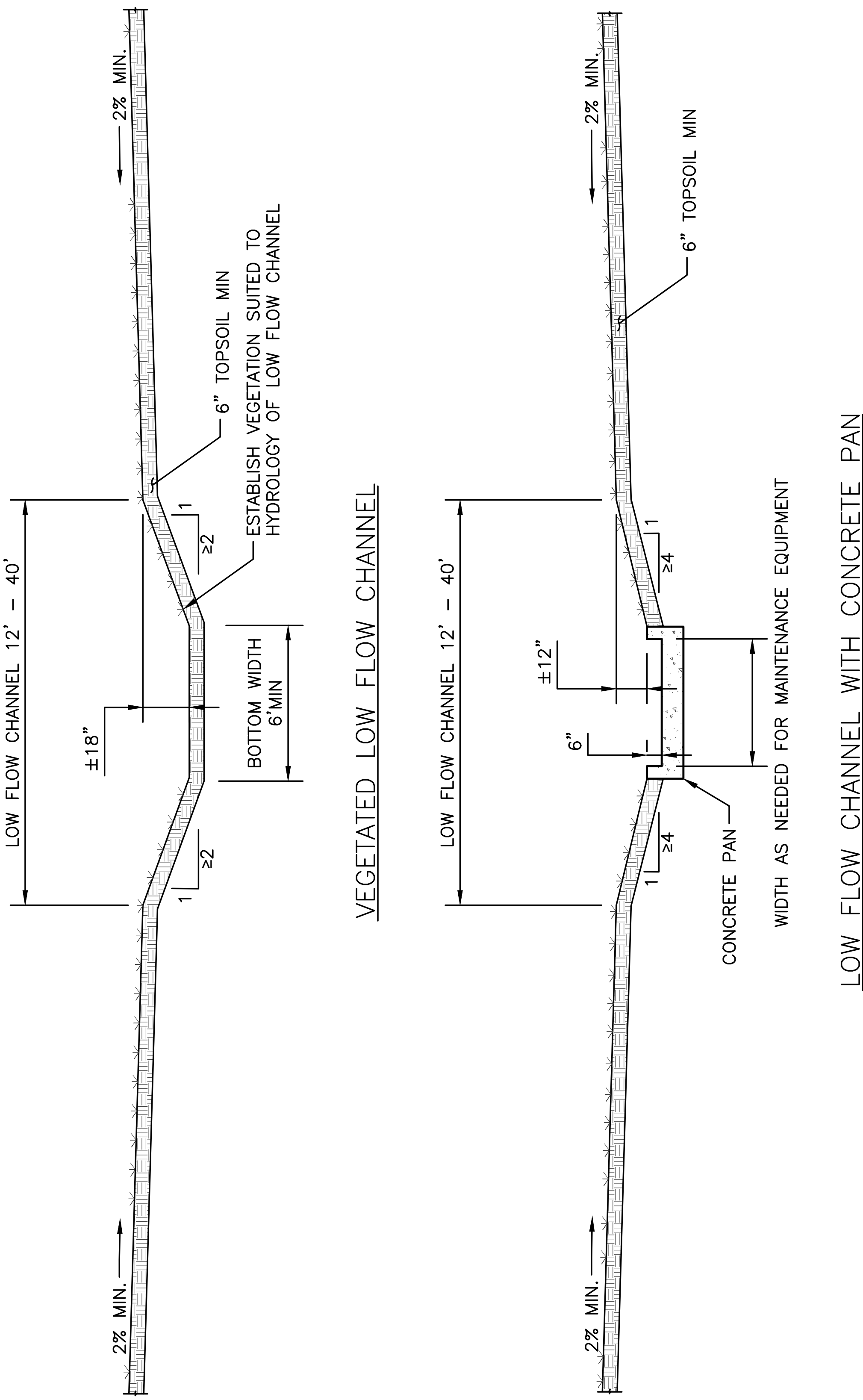
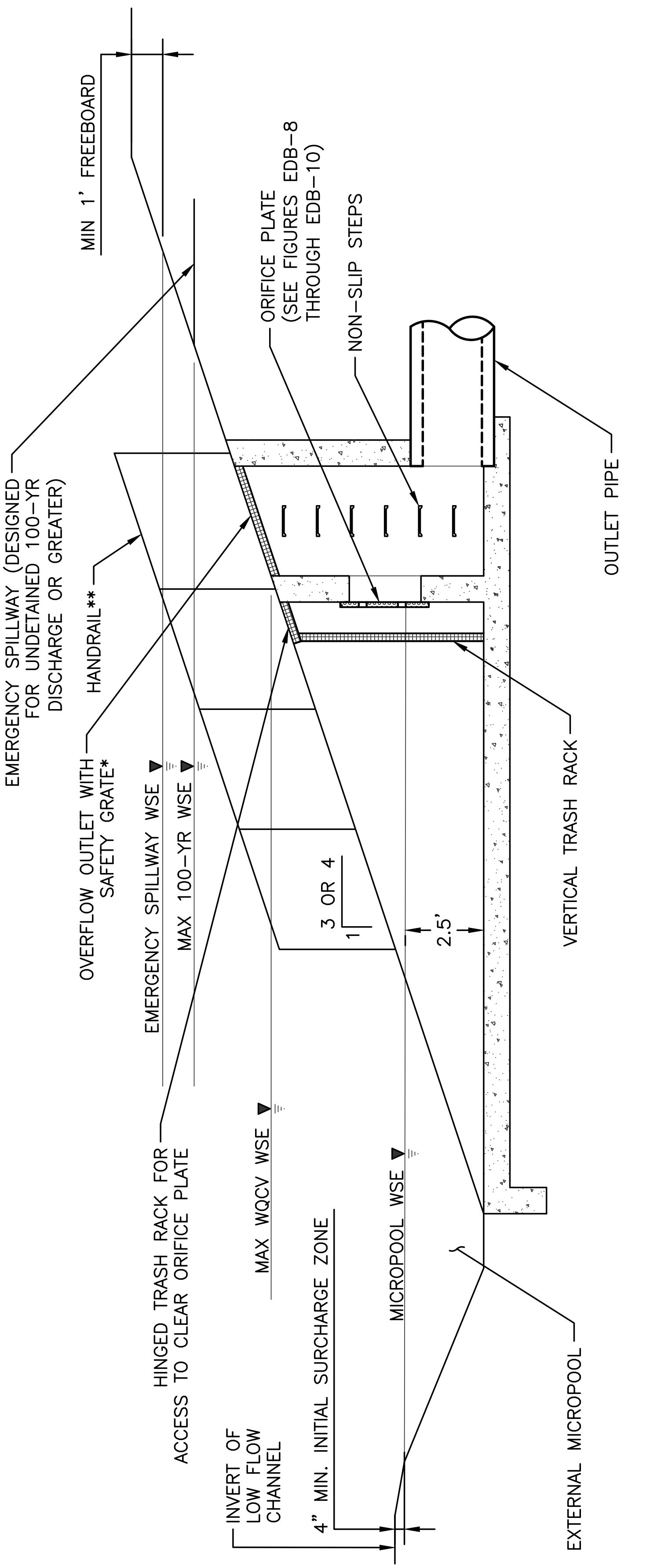


FIGURE EDB-2. CONCEPTUAL CROSS SECTIONS FOR LOW FLOW CHANNEL WITH AND WITHOUT CONCRETE PAN
SECTION VIEW (NOT TO SCALE)

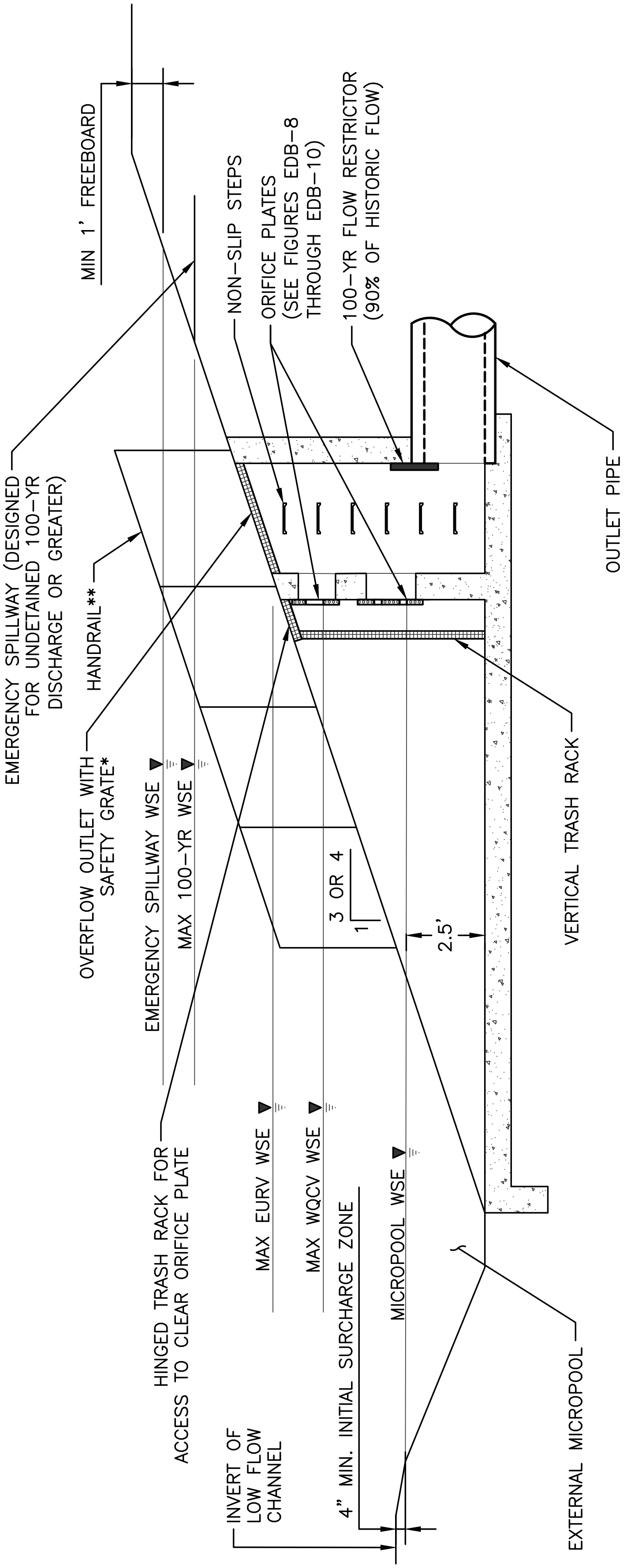


* PROVIDE HINGED ACCESS DESIGNED SO SIZE AND WEIGHT OF GRATE ALLOWS SAFE ACCESS. PROVIDE STEPS ON THE WALL BELOW ACCESS.

** HANDRAIL DRAWN SCHEMATICALLY ONLY. ENGINEER SHALL DESIGN HANDRAIL ON A SITE-SPECIFIC BASIS TO MANAGE ACCESS AND SAFETY.

NOTE: CONFIGURATION ASSUMES ORIFICES ARE LARGE ENOUGH THAT A WELL SCREEN IS NOT REQUIRED. IF WELL SCREEN IS NEEDED, SEE FIGURES EDB-11 THROUGH EDB-13 FOR ADDITIONAL DETAILS.

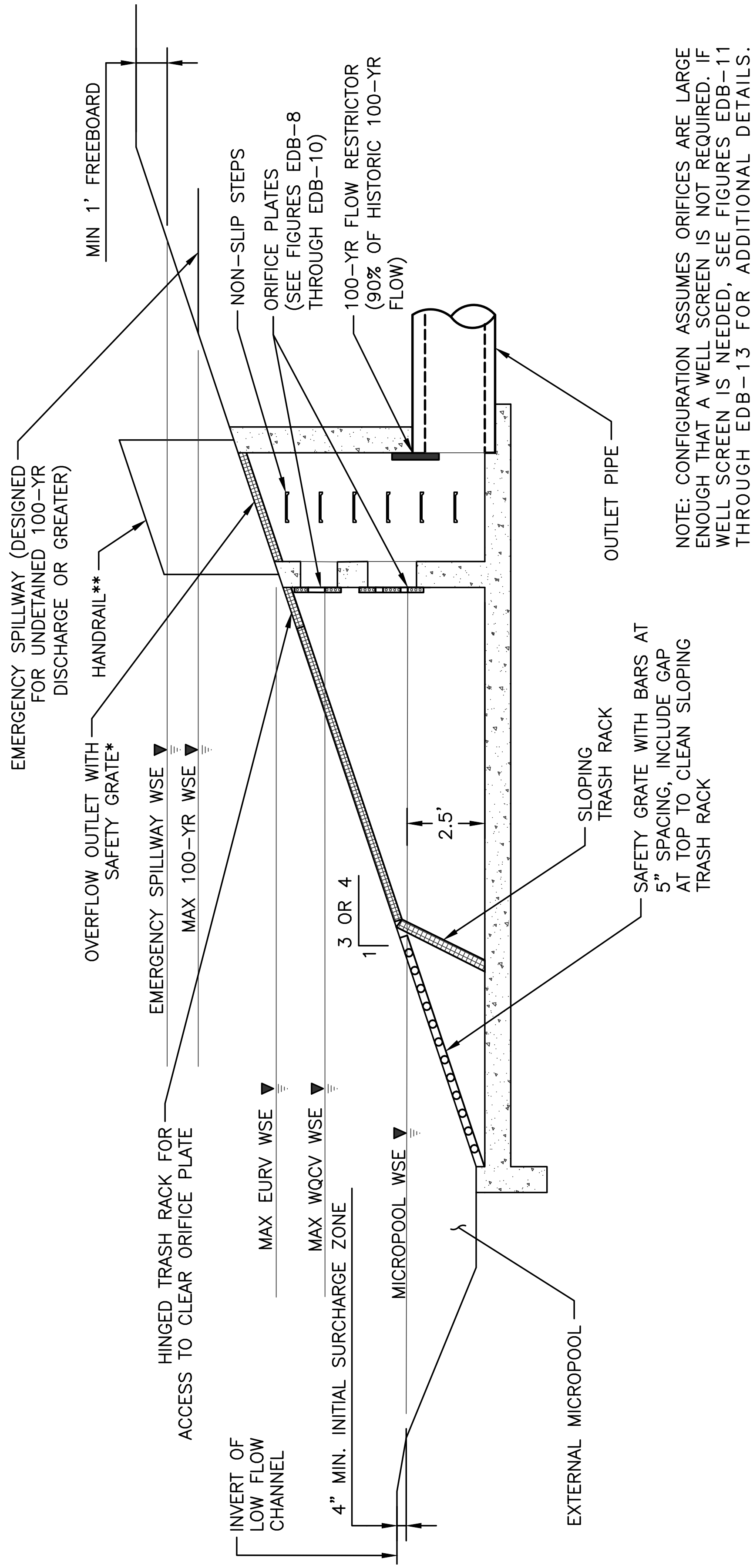
FIGURE EDB-3. OUTLET STRUCTURE FOR WQCV TREATMENT WITH EXTERNAL MICROPOOL & VERTICAL TRASH RACK
SECTION VIEW (NOT TO SCALE)



* PROVIDE HINGED ACCESS DESIGNED SO SIZE AND WEIGHT OF GRATE ALLOWS SAFE ACCESS. PROVIDE STEPS ON THE WALL BELOW ACCESS.
** HANDRAIL DRAWN SCHEMATICALLY ONLY. ENGINEER SHALL DESIGN HANDRAIL ON A SITE-SPECIFIC BASIS TO MANAGE ACCESS AND SAFETY.

NOTE: CONFIGURATION ASSUMES ORIFICES ARE LARGE ENOUGH THAT A WELL SCREEN IS NOT REQUIRED. IF WELL SCREEN IS NEEDED, SEE FIGURES EDB-11 THROUGH EDB-13 FOR ADDITIONAL DETAILS.

FIGURE EDB-4. OUTLET STRUCTURE FOR FULL SPECTRUM DETENTION WITH EXTERNAL MICROPOOL & VERTICAL TRASH RACK
SECTION VIEW (NOT TO SCALE)



* PROVIDE HINGED ACCESS DESIGNED SO SIZE AND WEIGHT OF GRATE ALLOWS SAFE ACCESS. PROVIDE STEPS ON THE WALL BELOW ACCESS.

** HANDRAIL DRAWN SCHEMATICALLY ONLY. ENGINEER SHALL DESIGN HANDRAIL ON A SITE–SPECIFIC BASIS TO MANAGE ACCESS AND SAFETY.

FIGURE EDB-5. OUTLET STRUCTURE FOR FULL SPECTRUM DETENTION WITH EXTERNAL MICROPOOL & SLOPING TRASH RACK

SECTION VIEW (NOT TO SCALE)

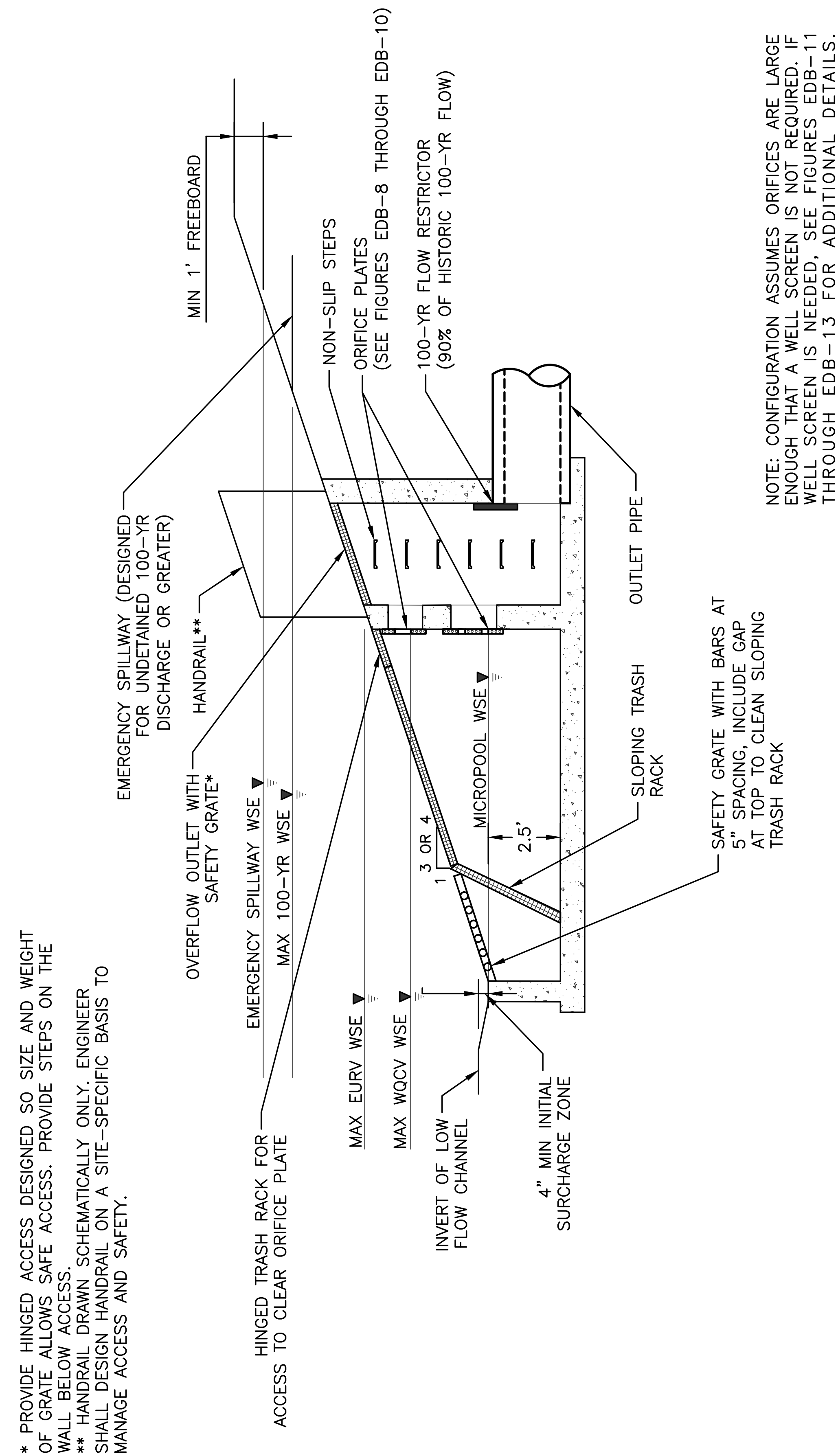


FIGURE EDB-6. OUTLET STRUCTURE FOR FULL SPECTRUM DETENTION WITH INTERNAL MICROPOOL & SLOPING TRASH RACK
SECTION VIEW (NOT TO SCALE)

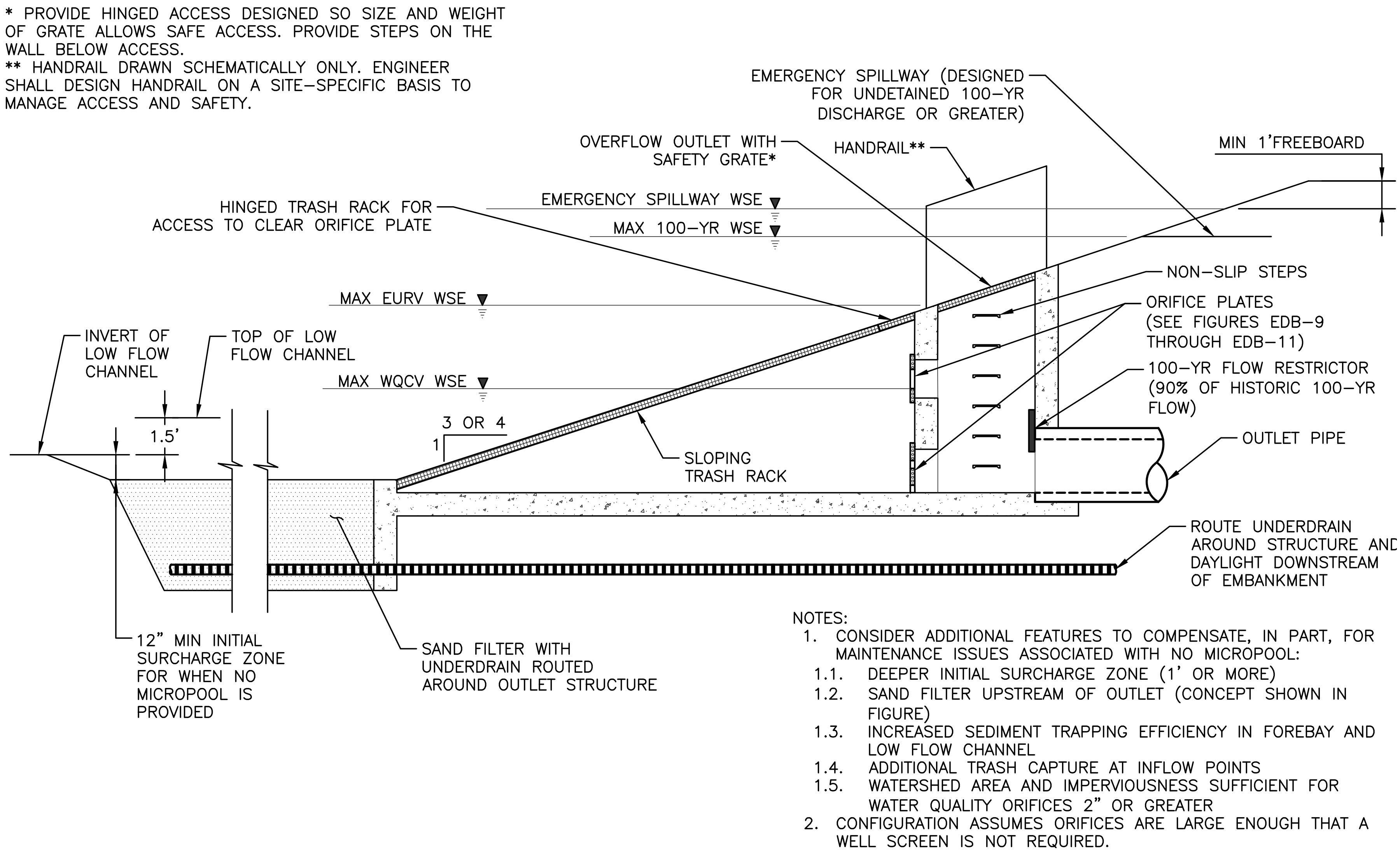


FIGURE EDB-7. OUTLET STRUCTURE FOR FULL SPECTRUM DETENTION WITHOUT MICROPOOL & WITH SLOPING TRASH RACK
SECTION VIEW (NOT TO SCALE)

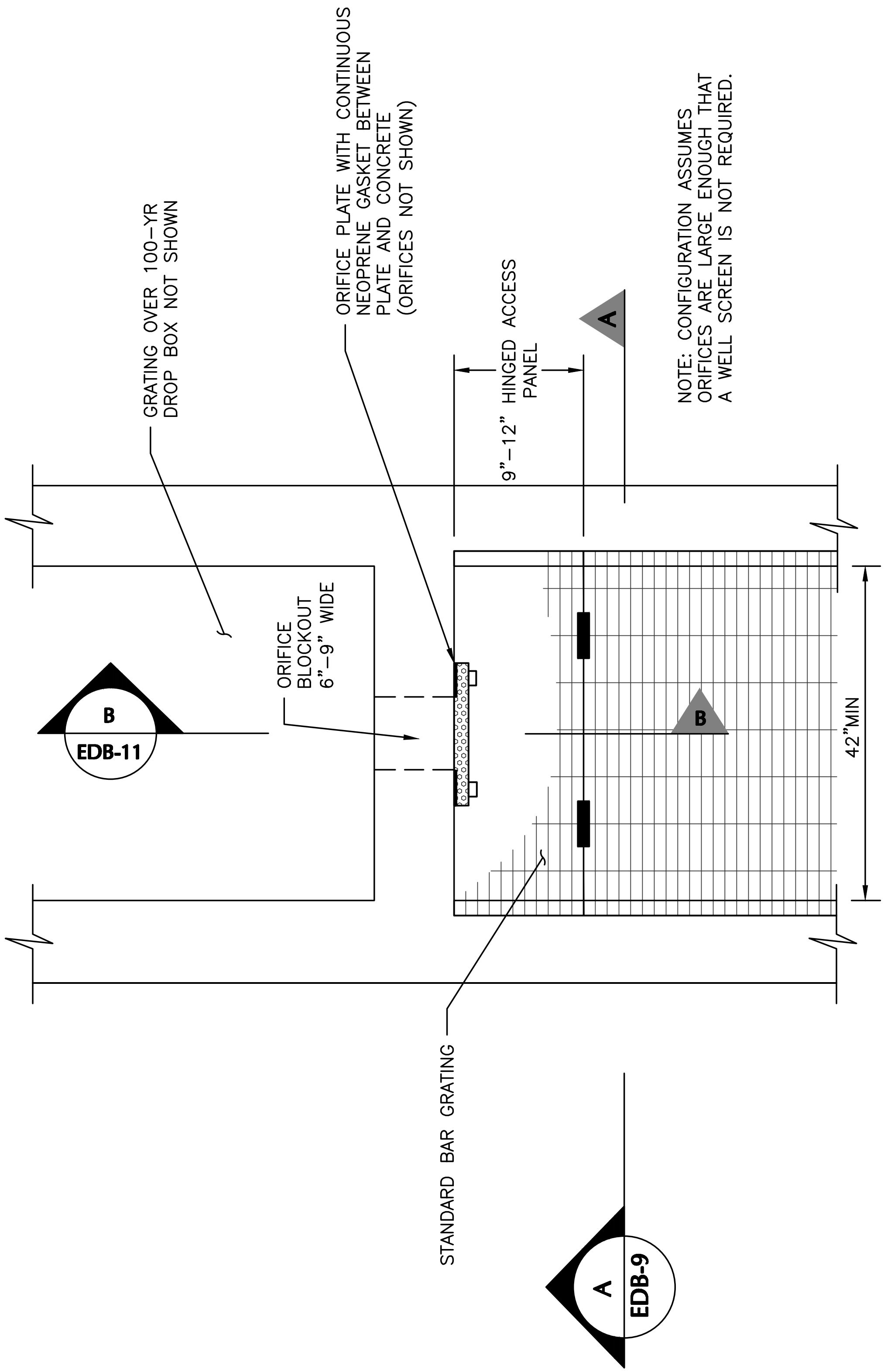


FIGURE EDB-8. CONCEPTUAL PLAN VIEW OF ORIFICE PLATES WITH STANDARD BAR GRATING
PLAN VIEW (NOT TO SCALE)

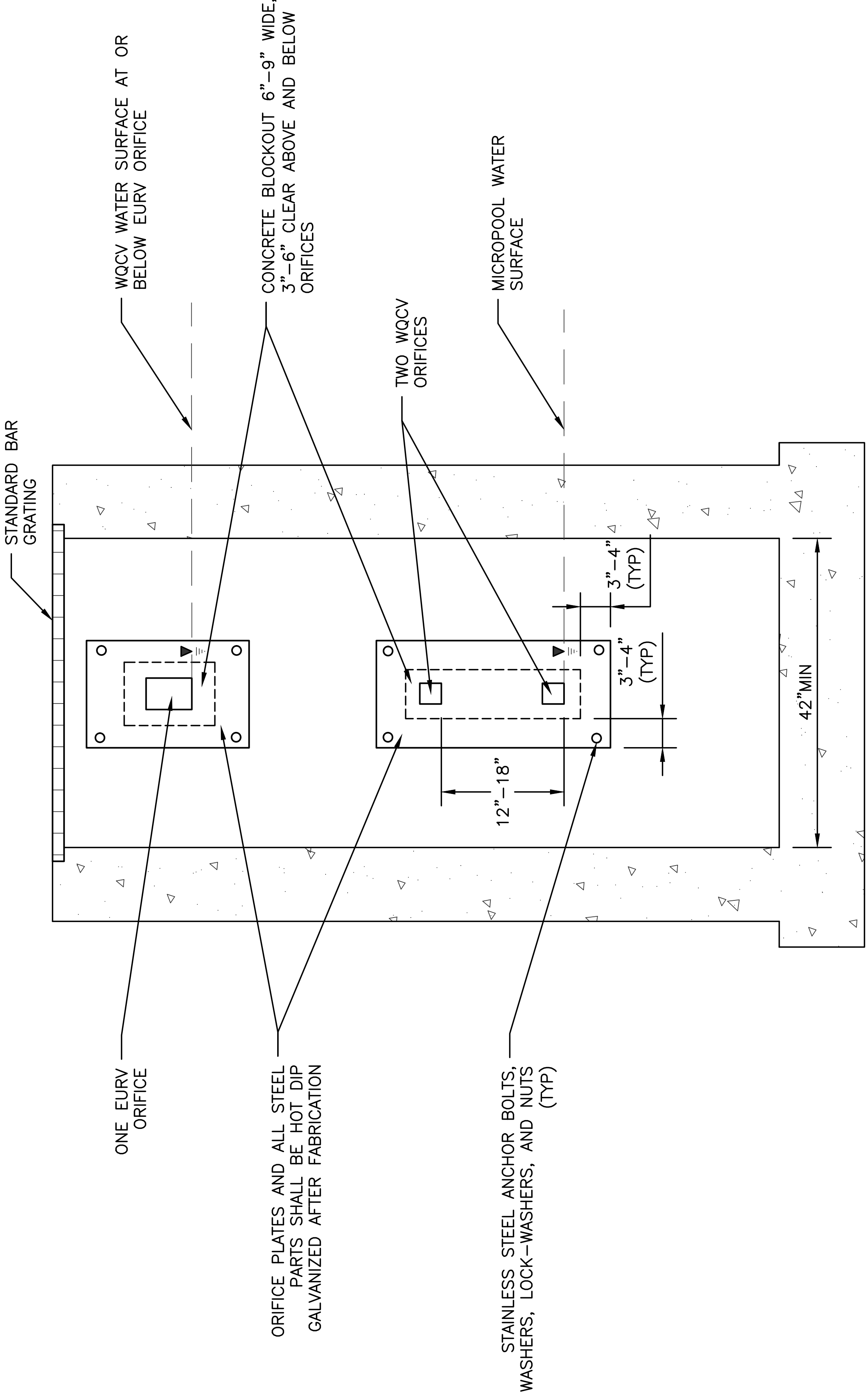


FIGURE EDB-9. CONCEPTIAL FRONT VIEW OF ORIFICE PLATES WITH STANDARD BAR GRATING - SECTION A
SECTION VIEW (NOT TO SCALE)

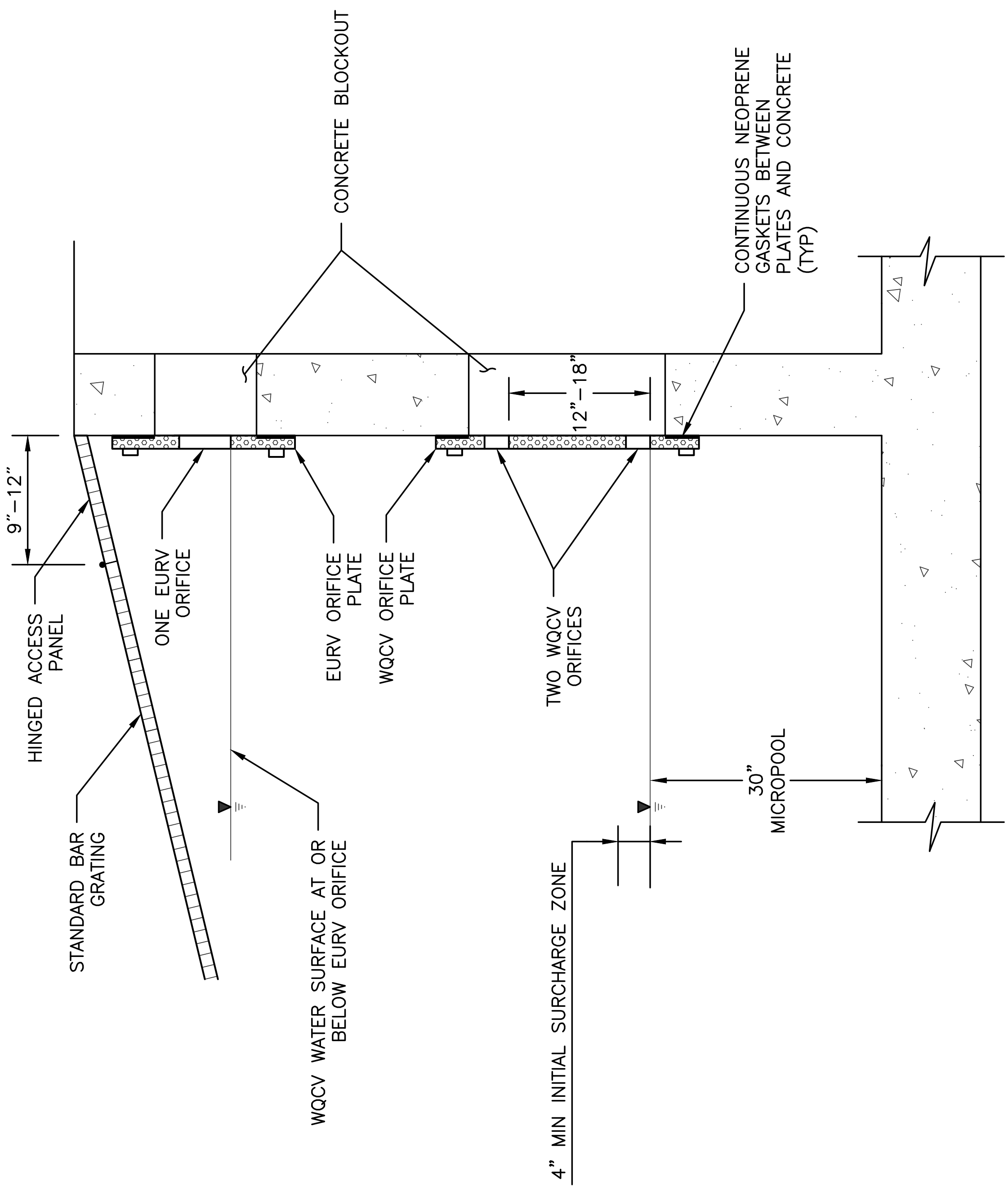


FIGURE EDB-10. CONCEPTUAL SIDE VIEW OF ORIFICE PLATES WITH STANDARD BAR GRATING - SECTION B
SECTION VIEW (NOT TO SCALE)

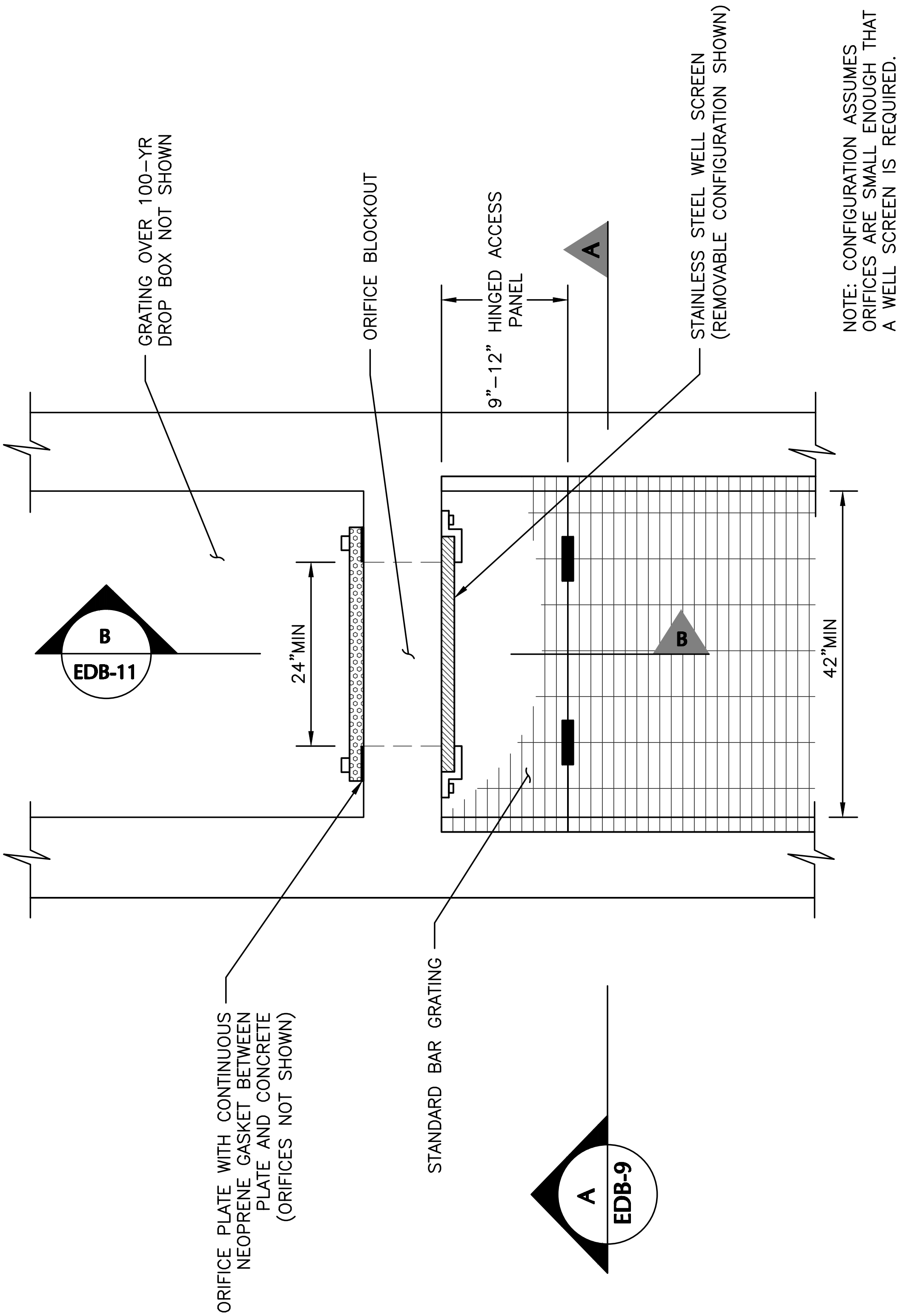


FIGURE EDB-11. CONCEPTIAL PLAN VIEW OF ORIFICE PLATES WITH WELL SCREEN
PLAN VIEW (NOT TO SCALE)

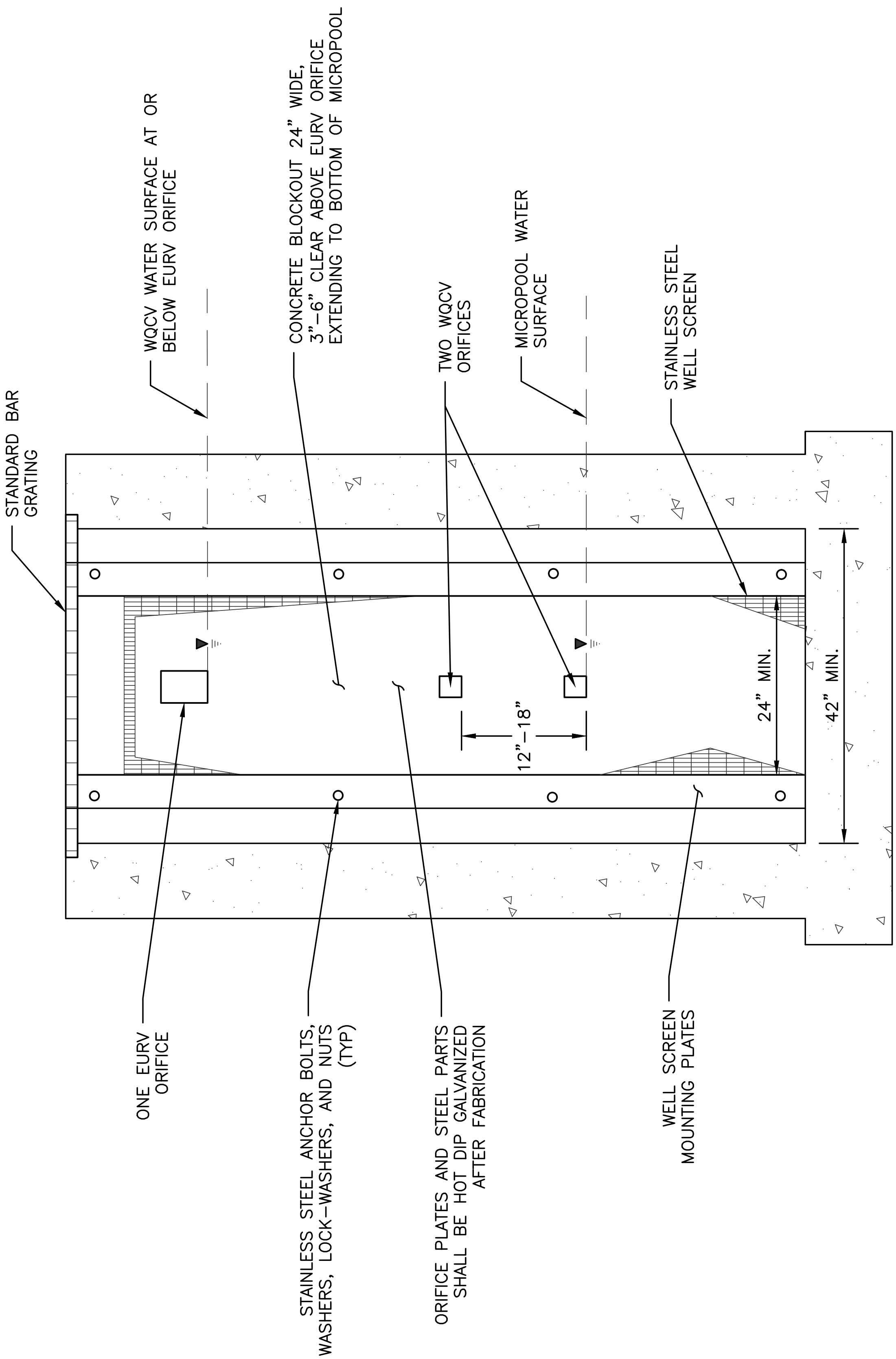


FIGURE EDB-12. CONCEPTUAL FRONT VIEW OF ORIFICE PLATES WITH WELL SCREEN - SECTION A
SECTION VIEW (NOT TO SCALE)

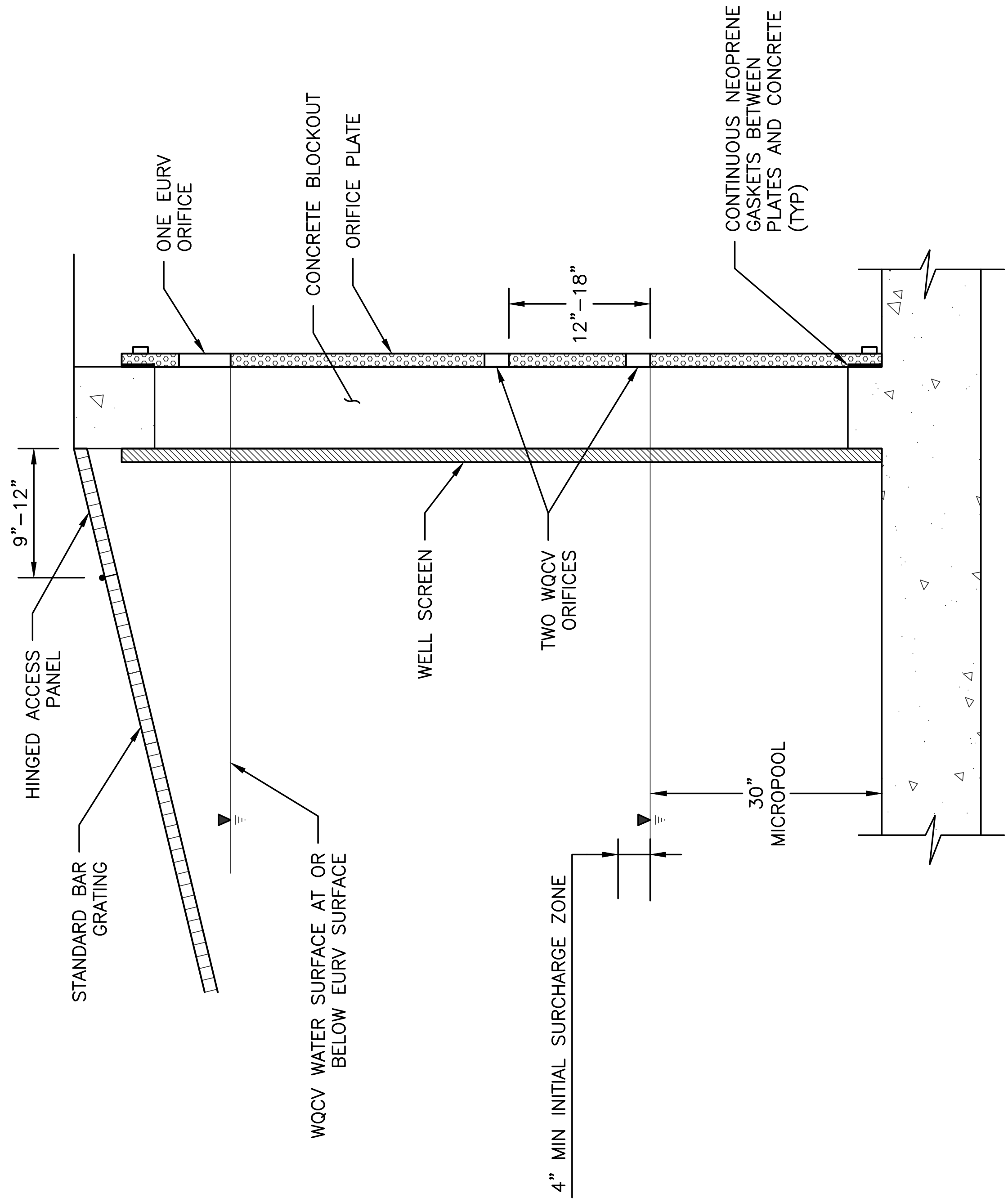


FIGURE EDB-13. CONCEPTIAL SIDE VIEW OF ORIFICE PLATES WITH WELL SCREEN - SECTION B
SECTION VIEW (NOT TO SCALE)

T-7 RETENTION PONDS & CONSTRUCTED WETLAND PONDS

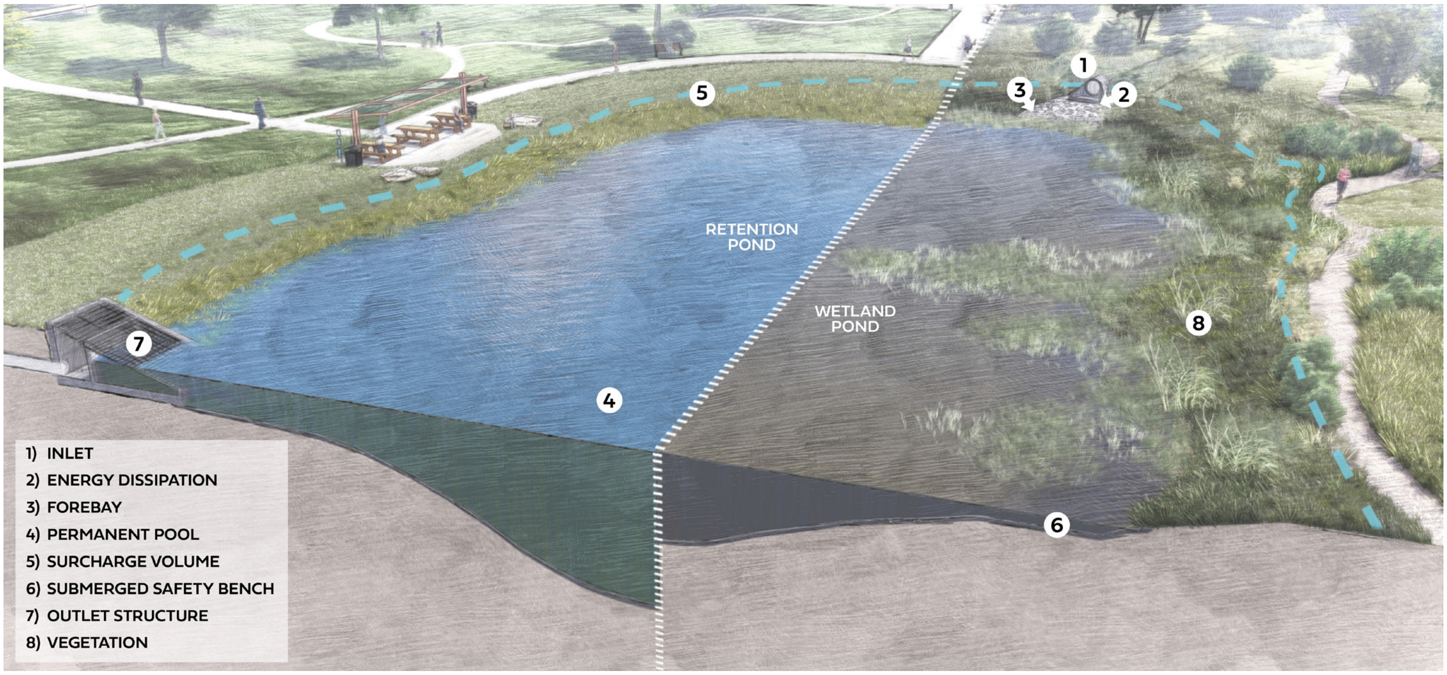


Figure RP/CWP-1. Retention Pond and Constructed Wetland Pond Components

DESCRIPTION

Retention ponds and constructed wetland ponds are SCMs that include a permanent pool of water with capacity above the permanent pool designed to capture and slowly release the water quality capture volume (WQCV) over an extended drain time of 12 hours for retention ponds and 24 hours for constructed wetland ponds.

The permanent pool is replaced, in part, with stormwater during each runoff event, mixing stormwater runoff with the permanent pool water. This allows for a reduced drain time compared to that of the extended detention basin (EDB). Slow release helps to replicate pre-development flows for frequent events and reduce the potential for short-circuiting treatment in smaller ponds.

Retention ponds and constructed wetland ponds can be very effective in removing suspended solids, organic matter, and metals through sedimentation, as well as removing soluble pollutants like dissolved metals and nutrients through biological processes. However, these types of ponds require water rights due to the fact that evaporation from the permanent pool surface has the potential to cause depletions of water that would otherwise flow downstream (CDWR 2023; CDWR 2012).

TABLE RP/CWP-1. RP/CWP OVERVIEW

RETENTION PONDS AND CONSTRUCTED WETLAND PONDS	
MS4 Permit Applicability (Dependent on design and level of treatment)	
Meets Runoff Reduction Standard	No
Meets WQCV Capture Standard	Yes
Meets Pollutant Removal Standard	Yes
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	High
Total Phosphorus	Medium-High
Total Nitrogen	Medium
Total Metals	Medium-High
Bacteria	Medium
Common Applications	
Runoff Reduction (General)	No
Used for Pretreatment	No
Integrated with Flood Control	Yes

SCM COMPONENTS

The primary components of retention ponds and constructed wetland ponds (referred to as ponds, in general) include the pond inlet(s), the permanent pool, the temporary surcharge pool for the WQCV and flood events, the vegetation in and around the pond, and the pond outlet (Table RP/CWP-2 and Figure RP/CWP-1). An important feature of the permanent pool is a shallow safety bench around the edge of the pond that minimizes potential for people to inadvertently fall into deep water.

TABLE RP/CWP-2. RP/CWP COMPONENTS

COMPONENT	INTENT
Inlet	Allows stormwater to enter the SCM.
Energy Dissipation	Protects against erosion when inlet is elevated above the permanent pool.
Forebay	Facilitates removal of trash and coarse sediments. This is the primary location for sediment removal.
Permanent Pool	Provides for quiescent sedimentation and biochemical processes that remove or transform pollutants between runoff events.
Surcharge Volume	Provides the WQCV for slow release through the outlet.
Submerged Safety Bench	Minimizes safety hazard of people inadvertently stepping into deep water or onto steep, wet slope.
Outlet Structure	Ensures slow release of water to provide treatment and reduce erosion in the receiving stream.
Vegetation	Filters runoff, provides biological uptake of pollutants, creates habitat, and mediates biochemical reactions in the soil.

SITE CONSIDERATIONS

Retention ponds and constructed wetland ponds require groundwater and/or dry-weather base flow if the permanent pool elevation is to be maintained year-round. Adequate physical supply and legal rights to store water are required for these types of ponds (CDWR 2023) along with "pond well" permits related to exposed groundwater (CDWR 2012). Water rights requirements are a primary reason that EDBs are used far more frequently in Colorado than "wet" ponds such as retention ponds or constructed wetland ponds. Consider the overall water budget for the pond to verify that the baseflow will exceed evaporation, evapotranspiration, and seepage losses (unless the pond is lined). Because high exfiltration rates can make it difficult to maintain a permanent pool in an unlined pond, line or otherwise seal the bottom and sides of the permanent pool for ponds on permeable soils and leave the areas above the permanent pool unsealed to promote infiltration of the stormwater detained in the surcharge storage volume. For ponds that have a permanent pool that is sustained by groundwater, lining is not necessary, but a pond well permit is required (CDWR 2012).

Studies show that ponds with permanent pools can cause an increase in outflow temperatures relative to inflows due to warming of water in the permanent pool between runoff events (EPA 2009). Retention ponds are discouraged upstream of receiving waters that are sensitive to increases in temperature (e.g., fish spawning or hatchery areas, streams identified as

BENEFITS OF RETENTION PONDS AND CONSTRUCTED WETLAND PONDS

- Provides recreation, aesthetic, and open space amenities to residents.
- Creates wildlife and aquatic habitat.
- Suited for larger tributary watersheds.

LIMITATIONS OF RETENTION PONDS AND CONSTRUCTED WETLAND PONDS

- Open water creates safety issues that must be addressed in design.
- Physical supply of water and a legal availability (in Colorado) to impound water required.
- Sediment, floating litter, and algae blooms can be difficult to remove or control.
- May attract waterfowl that can add to the nutrients and bacteria leaving the pond.
- Ponds increase water temperature.
- Not suitable near airports due to Federal Aviation Administration (FAA) requirements related to bird-strike hazards as described in FAA Advisory Circulars 150/5320-5D and 150/5200-33B (FAA 2007 & 2013).

Photograph RP/CWP-1. Retention ponds and constructed wetland ponds treat stormwater though sedimentation and biological processes including uptake.

Photograph RP/CWP-2. Constructed wetland pond with diverse vegetation provides sedimentation, filtering and biological treatment.

impaired for elevated temperature). Temperature effects should also be considered for constructed wetland ponds, given the warming that will occur in areas of the wetland with shallow permanent pools.

Use caution when placing this SCM in a watershed 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 of flows. In developing watersheds, frequent maintenance of the forebay may be necessary. Protect the pond from excessive sedimentation by providing effective erosion and sediment control measures in disturbed areas of the developing watershed.

COMMUNITY VALUES

Ponds are often designed to provide aesthetic amenities and other benefits to the surrounding community and may be designed as feature attractions that provide open water and diverse vegetation, integrated with water quality treatment and detention for flood events. Ponds can support ecologically diverse vegetation and provide habitat for wildlife and also provide experiential opportunities for visitors. Because of the importance of these broader objectives, the aesthetic and experiential aspects of retention and constructed wetland ponds are essentials considerations in the design process.

Pond design objectives and aesthetics vary greatly depending on the surroundings, ranging from architectural design approaches featuring hard edges and manicured turf surcharge areas to naturalized designs with diverse vegetation in zones with varying hydroperiods to promote biological processes in the water and soil. Depending on project objectives, ponds may be very simple, or may be enhanced with public art, fountains, recirculating water features, bridges, boardwalks, and other elements to enhance experiential design objectives.

Ponds are successful as site amenities when they are integrated with their surroundings in ways that make them features of the landscape that do not stand out as heavily engineered drainage structures. Minimizing the visual prominence of components such as energy dissipation structures, pre-cast flared end sections, outlet structures, and other concrete features helps to blend the SCM with the surroundings. These elements often can be hidden from view, or visually receded and blended with the overall landscape and minimize visual impacts.

Pay attention to the landforms that define the ponds. These should reinforce the chosen design aesthetic, whether formal or naturalistic. Focus on experiential aspects of the design, such as creating and framing special views of the ponds, creating destination areas and water access points for visitors, planning site pathways that provide interesting journeys, and possibly even highlighting the architecture of site buildings, depending on the overall objectives of the project.

Retention ponds are often more manicured than constructed wetland ponds, with more defined transitions between the permanent pool area and surcharge area and embankments and fewer wetland fringe areas. Many retention ponds have an aesthetic of park or golf course ponds, with a more ordered image of "nature" guiding the overall appearance. These ponds tend to be more adaptable to urban and suburban sites, where space limitations, maintenance requirements, and developer objectives tend to compress the overall area that can be dedicated to a pond. These types of ponds may have hard edges to create a more formal appearance or to aid in maintenance. These ponds provide fewer water quality and ecological benefits than naturalized ponds and generally require more frequent maintenance than more natural ponds in open space areas that incorporate soft, vegetated edges.

Constructed wetland ponds have more areas of shallow water within the permanent pool area that allow emergent wetland vegetation to develop and zones within and around the pond with varying hydroperiods supporting diverse vegetation that are well suited for a naturalized aesthetic. Vary side-slope grades and widths and shape the pond to create natural edges that appear to have been formed by flowing water. Use organic shapes and curves in place of straight lines and rectilinear forms for pond edges and elements. Compared to retention ponds, constructed wetland ponds should have more gradual transitions between open water and wetlands. Because of diverse wetland and riparian zones, constructed wetland ponds tend to attract more wildlife and have more ecological diversity than retention ponds and are more appropriate within a larger natural context. Once established, these types of ponds tend to evolve and change due to natural processes, developing seed banks that allow different types of vegetation to thrive depending on hydrologic conditions in different zones of the pond. Weed control is critical in the first few years of establishment.

Specific recommendations to make sure that ponds are community amenities include:

- **Design for safety.** Ponds are attractive features that are inviting to people. The pond design must provide measures to dissuade visitors from entering the pond. Create a safe surface that allows anyone who inadvertently falls or enters the pond to recover and easily walk out to safety. Specific measures include the following:
    - » Create natural barriers along pond edges using vegetation. Dense plantings of vigorous growing riparian shrubs such as coyote willow and other riparian/wetland shrub species can be excellent deterrents to pond access. In public areas, especially where children may be present, consider low visibility wire fencing. These fences can be located in areas of tall shrub and grass growth to minimize their visibility and impact to aesthetics.

Photograph RP/CWP-3. Variations in slope and texture around the pond, trails, and pavilions connect this retention pond to the community as a recreational and aesthetic amenity.

Photograph RP/CWP-4. Landscape elements such as vegetation and stone highlight the irregularly shaped pond edge, making it appear more natural. Photograph courtesy of Design Concepts.

Photograph RP/CWP-5. Landscape elements including diverse vegetation and a wetland fringe, in combination with the irregularly shaped pond edge, create a natural appearance. Sign states, "No Swimming" and warns "Ice Unsafe."

  - If the pond will be accessible (e.g., not fenced off), design a mildly sloped, shallow safety bench in accordance with the side slope criteria in the Design Procedures and Criteria below.

- **Create vegetation plans based on the water regimes that are anticipated post-construction.** Plant wetland species around the edges of ponds, in areas of shallow ponding, and in areas where saturated soils are expected near the water table. See the Design Procedures and Criteria for more information.

- **Develop custom designs for structural elements such as outfalls, energy dissipaters, grade control structures, and spillway weirs to fit the specific attributes of the site.** Each site is unique, so using standard details for these elements without developing site-specific designs will fail to address the opportunities and constraints that each site presents. Choose materials based on the intent of each feature, either blending it with the site or purposefully creating a feature that stands out as "artful infrastructure," where the design elements are intended to contrast the natural environment. Natural materials such as stone provide a more organic quality to structural elements, whereas concrete can be used to create bold counterpoints to the natural environment. Coloring and texturing concrete is another way to create desired effects with structural design elements and may help to blend the structures into the natural context.

- **Create unity in the design through repeated use of materials.** This is especially effective if the functional structures are made of the same materials as other landscape elements (such as seating areas, and terraces) throughout the site and contribute to creating a coherent and unified design.

- **Design for human experience by thinking about how people will use the site and providing elements that enhance their experiences.** Some examples of these types of elements include:

  - Trails – A trail network that creates walking loops around the site (preferably combined with maintenance access), with connections to nearby neighborhoods and other nearby trails. Consider where gateway elements should be located, as well as demarcation of key viewpoints.

  - Water access points – Consider creating informal "destination stone slabs" to accommodate visitors' desires to be close to the water.

  - Seating and shade – These can be informal or formal features, depending on the overall character of the pond and objectives of the site development and can range from boulders under cottonwood trees to benches under small shade shelters. Locate seating to take advantage of high points and good views.

MAINTENANCE

Recommended ongoing maintenance practices for all SCMs are provided in Chapter 6 of this manual. During design, considered the following to facilitate maintenance over the long-term:

- Provide pretreatment for trash and coarse sediment upstream of the permanent pool using a forebay that is elevated and accessible.
- Provide maintenance access to the forebay, permanent pool, and outlet structure.
- For retention ponds, greater depth deters algae growth by moderating temperature and providing deeper areas in the pond that receive less sunlight.
- Periodic removal of sediment from the pond bottom will be required to maintain depth and volume, reduce internal nutrient loading from sediment (Taguchi et al. 2020), and support beneficial habitat. Be aware that nutrient-rich inflows will produce algae blooms in ponds. Implementing source controls such as reduced fertilizer use, phosphorus-free fertilizer use, and irrigation management may help to reduce the potential for algae blooms and associated increased maintenance.
- Sediment removal typically requires dewatering of the pond. As part of the pond design and maintenance plan, provide and identify maintenance access for necessary equipment and identify an area nearby to spread out and drain wet sediments removed from the pond before hauling to a disposal location.

Photograph RP/CWP-6. Exceeding the minimum requirements for the permanent pool volume and depth can help to mitigate excessive growth of algae. Source control measures in the watershed that reduce nutrient loading may also be necessary.

DESIGN PROCEDURES & CRITERIA

The following steps outline the design procedures and criteria for retention ponds and constructed wetland ponds. Figure RP/CWP 1 shows a conceptual configuration of a retention pond, and Figure RP/CWP-2 depicts a constructed wetland pond. The *SCM Design* workbook available on MHFD's website is an Excel-based workbook that performs many of the design calculations based on the criteria in this fact sheet. *MHFD-Detention*, another workbook available on MHFD's website, can be used to develop and route storm hydrographs through a retention pond and design the outlet structure for the WQCV, the EURV and 100-year storage volume, as applicable.

1. **Site Assessment Considerations Related to Baseflow Availability**: Unless the permanent pool is established by groundwater, a perennial baseflow that exceeds water losses, including evaporation, evapotranspiration, and seepage, must be physically and legally available. Low inflows in relation to the pond volume can result in poor water quality due to stagnation. Perform net influx calculations to account for the range of annual and seasonal variations in hydrologic conditions. Estimate evaporation from existing local studies, pan evaporation data from nearby climate stations, or from the National Weather Service (NWS) Climate Prediction website. NOAA Technical Report NWS 33 is used by the State Engineer's Office and provides a spatial map of annual evaporation from free water surfaces for Colorado (NOAA 1982). Annual evaporation for Denver County ranges between 40 and 45 inches. Potential evapotranspiration (which occurs when water supply to both plant and soil surface is unlimited) can be approximated as the evaporation from a large, free-water surface such as a lake (Bedient and Huber 1992). When ponds are placed above the groundwater elevation, a pond liner is recommended, unless evaluation by a geotechnical engineer determines this to be unnecessary.

2. **Inlet and Forebay:** Design inlet(s), forebay(s), and energy dissipation in accordance with Section 5.0 *SCM Inflow Features* of this chapter and the *Hydraulics Structures* chapter of Volume 2, which addresses design of impact basins and drop structures. In some cases, an offline trash vault or a manufactured treatment device to collect trash and sediment prior to the stormwater outfall into the pond can greatly reduce the amount of trash that ends up in the wetland area where it is more difficult to remove.

3. **Design Storage Volume:** Calculate the design volume for the surcharge volume above the permanent pool based on a 12-hour drain time for retention ponds and a 24-hour drain time for constructed wetland ponds. Determine the required WQCV or EURV (watershed inches of runoff) using Chapter 3 of Volume 3 (for WQCV) or equations provided in the *Storage* chapter of Volume 2 (for EURV).

4. **Permanent Pool Volume:** The permanent pool provides stormwater quality enhancement between storm runoff events through biochemical processes and quiescent sedimentation. Calculate the volume of the permanent pool:

$$V_p \geq C_V \left[\frac{WQCV}{12} \right] A$$

<u>**Equation RP/CWP-1**</u>

Where:

V_p = permanent pool volume (acre-ft)

C_V = volume sizing coefficient:

- 1.2 for <u>retention ponds</u>
- 0.75 for <u>constructed wetland ponds</u>

A = tributary catchment drainage area (acres)

5. **Pond Geometry and Features:** Always maximize the distance between the inlet and the outlet. A minimum pond length to width ratio of 2:1 helps avoid short-circuiting. Adjust the inlet and outlet locations as needed through the use of pipes, swales, or channels to accomplish this.

- **Depth Zones**:

  » Safety Wetland Bench: Provide a safety bench along the perimeter of the permanent pool(s) in retention and constructed wetland ponds, 6 to 12 inches deep and a minimum of 4 feet wide. The safety wetland bench provides a shallow area that allows people or animals who inadvertently enter the open water to gain footing to get out of the pond. Aquatic plant growth along the perimeter of the permanent pool can also help strain surface flow into the pond, protect the banks by stabilizing the soil at the edge of the pond, and provide biological uptake.

  » For a <u>retention pond</u>, the remaining pond area should be open water, providing a volume to promote sedimentation and nutrient uptake by phytoplankton and depths that limit aquatic vegetation growth at the bottom of the pond. To avoid anoxic conditions, the maximum depth in the pool should not exceed 12 feet, unless an aeration system is provided. At greater depths, stratification has the potential to occur, which can deplete oxygen in the pond bottom and result in release of pollutants from accumulated sediments that can be flushed out in a subsequent runoff event. The best way to avoid the need for aeration is to ensure that there is adequate baseflow of suitable quality (e.g., not nutrient-rich) and that the pond inlets and outlet are positioned to avoid short-circuiting and zones of stagnation as baseflows pass through the pond. Pumped recirculation of water in the pond can be designed to provide mixing in zones that are less mixed by baseflows and also provides aesthetic benefits (e.g., fountains or small "waterfalls" of recirculating water at points around edges). Aeration systems are typically needed in remedial situations where a combination of long hydraulic residence times, nutrient rich inflows, warm temperatures, and zones of stagnation result in algae blooms that affect the appearance, water quality, odor, and overall function of the pond. In these cases, a variety of alternatives exist for aeration from bubbler systems placed on the bottom of ponds to floating solar pumps that move around the surface of the pond recirculating water.

» For a constructed wetland pond, distribute wetland habitat within and surrounding the permanent pool using vegetation suited for variations in the pool depths and the runoff hydroperiod at varying elevations to establish diverse ecology. Distribute pond area in accordance with Table RP/CWP-3.

VARIATION IN WETLANDS

Diverse wetlands are healthy wetlands. Create zones with different depths and plant a variety of vegetation.

TABLE RP/CWP-3. RECOMMENDED OPEN WATER SURFACE AREA AND DESIGN DEPTH RANGES FOR CONSTRUCTED WETLAND POND ZONES

POND ZONES	PERCENT OF POND SURFACE AREA	DESIGN WATER DEPTH
Forebay, outlet, and open water surface areas	30% to 50%	2 to 4 feet
Wetland zones with emergent vegetation	50% to 70%	6 to 12 inches[1]

[1] One-third to one-half of this zone should be 6 inches deep

6. **Side Slopes:** Side slopes must be stable and sufficiently mild to limit rill erosion and facilitate maintenance. Side slopes above the safety wetland bench should be no steeper than 4:1, preferably flatter. The safety wetland bench should be relatively flat with the depth between 6 to 12 inches and should extend at least 4 feet into the pond from the edge of water. The side slope below this 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 be beneficial to deterring algae growth as it will reduce the shallow area of the pond, thereby reducing the amount of sunlight that penetrates the pond bottom.

7. **Vegetation:** Vegetation is a key component of ponds and wetland basins, providing multiple functions related to nutrient uptake, erosion control around the perimeter, and overall site stability. Plant berms and side-slopes with native grasses and vegetate the safety wetland bench with native aquatic species.

For retention ponds, transition from wetland to riparian vegetation over a depth of approximately 30 inches above the permanent pool, and transition from riparian to upland vegetation from 30 inches to 5 feet. Pay special attention to specification of vegetation in pond surcharge areas because vegetation in these areas must be able to tolerate moderate periods of inundation, as well as prolonged dry conditions between large rain events.

For constructed wetland ponds, plant wetland vegetation based on tolerance for permanent inundation at depths of 6 to 12 inches and riparian vegetation on banks that are inundated by the WQCV.

Retention and constructed wetland ponds present great opportunities for designers to use a wide variety of plant species to create biodiversity and provide flowering plants for pollinators. Dense vegetation around the perimeter of an open water body can discourage frequent use of the pond by geese and filter (strain) pollutants entering the pond.

8. **Outlet:** Design the outlet to release the WQCV over a 12-hour period for retention ponds and over a 24-hour period for constructed wetland ponds. The MHFD-Detention workbook, available at www.mhfd.org, performs these calculations, as well as sizing calculations for the EURV and 100-year storage volume for retention ponds that also are designed for flood control. See Section 6.0 *SCM Outflow Features* of this chapter for additional criteria pertaining to structure geometry, grates, trash racks, the orifice plate, other necessary components, and detailing.

   Maximize the orifice size, potentially just providing one orifice for retention ponds and constructed wetland ponds with the goal of meeting criteria to use a standard bar grate trash rack in lieu of a well screen. Provide a trash rack of sufficient size to allow for water flow to the orifice plate with a partially clogged trash rack. Extend the trash rack into the permanent pool a minimum of 28 inches to allow for water flow under the permanent pool in the event the exposed portion of the trash rack is clogged (similar to a micropool for an EDB).

   See Section 6.0 *SCM Outflow Features* of this chapter for additional information on designing trash racks for debris and for safety.

9. **Emergency Spillway and Overflow Embankment:** At a minimum, design the emergency spillway to convey the fully developed, undetained peak discharge for the 100-year design storm event. Design spillway structures in accordance with the *Storage* chapter, applicable Colorado dam safety regulations, and any local drainage criteria.

   Design the embankment to be stable during the 100-year storm. If the embankment falls under the jurisdiction of the State Engineer's Office (SEO), also meet SEO requirements for dam safety. Design embankment slopes to be no steeper than 4:1, preferably flatter, and planted with turf grasses. Excavate and replace poorly compacted native soils. Compact embankment soils to 95% of maximum dry density for ASTM D698 (Standard Proctor) or 90% for ASTM D1557 (Modified Proctor). Consider the use of stabilizing materials such as buried soil riprap or turf reinforcement mats installed per manufacturer's recommendations rather than exposed riprap.

Photograph RP/CWP-7. This pond outlet structure is accessible and functional while not interfering with the overall pond aesthetic.

Photograph RP/CWP-8. Barnum Park constructed wetland park shows transition from hydrophytic rushes to upland grasses.

10. **Pond Drain for Maintenance:** Provide a means to drain the pond to allow the pond to dry out when it must be "mucked out" to restore volume lost due to sedimentation. Provide drainage via gravity when feasible. An underdrain around the perimeter of the pond with a valved connection to the outlet structure may achieve this objective. Other alternatives include providing a drywell with a piped connection to the outlet structure or to a downstream conveyance element or connecting a valved pipe directly to the outlet structure. The pipe should include a valve that will only be opened for maintenance.

11. **Maintenance Access:** Provide all-weather stable access to the pond bottom, forebay, and outlet for maintenance vehicles. Use a minimum path width of 10 feet when designing for vehicle access. Do not exceed grades of 10% for haul road surfaces and 20% for skid-loader and backhoe access. Stabilized access includes concrete, articulated concrete block, concrete grid pavement, reinforced turf pavement, and other surfacing as accepted by the municipality. Provide a cross-slope for the access path of 2%.

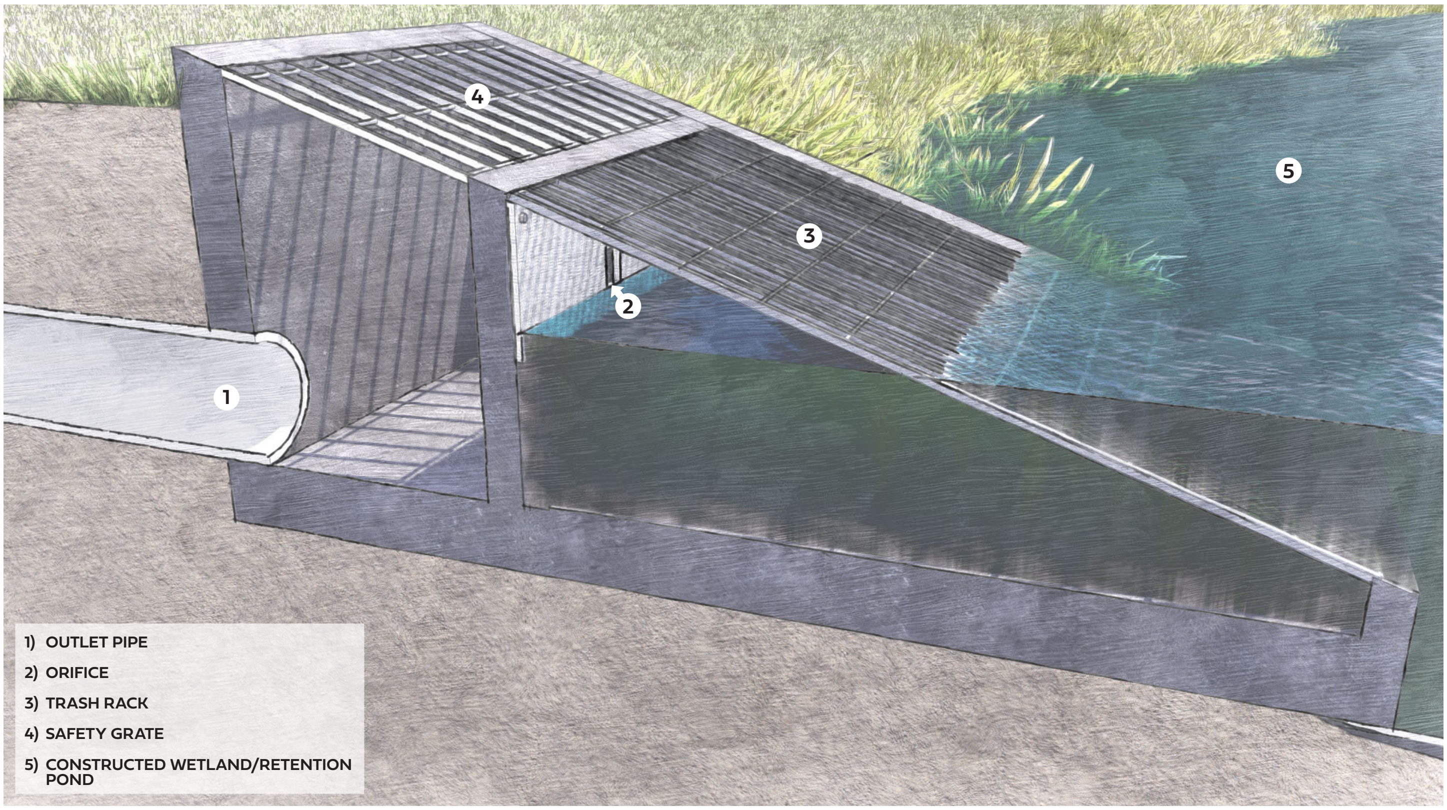


Figure RP/CWP-2. Retention Pond/Constructed Wetland Basin Outlet Structure

CONSTRUCTION CONSIDERATIONS

Successful construction of a retention or constructed wetland pond requires attention to management of water, installation of a liner (if used), and installation and establishment of the vegetation. Key construction considerations include:

- When using the pond area as a sedimentation basin during construction, fully rehabilitate the area to remove sediment and other materials accumulated during construction prior to filling and revegetating the pond.
- If the pond is located on a perennial or ephemeral drainageway, a temporary diversion may be required for construction of the SCM. See the Temporary Diversion fact sheet (SM-08) in Chapter 7 for additional information.
- If construction dewatering is required, a construction dewatering discharge permit from the Colorado Department of Public Health and Environment and/or local governments may be required.

- Plant health is critical to establishing a constructed wetland or retention pond. Inspect plants prior to installation to ensure they are healthy.
- After planting wetland species in a constructed wetland pond or on a wetland safety bench in a retention pond, the permanent pool should be kept at 3 to 4 inches deep in the newly-planted emergent plant zones to allow growth and to help establish the plants. Once vegetation is established, raise the pool to its final operating level.
- Plan for selective weed control during the vegetation establishment period. Use of herbicides is not recommended within the pond area since it is a water quality facility.
- When ponds are lined to reduce or eliminate seepage from the permanent pool, quality assurance/quality control is critical for liner installation to avoid puncturing the liner, leaky seams, improper anchoring, or other problems that can damage or reduce the lifespan of the liner.
- Temporary irrigation may be needed to establish wetland, transitional, and upland vegetation, especially if drier than normal conditions occur during the establishment period.

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T-8 MANUFACTURED TREATMENT DEVICES

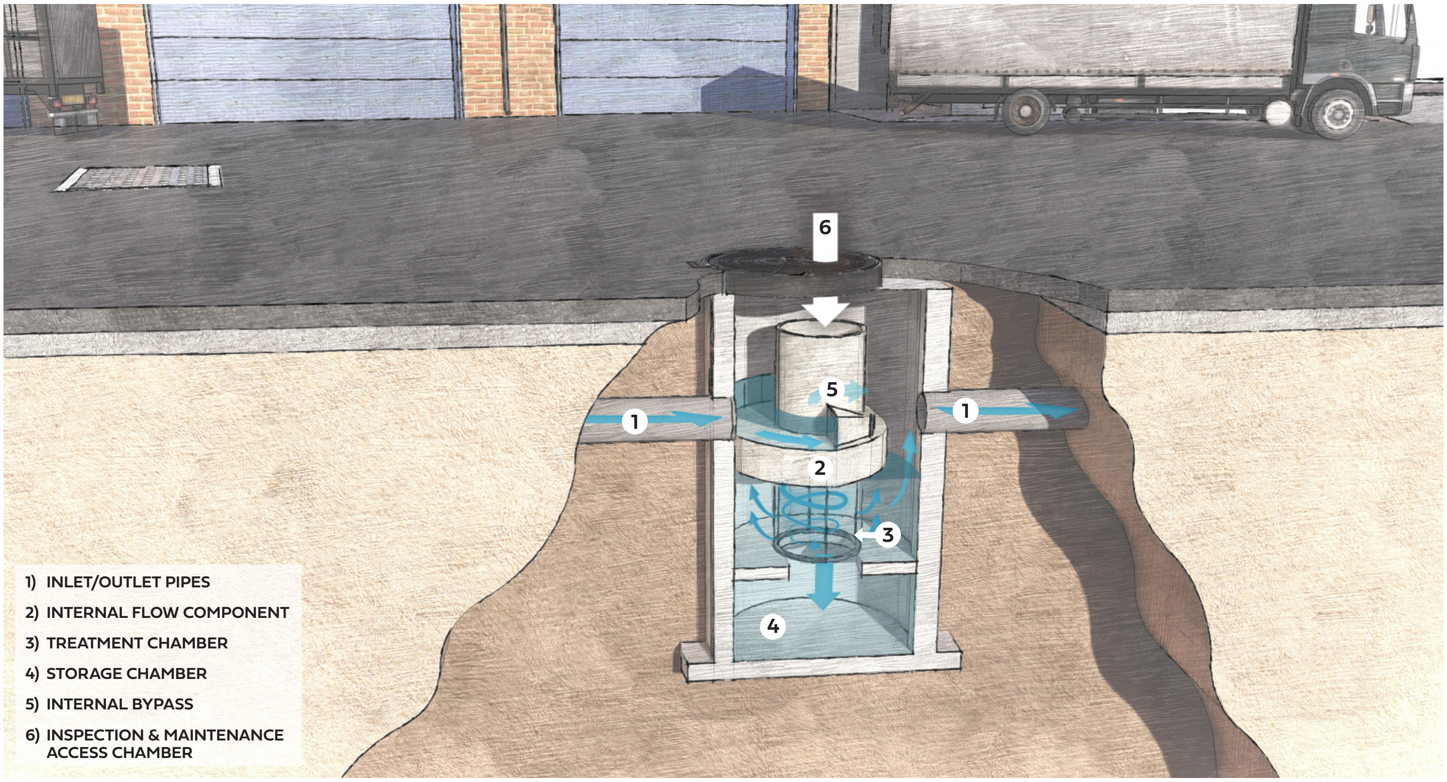

Figure MTD-1. Sedimentation MTD: Hydrodynamic Separator (Typical)

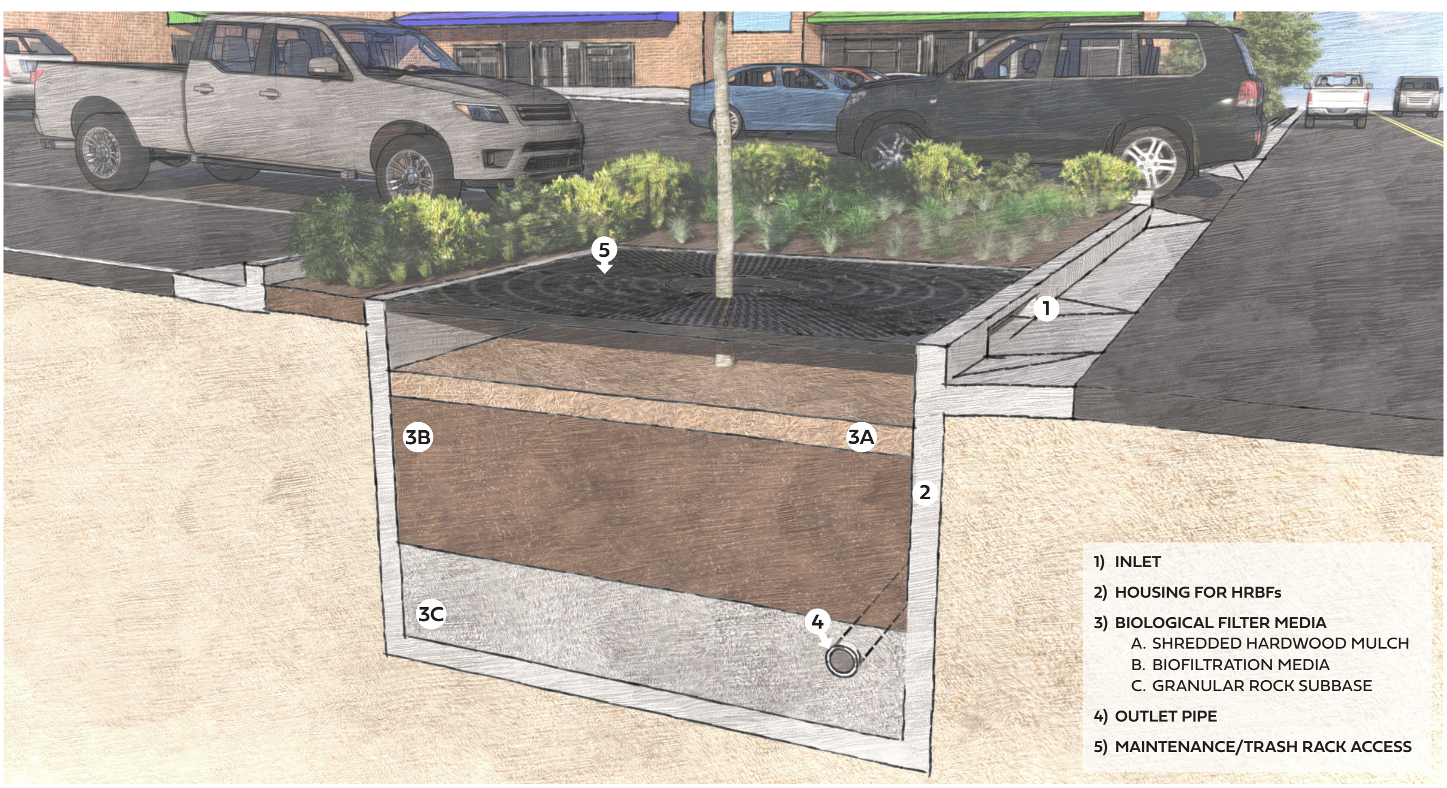

Figure MTD-2. Filtration MTD: High Rate Biofilter

GENERAL DESCRIPTION

Manufactured Treatment Devices (MTDs) include many different types of proprietary devices that use various treatment processes and designs to remove targeted pollutants. For example, some MTDs are suitable for pretreatment and gross solids removal, whereas others incorporate advanced designs targeting specific metals, nutrients, and other pollutants in stormwater runoff. Standardized testing protocols and third-party performance verification can be used to support selection of MTDs that meet treatment objectives for a site.

This fact sheet discusses two general categories of MTDs: sedimentation MTDs and filtration MTDs. Sedimentation MTDs use sedimentation processes to remove pollutants. The most common sedimentation MTDs are hydrodynamic separators (HDSs). Filtration MTDs utilize various filtration processes to remove pollutants and are subcategorized in this fact sheet as high-rate media filtration (HRMF) and high-rate biofiltration (HRBF) devices. Other types of MTDs are also available on the market but are not discussed in this fact sheet.

TABLE MTD-1. MTD OVERVIEW

MANUFACTURED TREATMENT DEVICES	HDS	HRMF	HRBF
MS4 Permit Applicability (Design-Dependent)			
Meets Runoff Reduction Standard	No	No	No[3]
Meets WQCV Capture Standard	No	No	No
Meets Pollutant Removal Standard	No[1]	Yes	Yes
Typical Effectiveness for Targeted Pollutants[1,2]			
Sediment/Solids	Medium	High	High
Total Phosphorus	Low	High[4]	High[4]
Total Nitrogen	Low	Medium	Medium
Total Metals	Low	High	High
Bacteria	Low	Low-Medium	Low-Medium
Common Applications			
Runoff Reduction (General)	No	No	No[3]
Pretreatment (in Treatment Train)	Yes	No	No
Primary Treatment	No	Yes	Yes
Integration with Flood Control[5]	No	No	No

[1] Typical effectiveness for HDSs is based on New Jersey Department of Environmental Protection laboratory testing protocol for HDSs (NJDEP 2021), with testing requirements for specific composition and gradation, average particle size, influent concentration, required inflow rates, and other parameters.

[2] Filtration MTD performance varies based on proprietary media/filter designs and targeted pollutants. "Typical" effectiveness descriptions are based on a combination of Washington Ecology's approved treatment technologies based on the Technology Assessment Protocol–Ecology (TAPE) use designation and the International Stormwater BMP Database 2020 Summary Statistics.

[3] The Runoff Reduction Standard is not typically met with HRBF devices sold as-is. HRBFs can be designed/retrofitted with additional appurtenances, such as extra underdrain pipe(s) or a chamber on the downstream side of the device, which will detain and regulate the release of treated stormwater and allow for infiltration. Open-bottomed HRBFs may meet the runoff standard, depending on site-specific conditions.

[4] Total phosphorus removal is typically high when it is specifically targeted for removal with proprietary media.

[5] MTDs can be added upstream of flood control facilities in a treatment train, but flood control is not typically provided within the MTD itself.

SEDIMENTATION MTD DESCRIPTION

Sedimentation MTDs include hydrodynamic separators (HDSs) and other MTDs utilizing sedimentation processes. These devices typically use gravity and/or centripetal force coupled with strategically placed components to separate, settle, trap, and retain coarse particulates. The primary target pollutant of sedimentation MTDs is suspended sediment.[1] Some systems target sediment exclusively, while others also provide trash and debris removal and/or oil and grease separation. Collected pollutants are typically directed to and stored in a collection chamber within the

[1] Suspended solids are often measured as suspended sediment concentration (SSC), which is similar to total suspended solids (TSS), but typically is a slightly higher concentration due to the inclusion of larger particles as a result of the SSC sampling method. See Gray (2000) for additional information.

device, and treated stormwater is discharged back into the storm drain system.

Most sedimentation MTDs are constructed as concrete vaults with maintenance access; however, some sedimentation MTDS are housed in plastic pipe, depending on the specific device and manufacturer. These structures serve as housing for the internal components of the MTD. The inner components and configurations differ among products and manufacturers.

HDSs are the most common sedimentation MTD in the Front Range of Colorado. Unlike SCMs that detain and release, filter, or infiltrate the WQCV, HDSs treat stormwater over a short residence time, typically providing a lower level of treatment than storage-, filtration-, or infiltration-based SCMs. As stand-alone practices, sedimentation MTDs do not meet the Runoff Reduction, WQCV, or Pollutant Removal Standards[2] in Colorado MS4 Permits. Therefore, these MTDs are most appropriate for a stormwater treatment train system as a pretreatment component. For example, many HDSs can remove coarse particulates and buoyant materials like trash and debris; therefore, they can play an important role in providing pretreatment to reduce maintenance requirements and costs for downgradient SCMs in a treatment train.

When evaluating sedimentation MTDs, it is important to evaluate the maintenance frequency needed to maintain performance. For most MTDs, the volume of sediment is the primary indicator for when maintenance is needed. In this case, frequency of maintenance is ultimately a function of available storage capacity. Storage capacities vary widely among the many available sedimentation MTDs on the market today. If unavailable from the manufacturer, consider referencing the NJDEP certification letter for the MTD, which lists verified storage capacities.

SEDIMENTATION MTD TERMINOLOGY

There are several commonly used terms that are used to define how a sedimentation MTD functions, such as swirl concentration, cyclonic separation, vortex separation, and screening. These terms are synonymous, each referencing the process of using centripetal force and/or gravity, coupled with a target velocity, to provide the hydraulics required to remove a specified amount of sediment of a specified particle size gradation from stormwater. This process has become most widely referred to as hydrodynamic separation, and the MTDs that perform this process are called HDSs.

SEDIMENTATION MTD COMPONENTS

Sedimentation MTDs include a variety of designs to promote sedimentation. For HDSs, the primary components typically include: 1) an inflow pipe that conveys runoff into the device, 2) a "swirl" and/or treatment chamber that removes pollutants, 3) a storage chamber for removed pollutants, 4) various internal plates and/or weirs that promote sedimentation, 5) an outlet pipe that conveys treated runoff to the downstream storm drain system, and 6) a maintenance hole that provides access to the chambers to allow sediment removal (Table MTD-2). These components often are housed in a precast concrete vault or maintenance hole. The internal components of the MTD create unique hydraulics that remove and retain sediment and other pollutants while allowing runoff that is treated to pass through the MTD.

[2] As of 2022, HDSs have not met the 30 mg/L effluent Pollutant Reduction Standard when following standard TAPE or NJDEP (2021) laboratory testing protocols.

TABLE MTD-2. HDS COMPONENTS

HDS COMPONENTS	INTENT
Inlet Pipe(s)	Convey runoff into the MTD.
Internal Flow Components	Create hydraulic conditions to remove sediment, trash, debris, and other pollutants (components vary by device).
Treatment Chamber	Provides an environment where hydrodynamic separation and/or gravitational settling occurs. The treatment chamber often has a cylindrical shape to create a vortex as runoff flows through the device. Sediment is removed by gravitational settling, centripetal forces, and/or screens and weirs.
Storage Chamber	Stores pollutants removed from the treatment chamber.
Internal Bypass	Provides integrated internal bypass mechanism to convey flows that exceed the peak design flow of the system.
Outlet Pipe	Conveys runoff from the BMP into the storm drain.
Maintenance Access	Allows access for inspection and maintenance of chambers via a maintenance hole or access hatch at grade.

FILTRATION MTD DESCRIPTION

Filtration MTDs, including high-rate media filters (HRMFs) and high-rate biofilters (HRBFs), treat stormwater by filtering it through engineered media at high hydraulic loading rates. As a result, HRMFs and HRBFs require a smaller footprint than traditional bioretention and sand filter SCMs to treat a given runoff volume.

HRMFs use one or more media types to remove pollutants from stormwater. Commonly used materials include sand, peat, crushed rock, volcanic rock, granular activated carbon, compost, minerals, granular organic materials, and fabrics. Consult with the manufacturer for information on media types targeted to treat specific pollutants. The filter media, configuration of internal parts, and hydraulics of HRMFs are proprietary and differ among HRMFs.

HRBFs treat stormwater with engineered media that supports vegetation. Physical, biological, and chemical processes occur between the media and the vegetation of an HRBF. Treatment processes include filtration, transpiration, evaporation, settling, biological uptake, microbiological uptake, and pollutant transformation.

Both HRMFs and HRBFs can be well suited to provide treatment in densely developed urban settings, new developments with limited available space, urban retrofits, and large-scale projects where traditional bioretention is cost-prohibitive due to the surface area required to meet large-volume treatment goals.

FILTRATION MTD COMPONENTS

The primary components of HRMFs and HRBFs include: 1) an inflow pipe that conveys runoff into the MTD, 2) a chamber that contains the various layers of biological filter media (HRBF) or non-biological filter media (HRMF) to remove pollutants, 3) one or more storage chambers for removed pollutants (HRMFs and some HRBFs), 4) an outlet pipe to convey treated runoff to the downstream storm system or other outfalls, and 5) maintenance access points to the filter media and storage chambers (Table MTD-3). For HRBFs, the filter media layers typically include shredded hardwood mulch as the top layer, a proprietary biological media mixture, and a well-draining, compactible gravel subbase layer with an underdrain to facilitate drainage to the outlet. Some types of HRBFs are installed similarly to conventional bioretention and may not require a housing chamber.

HRMFs and HRBFs are considered “high rate” when stormwater can infiltrate through the media at a faster rate than the infiltration rate of typical saturated Type A and B soils. Some products have been third-party verified as having infiltration rates up to 175 inches per hour while also meeting target treatment performance standards (Washington Ecology 2020). Although stand-alone HRBFs typically do not meet the Runoff Reduction Permit Standard, they can be configured as a treatment train with a pipe or downstream storage chamber that enables infiltration of treated stormwater.

TABLE MTD-3. HRMF AND HRBF COMPONENTS

HRMF AND HRBF COMPONENTS		INTENT
Inlet Pipe		Convey runoff into the MTD.
Housing Chamber		Houses internal components in concrete vaults, maintenance holes, steel containers, plastic containers, or steel mesh baskets.
Filter Media (for HRMFs)		Removes targeted pollutants via filtration through proprietary media and a specific type of filtration process. Media filter and hydraulic configurations vary substantially among devices (e.g., cartridges or other filter units, upflow or downflow).
Biological Filter Media (for HRBFs)	Shredded Hardwood Mulch	Removes coarse particulates and other buoyant materials from runoff, helps media retain water for later vegetative use, provides pretreatment for the other filter media layers.
	Biofiltration Media	Filters and treats stormwater through physical, biological, and chemical processes and biological interaction with vegetation. Decomposes organics, reduces heavy metals through adsorption and removes fine particulates and hydrocarbons. Enables biological growth.
	Subbase & Underdrain	Provides gravel layer with underdrain to facilitate drainage to the outlet pipe.
Pollutant Storage Chamber(s)		Provides internal storage for collected pollutants.
Outlet Pipe		Conveys stormwater out of the filtration MTD.
Maintenance Access		Provides access to pollutant storage chambers and media chambers to facilitate inspection and maintenance activities. Enables repairs and part replacements (e.g., replace filter cartridges, wash filters).

SITE CONSIDERATIONS FOR MTDS

MTDs are most applicable in highly developed, space-limited urban areas because they require a nominal area of land at grade. Underground MTDs generally are located beneath parking lots, sidewalks, and low-traffic streets. HRBFs are often situated along sidewalks, curbs, parking islands, or landscaped areas.

Consider the following factors when determining if an MTD is suitable for a site:

- **Tributary Area:** As the first step in MTD selection and sizing, characterize the tributary drainage area of the site, land use and imperviousness, pollutant types and sources, and soil erosion characteristics. Use this information to evaluate whether various MTDs can effectively control pollutants at the site. For example, a sedimentation MTD is unlikely to provide meaningful treatment for areas where targeted pollutants are fine sediment, nutrients, or dissolved pollutants. Conversely, if a site has coarse sediment, trash, and debris, an appropriately sized and maintained sedimentation MTD can serve as effective pretreatment practice to reduce long-term O&M costs for downstream control measures.
- **Assess the Need for Pretreatment:** For filtration-based MTDs, assess conditions in the tributary area to determine whether pretreatment may be needed to prevent overloading of filter media.
- **Third-Party Verification for Treatment Objectives:** Review information provided in third-party verification programs to verify whether performance expectations for the MTD meet the treatment needs at the site and/or MS4 permit design standards. For example, treatment objectives could include pretreatment for a stormwater facility, treatment for targeted pollutants, or specific pollutant removal objectives in critical areas. Treatment capabilities among MTDs vary; therefore, review of third-party performance verification is a required step in MTD selection.

TABLE MTD-4. TYPICAL BENEFITS AND LIMITATIONS OF SELECTED MTD TYPES

TYPICAL BENEFITS AND LIMITATIONS OF SELECTED MTD TYPES			
Characteristic	HDS	HRMF	HRBF
Removes trash, debris, and other buoyant materials and stores material below ground (out of sight).	Yes[1]	Yes	No[2]
Depending on the product, it may include processes to remove oil and grease.	Yes	Yes	Yes
Effective pretreatment for primary treatment SCMs and detention facilities.	Yes	No[3]	No[3]
Effective treatment at high surface loading rates with a small footprint. Suitable for constrained sites in highly urbanized areas (space-efficient).	Yes	Yes	Yes
Delivered as one package for assembly and/or installation.	Yes	Yes	Yes
Provides vegetated features in urban areas.	No	No	Yes
Allows other uses of surface area due to underground installations and/or small surface footprint.	Yes	Yes	Yes
Meets one or more MS4 Permit design standards. (Effective for stand-alone treatment of stormwater.)	No	Yes	Yes
Depending on the product and its media design, it may remove fine particles, targeted metals, or phosphorus.	No	Yes	Yes
Potential for resuspension of captured pollutants.	Yes[4]	No	No
Maintenance needs are visible at surface.	No	No	Yes

[1] Most HDS systems remove trash, but not all have appropriate configurations to retain captured trash and still provide the same level of performance for retaining sediment. If add-ons are proposed to provide trash capture, it is important to verify treatment performance is not adversely affected. This can be done by contacting the manufacturer or verifying whether the specific MTD reviewed by NJDEP included the proposed add-ons. If the device verified by NJDEP did not include add-ons, reported performance levels may be affected. If trash capture is a specific objective, California State Water Control Boards (2021) provides recommendations for MTDs suitable for trash removal.

[2] Can remove trash and other materials, but the captured material is typically stored aboveground.

[3] Considered primary treatment SCMs.

[4] Most modern HDS systems have been tested for scour through the NJDEP protocol at 200% of the maximum treatment flow rate. Additionally, ASTM has developed a standard for testing for scour. Check test results to confirm that scour rates are acceptable.

- **Geotechnical Considerations:** Consult with a geotechnical engineer to determine if soils on a site will provide the necessary bearing capacity for the MTD without settlement over time and to identify any soil preparation or backfill requirements needed for a stable foundation and appropriate backfill around the device. Additionally, in areas of shallow bedrock, ensure that there is enough depth available to accommodate the specified MTD. If soils are contaminated and the MTD does not require imported fill to be used as backfill, consider specifying a soil-tight MTD.
- **High Water Table:** Exercise caution when using underground MTDs in areas with a shallow water table due to potential issues with the exfiltration of stormwater to groundwater or infiltration of groundwater into the device. Surface-based MTDs are more appropriate in areas with high water tables because they require less depth to install than underground MTDs. MTDs should also be used with caution in areas with contaminated soils. Additional waterproofing may be necessary to prevent the exfiltration of stormwater from the MTD into the contaminated soils or infiltration of contaminated water into the MTD system. In some cases, high groundwater is not anticipated or evaluated during design and prior to construction. In such cases, waterproofing methods similar to those used for sanitary maintenance holes are recommended. When systems are expected to be partially submerged in groundwater for periods of time, buoyancy must be evaluated. Consult with the manufacturer and review buoyancy calculations.

- **Location and Access:** Evaluate land uses that will occur above the MTD to ensure clear and unobstructed access for routine and emergency inspection and maintenance activities. Areas directly above the MTD should be clear of structures, vehicles, and other items that could obstruct access or visual inspection at any time. When feasible, avoid locating maintenance holes or vaults beneath traffic lanes so that traffic control is not required for routine maintenance activities. When possible, provide signage related to the facility to ensure others do not block maintenance access or use the location as a staging area (for materials or snow storage). Additionally, if the device is located under a street or parking lot, the MTD will need to be rated for traffic loads.
- **Parking Structures and Other Structures Built Above MTDs:** Avoid installing MTDs beneath parking structures or other types of buildings. In cases where no alternatives are feasible, local governments should consider additional requirements to ensure adequate maintenance access and operation throughout the MTD's life cycle. Coordination with geotechnical and structural engineers is required to ensure that the device will not interfere with the building foundation, structural support, dewatering systems, or other utility lines. MTDs installed beneath parking garages or other structures must be accessible at all times (e.g., maintenance access holes cannot be located beneath parking spots, frequent access routes, or storage areas). Parking garages often limit height clearances and do not provide enough vertical clearance for maintenance vehicles to enter and access subsurface MTDs during maintenance operations.
- **Elevation Constraints:** Evaluate elevation constraints. The depth of the MTD and the invert elevations of the inlet and outlet pipes often depend on the elevation of the local storm drain outfall when a site discharges treated stormwater into a public storm drain system. When discharging to a stream or river, consider the normal high-water elevation. Verify that the MTD will work with the operational head provided from the inlet pipe to outlet pipe and is consistent with the system tested for pollutant removal through TAPE or NJDEP. The operational head

ORGANIZATIONS WITH TESTING PROTOCOLS FOR MTDS

TAPE – Technology Assessment Protocol–Ecology (TAPE) is the stormwater quality treatment certification program implemented by the Washington State Department of Ecology for evaluating the performance of emerging technologies to treat polluted stormwater (WSDOE 2018a&b). The TAPE protocol is recognized in dozens of states and municipalities across the country to assist with approving MTDs and innovative stormwater treatment technologies.

TARP – Technology Acceptance Reciprocity Partnership was the stormwater treatment certification protocol used by New Jersey Department of Environmental Protection prior to 2015 to certify the level of treatment performance of MTDs. This program was disbanded in 2015.

NJDEP HDS Protocol – New Jersey Department of Environmental Protection published the Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Devices in 2021 (NJDEP 2021). (This protocol essentially supplants the TARP program.) Additionally, NJDEP certifies performance using the HDS or filter protocol, as opposed to "verifying" manufacturer claims.

NJCAT – New Jersey Corporation for Advanced Technology has a Technology Verification Program that specifically encourages collaboration between vendors and users of technology. This program evaluates vendor-specific performance claims. Be aware that NJCAT verification is not synonymous with NJDEP certification.

STEPP –The National Municipal Stormwater Alliance (NMSA) established the National Center for Stormwater Testing and Evaluation for Products and Practices (STEPP) to promote development of a national testing and verification program for MTDs and public domain stormwater practices. STEPP will provide a program for third-party testing and verification of pretreatment MTDs, primary treatment MTDs, and traditional surface-based SCMs that will be a useful reference for designers and reviewers once the program is launched.

ASTM – American Society for Testing and Materials is currently developing a national standard for the performance of MTDs under ASTM Committee E64 on Stormwater Control Measures. The standard is consistent with the NJDEP laboratory testing protocol and, once published, can be used to evaluate the performance of MTDs. Additionally, a field-testing protocol is under development similar to the TAPE protocol.

is a critical variable; if there is not enough head, the system may not achieve the desired flow rates and pollutant removal demonstrated in the verification testing. Verify that the MTD will work with pipes installed at elevations that give enough fall to the public storm drain system or receiving water and that the depth of the device is adequate to provide the necessary treatment and storage volumes. Assess the potential effects of tailwater from the downstream conveyance system. Tailwater effects can impede MTD performance by affecting the hydraulics of the device. Many MTDs can be designed with customized internal flow controls to accommodate tailwater conditions.

- **Existing Underground Utilities:** For retrofits or projects proposed in developed areas, identify existing underground utilities that may constrain the footprint and depth at which the MTD can be placed.

COMMUNITY VALUES

The primary benefit of underground MTDs to the surrounding community is maximizing the amount of surface space dedicated to other uses in dense urban environments, including plazas, parking areas, and other services that benefit the community. MTDs can create space available for recreation, benches, parks, and landscaping, street trees, and other public amenities.

For MTDs with dead storage and standing water, care must be taken to avoid creating nuisance conditions. Performing regular maintenance can prevent nuisances such as mosquitos and odor in the summer months. Additionally, if vector control is a specific issue for the site, some manufacturers can provide solutions to address and control the issue.

In the case of HRBFs, the vegetated surface area, which may include native plants and/or trees, can serve as an aesthetic amenity in urban areas while still having a relatively small surface footprint. Many HRBF vendors can provide a regional plant list to help select appropriate plants for the Front Range climate. Provide irrigation for establishment of vegetation and use drought-tolerant species.

MAINTENANCE

Maintenance requirements are a fundamental consideration when specifying an MTD. Proper routine maintenance is critical for the adequate function of the MTD. Before MTD selection, obtain and review manufacturer's maintenance guidance, including inspection methods, maintenance frequency, types of maintenance activities, equipment, maintenance methods, and cost. The guidance should clearly describe how to inspect and maintain the device, triggers for maintenance, and methods for measuring sediment to determine when maintenance is needed. Pollutant loading and characteristics can vary based on site characteristics; therefore, adjust maintenance frequency and costs accordingly. Also, consider confined space entry requirements, availability of maintenance contractors, materials replacement cost/frequency, and sediment disposal requirements. Maintenance requirements can vary significantly depending on the specific MTD. An operations and maintenance plan is needed for each installation. As part of the MTD selection process, request estimates of life-cycle costs from the manufacturers.

Most sedimentation MTDs require a vacuum truck with a hose that will extend to the storage chamber. This can remove most trash and debris in addition to sediment. In some MTDs, trash, litter, and debris are stored in a separate compartment from accumulated sediment, and access may be through a different maintenance hole or hatch. Confined space entry access may be necessary.

For sedimentation MTDs that act as traps for trash, debris, and sediment, the need for maintenance is indicated by sediment accumulation, with triggers for maintenance typically specified by the manufacturer. Frequency of maintenance is ultimately a function of available storage capacity, pollutant loading rates for the tributary watershed, and the removal efficiency of the treatment devices.

HRMF maintenance focuses on its filter media and filter configuration; therefore, each HRMF has a unique set of maintenance requirements based on media type and the unit's hydraulics. Typical maintenance involves either cleaning the filter media or replacing it with new media. The former usually involves thoroughly rinsing the filter media with clean water and removing any collected pollutants. When maintenance requires the replacement of filters or a component of the filter, the manufacturer's instructions should provide clear information on methods, costs, expected frequencies, and proper disposal of materials.

Maintaining HRBFs typically requires routine replacement of the shredded mulch on the top layer of the MTD and removal of trash and debris that has accumulated on top of the mulch or against the inlet trash rack or grate. Over time, sediment will clog the mulch layer and inhibit stormwater from flowing through the underlying media layer as intended. The shredded hardwood mulch specified by the manufacturer should be used exclusively when replacing the mulch layer. When properly maintained on a regular basis, biofilter media below the mulch layer and the plants of some HRBFs has been reported to have a low media replacement frequency (e.g., some manufacturers report 8-10 years).

Similar to other vegetated SCMs, irrigation of HRBFs may be necessary; therefore, water availability for irrigation can be an essential consideration for HRBF selection. Some HRBFs can customize internal components to provide additional water availability for vegetation in arid conditions. Drought-tolerant species may also alleviate or reduce the volume of water needed for irrigation. If a limited water supply is available for irrigation, the smaller footprint of HRBFs may require less irrigation compared to other SCMs.

MAINTENANCE CONSIDERATIONS DURING MTD SELECTION

To avoid selection of MTDs with onerous maintenance requirements, consider the following:

- Review manufacturer's maintenance guide to determine the frequency and types of maintenance activities required. The guidance should clearly describe how to inspect and maintain the device, triggers for maintenance, and methods for measuring accumulated pollutants to determine when maintenance is needed.
- MTD collection chambers must be accessible by maintenance equipment and unimpeded by internal weirs and baffles. MTDs that allow visual observation of collected pollutants are easier to inspect and maintain than devices that do not provide visual indicators.
- Assess how much time it will take to inspect and maintain the MTD and whether the time requirement is a reasonable expectation for the entity responsible for maintenance.
- Avoid MTDs that require confined space entry for routine maintenance activities. Be aware of confined space entry requirements for clearing out clogged orifices, pipes, and weirs that will likely be required under certain conditions for underground MTDs.
- Identify and review documents, forms, and tools needed for inspection and maintenance. These may include an inspection and maintenance plan, inspection forms, required personal protective equipment, and equipment necessary for maintaining the MTD.
- For HDSs, identify how a vacuum truck will access the different chambers of the MTD and ensure that standard suction hose lengths can reach the bottom of the vault of the maintenance hole. MTD designs should allow easy access with the suction hose to maneuver the vacuum suction hose to extend to the bottom and the full extent of each device's chamber.
- Salts from deicing contribute to the deterioration of concrete and other materials in sedimentation MTDs. Therefore, for installations where deicing activities regularly occur during the winter, plan on a few additional inspection and maintenance visits during winter to rinse accumulated salts out of the device with a hose. Salt may also affect plant growth in HRBFs. If salt is a concern, HRBF manufacturers may offer salt tolerant plantings.

DESIGN PROCEDURE

Design procedures and criteria are specific to the type of MTD selected and must follow the manufacturer's design and specification procedure, as well as local jurisdiction requirements. Most sedimentation- and filtration-MTDs are sized based on flow rate; however, some can be sized based on volume and/or flow rate. The general steps for sizing and specification based on flow rate are described below as general guidance, recognizing that some variation in the procedure may be required or help to optimize application of various MTDs for different site requirements. The generalized procedure below is typically applicable to sedimentation MTDs; where this design procedure conflicts with the manufacturer's design procedure, follow the manufacturer's design procedure, provided that the water quality event defined in Volume 1 is treated. Some steps below may apply only to certain types of MTDs.

1. **Calculate the water quality event peak flow rate, WQPF:** Sedimentation and filtration MTDs are typically sized based on a design peak flow rate. The water quality event peak flow rate (WQPF) is the peak discharge associated with the 80th percentile runoff event, corresponding to a storm depth of 0.6 inches. See the *Runoff* chapter in Volume 1 for guidance on calculating the discharge associated with the water quality event.

2. **Determine the maximum treatment flow rate, Q_{MAX}:** The maximum treatment flow rate is the greatest flow rate that can be discharged through an MTD while still achieving specific treatment efficiency goals such as percent TSS removal and/or maximum effluent concentrations of TSS. Compare the WQPF with the maximum treatment flow rate (Q_{MAX}) for a given MTD. The MTD is acceptable for further consideration if Q_{MAX} is greater than or equal to WQPF. Third-party verification of maximum treatment flow rates is important to ensure the MTD does not surcharge or experience excessive scouring of accumulated sediment at the Q_{MAX}.

   For HDSs, the manufacturer specifies the maximum treatment flow rate for a given HDS type and size. To ensure that the selected HDS provides adequate performance at the Q_{MAX}, verify that that the HDS is included on the "Laboratory Verified and NJDEP Certified" list and also verify the HDS hydraulic loading rates specified in the NJDEP Certification letter.[3]

   For HRMFs and HRBFs, the manufacturer specifies Q_{MAX} for a given HRMF/HRBF type and size. To ensure that the selected HRMF/HRBF provides adequate performance at the Q_{MAX}, verify the HRMF/HRBF infiltration or hydraulic loading rates specified in the TAPE GULD approval letter.[4]

3. **Identify potentially appropriate MTDs:** Because various MTDs will meet the WQPF requirements for a given site, consider which devices are best suited to site characteristics, the pollutants targeted at the site, and the ability to meet MS4 permit design standards. Verify performance claims based on data obtained through established testing protocols, including established third-party verification programs (see text box). Verify that the hydraulic loading rate of the proposed MTD is equal to or less than the hydraulic loading rate approved by third party verification programs.

4. **Evaluate inflow and outflow pipes configurations:** Allowable pipe configurations vary widely between products, and designers must understand vertical and horizontal pipe placement constraints. The angle between the inlet and outlet pipe, often dictated by the proposed storm drain system layout, is crucial for sedimentation MTDs to function

SIMPLIFIED DESIGN PROCEDURE OVERVIEW

A simplified overview of key steps in the design procedure for MTDs includes:

1. Calculate the water quality event design flow for the site.
2. Calculate peak bypass flow for the site.
3. Select an approved MTD based on project requirements. Use the NJDEP list of approved MTDs for projects that only require sedimentation (pre-treatment). Use the Washington State Department of Ecology list of MTDs with a General Use Level Designation (GULD) for Basic, Enhanced, or Phosphorus for projects that require filtration to meet the Colorado MS4 performance standard of 30 mg/L.
4. Confirm the MTD meets the needs of the site and can be installed per manufacturer's recommendations. If not, return to step 3.

[3] For a list of NJDEP-certified devices, see https://www.nj.gov/dep/stormwater/treatment.html.

[4] For a list of TAPE-approved technologies, see https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Emerging-stormwater-treatment-technologies.

as intended. The design engineer must understand the manufacturer's allowable pipe layouts and entrance/exit locations, any pipe orientation or angle constraints, and horizontal and vertical placement requirements for the MTD. Some sedimentation MTDs accommodate multiple inlet pipes, while others only allow one inlet and one outlet pipe. Some devices require a 180-degree angle between the inlet and outlet pipes, while others allow for variable angles and multiple inlet pipes. During design, check that inflow and outflow elevations are appropriate for the MTD being specified and within the design flow recommendations from the manufacturer. Some MTDs are very sensitive to inlet and outlet elevations. For example, filtration MTDs often require specific operational head (drop from inlet to outlet). Elevations that differ from the tested and verified configuration can influence whether the MTD functions as intended. If atypical elevations or operational head are present, consult with the manufacturer to build in redundancy and conservatism in order to meet treatment objectives.

5. **Evaluate internal flow components:** Internal flow components in a sedimentation MTD facilitate sedimentation and retain captured pollutants despite the short hydraulic residence times of runoff in these devices. Internal flow components may include baffles, weirs, deflection plates, screens, and other features and are typically standard features designed by the manufacturer rather than the design engineer. Therefore, the designer should evaluate

VERIFYING PERFORMANCE WHEN SELECTING AN MTD

MHFD does not have a technology verification program or maintain a list of "approved" MTDs. Instead, designers should utilize information available through other state and national verification programs to support MTD selection. National verification programs such as STEPP, supported by new ASTM standards, are under development as of publication of this fact sheet and may be appropriate for use in the future. Two existing well-established programs that can be used to support MTD selection are described below. Ultimately, it is the responsibility of the design engineer, not the manufacturer, to ensure that the specified MTD will meet the water quality requirements for a given project.

NJDEP FOR SEDIMENTATION MTDS

Sedimentation MTDs on the "Stormwater Technologies: Laboratory Verified and NJDEP Certified" list on the NJDEP's website (https://www.nj.gov/dep/stormwater/) are verified to provide levels of treatment that are suitable for pretreatment of runoff (i.e., 50% TSS removal). If a product claims to be "NJCAT-verified" but is not on the list referenced above, it is not an acceptable pretreatment device. This is because NJCAT "verification" is not synonymous with meeting the NJDEP protocol. A product can receive verification from NJCAT for any performance criterion it can demonstrate it meets; however, the performance criterion for which it receives verification may not meet the performance standards in the NJDEP (2021) Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation MTD (and likely does not meet them). See NJDEP (2022) and NJDEP (2021) for additional information.

More than a dozen sedimentation MTDs on the NJDEP list are verified and certified to meet the performance standards outlined in the NJDEP HDS protocol; however, not all offer internal bypass capability. Most devices target TSS, but not trash, and many, but not all, can remove oil and grease using absorbent pads. Storage capacities vary widely between the different devices, as do maximum treatment flow rates necessary to meet the pollutant removal standard for a given device size.

TAPE FOR FILTRATION MTDS

The Technology Assessment Protocol – Ecology (TAPE) is the program implemented by Washington State Department of Ecology for reviewing and certifying proprietary MTDs. The agency's website https://ecology.wa.gov/ (use search terms "TAPE" or "Stormwater Treatment Technologies"), categorizes proprietary products approved for use in Washington State based the level of use each product has been approved for, and the type of treatment each product provides, in accordance with the TAPE program.

Filtration MTDs expected to meet Colorado's MS4 performance standard for 30 mg/L TSS include those with a General Use Level Designation (GULD) for Basic, Enhanced, or Phosphorus treatment categories under the TAPE program.

the ability of internal flow components to control targeted pollutants, ease of maintenance, and durability when comparing MTD alternatives.

6. **Assess storage chamber size and access:** Most sedimentation MTDs have a separate chamber or sump area that stores collected pollutants. The storage chamber is designed to retain sediment, litter, and debris removed in the treatment chamber and minimize the potential for resuspension. Consider the sediment, trash, and debris loads from the contributing drainage area, and select a device with sufficient storage to limit routine maintenance to once or twice per year. An undersized storage chamber leads to nuisance conditions and frequent maintenance. Provide direct access from the street level to the storage chamber for inspection and maintenance.

7. **Size the internal bypass:** An internal bypass is built into some sedimentation MTDs to divert flow that exceeds the water quality event peak flow rate and convey flow around the treatment and storage chambers to prevent resuspension of pollutants. This mechanism is called an "internal bypass" because the pipe or weir that bypasses the larger flows are typically incorporated as a component within the MTD. Internal bypasses are typically less expensive than an external bypass, which requires additional maintenance holes and pipe. Internal bypass configurations may vary widely across devices; however, the layout of the bypass must be hydraulically compatible with the storm drain system's upstream and downstream elevations. Size the internal bypass peak flow rate for the maximum design flows expected in the upstream and downstream storm drains. If a sedimentation MTD does not have an internal bypass, an external bypass is required.

8. **Compute the Hydraulic Grade Line (HGL) and Energy Grade Line (EGL):** Compute the HGL and EGL for the MTD and the upstream and downstream storm drain system following procedures and criteria in the *Streets, Inlets, and Storm Drains* chapter of Volume 1. The bypass should be designed to avoid pressurized flow and prevent resuspension of accumulated pollutants. When backwater conditions are present, account for high tailwater when evaluating the hydraulics of the MTD and bypass and verify that the device will operate as intended (some MTDs require a specific range of velocities within the treatment chamber to create unique hydraulic effects to remove sediment). When evaluating emergency overflows, calculate the HGL and EGL for design flow rates assuming that the filter is completely plugged and passes no flow.

9. **Plan access to all chambers:** Maintenance access configurations vary between products. Direct, unobstructed access to all chambers of a sedimentation MTD is required for maintenance operations and repair.

10. **Confirm the selected MTD.** Once the MTD has been selected (based on the process and considerations above), complete any remaining design steps for the specified MTD per the manufacturer's requirements and recommendations.

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Chapter 5
Source Control BMPs

Contents

Tables

1.0 Introduction

Proactively controlling pollutants at their source is fundamental to effective stormwater quality management and is part of the Four Step Process outlined in Chapter 1 of this manual. Typically, it is easier and more cost-effective to prevent stormwater pollution than to remove contaminants once they have entered the storm sewer system or receiving water. Local governments, industries, businesses and homeowners all have opportunities to implement source control practices that help prevent pollution. A good source control BMP is one that is effective at stopping and/or redirecting pollutants prior to entering the storm sewer system. A source control BMP can be a structural component of a planned site (e.g. a covered area for material storage) or a procedural BMP. The latter depend on behavior change accomplished through public education, training and development of standard operating procedures.

This chapter provides BMP Fact Sheets for common source control practices that can be integrated into overall stormwater management plans by local governments, industries and businesses. BMPs applicable to homeowners can also be used for integration into local government public education and awareness efforts related to stormwater quality.

Effective source control also requires awareness of discharges such as commercial washing of outdoor structures, which produces process wastewater that is not appropriate for discharge to the storm drain system. Table 5-1 summarizes types of pollutants generated at various types of facilities that may be reduced from implementation of the source controls found in this chapter. General guidance for selecting source control practices follows, along with the Source Control BMP Fact Sheets.

Table 5-1. Potential Pollutant Sources and Types with Applicable Source Control BMPs

	Type of Facility				Pollutants Associated with Activity					Source Control BMP Fact Sheets
Potential Pollutant Sources	Municipal	Industrial	Commercial	Residential	Sediment/ Litter/ Debris	Nutrients/ Organic Matter	Bacteria	Hydro-carbons	Toxics/ Chemicals/ Paint	
Outdoor Material Storage and Handling	x	x	x		x	x		x	x	Covering Outdoor Storage & Handling Areas Spill Prevention, Containment & Control
Heavy Equipment and Vehicle Maintenance/Storage Activities	x	x	x					x	x	Covering Outdoor Storage & Handling Areas Spill Prevention, Containment & Control Vehicle Maintenance, Fueling & Storage
Parked Vehicles	x	x	x	x	x			x		Vehicle Maintenance, Fueling & Storage
Vehicle Fueling	x	x	x					x		Vehicle Maintenance, Fueling & Storage
Roads	x	x	x		x	x	x	x		Street Sweeping
Deicing Chemicals/Snow Storage	x	x	x	x	x	x	x	x		Snow and Ice Management
Waste Storage/Disposal Practices	x	x	x	x	x	x	x	x	x	Good Housekeeping Illicit Discharge Control
Landsapes (e.g. fertilizers, herbicides, pesticides, excessive irrgation)	x	x	x	x	x	x	x	x	x	Landscape Management Pesticide, Herbicide& Fertilizer Application & Handling
Storm Drain System (accumulated materials)	x				x	x	x	x	x	Storm Sewer System Cleaning
Pets				x		x	x			Good Housekeeping Illicit Discharge Control

2.0 Structural Source Controls

Photograph 5-1. This commercial materials storage area drains directly to a storm drain. Effective site design would have located this storage area away from a storm drain and directed runoff to a landscape bed or provided additional covering and containment that would both protect the material and reduce pollutant loading to the storm sewer.

Site operations and potential pollution source control needs should be considered early in the planning and design process. This will reduce the load of pollutants into stormwater and may also facilitate site operations and reduce maintenance requirements for on-site treatment BMPs. Representative questions that should be considered prior to finalizing the site layout include:

1. What materials are stored on-site?
2. How are these materials handled and moved through the site?
3. What on-site operations take place that could potentially cause materials to enter the storm sewer system?
4. Where and how might these materials enter the storm sewer?
5. How can storage and handling areas and drainage facilities be designed to reduce pollutant loading? Is it feasible to cover these areas?
6. When a spill occurs, how and where will it be controlled and contained? Are structural spill containment measures needed? What is the relationship between these areas and planned treatment BMPs (Chapter 2) for the site?

Use good judgment when planning your site and consider BMP Fact Sheets *S-1 Covering of Storage and Handling Areas* and *S-2 Spill Prevention, Containment and Control* early in the planning and design process. Structural source control measures must also be combined with appropriate employee training. For example, if a covered structure and spill containment area are constructed at an industrial site, but employees conduct operations subject to spills (e.g., drum storage) in other portions of the site, the structural BMP will not be effective.

3.0 Procedural Source Control BMPs

Procedural BMPs are actions or procedures that can be implemented to reduce pollutant loading. These practices are critical at stormwater "hotspots," but can also be effective when behavior change in residential areas occurs over entire watersheds. Examples of stormwater hotspots and the operations that cause pollution at hotspots are provided in the inset on the following page and in Table 5-2.

3.1 Municipal Operations

Communities regulated under Phase 1 or Phase 2 of the NPDES program are required to develop a program to:

- Prevent or reduce the amount of polluted stormwater generated by municipal operations;
- Educate employees to incorporate pollution prevention and good housekeeping practices into municipal operations; and
- Identify BMPs and measurable goals for the prevention or reduction of the amount of polluted stormwater that is generated by municipal operations.

Examples of Stormwater "Hotspots"

- Fleet storage areas
- Solid waste facilities
- Wastewater treatment plants
- Composting facilities
- Nurseries and garden centers
- Restaurants
- Industrial rooftops
- Recycling facilities
- Maintenance facilities
- Gas stations
- Fast-food drive-thru areas
- Airports

Developing an effective municipal pollution prevention and good housekeeping program involves implementing a program that 1) is specifically designed for a community, taking into consideration how information is communicated and how training is provided and received, and 2) incorporates sound standard practices for various operations. Many communities nationally and in the metro Denver area have developed such standard operating procedures. The Fact Sheets provided in this chapter may be used to develop such procedures or to supplement existing procedures. Development of a program that is specifically tailored to a community should begin with evaluation of the following questions (Center for Watershed Protection 2008):

1. What municipal operations are conducted within the community?
2. What stormwater pollutants are associated with the operations?
3. Who is responsible for managing each of the operations?
4. What is the primary pollutant of concern in the subwatershed?
5. Which of the operations has the greatest influence on water quality and should be the focus of the community's pollution prevention/good housekeeping efforts?
6. What specific pollution prevention/good housekeeping practices should be implemented to improve the operations?
7. How much will the pollution prevention/good housekeeping practices cost?
8. Who will be responsible for implementing the pollution prevention/good housekeeping practices?
9. How will progress made in pollution prevention/good housekeeping be evaluated?

Developing a Municipal Program

Urban Subwatershed Restoration Series Manual 9: Municipal Pollution Prevents/Good Housekeeping Practices prepared by The Center for Watershed Protection (2008), outlines a detailed approach for developing a municipal pollution prevention/good housekeeping program. The manual is available to download at no cost at www.cwp.org.

Table 5-2. Polluting Activities Associated With Common Hotspot Operations

(Source: Center for Watershed Protection 2005)

Polluting Activities Associated With Common Hotspot Operations	
Hotspot Operation	Polluting Activity
Vehicle Operations	▪ Improper disposal of fluids down shop and storm drains ▪ Spilled fuel, leaks and drips from wrecked vehicles ▪ Hosing of outdoor work areas ▪ Wash water from cleaning ▪ Uncovered outdoor storage of liquids/oils/batteries spills ▪ Pollutant wash-off from parking lot
Outdoor Materials	▪ Spills at loading areas ▪ Hosing/washing of loading areas into shop or storm drains ▪ Wash-off of uncovered bulk materials and liquids stored outside ▪ Leaks and spills
Waste Management	▪ Spills and leaks of liquid ▪ Dumping into storm drains ▪ Leaking dumpsters ▪ Dumpster juice ▪ Wash-off of dumpster spillage
Physical Plant Maintenance	▪ Discharges from power washing and steam cleaning ▪ Wash-off of fine particles from painting/sandblasting operations ▪ Rinse water and wash water discharges during cleanup ▪ Temporary outdoor storage ▪ Runoff from degreasing and re-surfacing
Turf and Landscaping	▪ Non-target irrigation ▪ Runoff of nutrients and pesticides ▪ Deposition and subsequent wash-off of soil and organic matter on impervious surfaces ▪ Improper rinsing of fertilizer/pesticide applicators

3.2 Commercial and Industrial Operations

Commercial and industrial source controls focus primarily on reducing exposure of materials to rainfall and runoff and preventing non-stormwater discharges to storm sewers. Check federal and state requirements for obtaining and complying with stormwater discharge permits. The following BMP Fact Sheets are targeted to commercial and industrial operations:

- S-1 Covering Outdoor Storage & Handling Areas
- S-2 Spill Prevention Containment and Control
- S-5 Good Housekeeping

- S-6 Preventative Maintenance
- S-7 Vehicle Maintenance, Fueling & Storage
- S-10 Snow and Ice Management

Other fact sheets related to landscape management may also be helpful at commercial and industrial sites with landscaping.

3.3 Residential Activities

Although residential activities that may pollute stormwater runoff are typically conducted on a smaller scale than industrial, commercial and municipal operations, the cumulative impact of residential sources of pollution can be significant. As discussed in Section 3.1, municipal stormwater programs should include efforts to reduce pollution from residential areas within their jurisdiction. This is often accomplished through a combination of ordinances, public education efforts and incentives. BMP Fact Sheets provided in this chapter that are applicable to residential sources of pollution include:

- S-3 Disposal of Household Waste
- S-4 Illicit Discharge Controls
- S-5 Good Housekeeping
- S-8 Use of Pesticides, Herbicides and Fertilizers
- S-9 Landscape Maintenance
- S-10 Snow and Ice Management

4.0 Combining Source Control BMPs to Target Pollutants of Concern

In many cases, local governments will need to combine multiple source control practices and strategies to target control of specific pollutants. For impaired streams that have been assigned Total Maximum Daily Loads (TMDLs), municipal stormwater discharge permittees may receive a wasteload allocation, resulting in specific requirements to reduce pollutant loading in their stormwater permits. For example, bacteria is a leading cause of stream impairment nationally and in Colorado. Table 5-3 provides an example of a multi-faceted source control plan targeted toward reducing bacteria loading to streams. Similar combinations of source control practices can be targeted toward nutrients and other pollutants. To produce long-term behavioral change, a well-planned and executed public education campaign may be needed, combined with incentives and fines.

Table 5-3. Example Source Control Plan Targeting Bacteria
(Source: Colorado E. coli Work Group and WWE 2009)

Bacteria Source	**Potential BMP/Management Strategy**
Urban Areas	
Domestic Pets (dogs and cats)	Signage to pick up dog waste, providing pet waste bags and garbage cans. Enforcement of pet waste ordinances. Use of dog parks away from environmentally sensitive areas.
Urban Wildlife	Reduce food waste sources from commercial waste/grease spillage entering the storm drain.
Illicit Connections to Storm Sewers	Identification and removal of illicit sanitary and floor drain connections through municipal stormwater dry weather survey programs.
Leaking Sanitary Sewer Lines	"TVing" sanitary sewer lines to identify leaks or breaks that may cause seepage of untreated sanitary wastewater to streams or storm sewers.
Illegal Dumping	Enforcement, by municipal stormwater programs, related to illegal dumping.
Runoff from Urban Areas	Encouraging low impact development and development designs that minimize directly connected impervious areas, allowing stormwater to seep into the ground rather than run off into storm sewers. See Chapters 3 and 4.
Dry Weather Irrigation Flows	Dry weather flows from storm sewers can be reduced through better-controlled lawn/park irrigation practices.
Transient Populations	Support of city shelters and services to reduce homelessness.
Open Space	
Waterfowl Canadian Geese	Population controls (e.g., egg oiling, addling, dog harassment). See www.geesepeace.org for more information. Habitat modification is another potential BMP. Restoration of degraded riparian buffers.
Wildlife: Beavers, deer, raccoons, coyotes, mice	Consult with Colorado Division of Wildlife (CDOW); consider controls to make storm drains less desirable as animal homes; beaver trapping and relocation may be a consideration. Restoration of degraded riparian buffers.
Domestic Pets	See description above. In addition, strategic trail design incorporating vegetative buffers and grading away from the stream. Restoration of degraded riparian buffers.

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Description

Photograph CS-1. Covered truck loading dock helps reduce exposure of materials to runoff.

When raw materials, byproducts, finished products, storage tanks, and other materials are stored or handled outdoors, stormwater runoff that comes in contact with the materials can become contaminated. Proactively covering storage and handling areas can be an effective source control for such areas. Coverings can be permanent or temporary and consist of tarp, plastic sheeting, roofing, enclosed structures, or other approaches that reduce exposure of materials to rainfall, runoff, and wind.

Appropriate Uses

Covering is appropriate for areas where solids (e.g., gravel, salt, compost, building materials) or liquids (e.g., oil, gas, tar) are stored, prepared, or transferred. Consider covering the following areas:

- **Loading and Unloading**: Loading and unloading operations usually take place outside on docks, truck terminals, or outside storage or staging areas at industrial and commercial sites. Materials spilled, leaked, or lost during loading and unloading may collect in the soil or other surfaces and be carried away by runoff, or when the area is cleaned. In addition to spills to the ground surface, rainfall may wash pollutants off machinery used to unload and load materials. Materials may be spilled during transfer between storage facilities and truck or rail car during pumping of liquids, pneumatic transfer of dry chemicals, mechanical transfer using conveyor systems, or transfers of bags, boxes, drums, or other containers by forklift, trucks, or other material handling equipment.

- **Aboveground Tanks/Liquid Storage**: Accidental releases of chemicals from above-ground liquid storage tanks can contaminate stormwater with a variety of pollutants. Several common causes of accidental releases from above-ground tanks include: external corrosion and structural failure, problems due to improper installation, spills and overfills due to operator error, failure of piping systems, and leaks or spills during pumping of liquids or gases between trucks or rail cars to a storage facility.

- **Outside Manufacturing**: Common outside manufacturing activities may include parts assembly, rock grinding or crushing, metals painting or coating, grinding or sanding, degreasing, concrete manufacturing, parts cleaning or operations that use hazardous materials. These activities can result in dry deposition of dust, metal and wood shavings and liquid discharges of dripping or leaking fluids from equipment or processes and other residuals being washed away in storm runoff. In addition to the manufacturing process, outside storage of materials and waste products may occur in conjunction with outside manufacturing.

- **Waste Management**: Wastes spilled, leached, or lost from outdoor waste management areas or outside manufacturing activities may accumulate in soils or on other surfaces and be carried away by rainfall runoff. There is also the potential for liquid wastes from surface impoundments to overflow to surface waters or soak the soil where they can be picked up by runoff. Possible stormwater contaminants include toxic compounds, oil and grease, oxygen-demanding organics, paints and solvents, heavy metals and high levels of suspended solids. Lack of coverage of waste receptacles can result in rainwater seeping through the material and collecting contaminants or the material being blown around the site and into the stormwater collection system. Typical contaminant sources include: landfills, waste piles, wastewater and solid waste treatment and disposal, land application sites, dumpsters, or unlabeled drums.

- **Outside Storage of Materials**: Raw materials, intermediate products, byproducts, process residuals, finished products, containers, and materials storage areas can be sources of pollutants such as metals, oils and grease, sediment and other contaminants. Pollutant transport can occur when solid materials wash off or dissolve into water, or when spills or leaks occur.

- **Salt Storage:** Salt left exposed to rain or snow may migrate to the storm sewer or contaminate soils. Salt spilled or blown onto the ground during loading or unloading will dissolve in stormwater runoff. Stormwater contaminated with salt in high concentrations can be harmful to vegetation, aquatic life and groundwater quality. Typical contaminant sources include salt stored outside in piles or bags, salt loading and unloading areas, and salt/sand storage piles used for deicing operations.

Practice Guidelines

- Where practical, conduct operations indoors. Where impractical, select an appropriate temporary or permanent covering to reduce exposure of materials to rainfall and runoff.

- The type of covering selected depends on a variety of factors such as the type and size of activity being conducted and materials involved. Types of cover range from relatively inexpensive tarps and plastic sheeting to overhead structures or fully enclosed buildings equipped with ventilation, lighting, etc.

- Covering practices should be combined with Good Housekeeping BMPs to be most effective. Spill containment berms are also often needed at industrial sites.

- Measures such as tarps and plastic sheets typically require more frequent inspection and maintenance than constructed facilities.

Spill Prevention, Containment and Control S-2

Description

Photograph SPCC-1. Use of secondary containment around supplies stored outside helps to reduce the likelihood of spill and leaks reaching the storm sewer system in runoff. Photo courtesy of Tom Gore.

Spills and leaks of solid and liquid materials processed, handled or stored outdoors can be a significant source of stormwater pollutants. Spilled substances can reach receiving waters when runoff washes these materials from impervious surfaces or when spills directly enter the storm sewer system during dry weather conditions.

Effective spill control includes both spill prevention and spill response measures and depends on proper employee training for spill response measures and may also include structural spill containment, particularly at industrial locations. Structural spill containment measures typically include temporary or permanent curbs or berms that surround a potential spill site. Berms may be constructed of concrete, earthen material, metal, synthetic liners, or other material that will safely contain the spill. Spill control devices may also include valves, slide gates, or other devices that can control and contain spilled material before it reaches the storm sewer system or receiving waters.

Appropriate Uses

Implement spill prevention, containment and control measures at municipal, commercial and industrial facilities in areas where materials may be spilled in quantities that may adversely impact receiving waters when discharged directly or through the storm sewer system. Check local, state, and/or federal regulations to determine when spill containment and control measures are required by law. Spill Prevention, Control and Countermeasures Plans may be required for certain facilities handling oil and hazardous substances sunder Section 311(j)(1)(C) of the federal Clean Water Act.

Practice Guidelines

Also See These BMP Fact Sheets

- Covering Storage/Handling Areas
- Good Housekeeping
- Vehicle Fueling, Maintenance, Washing & Storage
- Preventative Maintenance

Spill Prevention Measures

- Train employees on potential sources of pollution on-site and provide clear, common-sense spill prevention practices. Require that these practices be strictly followed.
- Identify equipment that may be exposed to stormwater, pollutants that may be generated and possible sources of leaks or discharges.
- Perform regular inspection and preventative maintenance of equipment to ensure proper operation and to check for leaks or evidence of discharge (stains). Provide clear procedures to ensure that needed repairs are completed and provide temporary leak containment until such repairs can be implemented.

- Drain or replace motor oil and other automotive fluids in a designated area away from storm sewer inlets. Collect spent fluids and recycle or dispose of properly. Never dispose of these fluids in the storm sewer or sanitary sewer.

- In fueling areas, clean up spills with dry methods (absorbents) and use damp cloths on gas pumps and damp mops on paved surfaces. Never use a hose to "wash down" a fuel spill.

- Where practical, reduce stormwater contact with equipment and materials by implementing indoor or covered storage, implementing stormwater run-on control measures and following good housekeeping practices.

Identification of Spill Areas

Identify potential spill areas, potential spill volumes, material types, frequency of material use, and drainage paths from spill areas with relation to storm sewer inlets, adjacent waterbodies, structural BMPs, and containment structures. Use this information to determine the types of spill prevention and control measures needed specific to the site conditions. Examples of potential spill locations include:

- Loading and unloading areas

- Outdoor storage areas

- Outdoor manufacturing or processing activities

- Waste disposal/storage areas

- Areas that generate significant dust or particulates (that may be subsequently deposited on the ground)

- Salt piles

- Areas prone to spills based on past experience at the site

- Locations where other routine maintenance activities occur such as equipment maintenance and cleaning, pesticide/fertilizer application, etc.

Additionally, areas where smaller leaks may occur such as parking should also have basic spill cleanup procedures.

Material Handling Procedures

From a water quality perspective, the primary principle behind effective material handling practices is to minimize exposure to stormwater. This can be accomplished by storing the material indoors under weather-resistant covering, elevating the material off the ground by using pallets, and diverting stormwater around materials storage areas. Representative outdoor materials handling procedures include:

- Keep bulk solid materials such as raw materials, sand, gravel, topsoil, compost, concrete, packing materials, metal products and other materials covered and protected from stormwater.

- When practical, store materials on impermeable surfaces.

- Store hazardous materials according to federal, state, and local hazardous materials requirements.

- Adopt procedures that reduce the chance of spills or leaks during filling or transfer of materials.
- Substitute less toxic or non-toxic materials for toxic materials.
- Store containers that are easily punctured or damaged away from high traffic areas (i.e., adopt a materials flow/plant layout plan).
- Add waste-capture containers such as collection pans for lubricating fluids.
- Store drums and containers with liquid materials on impermeable surfaces and provide secondary containment where appropriate. Drums stored outdoors should be located on pallets to minimize contact with runoff.

Spill Response Procedures and Equipment

Spill response procedures should be tailored to site-specific conditions and industry-specific regulatory requirements. General spill response procedures include:

- Containment and cleanup of spills should begin promptly after the spill is observed.
- Sweep up small quantities of dry chemical or solids to reduce exposure to runoff. Shoveling may be used for larger quantities of materials.
- Absorbents should be readily accessible in fueling areas or other areas susceptible to spills.
- Wipe up small spills with a shop rag, store shop rags in appropriate containers, dispose of rags properly or use a professional industrial cleaning service.
- Contain medium-sized spills with absorbents (e.g., kitty litter, sawdust) and use inflatable berms or absorbent “snakes” as temporary booms for the spill. Store and dispose of absorbents properly. Wet/dry vacuums may also be used, but not for volatile fluids.
- Develop procedures and locations for containing and storing leaking containers.
- Install drip pans below minor equipment leaks and properly dispose of collected material until a repair can be made.
- For large spills, first contain the spill and plug storm drain inlets where the liquid may migrate off-site, then clean up the spill.
- Excavation of spill areas to removed contaminated material may be required where large liquid spills occur on unpaved surfaces.
- An inventory of cleanup materials should be maintained onsite and strategically located based on the types and quantities of chemicals present.

Structural Spill Containment Measures

Two general approaches are often used when implementing spill containment measures. The first approach is designed to contain the entire spill. The second approach uses curbing to route spilled material to a collection basin. Both containment berming and curbing should be sized to safely contain or convey to a collection basin a spill from the largest storage tank, rail car, tank truck, or other containment device in the possible spill area. The spill containment area must have an impermeable surface (e.g., impermeable liner, asphalt or concrete) to prevent groundwater contamination. The containment system must be designed to enable collection and removal of spilled material through a pump or vacuum trucks, use of sorbent or gelling material, or other measures. Material removed from the spill area must be disposed of or recycled according to local, state, and federal standards.

If the capacity of the containment berming or the collection basin is exceeded, supplemental spill control measures should be available such as a portable containment device, sorbent materials, or gelling agents that eventually solidify the material. Water that collects within containment areas due to rainfall or snowmelt must be appropriately treated before release from the spill area.

Spill Plan Development

Many industries are required by federal law to have a Spill Prevention, Control and Countermeasures Plan (SPCC) that meets specific regulatory criteria when certain types and quantities of materials are used or processed at a site. These plans can be instrumental in developing a spill control plan for stormwater management purposes. Even if an SPCC plan is not legally required at a site, a spill control plan for stormwater management purposes may be necessary. Representative information appropriate for a spill control plan, building on concepts previously introduced in this Fact Sheet, includes:

- Site plan showing where materials are stored and handled, and where associated activities occur.
- Notification procedures to be used in the event of an accident
- Instructions for clean-up procedures.
- A designated person with spill response and clean-up authority.
- Training of key personnel in plan and clean-up procedures.
- Signs posted at critical locations providing a summary of SPCC plan information, phone numbers, contacts, equipment locations, etc.
- Provisions requiring spills to be cleaned up, corrective actions taken, or countermeasures implemented immediately.
- Provisions for absorbents to be made available for use in fuel areas, and for containers to be available for used absorbents.
- Prohibition on washing absorbents into the storm drainage system or into the sanitary sewer system via floor drains.
- Provision for emergency spill containment and clean-up kits in accessible and convenient locations. Kits should contain the appropriate clean-up materials applicable to the materials stored at the site.

Key Spill Notification Contacts in Colorado

- Colorado Department of Public Health and Environment Toll-Free 24-hour Environmental Emergency Spill Reporting Line: 1-877-518-5608
- National Response Center: 1-800-424-8802 (24-hour)
- Local Emergency Planning Committee (OEM): 303-273-162
- Division of Oil & Public Safety-Storage Tanks: 303-318-8547
- Oil and Gas Conservation Commission: 303-894-2100 or 1-888-235-1101 (toll-free spill/complaint line)

Description

Improperly disposed household wastes are a source of stormwater pollution. These wastes can include household chemicals, pet waste, yard waste, litter, automotive maintenance waste, and others. These materials can be transported in stormwater when the materials are dumped directly into the storm drains or when they are spilled on impervious surfaces and washed into the storm sewer system. Household wastes can contribute solids, nutrients, oxygen demanding substances, toxic substances, and bacteria to receiving waters. Improper disposal of household wastes on the ground surface can also lead to groundwater contamination.

Photograph DHW-1. Placing storm drain markers (or stenciling) at storm sewer inlets is a public education tool that can be used to educate citizens and discourage improper disposal of household waste in storm drains. Photo courtesy of Nonpoint Source Colorado.

Proper disposal of household waste is dependent on behavioral change, which can be encouraged through public education programs and local ordinances that prohibit improper disposal of household waste. Additionally, local governments can provide appropriate facilities for proper disposal of waste.

This Fact Sheet focuses primarily on household waste. See the Good Housekeeping Fact Sheet for additional information on waste management at commercial and industrial sites.

Appropriate Uses

Educational efforts related to proper disposal of household waste can be targeted to homeowners and businesses through municipal programs, civic groups, and others. Local governments should consider measures needed in the following general categories:

- **Household/Commercial Waste**: Household waste includes materials discarded on the land surface or into the stormwater system from residential and commercial areas. Wastes from commercial businesses are generated by stores, restaurants, hotels, offices, and other non-manufacturing activities. Household waste disposal objectives include containing and properly disposing of refuse (garbage), reducing litter, and encouraging proper household toxic waste disposal through public education and access to appropriate disposal facilities.

- **Litter**: Most litter is biodegradable and can create an oxygen demand in water as it decomposes. Examples of litter are paper products, used diapers, etc. Research by Keep America Beautiful, Inc. (1990) has shown that people litter where litter has already accumulated. Also according to Keep America Beautiful, Inc. (1987), pedestrians and motorists account for less than 25 percent of litter, with the other sources being household waste, commercial and industrial waste, haulage vehicles, loading docks, and construction sites. Reduction of litter through proper disposal can reduce its accumulation on the urban landscape and its eventual entry into the stormwater system.

- **Pet Waste**: Pet waste deposited on the ground can be transported by the storm drainage system to receiving waters or by overland flow into waterways. Fecal matter potentially contains pathogenic viruses and bacteria; it also creates an oxygen demand in water. The majority of improperly disposed pet waste occurs in public areas, such as streets and parks. Pet waste ordinances are common in municipalities; however, these are difficult to enforce, especially with limited municipal resources. Education can help bring this problem to the public's attention, and can thereby reduce deposition of pet waste on urban surfaces.

- **Yard Waste**: Yard waste includes limbs, leaves and grass clippings that can contribute nutrients, lawn chemicals, and oxygen demand to receiving waters when washed into storm sewers and waterways. Public education efforts on the benefits of composting and on proper disposal of yard waste can help to reduce the volume of yard waste entering the stormwater system and receiving waters. Most yard waste can be reused following composting, with the exception of weeds and diseased plant materials.

Composting

Composting is a natural method for recycling organics such as yard trimmings and food scraps, which comprise nearly a quarter of municipal solids waste generated (Keep America Beautiful 2010). Nearly half of all U.S. states now ban yard waste from landfills because it represents such a large volume that can be productively composted. Composted yard waste used as mulch or soil amendment can provide landscape water conservation benefits, reduce the burden on landfills and is protective of water quality.

- **Used Oil and Automotive Fluids**: Used oil and automotive fluids including antifreeze, brake fluid, transmission fluid, grease, other lubricants, and petroleum-based cleaning solvents are wastes generated during automobile maintenance by residential households and commercial businesses. These can enter the storm drainage system if poured directly into storm inlets or from residual on concrete or asphalt exposed to precipitation. Improper disposal of used oil and automotive fluids causes receiving waters to become contaminated with hydrocarbons and residual metals that can be toxic to stream organisms. Used oil and other petroleum products can be recycled and are accepted by many auto parts stores and repair shops. Public education on the location of these centers, the benefits of recycling, prevention of fluid leaks, and the importance of proper disposal for improving stormwater quality can reduce the amounts of oil and used automotive fluids reaching receiving waters.

- **Toxic Wastes**: Toxic wastes are generated in small quantities by residential households and commercial businesses. Examples include paint, solvents, putties, cleaners, waxes, polishes, oil products, aerosols, acids, caustics, pesticides, herbicides, and certain medicines or cosmetics. These products and their containers should always be disposed of in accordance with the product label or recycled, if appropriate. When such toxic substances are improperly disposed of by dumping on impervious surfaces or into street gutters or storm inlets, stormwater can transport these materials to receiving waters.

Municipal Recycling Programs

Many communities throughout the country have implemented municipal recycling programs, rather than relying on citizens to research and seek out recycling opportunities on their own. Curbside recycling programs and municipal education campaigns can improve the success of recycling programs. For more information on implementing a municipal recycling program, visit a variety of U.S. Environmental Protection Agency websites such as: http://www.epa.gov/epawaste/conserve/rrr/index.htm and http://www.epa.gov/region4/waste/rcra/mgtoolkit/index.html or review well developed local programs such as Denver Recycles.

Practice Guidelines

To reduce improper disposal of household waste, implement public education efforts regarding how improper disposal of wastes can degrade the quality of streams, rivers, lakes, and wetlands. Local governments have many public education options that can be tailored to fit local needs and budget constraints the best. Within local governments, opportunities for coordinated efforts among multiple departments may be beneficial. For example, properly composting of yard waste can provide a stormwater benefit when these materials are kept out of the gutter, as well as a water conservation benefit when the materials are reused as mulch and a solid waste management benefit when these materials are kept out of landfills. Similarly, public works and parks and recreation departments both benefit from efforts related to pet waste disposal signage as well as disposal facilities in parks.

Photograph DHW-2. Check with state and local water quality agencies for public education materials such as this door hanger developed by the Keep It Clean Partnership that can be adopted for use in your community. Photo courtesy of Nonpoint Source Colorado.

Representative public education strategies may include:

- Development, publication, and distribution of brochures.
- Utility bill inserts, flyers, and handbills.
- Newspaper articles and/or advertisements.
- Development and distribution of educational videos.
- Public workshops, field demonstrations, or presentations to targeted civic organizations, youth organizations, etc.
- Developing and offering school curricula or assembly programs.
- Creating posters, signs, and graphics for installation at parks, school hallways, trails, etc.
- Storm drain stenciling to discourage dumping of materials into storm drains.
- Signs, including graphics, on dumpsters and other locations encouraging proper waste disposal.
- Signs in parks and along streets on pet waste control and ordinances.
- Brochures and utility bill inserts on separation of wastes and recycling.
- Advertising the locations of existing toxic disposal sites and waste recycling centers.
- Advertising the locations of existing automobile fluids and used oil disposal sites.

- Developing campaigns promoting voluntary neighborhood clean-up efforts.
- Advertisements or notices of private locations accepting yard waste for composting.
- Information on backyard or neighborhood composting and proper disposal of yard waste.

In addition to public education efforts, local governments can provide facilities that provide readily available proper disposal opportunities. These practices include:

- Establishing and maintaining household toxics disposal sites.
- Annual or curbside collection of household toxics.
- Pet waste disposal bags in public parks.
- Providing waste containers in problem litter areas.
- Requiring waste-haulage truck covers.
- Seasonal or on-going collection programs for grass clippings, tree branches, and leaves with disposal at composting or chipping facilities, paired with distribution programs for reuse of composted or chipped materials.

With regard to household toxics, local governments should be aware that collection and disposal of household wastes is expensive. Such programs require adequate training of operators, analysis of unknown materials, safe transport and containers, extensive recordkeeping and awareness of regulatory requirements (e.g., the federal Resource Conservation and Recovery Act) regarding disposal of such materials.

Description

Photograph IDC-1. Mapping and dry weather investigation of storm sewer outfalls is an important tool in identifying and removing illicit connections. Photo courtesy of WWE.

Illicit discharges are non-stormwater discharges into a storm drain system, with some limited exceptions specified in state and local discharge permits (e.g., fire fighting water, springs, and others). Examples of illicit discharges include illegal dumping (e.g., used oil), accidental spills, failing septic systems, improper disposal of sewage from recreational activities such as boating or camping, and improper plumbing of sanitary discharges from residences and commercial or industrial establishments into the storm sewer system. A common cause of illicit discharges is connection of building or garage or floor drains to the storm sewer system.

Control of illicit discharges involves a multi-faceted effort based on knowledge of the storm sewer system, use of ordinances to prohibit illicit discharges, development of a coordinated plan to detect and address illicit discharges, and a public education program to increase awareness of the problems caused by illicit discharges.

Appropriate Uses

Illicit discharge control measures are usually implemented by municipal governments and metropolitan districts, but may also be relevant to campus-scale developments or industries. Illicit discharge controls are closely related to practices identified in the Good Housekeeping BMP Fact Sheet.

Practice Guidelines

Practice guidelines for illicit discharge controls are discussed in three general categories:

1. Public education to reduce illegal dumping and discharges,

2. Municipal actions to identify and remove illegal connections to the storm sewer system, and

3. Accidental spill response measures.

Public Education to Reduce Illegal Dumping and Discharges

Public education and awareness are the foundation for reducing illegal dumping and some types of illicit discharges. For example, many citizens may not be aware that storm sewers drain to streams rather than wastewater treatment plants or may not be aware of the environmental damage caused by discharging soapy water, pet waste and other household wastes into the storm sewer system. Local governments should select public awareness and education approaches most effective for their communities, which may include a combination of some of these practices:

- Enactment of clearly written ordinances prohibiting illegal dumping and illicit connections. Many local governments already have such ordinances; however, citizens are often unaware of these. Publicity including news articles, door hangers, utility bill inserts, radio or TV advertisements, website highlights and other measures can be used to increase awareness. Such efforts may be particularly effective when connected to a specific water quality problem such as stream or lake impairments due to bacteria and/or nutrients.

- Storm drain stenciling involves placing a marker or using a stencil to paint a message on storm drains to discourage dumping down the storm drain. These messages are a public education tool so that citizens are aware that the materials that they dump down to the storm drain are discharged to a stream, as opposed to a wastewater treatment plant.

- Provide citizens with readily available contact information to report illegal dumping. Install a "hotline" telephone number to handle calls from citizens reporting illegal dumping or accidental spills.

- Create brochures and other guidance for businesses related to illegal discharges to the storm drain. Educational efforts should not only alert business owners that non-stormwater discharges are not allowed, but also provide guidance on BMPs to implement. For example, power washing discharges are process wastewater that may not be discharged to the storm sewer system. When power washing is conducted, storm drain inlet protection, wet vacuuming, collection systems, and/or other appropriate measures to prevent washwater from entering the storm drain system should be implemented.

Illicit Connections

Eliminating illicit connections plumbed into the storm drain system involves two different components:

1. Identifying and removing existing illicit connections; and

2. Preventing new illicit connections.

<u>Removing Existing Connections</u>

Existing illicit connections of sanitary sewers to the storm drainage system in existing developments can be identified by a systematic dry weather inspection of storm sewer outfalls following readily available illicit discharge detection and elimination guidance available from EPA. Initial screening typically involves mapping all storm sewer outfalls and conducting field inspections to identify suspect outfalls based on odor, sewage-related residue (e.g., toilet paper), discoloration, dry weather flows, etc. Grab samples of dry-weather discharges can be collected at suspect locations and analyzed for targeted water quality constituents (e.g., E. coli, temperature, pH, surfactants). Where illicit connections are probable, more advanced techniques can be used to isolate the likely source of the connection. Techniques such as temperature probes (to track diurnal temperature changes indicative of shower use suggesting a sanitary connection to a storm sewer), optical brightener screening (indicator of detergents), zinc chloride smoke testing, fluorometric dye testing, television camera inspections and other approaches can be used as follow-up measures. Once the illicit connection has been identified, the plumbing can be corrected and proper connections to the sanitary sewer system implemented.

<u>Preventing Illicit Connections</u>

Program elements to prevent illicit connections include:

- Ensure that existing building and plumbing codes prohibit physical connections of non-stormwater discharges to the storm drain system.
- Have a program in place to review and approve any proposed connection into a storm sewer.
- Require visual inspection of new developments or redevelopments during the construction phase to ensure that proper plumbing connections are implemented. Train field inspectors and develop field inspection procedures that prevent new illicit connections of sanitary sewer lines to storm sewers.

Accidental Spill Response

Although the storage, transport and disposal of hazardous and toxic substances is a highly regulated activity under state and federal laws, accidents will inevitably occur, resulting in potential release of chemicals and wastes into the storm sewer system. Most local police, fire, or other departments are trained and equipped to respond to such spills. Local governments should work with response personnel to ensure current mapping of storm drains and BMPs and review training procedures for spill response and cleanup. Proper training combined with readily available knowledge of the storm sewer system and appropriate spill control materials can result in more effective protection and blocking of the drainage system during spill response.

Additional Illicit Discharge Detection and Elimination Guidance

The Center for Watershed Protection and Robert Pitt (2004) prepared *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments* under EPA funding to provide guidance to communities in developing effective management programs and field guidance to reduce illicit discharges. This manual provides detailed guidance and field forms that can be used identify illicit connections.

Description

Photograph GH-1. Use dry clean-up methods to remove spilled materials. Photo courtesy of Colorado Nonpoint Source Program.

Good housekeeping practices are designed to maintain a clean and orderly work environment. The most effective first steps towards preventing pollution in stormwater from work sites simply involve using common sense to improve the facility's basic housekeeping methods. Poor housekeeping practices result in increased waste and potential for stormwater contamination.

A clean and orderly work site reduces the possibility of accidental spills caused by mishandling of chemicals and equipment and should reduce safety hazards to personnel. A well-maintained material and chemical storage area will reduce the possibility of stormwater mixing with pollutants.

Some simple procedures a facility can use to promote good housekeeping include improved operation and maintenance of machinery and processes, material storage practices, material inventory controls, routine and regular clean-up schedules, maintaining well organized work areas, signage, and educational programs for employees and the general public about all of these practices.

Appropriate Uses

Good housekeeping practices require education and training, typically targeted to industries and businesses, municipal employees, as well as the general public.

Practice Guidelines

Good housekeeping practices include these general areas:

- Operation and Maintenance
- Material Storage
- Material Inventory
- Training and Participation.

Operation and Maintenance

Consider implementing the following practices:

- Maintain dry and clean floors and ground surfaces by using brooms, shovels, vacuums or cleaning machines, rather than wet clean-up methods.
- Regularly collect and dispose of garbage and waste material.

- Routinely inspect equipment to ensure that it is functioning properly without leaking and conduct preventative maintenance and needed repairs.
- Train employees on proper clean up and spill response procedures.
- Designate separate areas of the site for auto parking, vehicle refueling and routine maintenance.
- Promptly clean up leaks, drips and other spills.
- Cover and maintain dumpsters and waste receptacles. Add additional dumpsters or increase frequency of waste collection if overflowing conditions reoccur.
- Where outdoor painting and sanding occur, implement these practices:
  - Conduct these activities in designated areas that provide adequate protection to prevent overspray and uncontrolled emissions. All operations should be conducted on paved surfaces to facilitate cleanup.
  - Use portable containment as necessary for outside operations.
  - Clean up and properly dispose of excess paint, paint chips, protective coatings, grit waste, etc.
- Maintain vegetation on facility grounds in a manner that minimizes erosion. Follow the Landscape Maintenance and Pesticide, Herbicide and Fertilizer Usage BMPs to ensure that minimum amounts of chemicals needed for healthy vegetation are applied in a manner that minimizes transport of these materials in runoff.

Material Storage Practices

Proper storage techniques include the following:

- Provide adequate aisle space to facilitate material transfer and ease of access for inspection.
- Store containers, drums, and bags away from direct traffic routes to reduce container damage resulting in accidental spills.
- Stack containers according to manufacturer's instructions to avoid damaging the containers from improper weight distribution. Also store materials in accordance with directions in Material Safety Data Sheets (MSDSs).
- Store containers on pallets or similar devices to prevent corrosion of containers that results from containers coming in contact with moisture on the ground.
- Store toxic or hazardous liquids within curbed areas or secondary containers.

Material Inventory Practices

An up-to-date materials inventory can keep material costs down by preventing overstocking, track how materials are stored and handled onsite, and identify which materials and activities pose the most risk to the environment. Assign responsibility of hazardous material inventory to individuals trained to handle such materials. A material inventory should include these steps:

- Identify all chemical substances present at work site. Perform a walk-through of the site, review purchase orders, list all chemical substances used and obtain Material Safety Data Sheets (MSDS) for all chemicals.

- Label all containers. Labels should provide name and type of substance, stock number, expiration date, health hazards, handling suggestions, and first aid information. Much of, this information can be found on an MSDS.

- Clearly identify special handling, storage, use and disposal considerations for hazardous materials on the material inventory.

- Institute a shelf-life program to improve material tracking and inventory that can reduce the amount of materials that are overstocked and ensure proper disposal of expired materials. Careful tracking of materials ordered can result in more efficient materials use. Decisions on the amounts of hazardous materials that are stored on site should include an evaluation of any emergency control systems that are in place. All storage areas for hazardous materials should be designed to contain spills.

Training and Participation

Frequent and proper training in good housekeeping techniques reduces the likelihood that chemicals or equipment will be mishandled. To promote good housekeeping, consider implementing these practices:

- Discuss good housekeeping practices in training programs and meetings.

- Publicize pollution prevention concepts through posters or signs.

- Post bulletin boards with updated good housekeeping procedures, tips and reminders.

Description

Preventative maintenance involves proactive routine inspection and testing of plant equipment and operational systems to prevent leaks and spills. A preventative maintenance program should also include inspections of conveyance channels, storm sewers, inlets, catch basins, stormwater detention areas, and other water quality treatment systems associated with the site.

Photograph PM-1. Preventative maintenance can reduce the frequency and occurrence of leaked or spilled material that can be transported in stormwater runoff.

Appropriate Uses

This BMP is applicable to municipal, industrial and commercial sites. Preventative maintenance programs typically incorporate practices identified in the Good Housekeeping, Materials Storage and Handling, Vehicle Fueling, Maintenance and Storage, and other source control BMPs. See the Structural BMP Maintenance chapter for preventative maintenance for stormwater BMPs.

Practice Guidelines

Elements of a good preventative maintenance program should include:

- Identification of equipment or systems, which may malfunction and cause spills, leaks, or other situations that could lead to contamination of stormwater runoff. Typical equipment to inspect includes pipes, pumps, storage tanks and bins, pressure vessels, pressure release valves, process and material handling equipment.
- Once equipment and areas to be inspected have been identified at the facility, establish schedules and procedures for routine inspections and scheduling repairs.
- Periodic testing of plant equipment for structural soundness is a key element in a preventative maintenance program.
- Promptly repair or replace defective equipment found during inspection and testing.
- Keep spare parts for equipment that needs frequent repair.
- Replace worn parts prior to failure.
- Implement, maintain and regularly review a record keeping system for scheduling tests and documenting inspections in the preventative maintenance program. Be sure to follow inspections promptly with completion of needed repairs. Clearly record the problem and the specific actions taken to correct the problem. Photos can be helpful components of such records. An annual review of these records should be conducted to evaluate the overall effectiveness of the preventative maintenance program. Refinements to the preventative maintenance procedures and tasking should be implemented as necessary.

Description

Photograph VF-1. Use drip pans to collect leaks from vehicles until repairs can be completed. Photo courtesy of Tom Gore.

Areas where vehicles are fueled, maintained, and stored/parked can be pollutant "hot spots" that can result in hydrocarbons, trace metals, and other pollutants being transported in stormwater runoff. Proper fueling operations, storage of automotive fluids and effective spill cleanup procedures can help reduce contamination of stormwater runoff from vehicle maintenance and fueling facilities.

Fuel-related spills can occur due to inattention during fueling or "topping off" fuel tanks. Common activities at commercial, industrial and municipal maintenance shops include parts cleaning, vehicle fluid replacement, and equipment replacement and repair. Some of the wastes generated at automobile maintenance facilities include solvents (degreasers, paint thinners, etc.), antifreeze, brake fluid and brake pad dust, battery acid, motor oil, fuel, and lubricating grease. Fleet storage areas and customer and employee parking can also be a source of vehicle-related contamination from leaks, antifreeze spills, etc.

Appropriate Uses

These BMP guidelines are applicable to vehicle maintenance, fueling, fleet storage and parking facilities. Be aware that washing vehicles and equipment outdoors or in areas where wash water flows onto the ground can pollute stormwater. Vehicle wash water is considered process wastewater that should not be discharged to the storm sewer system. Consult state and federal discharge permit requirements for proper disposal of vehicle washwater, which is typically accomplished through discharge to the sanitary sewer system.

Practice Guidelines[1]

Vehicle Maintenance

The most effective way to minimize wastes generated by automotive maintenance activities is to prevent their production in the first place. Consider adopting these practices:

- Perform maintenance activities inside or under cover. When repairs cannot be performed indoors, be sure to use drip pans or absorbents.
- Keep equipment clean and free of excessive oil and grease buildup.

[1] Guidelines adapted from the USEPA Menu of BMPs.

- Promptly cleanup spills using dry methods and properly dispose of waste. When water is required, use as little as possible to clean spills, leaks, and drips.
- Use a solvent collection service to collect spent solvent used for parts cleaning. Where practical, use detergent-based, steam cleaning, or pressure-based cleaning systems instead of organic solvent degreasers when practical. (Be aware that cleaning water discharged into the sanitary sewer may require pre-treatment prior to discharge.)
- When using liquids for cleaning, use a centralized station to ensure that solvents and residues stay in one area. Locate drip pans and draining boards to direct solvents back into a solvent sink or holding tank for reuse.
- Store used oil for recycling in labeled tanks. Locate used oil tanks and drums away from storm drains, flowing streams, and preferably indoors.
- Use non-hazardous or less hazardous alternatives when practical. For example, replace chlorinated organic solvents with non-chlorinated ones like kerosene or mineral spirits.
- Properly recycle or dispose of grease, oil, antifreeze, brake fluid, cleaning solutions, hydraulic fluid, batteries, transmission fluid, worn parts, filters, and rags.
- Drain and crush oil filters before recycling or disposal.
- Drain all fluids and remove batteries from salvage vehicles and equipment.
- Closely monitor parked vehicles for leaks and place pans under any leaks to collect the fluids for proper disposal or recycling.
- Install berms or other measures to contain spills and prevent work surface runoff from entering storm drains.
- Develop and follow a spill prevention plan. This includes a variety of measures such as spill kits and knowing where storm drains are located and how to protect them (e.g., drain mat, berm) when larger spills occur. (See the Spill Prevention, Containment and Control BMP for more information.)
- Conduct periodic employee training to reinforce proper disposal practices.
- Promptly transfer used fluids to recycling drums or hazardous waste containers.
- Store cracked batteries in leak-proof secondary containers.
- Inspect outdoor storage areas regularly for drips, spills and improperly stored materials (unlabeled containers, auto parts that might contain grease or fluids, etc.). This is particularly important for parking areas for vehicles awaiting repair.
- Structural stormwater BMPs in vehicle hotspot areas require routine cleanout of oil and grease, sometimes monthly or more frequently. During periods of heavy rainfall, cleanout is required more often to ensure that pollutants are not washed through the trap. Sediment removal is also required on a regular basis to keep the BMP working efficiently.

Vehicle Fueling

- Designated fueling areas should be designed to prevent stormwater runoff and spills. For example, fuel-dispensing areas should be paved with concrete or an equivalent impervious surface, with an adequate slope to prevent ponding, and separated from the rest of the site by a grade break or berm that prevents run-on of stormwater.
- Fuel dispensing areas should be covered. The cover's minimum dimensions must be equal to or greater than the area within the grade break or the fuel dispensing area so that the fueling area is completely covered. It may be necessary to install and maintain an oil capture device in catch basins that have the potential to receive runoff from the fueling area.
- For facilities where equipment is being fueled with a mobile fuel truck, establish a designated fueling area. Place temporary "caps" over nearby catch basins or manhole covers so that if a spill occurs, it is prevented from entering the storm drain. A form of secondary containment should be used when transferring fuel from the tank truck to the fuel tank. Storm drains in the vicinity should also be covered. Install vapor recovery nozzles to help control drips, as well as reduce air pollution.
- Keep spill response information and spill cleanup materials onsite and readily available.
- Fuel-dispensing areas should be inspected regularly and repair promptly completed. Inspectors should:
    - Check for external corrosion and structural failure in aboveground tanks.
    - Check for spills and overfills due to operator error.
    - Check for failure of any piping systems.
    - Check for leaks or spills during pumping of liquids or gases from a truck or rail car to a storage facility or vice versa.
    - Visually inspect new tank or container installations for loose fittings, poor welds, and improper or poorly fitted gaskets.
    - Inspect tank foundations, connections, coatings, tank walls, and piping systems. Look for corrosion, leaks, cracks, scratches, and other physical damage that may weaken the tank or container system.
- Aboveground and belowground tanks should be tested periodically for integrity by a qualified professional.
- Dry cleanup methods should be employed when cleaning up fuel-dispensing areas. Such methods include sweeping to remove litter and debris and using rags and absorbents for leaks and spills. Water should not be used to wash these areas. During routine cleaning, use a damp cloth on the pumps and a damp mop on the pavement, rather than spraying with a hose. Fuel dispensing nozzles should be fitted with "hold-open latches" (automatic shutoff) except where prohibited by local fire departments. Signs can be posted at the fuel dispenser or island warning vehicle owners/operators against "topping off" vehicle fuel tanks.
- Written procedures that describe these BMPs should be provided to employees who will be using fueling systems.

Description

Pesticides, herbicides, fertilizers, fuel and other landscape maintenance chemicals must be properly applied, stored, handled and disposed of to prevent contamination of surface water and groundwater. Misuse of pesticides and herbicides can result in adverse impacts to aquatic life, even at low concentrations. Misuse of fertilizer can result in increased algae growth in waterbodies due to excessive phosphorus and nitrogen loading.

Photograph PHF-1. Pesticide, fertilizer, and herbicide applications should be applied in the minimum quantities necessary to achieve specific landscaping objectives, while keeping chemicals out of storm drain systems. Photo courtesy of WWE.

Appropriate Uses

This BMP applies to both commercial and municipal landscaping operations, as well as to homeowners and homeowner associations. For commercial operations, the scale of chemical usage and handling is greater; therefore, additional measures are often required under federal and state law.

Practice Guidelines[1]

Public education regarding appropriate landscape chemical application and handling is an important action that local governments can take to reduce the likelihood that landscape chemicals are washed into storm drains and receiving waters through runoff. Local governments can make landscape care information available on websites, in utility mailers, lawn care centers, and other locations. A variety of professional organizations for lawn care professionals already exist and can be contacted for additional information or partnered with for both public education and landscape professional educational efforts and certification programs (See www.ext.colostate.edu and www.greenco.org.).

General Guidelines for Pesticide, Herbicide, and Fertilizer Application

- Apply fertilizers, pesticides, and other chemicals according to manufacturer's directions. The label is the law for pesticide usage. Apply pesticides and herbicides only when needed and use in a manner to minimize off-target effects. See the Landscape Management Fact Sheet for fertilizer application guidelines.

- Accurately diagnose the pest. Disease and insect symptoms can mimic each other in many plants. A fungicide will not control an insect, and an insecticide will not control a disease.

- Be aware that commercial chemical applicators must receive thorough training, licensure and proper certification prior to chemical use. Consult Colorado Department of Agriculture (CDA) Regulations for specific requirements.

[1] These practice guidelines have been adapted from the *GreenCO Best Management Practices for the Conservation and Protection of Water Quality in Colorado: Moving Toward Sustainability* (GreenCO and WWE 2008). See that manual for additional detail and references.

- Know characteristics of the application site, including soil type and depth to groundwater to avoid migration of chemicals into groundwater.
- Select pesticides and herbicides best suited to the characteristics of the target site and the particular pest or weed. Half-life, solubility, and adsorption should be compared to site characteristics to determine the safest chemical. Choose least toxic and less persistent sprays whenever possible based on comparison of labels and associated material safety data sheets.
- Employ application techniques that increase efficiency and allow the lowest effective application rate. Carefully calibrate application equipment and follow all label instructions.
- Recognize that it is not realistic for a landscape to be completely pest-free or weed-free. Consider using Integrated Pest Management (IPM) strategies to minimize chemical usage.
- Keep pesticide and fertilizer equipment properly calibrated according to the manufacturer's instructions and in good repair. Recalibrate equipment periodically to compensate for wear in pumps, nozzles and metering systems. Calibrate sprayers when new nozzles are installed.
- All mixing and loading operations must occur on an impervious surface.

Integrated Pest Management (IPM)

Integrated pest management (IPM) (also known as Plant Health Care) is the practice of using targeted biological, chemical, cultural, and physical measures to manage pests while minimizing or eliminating the use of chemical pesticides. IPM measures benefit the landscape and help reduce the likelihood that lawn chemicals will be washed into storm drainage systems in stormwater runoff. The pros and cons of various tools should be weighed and used in an integrated manner to achieve pest control objectives in a safe, effective, and cost-effective manner. Basic IPM practices that can be adopted include:

- Consider spot treatments of pests rather than treating the entire area.
- Consider pest occurrence and history when developing pest management strategies.
- Time pesticide application to minimize host plant damage and maximize pest control.
- Rotate annual garden plants to reduce the buildup of soil-borne pests. Clean up plant litter and remove weeds before they go to seed. Remove infested plant residue from the garden in the fall so that pests do not over-winter there.
- Implement cultural controls such as proper plant selection, planting time, and planting method to reduce susceptibility to insects, pests, and diseases, thereby reducing pesticide usage.
- Implement mechanical and physical controls where practical as an alternative to chemical application. Examples include a wide variety of practices such as "collars" around seedlings, mulching, solar heating, syringing, handpicking, mowing, hoeing, and traps.
- Use biological controls where appropriate to reduce pesticide usage. For example, introduce natural enemies of pests such as lady beetles and green lacewings. (Note: pesticides may kill these natural enemies.)
- Consider applying environmentally friendly chemical alternatives such as insecticidal soaps, horticultural oils, and other such measures when practical and effective and when mechanical approaches are impractical.

Application Practices

- Keep records of pesticide application and provide signage as required by law.
- Do not apply pesticides or herbicides during high temperatures, windy conditions or immediately prior to heavy rainfall or irrigation.
- Treat for and control noxious weeds prior to installing the landscape using an herbicide targeted to the weeds that are present and applied in accordance with the product label.
- Be aware that some pesticide formulations are not compatible with other pesticides and combining them may result in increased potency and phytotoxicity.

Managing Mosquitoes in Stormwater Facilities
(Adapted from: Peairs and Cranshaw 2007)

The key to mosquito control is larval management. Larvae occur in specific areas and can be controlled by modifying the habitat through drainage or insecticides applied to larval breeding sites. Weekly mosquito inspections at stormwater facilities with targeted treatments are frequently less costly and more effective than regular widespread application of insecticides. These inspections can be performed by a mosquito control source and typically start in mid-May and extend to mid-September. Mosquito control measures must be cost effective and environmentally sound. Consider alternatives before application of conventional chemical insecticides.

- **Habitat Modification:** Eliminating breeding sites, or habitat modification, is an effective and long-term solution. Proper maintenance of stormwater BMPs to avoid shallow standing water is important.
- **Natural Predators:** Fish, dragonfly nymphs, and diving beetles are natural predators of mosquito larvae; dragonflies, birds, and bats feed on adults. Consult the Colorado Division of Wildlife for recommendations, restrictions and regulations regarding mosquito-eating fish.
- **Insecticides:** Microbial insecticides such as the bacteria "Bti" (*Bacillus thuringiensis israeliensis*) can be as effective as chemical insecticides. Bti is toxic only to mosquito and midge larvae. It is not hazardous to non-target organisms but can reduce midge populations that serve as fish food.

  "Soft" chemical insecticides, such as the insect growth regulator methoprene, are toxic only to insects and other arthropods. They are similar to certain insect hormones and create imbalances in the levels of hormones needed for proper mosquito growth and development. They do not directly harm fish or other wildlife but can reduce the amount of available food.

  Mosquito larvae also can be controlled by the application of larvicidal oils or chemical insecticides to the water where they occur or are suspected to occur. Remember, several alternatives to conventional chemical larvicides have been developed because of concerns about applying chemicals to water that might be used for drinking or that contains fish and other aquatic life.

If larval control fails, adult mosquito control may be necessary. Adult control generally is done with insecticide applications using ground equipment or aircraft. For more information visit: www.ext.colostate.edu/westnile/mosquito_mgt.html or www.ext.colostate.edu/westnile/faq.html.

- Maintain a buffer zone around wells or surface water where pesticides are not applied. Consult local regulations and landscape ordinances, as well as the product label, for distances, which may vary depending on the type of chemical and the sensitivity of the waterbody. The purpose of this practice is to keep pesticides and herbicides out of surface waterbodies.

Storage Practices

- Storage areas should be secure and covered, preventing exposure to rain and unauthorized access. Commercial and municipal facilities should provide basic safety equipment such as fire extinguishers, warning signs (e.g., "no smoking"), adequate light and ventilation, and spill clean-up materials should be present. Floors and shelves should be non-porous (e.g., metal, concrete) to prevent sorption of chemicals. If possible, temperature control should be provided to avoid excessive heat or cold. Storage areas should be kept clear of combustible material and debris.

- Commercial operations handling large quantities of pesticides and fertilizers should consult the Colorado Department of Agriculture for storage and handling requirements. Commercial greenhouses and nurseries that are storing recycled water laden with fertilizer may need to provide secondary containment to contain the water in the event of a tank rupture or leak.

- Store chemicals in their original containers, tightly closed, with labels intact. Also inspect them regularly for leaks. Store nitrate-based and other oxidizing fertilizers separately from solvents, fuels, and pesticides to reduce fire risk. Follow the general principle of storing like chemicals together. Dry chemicals should be stored above liquids and on pallets to ensure that they do not get wet.

- Locate chemical storage and maintenance areas, as well as vehicle refueling and maintenance areas, away from wells and surface waterbodies in accordance with local regulations, typically at least 50 to 100 feet away.

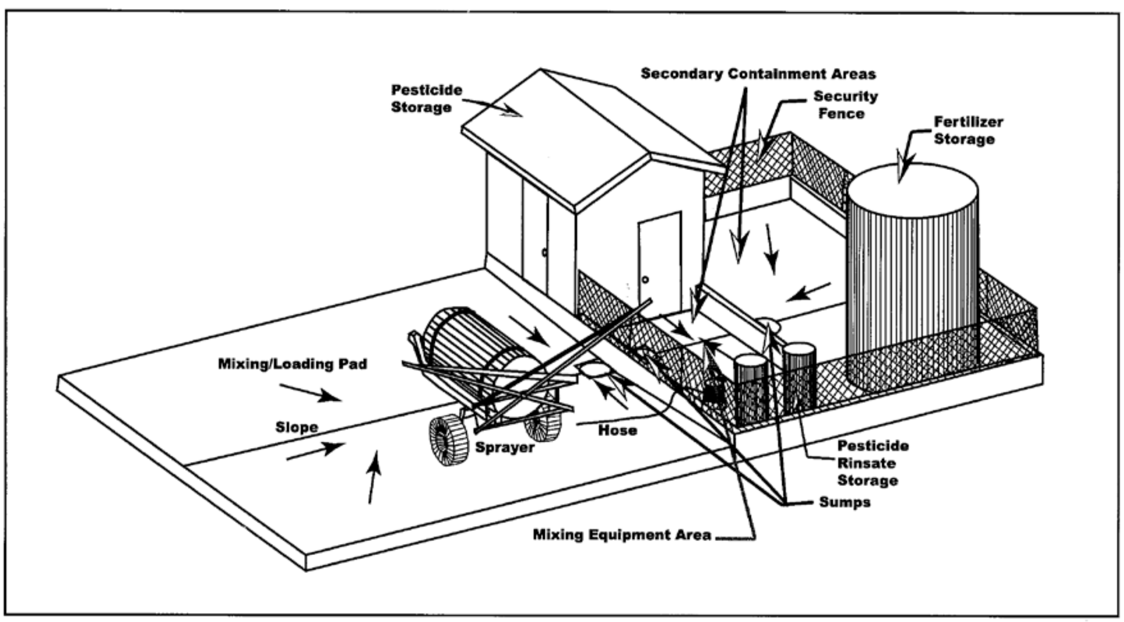


Figure PHF-1. Example Combined Pesticide and Fertilizer Storage and Mixing Area**.** Figure courtesy of *Designing Facilities for Pesticides and Fertilizer Containment*, Midwest Planning Service, Agricultural Engineering, Iowa State University 1991.

- Make available all Material Safety Data Sheets (MSDSs) in a readily accessible area. A list of all hazardous chemicals in the work place must be completed to ensure that all MSDSs are readily available.

- Do not store large quantities of pesticides for long periods of time. Adopt the "first in, first out" principle, using the oldest products first to ensure that the shelf life does not expire. Buy smaller quantities of pesticides and fertilizers, thereby reducing storage issues.

Spills and Disposal

- Never pour lawn and garden chemicals or rinse water down storm drains (or sanitary drains) and keep chemicals off impervious surfaces (e.g., streets, gutters) during application.

- Follow label directions for disposal. This typically involves triple-rinsing empty containers, puncturing and crushing. All visible chemicals should be cleaned from the container prior to disposal. Use local recycling or hazardous waste collection centers to dispose of unused chemicals.

- Properly manage chemical spills by cleaning them up as soon as possible, controlling actively spilling or leaking materials, containing the spilled material (e.g., with absorbents, sand), collecting the spilled material, storing or disposing of the spilled material, and following relevant spill reporting requirements. "Washing down" a spill with water is not an appropriate cleanup approach.

- Commercial operations should be aware of and comply with basic spill reporting requirements required by law, and keep chemical spill cleanup equipment, personal protective equipment and emergency phone numbers available when handling chemicals and their containers.

For More Information on Legal Requirements

Many federal and state regulations address pesticide, herbicide, and other chemical usage. These sources should be consulted for the most current legal requirements related to chemical handling, storage, application, disposal, and reporting of chemical spills. Examples include the federal Insecticide, Fungicide and Rodenticide Act (FIFRA), the Superfund Amendments and Reauthorization Act (SARA), the Emergency Planning and Community-Right-to-Know Act (EPCRA), and Occupational Safety and Health Administration (OSHA) requirements, particularly the Hazard Communication Standard. Colorado-related regulations include the Colorado Pesticide Applicator's Act, and the Colorado Water Quality Control Act (25-8-601 and 25-8-606), Senate Bill 90-126, and The Agricultural Chemicals and Groundwater Protection Act, which identifies special requirements for facilities handling more than 3,000 pounds (or 500 gallons) of bulk-formulated pesticides.

Description

Proper landscape maintenance, including maintenance of vegetated stormwater BMPs, is important to reduce nutrient and chemical loading to the storm drain system, reduce nuisance flows and standing water in stormwater BMPs, and maintain healthy vegetation that helps minimize erosion. Additionally, when landscapes and vegetated BMPs are over-irrigated, the ground remains saturated and capacity to infiltrate runoff is reduced.

Photograph LM-1. Over-irrigation and overspray can wash fertilizers and lawn chemicals into the storm drain system. These flows can comingle with storm runoff and cause nuisance flow conditions in stormwater BMPs. Photo courtesy of the City of Westminster.

Appropriate Uses

Appropriate lawn care practices are applicable to residential, commercial, municipal, and some industrial operations.

Practice Guidelines[1]

Practice guidelines for a healthy lawn that reduces pollution during both wet and dry weather conditions include a combination of practices such as mowing, aeration, fertilization, and irrigation. Also, see the Pesticide, Herbicide, and Fertilizer Usage BMP for information on proper use of these chemicals and Integrated Pest Management (IPM) strategies.

Lawn Mowing and Grass Clipping Waste Disposal

- Keep lawn clippings and debris out of gutters. When blowing walkways or mowing lawns, direct equipment so that the clippings blow back onto the lawn rather than into the street, or collect clippings blown onto the street and properly dispose of them.
- Mulch-mowing turfgrass at a height of 2.5 to 3 inches helps turfgrass develop deeper root systems. No more than one-third of the grass blade should be removed in a single mowing. Mulched grass clippings can return roughly 25 to 30% of the needed nitrogen that grass requires to be healthy, thereby reducing fertilizer requirements. Avoid throwing grass clippings onto streets and sidewalks to reduce nutrient pollution to surface waterbodies.
- Minimize thatch development by mowing at appropriate frequencies and heights for the grass type, avoiding overwatering, preventing over fertilization, and aerating the turf.

[1] These practice guidelines have been adapted from the *GreenCO Best Management Practices for the Conservation and Protection of Water Quality in Colorado: Moving Toward Sustainability* (GreenCO and WWE 2008). See this manual for additional detail and references.

Lawn Aeration

- Aerate turf once or twice per year, as needed, in the early spring and/or late fall to aid in capturing the natural precipitation during non-weed germination periods and prior to adding organic materials and fertilizers. Aeration reduces soil compaction and helps control thatch in lawns while helping water and fertilizer move into the root zone.

- A lawn can be aerated at any time the ground is not frozen, but should not be done when it is extremely hot and dry. Heavy traffic areas will require aeration more frequently.

- Do not use spike-type aerators, which compact the soil. Holes should be two to three inches deep and no more than two to four inches apart. Lawns should be thoroughly watered the day before aerating so plugs can be pulled more deeply and easily. Mark all sprinkler heads, shallow irrigation lines, and buried cable TV lines before aerating so those lines will not be damaged.

Fertilizer Application

- Apply fertilizer when needed to achieve a clearly defined objective such as increasing shoot growth, root growth, flowering or fruiting; enhancing foliage color, and plant appearance; or correcting or preventing nutrient deficiencies.

- Because manufactured fertilizers can be relatively high in nutrient content, it is critical to follow the manufacturer's directions, using the minimum amount recommended. Over-application "burns" leaves and may lead to water pollution, thatch buildup, excessive mowing, and weed growth.

- Only apply nutrients the plants can use. Fertilizer labels identify product contents in terms of ratios that indicate percentage of ingredients by product weight.

Phosphorus

Phosphorus is commonly overused and application should be based on soil tests. Phosphorus washing into surface waterbodies leads to excessive algae growth.

Phosphorous does not move out of the soil like nitrogen, so constant additions are unnecessary.

Soil Testing

There are several qualified laboratories in Colorado that provide soils tests to determine recommendations for fertilizer type and application rates. There are also commercially available quick test kits that are less accurate but could be used by a homeowner. Without an analysis, a homeowner may be buying unnecessary fertilizer or applying too much. A $20 to $40 soil analysis has potential to save an owner much more.

The CSU Extension program offers a soil testing service. Contact the CSU Extension for your county or visit http://www.ext.colostate.edu for more information including a list of laboratories.

- When practical and appropriate, base fertilizer application on soil analysis. Be aware that at many new development sites, soil conditions following grading often no longer consist of topsoil. "Basement" soils with poor texture and low nutrient content may be present. As a result, soil amendment is often needed to improve the physical properties (tilth) of the soil to provide a better environment for plant roots to improve nutrient uptake. Soil analysis can help to identify soil amendments that improve both the physical and nutrient characteristics of the soil, as well as identify fertilization requirements.

- Utilize split applications of slow-release (controlled-release) fertilizer forms such as IBDU, sulfur-coated urea and natural organic-based fertilizers (not to be confused with raw manure) to minimize the risk of nutrients leaching into groundwater or running off in surface water. When properly applied, other forms of fertilizer can also be safely used, provided that over-watering and over-fertilization do not occur.

- When applying fertilizer, broadcast it uniformly over the targeted area of the landscape. Keep fertilizer off streets, sidewalks, and driveways to prevent water pollution. Fertilizer that inadvertently falls on impervious surfaces should be swept back onto the lawn.

- Recommendations for fertilizer application vary among industry professionals. CSU Extension's fertilizer recommendations for established Colorado lawns are provided in the table below. Site-specific conditions should also be considered when determining the need for fertilizer.

Table LM-1. CSU Extension Recommendations for Nitrogen Application Rate

	Nitrogen Application Rate in Pounds/1,000 sq. ft.				
Turfgrass Species	Mid-March to April[A,B]	May to Mid-June [B]	July to Early August [B]	Mid-August to Mid-September[B, C]	Early October to Early November[B, D]
High Maintenance Bluegrass Ryegrass	0.5-1	1	Not Required	1	1-2 (optional)
Low Maintenance Bluegrass	0.5	0.5-1	Not Required	1	1 (optional)
Tall Fescue	0.5	0.5-1	Not Required	1	1 (optional)
Fine Fescue	0.5	0.5-1	Not Required	0.5-1	None
Buffalo grass, Blue Grama, Bermuda grass	None	0.5-1	0.5-1	None	None

Notes:

[A] The March-April nitrogen application may not be needed if prior fall fertilization was completed. If spring green-up and growth is satisfactory, delay fertilizing to May or June.

[B] Application rates may be reduced by 1/4 to 1/3 when grass clippings are left on the lawn.

[C] On very sandy soils do not fertilize turf after late September to prevent nitrogen from leaching into groundwater during the winter months.

[D] Apply when the grass is still green and at least 2-3 weeks prior to the ground freezing. Optional nitrogen applications are indicated for use where higher quality or heavily-used turf is present.

Source: T. Koski and V. Skinner, CSU Extension, 2003.

- If possible, properly irrigate turf following fertilization to help grass utilize applied nutrients and to minimize the potential for fertilizer burn. Care should be taken to avoid excessive irrigation that would result in fertilizer being washed away. Similarly, avoid application of fertilizer immediately prior to heavy rainfall.

- Fall is the best time of year to fertilize bluegrass lawns. Over-application of nitrogen fertilizer in April may cause grass to grow too fast before roots can support the growth, resulting in less heat tolerance.

- Generally, the Colorado Nursery and Greenhouse Association recommends waiting until the second growing season to fertilize ornamental (woody) plants. Commercial fertilizer should not be used in the backfill where it comes in direct contact with the roots.

- Maintain a buffer zone around wells or surface waterbodies where fertilizers are not applied to minimize pollution. Consult the fertilizer product label and local regulations and landscape ordinances for appropriate distances. Research in this area is limited; however, CSU Extension recommends a buffer of 6 to 10 feet for mowed turf areas.

- In areas with sandy soils, it is particularly important to avoid over-application of fertilizer that could leach into groundwater. These areas may be particularly well suited to slow-release fertilizer forms and conservative application rates.

Lawn Irrigation

- The approximate amount of water that needs to be applied **each week** for an average, traditional lawn to supplement normal rainfall is listed in Table 2. (Water utilities may provide additional guidance in terms of suggested run-times for various sprinkler types; http://www.denverwater.org/Conservation/.)

Table LM-2. General Guideline for Approximate Supplemental Water for an Average Traditional Lawn (inches per week)

Condition[3]	April[1]	May	June	July	Aug	Sept	Oct[2]
Non-Drought Conditions	1/4"	1"	1½"	1½"	1¼"	1"	1/2"
During Drought Restrictions (approx. 20% reduction)	1/4"	3/4"	1¼"	1¼"	1"	3/4"	1/2"

[1] For established lawns, water may not be required during April. Base decision on weather conditions.
[2] For established lawns, water is typically not required after Oct 15.
[3]Under less-than-average rainfall conditions, the amounts shown in the chart should be increased. If there is greater-than-normal rainfall, then the amount of supplemental water should be reduced.

- Consult with the CSU Extension Turfgrass program for recommendations for irrigating turfgrasses with lower water requirements (e.g. blue grama, buffalo grass). For native grasses, irrigation may be unnecessary or limited to certain conditions.

- Irrigate the lawn uniformly until the soil is moist to a depth of 4 to 6 inches to encourage deep roots. Frequent, light sprinklings moisten only the surface and may cause shallow-rooted turf and increase weed seed germination. Properly maintain the irrigation system to ensure that the irrigation is being applied at appropriate rates and to the turfgrass, not the sidewalk.

- Maintain irrigation systems in good operating condition with uniform distribution of water. "Smart" irrigation controllers and weather sensors can reduce water waste by shutting off irrigation during storm events and helping owners water according to the needs of the plants to replace water lost to evapotranspiration (ET).
- Proper irrigation can minimize the amount of fertilizer and other chemicals that are leached below the root zone of the grass or washed away by runoff.

Description

For obvious safety reasons, snow removal in Colorado is important; however, snow removal and management practices can adversely impact vegetation, soils, water quality, and air quality. Snow removal contractors and operators should be knowledgeable of these potential impacts and choose management measures with the fewest adverse impacts, while still protecting the public safety, health and welfare.

Photograph SIM-1. Snow storage locations should be clearly communicated to snow removal contractors and located where they can drain to stormwater BMPs or landscaped areas. Photo courtesy of WWE.

Appropriate Uses

Snow and ice management procedures are relevant for homeowners, contractors, business owners, and transportation departments.

Practice Guidelines[1]

- Physical removal of snow and ice by shovels, snowplows, or snow blowers usually has the least water quality and landscape impacts, provided that storage areas are not piled directly on landscape plants or drained directly to receiving waters. Plan for snow storage locations that minimize water quality and landscape impacts prior to winter.
- Ensure that equipment is calibrated to optimum levels according to manufacturer's instructions.
- Consider placing barriers in targeted site-specific locations (i.e., along streams or direct drainages) to route deicing material away from waterbodies.
- Reduce plowing speed in sensitive areas to prevent exposure to deicing material.
- Designate snow storage areas in locations that enable runoff to be directed to stormwater BMPs for treatment, when practicable.
- The use of deicing chemicals can have a severe impact on plants growing near roads and sidewalks. This can become a water quality issue when plants die and erosion results. Many deicing chemicals are salts and can adversely affect plants through either direct contact with foliage or through buildup in the soil over time. Representative impacts include:

[1]These practice guidelines have been adapted from the *GreenCO Best Management Practices for the Conservation and Protection of Water Quality in Colorado: Moving Toward Sustainability* (GreenCO and WWE 2008). See this manual for additional detail and references.

  - o Direct contact often occurs when the deicing chemicals accumulate on the plants due to drift during application, or when snow or ice containing the chemical is shoveled or blown onto nearby plants. Because these chemicals are salts, direct contact with the foliage may result in burning due to a rapid dehydration effect.

  - o Buildup of de-icing chemicals in the soil may have even more detrimental effects. Repeated application over time (either during a particular winter season or over many seasons) may damage plants by making their roots unable to take up water. Symptoms will include wilting even when the soil is moist, leaf burn or needle tip burn, stunting or lack of vigor, and/or deficiency symptoms for one or more plant nutrients. The structure of clay soils can be changed to the point that they are unable to support plant life.

- Deicing chemicals that are considered safer to use around plants include calcium magnesium acetate (CMA) or calcium chloride. As with all chemicals used in the landscape, be sure to read and follow label instructions and do not over apply.

- The Colorado Department of Transportation (CDOT) has conducted multiple studies on deicing chemicals. The SeaCrest Group (2001) studied three groups of deicers for CDOT that were chloride-based, acetate-based, and sanding materials. The chloride-based deicers included magnesium chloride (FreezGard Zero® with Shield LS®, Ice-Stop™ CI, Caliber™ M1000, Ice Ban™ M50), calcium chloride (Liquidow®, Armor®), and sodium chloride (road salt and Ice Slicer®). The acetate-based deicers include Calcium Magnesium Acetate (CMA®), Potassium Acetate (CF7®), Sodium Acetate (NAAC®), and CMAK™ (a mixture of CMA and Potassium Acetate). Table 1 contains a partial summary of the study findings.

- Highlights of the SeaCrest (2001) study regarding impacts associated with the three categories include:

  - o The chloride-based deicers have been shown to have adverse effects on terrestrial vegetation. Damage to vegetation from deicing salts has been reported to a distance of 100-650 feet. However, there is a wide range of tolerance of different species of plants to the effects of chlorides. The chloride ions in deicers increase the salinity of the soil near the roadways where they are applied. The magnesium and calcium ions increase the stability and permeability of the soil, whereas sodium ions decrease soil stability and permeability.

  - o The acetate-based deicers are organic and have different kinds of effects on the environment than the chloride-based deicers. The acetate ions are broken down by soil microorganisms and may result in oxygen depletion of the soil, which can impact vegetation; however, the acetate deicers CMA and Potassium Acetate (CMAK) are not harmful to terrestrial vegetation at the concentrations typically used on roadways. However, NAAC may potentially have an adverse effect on vegetation because of the presence of the sodium ion, which decreases the stability and permeability of the soil. The depletion of oxygen in the soil from the breakdown of the acetate ion can have a negative effect on plant growth, but field evidence of this effect is limited.

  - o Sand is not a deicer, but is used for snow and ice control because it improves traction. Sand has a negative effect on water quality as a result of the increased turbidity caused by the presence of sand particles in water. Excessive quantities of sand can smother vegetation.

Table SIM-1. Potential Environmental Impacts of Various Deicers
(Source: The SeaCrest Group 2001)[2]

Deicer/ Parameter	Inhibited Magnesium Chloride (Liquid)	Caliber + Magnesium Chloride (Liquid)	Ice Ban + Magnesium Chloride (Liquid)	Sodium Chloride/ Ice Slicer (Solid)	Inhibited Calcium Chloride (Liquid)	CMA (Solid/ Liquid)	CMAK (Liquid)	Potassium Acetate (Liquid)	NAAC (Solid)	Sand
Chemicals	Trace metals	Trace metals, phosphorus, ammonia	Trace metals, phosphorus, ammonia, nitrates	Trace metals	Trace metals, ammonia, nitrates.	Trace metals	Trace metals, ammonia, nitrates.	Trace metals	Trace metals, phosphorus	Trace metals
Soil	Improves structure, increases salinity	Improves structure, increases salinity, oxygen depletion	Improves structure, increases salinity, oxygen depletion	Increases salinity; decreases stability	Improves structure, increases salinity	Improves structure; oxygen depletion	Improves structure; oxygen depletion	Improves structure; oxygen depletion	Decreases stability; oxygen depletion	Minimal effects
Water Quality	Increases salinity	Increases salinity; oxygen depletion	Increases salinity; oxygen depletion	Increases salinity	Increases salinity		Oxygen depletion	Oxygen depletion	Oxygen depletion	Increases turbidity
Air Quality	Minimal air pollution	Minimal air pollution	Minimal air pollution	Some air pollution	Minimal air pollution	Minimal air pollution	Minimal air pollution	Minimal air pollution	Some air pollution	High air pollution potential
Aquatic Organisms	Relatively low toxicity	Relatively low toxicity	Moderate toxicity	Relatively low toxicity	Relatively low toxicity	Relatively low toxicity	Moderate toxicity	Moderate toxicity	Relatively low toxicity	Can cover benthic organisms and cause mortality
Terrestrial Vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Minimal damage to vegetation	Minimal damage to vegetation	Minimal damage to vegetation	Effects to vegetation not determined	Can cover vegetation and cause mortality
Terrestrial Animals	Does not attract wildlife	Does not attract wildlife	Does not attract wildlife	Attracts wildlife contributing to road kills	Does not attract wildlife	Not expected to attract wildlife	Not expected to attract wildlife	Not expected to attract wildlife	May attract wildlife contributing to roadkills	May cover burrows of small animals and cause mortality

Note: Trace metals that may be present include arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, and zinc. Soil comments related to structure refer to the affect on soil stability, which relates to erosion. See http://www.coloradodot.info/programs/research/pdfs/2001/deicers.pdf/view for more information.

- Where practicable, do not use deicers to melt snow or ice completely, but to make their removal easier. Deicers melt down through the ice or snow to the hard surface, then spread out underneath. This undercuts and loosens the snow so shoveling and plowing can be done. For this reason, it is helpful to apply deicers prior to snow events in some cases.
- Research has shown that the shape of deicing particles affects the speed of their penetration through ice. Uniformly shaped spherical pellets of about 1/16 inch to 3/16 inch penetrate ice faster and more efficiently than other shapes.
- Try to avoid the use of rock salt since it is generally most damaging to plants, soils and concrete and metal surfaces. In areas where deicing salts are unavoidable, select plants with higher salt tolerances.

[2] The SeaCrest Group, 2001. *Evaluation of Selected Deicers Based on a Review of the Literature*, Report No. CDOT-DTD-2001-15. Prepared for Colorado Department of Transportation Research Branch.

- Do not plow snow directly into streams or wetlands. Snow storage and disposal areas should be located in an area where snowmelt can infiltrate into the ground, filter through a vegetated buffer or be otherwise treated prior to reaching streams and wetlands. Provide adequate storage volume to trap sediment left behind by melting snow and plan regular maintenance to remove accumulated sediment.

- In areas subject to heavy chemical deicing use, flushing the soil with water after the last freeze may alleviate burn potential. Year-round proper plant care will also make plants more tolerant to salt exposure. However, for the overall health of the landscape, the goal should be to reduce or minimize the use of deicing chemicals where they are not necessary for safety reasons.

- If an electric/mechanical snow melting device is used to dispose of removed snow (e.g., The Can snow melter, Snow Dragon, etc.), the owner or operator must obtain the appropriate permit prior to discharge. Snowmelt from melting machines is typically considered process wastewater.

Street Sweeping and Cleaning S-11

Description

Photograph SSC-1. Monthly street sweeping from April through November removed nearly 40,690 cubic yards of sediment/debris from Denver streets in 2009. Photo courtesy of Denver Public Works.

Street sweeping uses mechanical pavement cleaning practices to reduce sediment, litter and other debris washed into storm sewers by runoff. This can reduce pollutant loading to receiving waters and in some cases reduce clogging of storm sewers and prolong the life of infiltration oriented BMPs and reduce clogging of outlet structures in detention BMPs.

Different designs are available with typical sweepers categorized as a broom and conveyor belt sweeper, wet or dry vacuum-assisted sweepers, and regenerative-air sweepers. The effectiveness of street sweeping is dependent upon particle loadings in the area being swept, street texture, moisture conditions, parked car management, equipment operating conditions and frequency of cleaning (Pitt et al. 2004).

Appropriate Uses

Street sweeping is an appropriate technique in urban areas where sediment and litter accumulation on streets is of concern for aesthetic, sanitary, water quality, and air quality reasons. From a pollutant loading perspective, street cleaning equipment can be most effective in areas where the surface to be cleaned is the major source of contaminants. These areas include freeways, large commercial parking lots, and paved storage areas (Pitt et al. 2004). Where significant sediment accumulation occurs on pervious surfaces tributary to infiltration BMPs, street sweeping may help to reduce clogging of infiltration media. In areas where construction activity is occurring, street sweeping should occur as part of construction site stormwater management plans. Vacuuming of permeable pavement systems is also considered a basic routine maintenance practice to maintain the BMP in effective operating condition. See the maintenance chapter for more information on permeable pavement systems. Not all sweepers are appropriate for this application.

Practice Guidelines[1]

1. Post street sweeping schedules with signs and on local government websites so that cars are not parked on the street during designated sweeping days.

2. Sweeping frequency is dependent on local government budget, staffing, and equipment availability, but monthly sweeping during non-winter months is a common approach in the metro Denver urban

[1] Practice guidelines adapted from CASQA (2003) *California Stormwater BMP Handbook*, Practice SC-70 Road and Street Maintenance.

area. Consider increasing sweeping frequency based on factors such as traffic volume, land use, field observations of sediment and trash accumulation, proximity to watercourses, etc. For example:

- Increase the sweeping frequency for streets with high pollutant loadings, especially in high traffic and industrial areas.
- Conduct street sweeping prior to wetter seasons to remove accumulated sediments.
- Increase the sweeping frequency for streets in special problem areas such as special events, high litter or erosion zones.

3. Perform street cleaning during dry weather if possible.
4. Avoid wet cleaning the street; instead, utilize dry methods where possible.
5. Maintain cleaning equipment in good working condition and purchase replacement equipment as needed. Old sweepers should be replaced with more technologically advanced sweepers (preferably regenerative air sweepers) that maximize pollutant removal.
6. Operate sweepers at manufacturer recommended optimal speed levels to increase effectiveness.
7. Regularly inspect vehicles and equipment for leaks and repair promptly.
8. Keep accurate logs of the number of curb-miles swept and the amount of waste collected.
9. Dispose of street sweeping debris and dirt at a landfill.
10. Do not store swept material along the side of the street or near a storm drain inlet.

Changes in Street Sweeper Technology (Source: Center for Watershed Protection 2002)

At one time, street sweepers were thought to have great potential to remove stormwater pollutants from urban street surfaces and were widely touted as a stormwater treatment practice in many communities. Street sweeping gradually fell out of favor, largely as a result of performance monitoring conducted as part of the National Urban Runoff Program (NURP). These studies generally concluded that street sweepers were not very effective in reducing pollutant loads (USEPA, 1983). The primary reason for the mediocre performance was that mechanical sweepers of that era were unable to pick up fine-grained sediment particles that carry a substantial portion of the stormwater pollutant load. In addition, the performance of sweepers is constrained by that portion of a street's stormwater pollutant load delivered from outside street pavements (e.g., pollutants that wash onto the street from adjacent areas or are directly deposited on the street by rainfall). Street sweeping technology, however, has evolved considerably since the days of the NURP testing. Today, communities have a choice in three basic sweeping technologies to clean their urban streets: traditional mechanical sweepers that utilize a broom and conveyor belt, vacuum-assisted sweepers, and regenerative-air sweepers (those that blast air onto the pavement to loosen sediment particles and vacuum them into a hopper).

For more information, see
http://www.cwp.org/Resource_Library/Center_Docs/PWP/ELC_PWP121.pdf

Description[1]

Photograph SSC-1. Storm drain cleaning may help to remove pollutant sources and helps to maintain the capacity of the storm pipes.

Periodic storm sewer system cleaning can help to remove accumulated sediment, trash, and other substances from various components of the storm sewer system including inlets, pipes and stormwater BMPs. Some common pollutants found in storm drains include: trash and debris, sediments, oil and grease, antifreeze, paints, cleaners and solvents, pesticides, fertilizers, animal waste, and detergents. Routine cleaning reduces the amount of pollutants, trash, and debris both in the storm drain system and in receiving waters. Clogged drains and storm drain inlets can cause the drains to overflow, leading to increased erosion (Livingston et al. 1997). Cleaning increases dissolved oxygen, reduces levels of bacteria, and supports in-stream habitat. Areas with relatively flat grades or low flows should be given special attention because they rarely achieve high enough flows to flush themselves (Ferguson et al. 1997).

Appropriate Uses

Storm sewer system cleaning is typically conducted by local governments or state agencies; however, homeowners associations, businesses and industries are usually responsible for maintaining system components on their sites.

Due to the cost and time involved with storm sewer system cleaning, communities may target recurrent problem areas or use another type of prioritization system for maintenance. Also see the BMP Maintenance chapter for BMP-specific maintenance requirements.

Practice Guidelines

A variety of jet/vacuum vehicles can be used to remove debris from stormwater catch basins and pipes. This equipment breaks up clogged/accumulated material with high-pressure water jets and vacuums the material from the sewer. Water used in storm drain cleaning must be collected and properly disposed of, typically at a sanitary wastewater treatment facility.

Simpler methods in localized areas can also include manual trash collection and shoveling from inlets and outlets.

[1] Guidelines adapted from Center for Watershed Protection (2009) *Urban Stormwater Restoration Manual Series 8: Municipal Practices and Programs.*

Frequency and prioritization of storm sewer cleaning is affected by multiple factors such as the activity and intensity of use in the tributary area (e.g., parking lot, stadium), storm sewer system design, municipal budgets (staff and equipment), and other factors.

To be most effective, storm sewer cleaning needs an effective recordkeeping system and clearly defined procedures. CWP (2009) recommends the following practices:

- **Tracking**: The location and maintenance of storm drains should be tracked using a database and spatial referencing system (e.g., Global Positioning System or Geographic Information System). Additionally, knowing the type and era of the storm drain system may be of use since some inlets/catch basins are designed to be self-cleaning while others have some trapping capacity.

- **Frequency**: Should be defined such that blockage of storm sewer outlet is prevented and it is recommended that the sump should not exceed 40- 50 percent of its capacity. Semi-annual cleanouts in residential streets and monthly cleanouts for industrial streets are suggested by Pitt and Bissonnett (1984) and Mineart and Singh (1994). More frequent cleanouts should be scheduled in the fall as leaves can contribute 25% of nutrient loadings in catch basins.

- **Technology**: A variety of methods of cleaning catch basins are available, including manual cleaning, eductor vehicles, vacuum cleaning and vacuum combination jet cleaning. Choose the approach that is most effective for site conditions, taking into consideration budget, equipment, and staffing constraints.

- **Staff training**: Operators need to be properly trained in catch basin maintenance including waste collection and disposal methods. Staff should also be trained to report water quality problems and illicit discharges.

- **Material disposal**: Most catch basin waste is of acceptable quality for landfills. If it is suspected that catch basin waste contains hazardous material, it should be tested and disposed of accordingly. Maintenance personnel should keep a log of the amount of sediment collected and the removal date at the catch basin.

Chapter 6
BMP Maintenance

Contents

1.0 Introduction

In order for stormwater BMPs to be effective, proper maintenance is essential. Maintenance includes both routinely scheduled activities, as well as non-routine repairs that may be required after large storms, or as a result of other unforeseen problems. BMP maintenance is the responsibility of the entity owning the BMP; however, local governments with municipal separate storm sewer system (MS4) permits are responsible for ensuring that maintenance of privately owned BMPs occurs within their MS4.

BMPs should be designed with maintenance as one of the key design considerations. Planning-level design guidance pertaining to maintenance is included in the individual Fact Sheets contained within this manual. This chapter focuses on maintenance of in-service BMPs and provides recommendations for private BMP owners, as well as for MS4 permittees responsible for ensuring proper maintenance for both public and private facilities within their MS4.

2.0 Defining Maintenance Responsibility for Public and Private Facilities

Identifying who is responsible for maintenance of BMPs and ensuring that an adequate budget is allocated for maintenance is critical to the long-term success of BMPs. Maintenance responsibility may be assigned in different ways:

- Publically owned BMPs are maintained by the MS4 permittee.
- Publically owned regional drainage facilities located within the UDFCD service area may be maintained by UDFCD when specific maintenance eligibility criteria are met (subject to funding limitations).
- Privately owned BMPs typically are maintained by the property owner, homeowner's association, or property manager.
- Privately owned BMPs may be maintained by the MS4 permittee under a written agreement with the owner, with appropriate fees assessed for maintenance services.

MS4 permittees can utilize a variety of legal approaches to ensure maintenance of stormwater BMPs. Representative measures include:

- Agreements establishing legally binding BMP maintenance requirements and responsibilities.
- Permit obligations specifying BMP requirements; or
- Municipal legislative action or rulemaking authority.

Examples of some of the specific requirements for BMP maintenance suggested for legal agreements by the Watershed Management Institute (1997) include:

- **General Assurances:** Identify requirements for proper operation and maintenance, conditions for modification of facilities, dedicated easements, binding covenants, operation, and maintenance plans, and inspection requirements.
- **Warranty Period:** Require the original developer to be responsible for maintenance and operation during a defined short-term period and identify the entity responsible for long-term operation. The

party responsible for long-term maintenance must have appropriate legal authority to own, operate maintain, and raise funds to complete needed maintenance.

- **Proof of Legal Authority:** Require that the entity meet certain conditions verifying its legal authority to ensure maintenance.
- **Conditions for Phased Projects:** Clearly specify how maintenance responsibilities are allocated over the long-term for a project that is phased in over time. This includes identifying access points during each phase.
- **Remedies:** Clearly define remedies in the event that the facility is not being properly maintained.

For public facilities, one of the key issues is ensuring that adequate staff and budget are provided to the department responsible for maintenance. Ponds, lakes, and wetland BMPs should be built only if assurances are provided that adequate maintenance staff and resources are identified in advance.

Photograph 6-1. Sediment removal from a forebay at the regional Shop Creek BMP System.

For private facilities, such as those owned and maintained by homeowners' associations, there is often a lack of understanding of maintenance required for BMPs. Maintenance plans should be prepared and submitted as part of the development review/approval process and be provided to the owner(s) upon sale of the development. It is also important to educate the general public on the purpose and function of stormwater BMPs. This is critical in cases where Low Impact Development (LID) or landscape-based BMPs are distributed throughout multiple parcels in developments. In addition to legally binding maintenance agreements, it is also helpful to have easy-to-understand informational brochures that describe the functions and maintenance requirements for these facilities.

3.0 Developing a Maintenance Plan

Maintenance plans can be prepared as stand-alone documents, or be made part of a construction set. This is typically based on the preference of the reviewing entity or MS4 permittee. The following outlines key components of a maintenance plan:

1. A simple drawing of the site development showing the locations of all stormwater quality BMPs at the site and key components such as forebays, inlets, outlets, low flow channels or other components that require inspections or maintenance. The drawing should be kept on-site at the property or the property management office. Any changes to the facility over time should be noted on the drawing.
2. A brief description of the inspection and maintenance procedures and frequencies.
3. A brief description of the maintenance requirements and expected frequency of actions, which can be obtained from discussion within this chapter. Include instruction on how to access each

component of each BMP and with what equipment. It is important to identify all maintenance requirements related directly to the water quality functions of the BMP and provide information concerning future site work that could potentially impact the integrity of the BMP. This is particularly true for landscaped BMPs. For example, the following maintenance requirements may be important for a rain garden:

- Provide frequent weed control in the first three years following installation and as needed for the life of the facility. Weeding should be performed mechanically, either by hand or by mowing (after establishment of the vegetation).
- Remove debris from area and outlet.
- Ensure cleanout caps remains watertight.

Additionally, the maintenance plans should identify constraints and considerations for future work that have the potential to affect the performance of the BMP. For example, the following prohibitions would typically be included in a maintenance plan for a rain garden:

- Do not place conventional sod on the surface of the rain garden.
- Do not plant trees within 10 feet of the rain garden.
- Do not place fill in the rain garden.
- Do not puncture impermeable liner, (if present).

4. An inspection form or checklist appropriate for the facilities in place at the site. A log of inspection forms should be kept onsite or at the property management office to demonstrate that routine inspections and maintenance are occurring.
5. Contact information for the entity responsible for maintenance of the facility. For example, this could be a homeowner's association, municipality, or other entity. (For BMPs maintained by UDFCD, the owner, rather than UDFCD, should be contacted.)
6. Copies of legally binding agreements associated with the facility that show that the facility owner is aware of, and will abide by, their maintenance responsibilities.
7. Other items as appropriate for specific conditions, which may include any of the following:
   - For ponds, include a permanent control point and other critical elevations, (i.e. bottom of pond, EURV, 100-year WSE, or overflow).
   - Provide the estimated baseflow used for the design and other hydrologic information for larger watersheds.
   - List information pertaining to materials testing for any contaminant testing requirements for removed sediment.
   - Include post-maintenance considerations, (e.g., restoration of flow paths).
   - Provide for long-term monitoring requirements, (e.g., 404 permit reports).

It is also important to note that the guidelines included in this manual should always be combined with common sense and good judgment based on field observations and practical experience. Often, there will be maintenance requirements that are specific to a given site in addition to the general maintenance guidance provided in this manual.

On a general note with regard to BMPs that have a vegetation component or involve weed and pest control, UDFCD strongly advocates the use of Integrated Pest Management (IPM) practices that help to reduce the level of chemical applications through a variety of management practices. IPM is discussed in BMP Fact Sheet S-8 located in Chapter 5.

Although water quality monitoring is not typically required as part of maintenance agreements, it is encouraged as an effective tool for determining if the BMP is functioning effectively. Stormwater quality monitoring guidelines can be downloaded from the International Stormwater BMP Database website (www.bmpdatabase.org).

Additional References for Stormwater BMP Maintenance

City of Portland, Oregon. 2002. Maintaining Your Stormwater Management Facility: A Handbook for Private Property Owners. Portland, OR: Bureau of Environmental Services. http://www.portlandonline.com/Bes/index.cfm?a=54730&c=34980.

Low Impact Development Center. 2003. Low Impact Development Urban Design Tools. http://www.lid-stormwater.net/bio_maintain.htm; http://www.lid-stormwater.net/permpavers_maintain.htm

North Carolina State University Cooperative Extension. 2006. Bioretention Performance, Design, Construction, and Maintenance. http://www.bae.ncsu.edu/stormwater/PublicationFiles/Bioretention2006.pdf

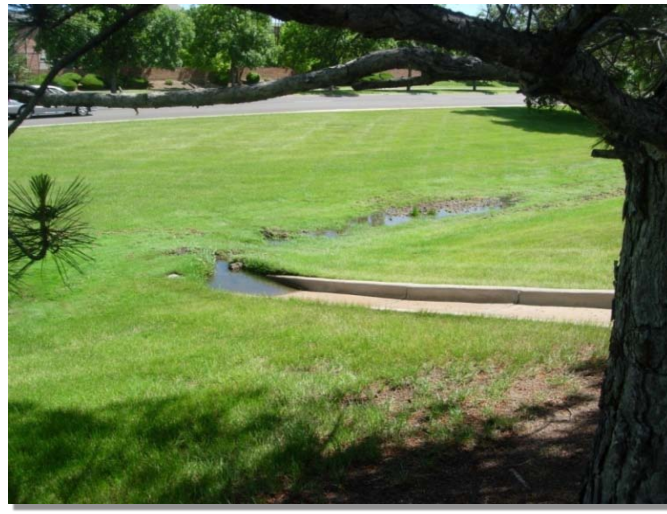
Santa Clara Valley Urban Runoff Pollution Prevention Program Example BMP Inspection and Maintenance Checklist. http://www.scvurppp-w2k.com/bmp_om_forms.htm

Southeast Metro Stormwater Authority (SEMSWA) Stormwater Management Facility Operation and Maintenance (O&M) Manual. www.semswa.org

Watershed Management Institute. 1997. Operation, Maintenance and Management of Stormwater Management Systems. Ingleside, MD: Watershed Management Institute.

4.0 Grass Buffers and Swales

Grass buffers and swales require maintenance of the turf cover and repair of rill or gully development. Healthy vegetation can often be maintained without using fertilizers because runoff from lawns and other areas contains the needed nutrients. Periodically inspecting the vegetation over the first few years will help to identify emerging problems and help to plan for long-term restorative maintenance needs. This section presents a summary of specific maintenance requirements and a suggested frequency of action.



Photograph 6-2. A lack of sediment removal in this grass swale has resulted in a grade change due to growth over the deposition and ponding upstream.

4.1 Inspection

Inspect vegetation at least twice annually for uniform cover and traffic impacts. Check for sediment accumulation and rill and gully development.

4.2 Debris and Litter Removal

Remove litter and debris to prevent rill and gully development from preferential flow paths around accumulated debris, enhance aesthetics, and prevent floatables from being washed offsite. This should be done as needed based on inspection, but no less than two times per year.

4.3 Aeration

Aerating manicured grass will supply the soil and roots with air. It reduces soil compaction and helps control thatch while helping water move into the root zone. Aeration is done by punching holes in the ground using an aerator with hollow punches that pull the soil cores or "plugs" from the ground. Holes should be at least 2 inches deep and no more than 4 inches apart.

Aeration should be performed at least once per year when the ground is not frozen. Water the turf thoroughly prior to aeration. Mark sprinkler heads and shallow utilities such as irrigation lines and cable TV lines to ensure those lines will not be damaged. Avoid aerating in extremely hot and dry conditions. Heavy traffic areas may require aeration more frequently.

4.4 Mowing

When starting from seed, mow native/drought-tolerant grasses only when required to deter weeds during the first three years. Following this period, mowing of native/drought tolerant grass may stop or be reduced to maintain a length of no less than six inches. Mowing of manicured grasses may vary from as frequently as weekly during the summer, to no mowing during the winter. See the inset for additional recommendations from the CSU Extension.

4.5 Irrigation Scheduling and Maintenance

Adjust irrigation schedules throughout the growing season to provide the proper irrigation application rate to maintain healthy vegetation. Less irrigation is typically needed in early summer and fall, with more irrigation needed during July and August. Native grass should not require irrigation after establishment, except during prolonged dry periods when supplemental, temporary irrigation may aid in maintaining healthy vegetation cover. Check for broken sprinkler heads and repair them, as needed. Do not overwater. Signs of overwatering and/or broken sprinkler heads may include soggy areas and unevenly distributed areas of lush growth.

Completely drain and blowout the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

CSU Extension Recommendations for Mowing Manicured Turf (Source: T. Koski and V. Skinner, 2003)

The two most important facets of mowing are mowing height and frequency. The minimum height for any lawn is 2 inches. The preferred mowing height for all Colorado species is 2.5 to 3 inches. Mowing to less than 2 inches can result in decreased drought and heat tolerance and higher incidence of insects, diseases and weeds. Mow the lawn at the same height all year. There is no reason to mow the turf shorter in late fall.

Mow the turf often enough so no more than 1/3 of the grass height is removed at any single mowing. If your mowing height is 2 inches, mow the grass when it is 3 inches tall. You may have to mow a bluegrass or fescue lawn every three to four days during the spring when it is actively growing but only once every seven to 10 days when growth is slowed by heat, drought or cold. Buffalograss lawns may require mowing once every 10 to 20 days, depending on how much they are watered.

If weather or another factor prevents mowing at the proper time, raise the height of the mower temporarily to avoid cutting too much at one time. Cut the grass again a few days later at the normal mowing height.

4.6 Fertilizer, Herbicide, and Pesticide Application

Use the minimum amount of biodegradable nontoxic fertilizers and herbicides needed to establish and maintain dense vegetation cover that is reasonably free of weeds. Fertilizer application may be significantly reduced or eliminated by the use of mulch-mowers, as opposed to bagging and removing clippings. To keep clippings out of receiving waters, maintain a 25-foot buffer adjacent to open water areas where clippings are bagged. Hand-pull the weeds in areas with limited weed problems.

Frequency of fertilizer, herbicide, and pesticide application should be on an as-needed basis only and should decrease following establishment of vegetation. See BMP Fact Sheet S-8 in Chapter 5 for additional information. For additional information on managing vegetation in a manner that conserves water and protects water quality, see the 2008 *GreenCO Best Management Practices Manual* (www.greenco.org) for a series of Colorado-based BMP fact sheets on topics such as irrigation, plant care, and soil amendments.

4.7 Sediment Removal

Remove sediment as needed based on inspection. Frequency depends on site-specific conditions. For planning purposes, it can be estimated that 3 to 10% of the swale length or buffer interface length will require sediment removal on an annual basis.

- **For Grass Buffers**: Using a shovel, remove sediment at the interface between the impervious area and buffer.

- **For Grass Swales**: Remove accumulated sediment near culverts and in channels to maintain flow capacity. Spot replace the grass areas as necessary.

Reseed and/or patch damaged areas in buffer, sideslopes, and/or channel to maintain healthy vegetative cover. This should be conducted as needed based on inspection. Over time, and depending on pollutant loads, a portion of the buffer or swale may need to be rehabilitated due to sediment deposition. Periodic sediment removal will reduce the frequency of revegetation required. Expect turf replacement for the buffer interface area every 10 to 20 years.

5.0 Bioretention (Rain Garden or Porous Landscape Detention)

The primary maintenance objective for bioretention, also known as porous landscape detention, is to keep vegetation healthy, remove sediment and trash, and ensure that the facility is draining properly. The growing medium may need to be replaced eventually to maintain performance. This section summarizes key maintenance considerations for bioretention.

5.1 Inspection

Inspect the infiltrating surface at least twice annually following precipitation events to determine if the bioretention area is providing acceptable infiltration. Bioretention facilities are designed with a maximum depth for the WQCV of one foot and soils that will typically drain the WQCV over approximately 12 hours. If standing water persists for more than 24 hours after runoff has ceased, clogging should be further investigated and remedied. Additionally, check for erosion and repair as necessary.

5.2 Debris and Litter Removal

Remove debris and litter from the infiltrating surface to minimize clogging of the media. Remove debris and litter from the overflow structure.

5.3 Mowing and Plant Care

- **All vegetation**: Maintain healthy, weed-free vegetation. Weeds should be removed before they flower. The frequency of weeding will depend on the planting scheme and cover. When the growing media is covered with mulch or densely vegetated, less frequent weeding will be required.

- **Grasses**: When started from seed, allow time for germination and establishment of grass prior to mowing. If mowing is required during this period for weed control, it should be accomplished with hand-held string trimmers to minimize disturbance to the seedbed. After established, mow as desired or as needed for weed control. Following this period, mowing of native/drought tolerant grasses may stop or be reduced to maintain a length of no less than 6 inches. Mowing of manicured grasses may vary from as frequently as weekly during the summer, to no mowing during the winter. See Section 4.4 for additional guidance on mowing.

5.4 Irrigation Scheduling and Maintenance

Adjust irrigation throughout the growing season to provide the proper irrigation application rate to maintain healthy vegetation. Less irrigation is typically needed in early summer and fall, while more irrigation is needed during the peak summer months. Native grasses and other drought tolerant plantings should not typically require routine irrigation after establishment, except during prolonged dry periods.

Check for broken sprinkler heads and repair them, as needed. Completely drain the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

5.5 Replacement of Wood Mulch

Replace wood mulch only when needed to maintain a mulch depth of up to approximately 3 inches. Excess mulch will reduce the volume available for storage.

5.6 Sediment Removal and Growing Media Replacement

If ponded water is observed in a bioretention cell more than 24 hours after the end of a runoff event, check underdrain outfall locations and clean-outs for blockages. Maintenance activities to restore infiltration capacity of bioretention facilities will vary with the degree and nature of the clogging. If clogging is primarily related to sediment accumulation on the filter surface, infiltration may be improved by removing excess accumulated sediment and scarifying the surface of the filter with a rake. If the clogging is due to migration of sediments deeper into the pore spaces of the media, removal and replacement of all or a portion of the media may be required. The frequency of media replacement will depend on site-specific pollutant loading characteristics. Based on experience to date in the metro Denver area, the required frequency of media replacement is not known. To date UDFCD is not aware of any rain gardens constructed to the recommendations of these criteria that have required full replacement of the growing media. Although surface clogging of the media is expected over time, established root systems promote infiltration. This means that mature vegetation that covers the filter surface should increase the life span of the growing media, serving to promote infiltration even as the media surface clogs.

6.0 Green Roofs

Photograph 6-3. When inspecting roof drains, remove any surrounding rock as well as the inlet grate and visually inspect the drainpipe to ensure it is free of any extraneous materials.

A five-year maintenance plan should be established prior to the completion of all new green roofs. Both plant maintenance and inspection of various roof structural elements will be required regularly. Additionally, green roof plants require regular attention and care including irrigation, weeding, fertilizing, pruning, and replanting. While the first several years following green roof construction are critical for establishing vegetation, controlling weeds, and detecting problems such as leaks, a long-term maintenance plan will also be necessary. During the first five years, the maintenance plan should be refined and adjusted based on experience to develop an effective long-term plan.

6.1 Inspection

Green roof inspection should be conducted at least three times per year. At a minimum, the following areas require inspection:

- Inspect joints, borders or other features that pass through the roof to remove roots and identify damage that could lead to leaks. For example, inspect abutting vertical walls, roof vent pipes, outlets, air conditioning units, and perimeter areas. Joints with facades must provide open access for inspection, maintenance, and upkeep.

- A vegetation-free zone of approximately one foot should be maintained at the border of roof edges and at drain openings on the roof. Vegetation-free zones should be lined with pavers, stones, or gravel. Drains must remain free of vegetation and foreign objects. In order to allow for regular inspections and maintenance, drains on a green roof must remain permanently accessible.

- Because of the severe consequences of drain backups, inspection of drainage flow paths is crucial. Remove the inlet cover and visually inspect drainage pipes for roots or other material that could impede the flow of water.

- Plants are susceptible to poor drainage in the soil. If too much water is present and unable to drain, the plants will drown or rot. Routine inspections of drains should take place approximately three times per year as well as after precipitation events of 0.6 inches or more.

- Inspect the irrigation system for leaks or malfunctions. Uneven vegetative growth or dying plants should serve as indicators of potential irrigation system problems.

6.2 Plant Care and Media Replacement

As with any garden, plant replacement will be required periodically throughout the life of a green roof. For green roofs serving stormwater functions, heat-tolerant plants with shallow, spreading and fibrous root systems are recommended. Plant selection is crucial on roofs with intense wind and light such as roofs of skyscrapers or roofs that receive reflected solar radiation from other structures. Additionally, certain portions of the roof may experience more intense sunlight and or reflected heat, requiring additional care or irrigation system adjustments.

Care of the plants on a green roof will require the most attention during the critical establishment phase. A horticultural professional should work with individuals caring for the new roof to organize schedules and routines for hand weeding, thinning, pruning, fertilizing, irrigation system scheduling and adjustments, and plant replacement. Watering and weeding are particularly important for the first two years of the green roof. For overall health of the green roof, weeds should be identified and removed early and often.

If the growing medium needs to be replaced, it should be replaced in accordance with the original design specifications, unless these specifications have been identified as a cause of poor plant growth or green roof performance. Any substitutions or adjustments to the original green roof media must be balanced carefully to meet loading limits, drainage requirements, and characteristics conducive to healthy plant growth.

When caring for plants or adjusting growing media, care should be taken to avoid use of materials likely to result in nutrient export from the green roof. For example, growing media and compost should have a low phosphorus index (P index). Appropriate plants with low fertilization requirements should be chosen. If used, fertilizer application should be minimized to levels necessary only for plant health.

6.3 Irrigation Scheduling and Maintenance

Green roofs in Colorado should be equipped with irrigation systems, even if the ultimate goal is for the plants to rely primarily on natural precipitation. Irrigation schedules should be based on the evapotranspiration (ET) requirements of the plants, the type of irrigation system used (e.g., drip or spray), and changing ET over the growing season. Irrigation systems equipped with advanced irrigation controllers based on soil moisture can help facilitate watering according to the changing water needs of the plants. If advanced systems are not used, irrigation should be manually adjusted during the growing season to replace water lost through ET. During the first two years of plant establishment, regular irrigation will likely be needed. After plant establishment, it may be possible to reduce supplemental irrigation during non-drought conditions.

Completely drain the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

7.0 Extended Detention Basins (EDBs)

EDBs have low to moderate maintenance requirements on a routine basis, but may require significant maintenance once every 15 to 25 years. Maintenance frequency depends on the amount of construction activity within the tributary watershed, the erosion control measures implemented, the size of the watershed, and the design of the facility.

7.1 Inspection

Inspect the EDB at least twice annually, observing the amount of sediment in the forebay and checking for debris at the outlet structure.

7.2 Debris and Litter Removal

Remove debris and litter from the detention area as required to minimize clogging of the outlet.

7.3 Mowing and Plant Care

When starting from seed, mow native/drought tolerant grasses only when required to deter weeds during the first three years. Following this period, mowing of native/drought tolerant grass may stop or be reduced to maintain a height of no less than 6 inches (higher mowing heights are associated with deeper roots and greater drought tolerance). In general, mowing should be done as needed to maintain appropriate height and control weeds. Mowing of manicured grasses may vary from as frequently as weekly during the summer, to no mowing during the winter. See Section 4 of this chapter for additional recommendations from the CSU Extension.

7.4 Aeration

For EDBs with manicured grass, aeration will supply the soil and roots with air and increase infiltration. It reduces soil compaction and helps control thatch while helping water move into the root zone. Aeration is done by punching holes in the ground using an aerator with hollow punches that pull the soil cores or "plugs" from the ground. Holes should be at least 2 inches deep and no more than 4 inches apart.

Aeration should be performed at least once per year when the ground is not frozen. Water the turf thoroughly prior to aeration. Mark sprinkler heads and shallow utilities such as irrigation lines and cable TV lines to ensure those lines will not be damaged. Avoid aerating in extremely hot and dry conditions. Heavy traffic areas may require aeration more frequently.

7.5 Mosquito Control

Although the design provided in this manual implements practices specifically developed to deter mosquito breeding, some level of mosquito control may be necessary if the BMP is located in close proximity to outdoor amenities. The most effective mosquito control programs include weekly inspection for signs of mosquito breeding with treatment provided when breeding is found. These inspections can be performed by a mosquito control service and typically start in mid-May and extend to mid-September. Treatment should be targeted toward mosquito larvae. Mosquitoes are more difficult to control when they are adults. This typically requires neighborhood fogging with an insecticide.

The use of larvicidal briquettes or "dunks" may be appropriate. These are typically effective for about one month and perform best when the basin has a hard bottom (e.g., concrete lined micropool).

Facts on Mosquito Breeding

Although mosquitoes prefer shallow, stagnant water, they can breed within the top 6 to 8 inches of deeper pools.

Mosquitoes need nutrients and prefer shelter from direct sunlight.

Mosquitoes can go from egg to adult within 72 hours.

The most common mosquitoes in Colorado include the *Aedes Vexans* and the *Culex Tarsalis*. Both have similar needs for breeding and development.

7.6 Irrigation Scheduling and Maintenance

Adjust irrigation throughout the growing season to provide the proper irrigation application rate to maintain healthy vegetation. Less irrigation is typically needed in early summer and fall, with more irrigation needed during July and August. Native grass and other drought tolerant plantings should not require irrigation after establishment.

Check for broken sprinkler heads and repair them, as needed. Completely drain the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

7.7 Sediment Removal from the Forebay, Trickle Channel, and Micropool

Remove sediment from the forebay and trickle channel annually. If portions of the watershed are not developed or if roadway or landscaping projects are taking place in the watershed, the required frequency of sediment removal in the forebay may be as often as after each storm event. The forebay should be maintained in such a way that it does not provide a significant source of resuspended sediment in the stormwater runoff.

Sediment removal from the micropool is required about once every one to four years, and should occur when the depth of the pool has been reduced to approximately 18 inches. Small micropools may be vacuumed and larger pools may need to be pumped in order to remove all sediment from the micropool bottom. Removing sediment from the micropool will benefit mosquito control. Ensure that the sediment is disposed of properly and not placed elsewhere in the basin.

7.8 Sediment Removal from the Basin Bottom

Remove sediment from the bottom of the basin when accumulated sediment occupies about 20% of the water quality design volume or when sediment accumulation results in poor drainage within the basin. The required frequency may be every 15 to 25 years or more frequently in basins where construction activities are occurring.

7.9 Erosion and Structural Repairs

Repair basin inlets, outlets, trickle channels, and all other structural components required for the basin to operate as intended. Repair and vegetate eroded areas as needed following inspection.

8.0 Sand Filters

Sand filters have relatively low routine maintenance requirements. Maintenance frequency depends on pollutant loads in runoff, the amount of construction activity within the tributary watershed, the erosion control measures implemented, the size of the watershed, and the design of the facility.

8.1 Inspection

Inspect the detention area once or twice annually following precipitation events to determine if the sand filter is providing acceptable infiltration. Also check for erosion and repair as necessary.

8.2 Debris and Litter Removal

Remove debris and litter from detention area to minimize clogging of the media. Remove debris and litter from the overflow structure.

8.3 Filter Surface Maintenance

Scarify the top 2 inches of sand on the surface of the filter. This may be required once every two to five years depending on observed drain times. After this has been done two or three times, replenish the top few inches of the filter with clean coarse sand (AASHTO C-33 or CDOT Class C filter material) to the original elevation. Maintain a minimum sand depth of 12 inches. Eventually, the entire sand layer may require replacement.

8.4 Erosion and Structural Repairs

Repair basin inlets, outlets, and all other structural components required for the BMP to operate as intended. Repair and vegetate any eroded side slopes as needed following inspection.

9.0 Retention Ponds and Constructed Wetland Ponds

9.1 Inspection

Inspect the pond at least annually. Note the amount of sediment in the forebay and look for debris at the outlet structure.

9.2 Debris and Litter Removal

Remove debris and litter from the pond as needed. This includes floating debris that could clog the outlet or overflow structure.

9.3 Aquatic Plant Harvesting

Harvesting plants will permanently remove nutrients from the system, although removal of vegetation can also resuspend sediment and leave areas susceptible to erosion. Additionally, the plants growing on the safety wetland bench of a retention pond help prevent drowning accidents by demarking the pond boundary and creating a visual barrier. For this reason, UDFCD does not recommend harvesting vegetation completely as routine maintenance. However, aquatic plant harvesting can be performed if desired to maintain volume or eliminate nuisances related to overgrowth of vegetation. When this is the case, perform this activity during the dry season (November to February). This can be performed manually or with specialized machinery.

If a reduction in cattails is desired, harvest them annually, especially in areas of new growth. Cut them at the base of the plant just below the waterline, or slowly pull the shoot out from the base. Cattail removal should be done during late summer to deprive the roots of food and reduce their ability to survive winter.

9.4 Mosquito Control

Weekly mosquito inspections with targeted treatments are frequently less costly and more effective than regular widespread application of insecticide.

Mosquito control may be necessary if the BMP is located in proximity to outdoor amenities. The most effective mosquito control programs include weekly inspection for signs of mosquito breeding with treatment provided when breeding is found. These inspections and treatment can be performed by a mosquito control service and typically start in mid-May and extend to mid-September. The use of larvicidal briquettes or "dunks" is not recommended for ponds due to their size and configuration.

9.5 Sediment Removal from the Forebay

Remove sediment from the forebay before it becomes a significant source of pollutants for the remainder of the pond. More frequent removal will benefit long-term maintenance practices. For dry forebays, sediment removal should occur once a year. Sediment removal in wet forebays should occur approximately once every four years or when build up of sediment results in excessive algae growth or mosquito production. Ensure that the sediment is disposed of properly and not placed elsewhere in the pond.

9.6 Sediment Removal from the Pond Bottom

Removal of sediment from the bottom of the pond may be required every 10 to 20 years 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.

For constructed wetland ponds, reestablish growth zone depths and replant if necessary.

10.0 Constructed Wetland Channels

10.1 Inspection

Inspect the channel at least annually. Look for signs of erosion.

10.2 Debris and Litter Removal

Remove debris and litter as needed.

10.3 Aquatic Plant Harvesting

Harvesting plants will permanently remove nutrients from the system although removal of vegetation can also resuspend sediment and leave areas susceptible to erosion. For this reason, UDFCD does not recommend harvesting vegetation as routine maintenance. However, aquatic plant harvesting can be performed if desired to maintain volume or eliminate nuisances related to overgrowth of vegetation. When this is the case, perform this activity during the dry season (November to February). This can be performed manually or with specialized machinery.

Photograph 6-4. This broom sweeper will only remove debris from the pavement surface. Broom sweepers are not designed to remove solids from the void space of a permeable pavement. Use a vacuum or regenerative air sweeper to help maintain or restore infiltration through the wearing course.

If a reduction in cattails is desired, harvest them annually, especially in areas of new growth. Cut them at the base of the plant just below the waterline, or slowly pull the shoot out from the base. Cattail removal should be done during late summer to deprive the roots of food and reduce their ability to survive winter.

10.4 Sediment Removal

If the channel becomes overgrown with plants and sediment, it may need to be graded back to the original design and revegetated. The frequency of this activity is dependent on the site characteristics and should not be more than once every 10 to 20 years.

11.0 Permeable Pavement Systems

The key maintenance objective for any permeable pavement system is to know when runoff is no longer rapidly infiltrating into the surface, which is typically due to void spaces becoming clogged and requiring sediment removal. This section identifies key maintenance considerations for various types of permeable pavement BMPs.

11.1 Inspection

Inspect pavement condition and observe infiltration at least annually, either during a rain event or with a garden hose to ensure that water infiltrates into the surface. Video, photographs, or notes can be helpful in measuring loss of infiltration over time. Systematic measurement of surface infiltration of pervious concrete, Permeable Interlocking Concrete Pavers (PICP), concrete grid pavement, and porous asphalt[1] can be accomplished using ASTM C1701 Standard Test Method for Infiltration Rate of In Place Pervious Concrete.

[1] Porous asphalt is considered a provisional treatment BMP pending performance testing in Colorado and is not included in this manual at the present time.

11.2 Debris Removal, Sweeping, and Vacuuming

- **All Pavements:** Debris should be removed, routinely, as a source control measure. Typically, sites that require frequent sweeping already plan for this activity as part of their ongoing maintenance program. For example, a grocery store may sweep weekly or monthly. Depending on the season, city streets also may have a monthly plan for sweeping. This is frequently performed with a broom sweeper such as the one shown in Photo 6-4. Although this type of sweeper can be effective at removing solids and debris from the surface, it will not remove solids from the void space of a permeable pavement. Use a vacuum or regenerative air sweeper to help maintain or restore infiltration. If the pavement has not been properly maintained, a vacuum sweeper will likely be needed.

- **PICP, Concrete Grid Pavements (with aggregate infill), Pervious Concrete, and Porous Asphalt[1]:** Use a regenerative air or vacuum sweeper after any significant site work (e.g., landscaping) and approximately twice per year to maintain infiltration rates. This should be done on a warm dry day for best results. Do not use water with the sweeper. The frequency is site specific and inspections of the pavement may show that biannual vacuuming is more frequent than necessary. After vacuuming PICP and Concrete Grid Pavers, replace infill aggregate as needed.

11.3 Snow Removal

In general, permeable pavements do not form ice to the same extent as conventional pavements. Additionally, conventional liquid treatments (deicers) will not stay at the surface of a permeable pavement as needed for the treatment to be effective. Sand should not be applied to a permeable pavement as it can reduce infiltration. Plowing is the recommended snow removal process. Conventional plowing operations should not cause damage to the pavements.

- **PICP and Concrete Grid:** Deicers may be used on PICP and grid pavers; however, it may not be effective for the reason stated above. Sand should not be used. If sand is accidently used, use a vacuum sweeper to remove the sand. Mechanical snow and ice removal should be used.

- **Pervious Concrete:** Do not use liquid or solid deicers or sand on pervious concrete. Deicers can damage the concrete and sand will reduce infiltration. Mechanical snow and ice removal should be used.

- **Porous Asphalt[2]:** Use liquid or solid deicers sparingly; mechanical snow and ice removal is preferred. Do not apply sand to porous asphalt.

11.4 Full and Partial Replacement of the Pavement or Infill Material

- **PICP and Concrete Grid:** Concrete pavers, when installed correctly, should have a long service life. If a repair is required, it is frequently due to poor placement of the paver blocks. Follow industry guidelines for installation and replacement after underground repairs.

  If surface is completely clogged and rendering a minimal surface infiltration rate, restoration of surface infiltration can be achieved by removing the first ½ to 1 inch of soiled aggregate infill

[2] Porous asphalt is considered a provisional treatment BMP pending performance testing in Colorado and is not included in this manual at the present time.

material with a vacuum sweeper. After cleaning, the openings in the PICP will need to be refilled with clean aggregate infill materials. Replacement of the infill is best accomplished with push brooms.

- **Porous Gravel:** Remove and replace areas of excessive wear or reduced infiltration as needed. The frequency is dependent on site characteristics including site uses, vegetation, and materials.
- **Pervious Concrete:** Partial replacement of pervious concrete should be avoided. If clogged, power washing or power blowing should be attempted prior to partial replacement because saw cutting will cause raveling of the concrete. Any patches should extend to existing isolated joints. Conventional concrete may be used in patches, provided that 90 percent of the original pervious surface is maintained.
- **Reinforced Grass:** Remove and replace the sod cover as needed to maintain a healthy vegetative cover or when the sod layer accumulates significant amount of sediment (i.e., >1.5 inches). Maintenance and routine repairs should be performed annually, with sod replacement approximately every 10 to 25 years. When replacing sod, use a high infiltration variety such as sod grown in sandy loam.
- **Porous Asphalt[3]:** Conventional asphalt may be used in patches, provided that 90 percent of the original permeable surface is maintained.

12.0 Underground BMPs

Maintenance requirements of underground BMPs can vary greatly depending on the type of BMP. Frequent inspections (approximately every three months) are recommended in the first two years in order to determine the appropriate interval of maintenance for a given BMP. This section provides general recommendations for assorted underground BMPs. For proprietary devices, the manufacturer should provide detailed maintenance requirements specific for the BMP.

12.1 Inspection

- **All Underground BMPs:** Inspect underground BMPs at least quarterly for the first two years of operation and then twice a year for the life of the BMP, if a reduced inspection schedule is warranted based on the initial two years. Specifically look for debris that could cause the structure to bypass water quality flows. Strong odors may also indicate that the facility is not draining properly. Inspection should be performed by a person who is familiar with the operation and configuration of the BMP.
- **Inlet Inserts:** Inspect inlet inserts frequently; at a minimum, inspect after every storm event exceeding 0.6 inches. Removal of flow blocking debris is critical for flood control.

12.2 Debris Removal, Cartridge Replacement, and Vacuuming

- **All Underground BMPs:** Follow the manufacturer's recommended maintenance requirements and remove any flow blocking debris as soon as possible following inspection.

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[3] Porous asphalt is considered a provisional treatment BMP pending performance testing in Colorado and is not included in this manual at the present time.

- **Filter Cartridges:** Inspection of filter cartridges is recommended twice yearly. Replacement of filter cartridges is anticipated on an annual basis. Depending on site characteristics, the replacement frequency may be extended to no less than once every three years. However, semi-annual inspection should continue to ensure that proper function of the system is maintained. Maintenance is required when any of the following conditions exist:
    - If there is more than 4 inches of accumulated sediment on the vault floor.
    - If there is more than ¼ inch of accumulation on the top of the cartridge.
    - If there is more than 4 inches of standing water in the cartridge bay for more than 24 hours after the end of a rain event.
    - If the pore space between media granules is full.
    - If inspection is conducted during an average rainfall event and the system remains in bypass condition (water over the internal outlet baffle wall or submerged cartridges).
    - If hazardous material release (automotive fluids or other) is reported.
    - If pronounced scum line (≥ 1/4" thick) is present above top cap.
    - If system has not been maintained for three years.
- **Hydrodynamic Separators:** Vacuum units at least once annually and more frequently as needed, based on inspections.

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Chapter 7
Construction BMPs

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1.0 Introduction

Effective management of stormwater runoff during construction activities is critical to the protection of water resources. The Federal Clean Water Act and the Colorado Water Quality Control Act require stormwater discharge permits during construction at development and redevelopment sites that disturb one or more acres of land. Some local governments also require these permits for sites that disturb less than one acre. Both erosion and sediment controls are necessary for effective construction site management as well as effective material management and site management practices (Figure 7-1). Protection of waterways from construction-related pollution is the ultimate objective of these practices.

This chapter provides an overview of erosion and sediment control principles and information on construction best management practices (BMPs). BMP Fact Sheets are provided, containing information on applicability, installation, maintenance, and design details with notes. The Fact Sheets are stand-alone documents that can be inserted directly into a Stormwater Management Plan (SWMP). Information is also provided on construction in or adjacent to waterways, construction dewatering, and linear construction projects, such as roadways and utilities.

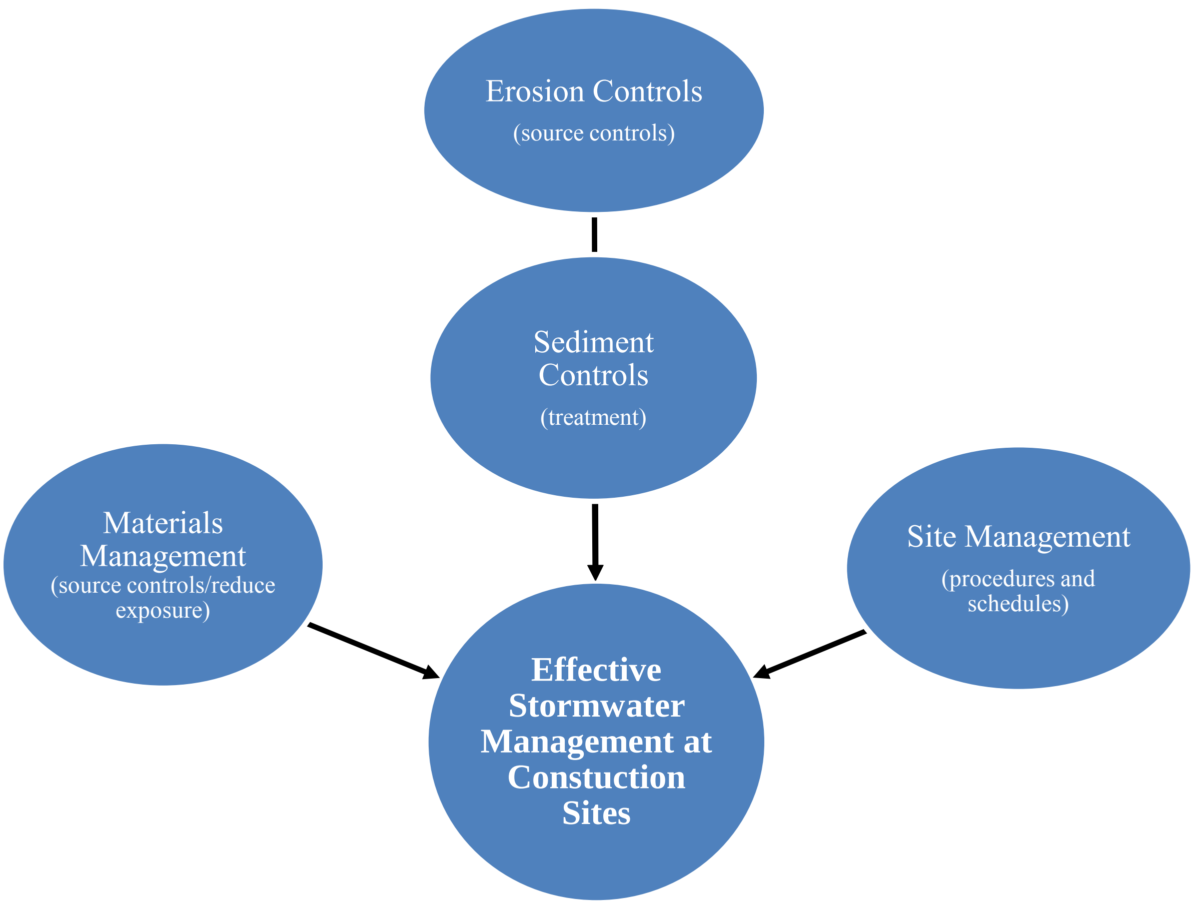

Figure 7-1. Components of Effective Stormwater Management at Construction Sites

2.0 Fundamental Erosion and Sediment Control Principles

2.1 Erosion

Soil erosion can generally be defined as the removal of soil by wind and water. Although soil erosion is a natural process, accelerated soil erosion occurs on construction sites due to activities that disturb the natural soil and vegetation.

Photograph 7-2. Erosion is a common occurrence during construction activities, which can result in sediment movement off site and deposition in waterways when not properly managed. (Photo courtesy of Douglas County)

Water erosion has five primary mechanisms: raindrop erosion, sheet erosion, rill erosion, gully erosion, and channel erosion. Raindrops dislodge soil particles, making them more susceptible to movement by overland water flow. Shallow surface flows on soil rarely move as a uniform sheet for more than several feet before concentrating in surface irregularities, known as rills. As the flow changes from a shallow sheet to a deeper rill flow, the flow velocity and shear stresses increase, which detach and transport soil particles. This action begins to cut into the soil mantle and form small channels. Rills are small, well-defined channels that are only a few inches deep. Gullies occur as the flows in rills come together into larger channels. The major difference between rill and gully erosion is size. Rills caused by erosion can be smoothed out by standard surface treatments such as harrowing. Gully erosion, however, typically requires heavy equipment to regrade and stabilize the land surface.

Wind erosion occurs when winds of sufficient velocity create movement of soil particles. The potential for wind erosion is dependent upon soil cover, soil particle size, wind velocity, duration of wind and unsheltered distance.

Erodibility of soils is affected by multiple factors including physical soil characteristics, slope steepness, slope lengths, vegetative cover, and rainfall characteristics. Physical properties of soils such as particle size, cohesiveness, and density affect erodibility. Loose silt and sand-sized particles typically are more susceptible to erosion than "sticky" clay soils. Rocky soils are less susceptible to wind erosion, but are often found on steep slopes that are subject to water erosion. Most of the soils in Colorado are susceptible to wind or water erosion, or both. When surface vegetative cover and soil structure are disturbed during construction, the soil is more susceptible to erosion. Vegetation plays a critical role in controlling erosion. Roots bind soil together and the leaves or blades of grass reduce raindrop impact forces on the soil. Grass, tree litter and other ground cover not only intercept precipitation and allow infiltration, but also reduce runoff velocity and shear stress at the surface. Vegetation reduces wind velocity at the ground surface, and provides a rougher surface that can trap particles moving along the ground. Once vegetation is removed, soils become more susceptible to erosion.

2.2 Sedimentation

Sedimentation occurs when eroded soil transported in wind or water is deposited from its suspended state. During a typical rainstorm in Colorado, runoff normally builds up rapidly to a peak and then diminishes. Because the amount of sediment a watercourse can carry is dependent upon the velocity and volume of runoff, sediment is eventually deposited as runoff decreases. The deposited sediments may be resuspended when future runoff events occur. In this way, sediments are moved progressively downstream in the waterway system.

2.3 Effective Erosion and Sediment Control

It is better to minimize erosion than to rely solely on sedimentation removal from construction site runoff. Erosion control BMPs limit the amount and rate of erosion occurring on disturbed areas. Sediment control BMPs attempt to capture the soil that has been eroded before it leaves the construction site. Despite the use of both erosion control and sediment control BMPs, some amount of sediment will remain in runoff leaving a construction site, but the use of a "treatment train" of practices can help to minimize offsite transport of sediment. The last line of treatment such as inlet protection and sediment basins should be viewed as "polishing" BMPs, as opposed to the only treatment on the site. Section 4 of this chapter provides an overview of erosion and sediment controls, followed by BMP Fact Sheets providing design details and guidance for effective use of various erosion and sediment control practices. BMPs should be combined and selected to meet these objectives:

- Conduct land-disturbing activities in a manner that effectively reduces accelerated soil erosion and reduces sediment movement and deposition off site.
- Schedule construction activities to minimize the total amount of soil exposed at any given time.
- Establish temporary or permanent cover on areas that have been disturbed as soon as practical after grading is completed.
- Design and construct temporary or permanent facilities to limit the flow of water to non-erosive velocities for the conveyance of water around, through, or from the disturbed area.
- Remove sediment caused by accelerated soil erosion from surface runoff water before it leaves the site.
- Stabilize disturbed areas with permanent vegetative cover and provide permanent stormwater quality control measures for the post-construction condition.

State Construction Phase Permitting

Stormwater runoff controls from construction sites are mandated by the Federal Water Pollution Control Act (Clean Water Act). In Colorado, the EPA has delegated authority to the Colorado Department of Public Health and Environment (CDPHE). CDPHE, specifically the Water Quality Control Division, issues stormwater and wastewater discharge permits under the Colorado Discharge Permit System (CDPS) Regulation promulgated by the Water Quality Control Commission.

3.0 Colorado Construction Stormwater Discharge Permits

Within UDFCD's boundary, development or redevelopment projects with one or more acres of potential disturbance are often required to obtain both local and state permits related to construction-phase stormwater discharges. The area of disturbance includes construction activities that are part of a larger common plan of development or sale and may include "separate" areas where construction practices will occur at different times. Areas used for staging, materials storage, temporary construction site access, off-site borrow areas and other construction related activities should also be included when determining the project area and area of disturbance permitted. In some cases, a construction discharge permit will be required by the local government, but not the state. Although CDPHE typically does not require permit coverage for construction activities that disturb less than one acre, provided the activities are not part of a large plan of development, some municipalities require stormwater permits for sites that disturb less than one acre, especially if construction is proximate to a floodplain and/or receiving water, steep slopes, and/or areas of known contamination.

The CDPHE typically issues construction permits under the CDPS General Permit for stormwater discharges associated with construction activities. Under certain conditions, CDPHE may require an individual permit. This may be required due to the size of disturbance, evidence of noncompliance under a previous permit, and/or quality and use of the receiving waters. The CDPS General Permit requires the owner and/or operator (frequently the contractor) to develop a SWMP. Although CDPHE does not require that the SWMP be submitted for approval, most local governments require submittal of a SWMP (or comparable document) which is reviewed by the local government and must be approved prior to issuance of construction-related permits (e.g., grading permit, land disturbance permit). Because SWMPs are "living documents" that must be updated and maintained as the phases of construction progress, ideally, one master document should be developed that is inclusive of both the state and local requirements, as opposed to maintaining duplicate records. Many local governments require documentation that goes beyond the state permit requirements.

Always obtain the state permit application and guidance directly from the state agency to ensure that all currently applicable requirements are met. In Colorado, this information can be obtained from the CDPHE CDPS General Permit for Stormwater Discharges Associated with Construction Activities. Also, check local government programs as they may have specific requirements more stringent than the minimum criteria specified by the state.

Table 7-1. Comparison of State and Local Construction-Phase Stormwater Permits in Colorado

	State	**Local Government** (programs vary, not inclusive)
Nomenclature	▪ Colorado Discharge Permit System (CDPS) General Permit for Stormwater Discharges Associated with Construction Activities ▪ CDPS Individual Permit for Stormwater Discharges Associated with Construction Activities	▪ Construction Activities Stormwater Discharge Permit (CASDP) ▪ Grading, Erosion, and Sediment Control Permit (GESC) ▪ Grading Permit ▪ Land Disturbance Permit ▪ Sewage Use and Drainage Permit (SUDP)
Triggers	▪ Area of potential disturbance is greater than one acre (This area includes construction activities that are part of a larger common plan of development or sale. Areas used for staging, materials storage, temporary construction site access, off-site borrow areas and other construction related activities should also be included.)	▪ State Construction Phase Stormwater Permit required ▪ Potential for erosion based on site characteristics (i.e. steep topography, highly erodible soils) ▪ Contaminated soils on site ▪ Sites within a designated 100-year floodplain and/or proximity to active waterway
Required Items	▪ Application ▪ Stormwater Management Plan (SWMP). In other parts of the country, this may be referred to as a Stormwater Pollution Prevention Plan (SWPPP) ▪ Annual Fee	▪ Application ▪ SWMP with requirements that frequently exceed the requirements listed in the state permit ▪ Fee

3.1 Preparing and Implementing a Stormwater Management Plan (SWMP)

A SWMP should be developed prior to construction and kept current for the duration of construction. This section includes recommendations for SWMP preparation and BMP inspection, maintenance and removal.

3.1.1 General SWMP Recommendations

- At a minimum, a SWMP should communicate and satisfy the following:
  - Identify all potential sources of pollution which may affect the quality of stormwater discharges associated with construction activity;
  - Describe the practices to be used to reduce the pollutants in stormwater discharges associated with construction activity including the installation, implementation and maintenance requirements; and
  - Be prepared in accordance with good engineering practices and be updated throughout construction and stabilization of the site.
- Implement the provisions of the SWMP as written and updated, from commencement of construction activity until final stabilization is complete. The SWMP typically requires additions or other modifications once construction commences, and documentation of all modifications and amendments is typically required by the construction stormwater permit. UDFCD recommends that the contractor maintain records of all inspections, BMP maintenance, and communications with the owner and/or engineer. This should be kept on-site, with the SWMP. UDFCD recommends that these records be recognized as part of the SWMP but that changes to the practices identified in the SWMP should not be made without the approval of an engineer.
- The SWMP should include additional discussion or plans for any special requirements of the site. Special requirements include Spill Prevention Control and Countermeasure (SPCC) plans under Section 311 of the Clean Water Act, or BMP programs otherwise required by another CDPS permit.

3.1.2 SWMP Elements

The SWMP should include the following as a minimum. When some sections are not applicable, include a statement to that effect.

- **Site Description:** Clearly describe the construction activity, including:
  - The nature of the construction activity at the site.
  - The proposed sequence for major activities.
  - Estimates of the total area of the site, and the area and location expected to be disturbed by clearing, excavation, grading, or other construction activities.
  - A summary of any existing data used in the development of the site construction plans or SWMP that describe the soil or existing potential for soil erosion.
  - A description of the existing vegetation at the site and an estimate of the percent vegetative ground cover.
  - The location and description of all potential pollution sources, including ground surface disturbing activities (see CDPHE Stormwater General Permit for description), vehicle fueling, storage of fertilizers or chemicals, etc.

- The location and description of any anticipated allowable sources of non-stormwater discharge at the site, e.g., uncontaminated springs, landscape irrigation return flow, construction dewatering, and concrete washout.
- The name of the receiving water(s) and the size, type and location of any outfall(s). If the stormwater discharge is to a municipal separate storm sewer system, the name of that system, the location of the storm sewer discharge, and the ultimate receiving water(s).

- **Site Map.** Include a legible site map(s), showing the entire site, identifying:
  - Construction site boundaries;
  - All areas of ground surface disturbance;
  - Areas of cut and fill;
  - Areas used for storage of building materials, equipment, soil, or waste;
  - Locations of dedicated asphalt or concrete batch plants;
  - Locations of all structural BMPs;
  - Locations of non-structural BMPs as applicable; and
  - Locations of springs, streams, wetlands and other surface waters.
- **Stormwater Management Controls.** Include a description of all stormwater management controls that will be implemented as part of the construction activity to control pollutants in stormwater discharges. The appropriateness and priorities of stormwater management controls in the SWMP should reflect the potential pollutant sources identified at the facility. The description of stormwater management controls should address the following components, at a minimum:
  - SWMP Administrator. Identify a specific individual(s), position, or title that is responsible for developing, implementing, maintaining, and revising the SWMP. This designated individual(s) should address all aspects of the facility's SWMP.
  - Identification of Potential Pollutant Sources. Identify and describe sources that may contribute pollutants to runoff, and provide means of control through BMP selection and implementation. At a minimum, evaluate each of the following potential sources of pollution:
    1. All disturbed and stored soils;
    2. Vehicle tracking of sediments;
    3. Management of contaminated soils;
    4. Loading and unloading operations;
    5. Outdoor storage activities (building materials, fertilizers, chemicals, etc.);
    6. Vehicle and equipment maintenance and fueling;
    7. Significant dust or particulate generating processes;

8. Routine maintenance activities involving fertilizers, pesticides, detergents, fuels, solvents, oils, etc.;
9. On-site waste management practices (waste piles, liquid wastes, dumpsters, etc.);
10. Concrete truck/equipment washing, including the concrete truck chute and associated fixtures and equipment;
11. Dedicated asphalt and concrete batch plants;
12. Non-industrial waste sources such as worker trash and portable toilets; and
13. Other areas or procedures where potential spills can occur.

- **BMPs for Construction Stormwater Pollution Prevention.** Identify and describe appropriate BMPs including those listed in this section. Provide enough detail for each BMP to ensure proper implementation, operation, and maintenance.
  - Structural Practices for Erosion and Sediment Control. (e.g., wattles/sediment control logs and temporary or permanent sediment basins).
  - Non-Structural Practices for Erosion and Sediment Control. (e.g., temporary vegetation and permanent vegetation).
  - Phased BMP Implementation. Describe the relationship between the phases of construction, and the implementation and maintenance of both structural and non-structural stormwater management controls. Project phases might include different operations such as clearing and grubbing; road construction; utility and infrastructure installation; vertical construction; final grading; and final stabilization.
  - Materials Handling and Spill Prevention. Materials of interest could include: exposed storage of building materials; paints and solvents; fertilizers or chemicals; waste material; and equipment maintenance or fueling procedures.
  - Dedicated Concrete or Asphalt Batch Plants.
  - Vehicle Tracking Control. This BMP includes minimizing (as practicable) the number of areas where construction vehicles are required to move from unpaved to paved areas as well as providing structural BMPs at each location.
  - Waste Management and Disposal, Including Concrete Washout.
  - Groundwater and Stormwater Dewatering. These activities often require a separate permit that includes sampling of processed waters. However, in some cases, these activities can be conducted without a separate permit when processed water is not discharged from the site as surface runoff or discharged into surface waters. The SWMP should describe how these waters will be used (i.e., land application, infiltration, evaporation) and how the specific practices at the site will ensure that these waters are not discharged via runoff.

- **Final Stabilization and Long-Term Stormwater Management**
  - The SWMP should describe the practices used to achieve final stabilization of all disturbed areas at the site and any planned practices to control pollutants in stormwater discharges that will occur after construction operations have been completed at the site.
  - Final stabilization practices for obtaining a vegetative cover should include, as appropriate: seed mix selection and application methods; soil preparation and amendments; soil stabilization practices (e.g., crimped straw, hydro mulch or rolled erosion control products); and appropriate sediment control BMPs as needed until final stabilization is achieved; etc.
  - Final stabilization is reached when all ground surface disturbing activities at the site have been completed, and uniform vegetative cover has been established with an individual plant density of at least 70 percent of pre-disturbance levels, or equivalent permanent, physical erosion reduction methods have been employed.
- **Inspection and Maintenance.** The SWMP should describe the inspection and maintenance procedures implemented at the site to maintain all erosion and sediment control practices and other protective practices identified in the SWMP in good and effective operating condition. UDFCD recommends providing an inspection checklist for the project.

3.2 Inspections

Routine and post-storm inspections of BMPs are essential to identify maintenance necessary for the BMPs to remain in effective operating conditions. The frequency of inspections is typically influenced by multiple factors including the weather, the phase of construction, activities on site, and the types of BMPs. Checklists and other forms of documentation are also important to meet the requirements of a construction stormwater permit.

3.2.1 Inspection Frequency

In Colorado, the CDPS General Permit requires documented inspections on a biweekly basis and within 24 hours of a storm event, with some limited, temporary exceptions for inactive sites. UDFCD recommends spot-checking BMPs every workday. This is typically reasonable to achieve and can help to ensure that the BMPs remain in good working condition. For example, vehicle tracking of sediment onto the roadway is a common problem that often requires maintenance more frequently than weekly. Curb socks, inlet protection and silt fence are other BMPs that are prone to damage and displacement, also benefiting from more frequent inspections.

When the site or portions of the site are awaiting final stabilization (e.g., vegetative cover), where construction is essentially complete, the recommended frequency of inspection is at least once every month. Be sure that this change is documented and in accordance with relevant permit requirements prior to reducing the inspection schedule.

When snow cover exists over the entire site for an extended period, inspections are not always feasible. Document this condition, including date of snowfall and date of melting conditions, and be aware of and prepare for areas where melting conditions may pose a risk of surface erosion.

Local inspection requirements may be more stringent than CDPS permit requirements. For example, many local governments require weekly, rather than bi-weekly, documented inspections. Some local governments may not allow relaxed inspection schedules for sites that have been completed, but are awaiting final stabilization or for winter conditions.

3.2.2 Inspection Records

Always check the requirements of the permit for required documentation of specific inspection items. Typically, these items can be incorporated into a checklist. Standard checklists may be developed and used for various types of construction projects (e.g., channel work, large-scale phased construction projects, or small urban sites). This kind of tool can help ensure the proper function of BMPs and provide a consistent approach to required documentation.

The checklist should always include the date and name/title of personnel making the inspection. It should include an area to note BMP failures, observed deviations from the SWMP, necessary repairs or corrective measures, corrective actions taken, and general observations.

Consider using a free internet application that provides real-time weather alerts to keep aware of inclement weather and plan ahead for staff to inspect and maintain BMPs.

3.3 Maintenance

Proactive maintenance is fundamental to effective BMP performance. Rather than maintaining the BMP in a reactive manner following failure, provide proactive maintenance that may help to reduce the likelihood of failure. The types and frequencies of maintenance are BMP-specific. The BMP Fact Sheets in this chapter describe the maintenance needs for each BMP, with some BMP types requiring more attention.

Maintain BMPs so that they function as intended. This includes removing accumulated sediment before it limits the effectiveness of the BMP. Identify needed maintenance activities during site inspections or during general observations of site conditions. Where BMPs have failed, repairs or changes should be initiated as soon as practical, to minimize the discharge of pollutants.

Where the BMPs specified in the SWMP are not functioning effectively at the site, modifications should be made that may include different or additional layers of BMPs. When new BMPs are installed or BMPs are replaced, check the permit for documentation requirements. This may require communication with the owner and/or engineer and, at a minimum, should be documented in the inspection and maintenance records (logbook).

3.4 Disposition of Temporary Measures

Most temporary erosion and sediment control measures must be removed within 30 days after final site stabilization is achieved. The BMP Fact Sheets in this chapter provide guidance for final disposition of temporary measures. This may be as simple as removing silt fence, or more complex such as removing accumulated sediment from a construction phase sedimentation basin that will be used as a post-construction extended detention basin. Some biodegradable BMPs, such as erosion control blankets, are designed to remain in place and would create new areas of disturbance if removed. See the BMP Fact Sheets for guidance on BMPs that may be left in place as a part of final stabilization. For some BMPs such as sediment control logs/straw wattles, some materials may be biodegradable (straw), but there may be components of the BMP that biodegrade slowly (stakes) or not at all (plastic netting). Always check local requirements for guidance on construction BMPs that may remain in place.

Temporary erosion control measures should not be removed until all areas tributary to the temporary controls have achieved final stabilization. It may be necessary to maintain some of the control measures for an extended period of time, until the upgradient areas have been fully stabilized, and vegetation has sufficiently matured to provide adequate cover. Trapped sediment and disturbed soil areas resulting from the disposal of temporary measures must be returned to final plan grades and permanently stabilized to prevent further soil erosion.

Whenever post-construction BMPs are used for sediment controls during construction, the plan should include the steps and actions needed to refurbish these facilities to a fully operational form as post-construction BMPs. The final site work will not be accepted by the local jurisdiction until these BMPs are in final and acceptable form as the original design calls for, which includes lines and grades, volumes, outlet structures, trash racks, landscaping and other measures specified in the site development plans prepared by the design engineer.

3.5 2009 Federal Effluent Limitation Guidelines

On December 1, 2009, the EPA published Effluent Limitation Guidelines in the Federal Register (Volume 74, Number 229, pages 62997-63057) establishing technology-based effluent limitation guidelines (ELGs) and new source performance standards (NSPS) for the construction and development industry. This rule requires construction site owners and operators to implement a range of erosion and sediment control measures and pollution prevention practices to control pollutants in discharges from construction sites. Additionally, the rule requires monitoring and sampling of stormwater discharges and compliance with a numeric standard for turbidity in these discharges for larger construction sites (i.e., 10 acres or more). The rule, including numeric effluent limits, was legally challenged in 2010 and, as of October 2010, EPA is in the process of reconsidering the numeric effluent limits from the rule. Other portions of the rule will remain in effect while EPA reevaluates the numeric limits.

In Colorado, unless constructing a federal project or working on an Indian reservation, construction stormwater discharge permits are issued by CDPHE under the CDPS General Permit for Stormwater Discharges Associated with Construction Activity (CDPS Permit No. COR-030000). This permit was first issued in 1997, and is effective through June 30, 2012. It is anticipated that CDPHE will issue a new general permit in 2012 that will reflect the guidelines, with the possible exception of the numeric limits which may still be under reevaluation at the time that CDPHE issues the new permit. Existing state stormwater requirements will remain in effect until a new general permit is issued.

4.0 Overview of Construction BMPs

Construction BMPs include not only erosion and sediment control BMPs, but also material management and site management BMPs. Related practices include dewatering and construction in waterways, which are discussed in Sections 6 and 7. The design details and notes for the BMPs identified in this section are provided in stand-alone Fact Sheets that also include guidance on applicability, design, maintenance, and final disposition. A key to effective stormwater management at construction sites is to understand how construction stormwater management requirements change over the course of a construction project, as summarized in Figure 7-2. Additionally, BMPs vary with regard to the functions they provide.

Table 7-2 provides a qualitative characterization of the roles that various BMPs provide with regard to serving erosion control functions, sediment control functions, or site/materials management roles. In particular, it is important to understand whether the primary role of the BMP is erosion control or sediment control. Effectively managed construction sites will provide a combination of BMPs that provide both functions.

Pre-Construction

- **Develop Site Plan**
- **Obtain Site Survey, Hydrology and Soils Information**
- **Prepare SWMP**
- **Obtain Stormwater Construction Permits (State and Local)**
- **Obtain Other Relevant Permits (e.g., 404 , Floodplain, Dewatering)**

Construction Phase

Representative Phases:

- **Clearing and Grubbing**
- **Rough Grading**
- **Road Construction**
- **Utility and Infrastructure Installation**
- **Vertical Construction (Buildings)**
- **Final Grading**

Management Practices:

- **Phase Construction Activities to Minimize Disturbed Area at a Given Time**
- **Sequence Contruction within Phases to Avoid Idle Disturbed Areas**
- **Install, Inspect and Proactively Maintain BMPs Appropriate for Each Phase of Construction**
- **Maintain and Update SWMP as Construction Progresses**

Final Stabilization

- **Revegetate Site**
- **Activate Post Construction BMPs (e.g., convert sediment basin to extended detention basin)**
- **Remove Temporary BMPs**
- **Closeout State and Local Stormwater Permits**

Figure 7-2. Construction Stormwater Management

Table 7-2. Overview of Construction BMPs

Functions	Erosion Control	Sediment Control	Site/Material Management
Erosion Control BMPs			
Surface Roughening	Yes	No	No
Temporary/Permanent Seeding	Yes	No	No
Soil Binders	Yes	No	Moderate
Mulching	Yes	Moderate	No
Compost Blankets and Filter Berms	Yes	Moderate	No
Rolled Erosion Control Products	Yes	No	No
Temporary Slope Drains	Yes	No	No
Temporary Outlet Protection	Yes	Moderate	No
Rough Cut Street Control	Yes	Moderate	No
Earth Dikes / Drainage Swales	Yes	Moderate	No
Terracing	Yes	Moderate	No
Check Dams	Yes	Moderate	No
Streambank Stabilization	Yes	No	No
Wind Erosion / Dust Control	Yes	No	Moderate
Sediment Control BMPs			
Silt Fence	No	Yes	No
Sediment Control Log	Moderate	Yes	No
Straw Bale Barrier	No	Moderate	No
Brush Barrier	Moderate	Moderate	No
Rock Sock (perimeter control)	No	Yes	No
Inlet Protection (various forms)	No	Yes	No
Sediment Basins	No	Yes	No
Sediment Traps	No	Yes	No
Vegetative Buffers	Moderate	Yes	Yes
Chemical Treatment	Moderate	Yes	No
Materials Management			
Concrete Washout Area	No	No	Yes
Stockpile Management	Yes	Yes	Yes
Good Houskeeping (multiple practices)	No	No	Yes
Site Management and Other Specific Practices			
Construction Phasing	Moderate	Moderate	Yes
Protection of Existing Vegetation	Yes	Moderate	Yes
Construction Fence	No	No	Yes
Vehicle Tracking Control	Moderate	Yes	Yes
Stabilized Construction Roadway	Yes	Moderate	Yes
Stabilized Staging Area	Yes	Moderate	Yes
Street Sweeping / Vacuuming	No	Yes	Yes
Temporary Diversion Channel	Yes	No	No
Dewatering Operations	Moderate	Yes	Yes
Temporary Stream Crossing	Yes	Yes	No
Temporary Batch Plants	No	No	Yes
Paving and Grinding Operations	No	No	Yes

4.1 Erosion Control Measures

Erosion control measures are source controls used to limit erosion of soil. These are typically surface treatments that stabilize soil that has been exposed by excavation or grading, although some limit erosion by redirecting flows or reducing velocities of concentrated flow. Fact Sheets for the following erosion control (EC) practices are provided in this chapter:

- EC- 1 Surface Roughening (SR)
- EC-2 Temporary and Permanent Seeding (TS/PS)
- EC-3 Soil Binders (SB)
- EC-4 Mulching (MU)
- EC-5 Compost Blanket and Filter Berm (CB)
- EC-6 Rolled Erosion Control Products (RECP) (*includes erosion control blankets [ECBs] and turf reinforcement mats [TRMs]*)
- EC-7 Temporary Slope Drains (TSD)
- EC-8 Temporary Outlet Protection (TOP)
- EC-9 Rough Cut Street Control (RCS)
- EC-10 Earth Dikes and Drainage Swales (ED/DS)
- EC-11 Terracing (TER)
- EC-12 Check Dams (CD) (*also includes Reinforced Check Dams [RCD]*)
- EC-13 Streambank Stabilization (SS)
- EC-14 Wind Erosion / Dust Control (DC)

4.2 Sediment Control Measures

Sediment control measures limit transport of sediment off-site to downstream properties and receiving waters. Sediment controls are the second line of defense, capturing soil that has been eroded. Sediment controls generally rely on treatment processes that either provide filtration through a permeable media or that slow runoff to allow settling of suspended particles. A third treatment process that is used in some parts of the country includes advanced treatment systems employing chemical addition (flocculent) to promote coagulation and settling of sediment particles. UDFCD discourages use of chemical treatment as misuse of chemicals can be more detrimental than the sediment being removed. CDPHE does not currently allow use of chemicals. Sediment control (SC) BMPs included as Fact Sheets in this chapter are:

- SC-1 Silt Fence (SF)
- SC-2 Sediment Control Log (SCL)
- SC-3 Straw Bale Barrier (SBB)
- SC-4 Brush Barrier (BB)
- SC-5 Rock Sock (RS)
- SC-6 Inlet Protection (IP) (*multiple types*)
- SC-7 Sediment Basin (SB)
- SC-8 Sediment Trap (ST)
- SC-9 Vegetated Buffers (VB)
- SC-10 Chemical Treatment (CT) (*also known as Advanced Treatment Systems [ATS]*)

4.3 Site Management

Site management is often ultimately the deciding factor in how effective BMPs are at a particular site. BMPs implemented at the site must not only be properly selected and installed, but also must be inspected, maintained and properly repaired for the duration of the construction project. In addition to general site management, there are a number of specific site management practices that affect construction site management. For example, effective construction scheduling (phasing and sequencing) helps minimize the duration of exposed soils. Protection of existing vegetation also minimizes exposed areas and can reduce the cost of final site stabilization. Stabilized construction entrances (vehicle tracking controls) and street sweeping are critical source control measures to minimize the amount of sediment that leaves a site. Additionally, there are several miscellaneous activities that must be carefully conducted to protect water quality such as dewatering operations, temporary batch plants, temporary stream crossings and other practices.

Resources for Construction Stormwater Management/Erosion and Sediment Control Training

Certified Professional in Erosion and Sediment Control Program (http://www.cpesc.org/)

Certified Inspector of Sediment and Erosion Control Program (http://www.cisecinc.org/)

Rocky Mountain Education Center (http://www.rrcc.edu/rmec/cetc.html)

International Erosion Control Association (http://www.ieca.org/)

Associated General Contractors of Colorado (www.agccolorado.org/)

As part of the construction kick-off meeting for the project (or for major phases of construction), an effective strategy is to include a training component related to construction site stormwater management. Such training should provide basic education to site personnel regarding the requirements of the state and local construction stormwater permits and the serious fines and penalties than can result from failure to comply with permit requirements. The individual or individuals responsible for inspection and maintenance of construction BMPs should have a practical understanding of how to maintain construction BMPs proactively in effective operating condition and to identify conditions where failure is eminent or has already occurred. In addition to site-specific training, several training courses are available in the metro Denver area regarding construction site stormwater management.

Site management (SM) practices addressed in Fact Sheets as part of this chapter include:

- SM-1 Construction Phasing/Sequencing (CP)
- SM-2 Protection of Existing Vegetation (PV)
- SM-3 Construction Fence (CF)
- SM-4 Vehicle Tracking Control (VTC) *(multiple types)*
- SM-5 Stabilized Construction Roadway (SCR)
- SM-6 Stabilized Staging Area (SSA)
- SM-7 Street Sweeping and Vacuuming (SS)
- SM-8 Temporary Diversion Channel (TDC)
- SM-9 Dewatering Operations (DW)
- SM-10 Temporary Stream Crossing (TSC) *(multiple types)*
- SM-11 Temporary Batch Plant (TBP)
- SM-12 Paving and Grinding Operations (PGO)

4.4 Materials Management

Materials management BMPs are source control practices intended to limit contact of runoff with pollutants commonly found at construction sites such as construction materials and equipment-related fluids. By intentionally controlling and managing areas where chemicals are handled, the likelihood of these materials being transported to waterways is reduced. Materials management (MM) BMPs provided as Fact Sheets in this chapter include:

- MM-1 Concrete Washout Area (CWA)
- MM-2 Stockpile Management (SP)
- MM-3 Good Housekeeping Practices (GH) (including *Spill Prevention and Control, Material Use, Material Delivery and Storage, Solid Waste Management, Hazardous Waste Management, Sanitary/Septic Waste Management, and Vehicle & Equipment Fueling, Maintenance and Cleaning*)

4.5 Proprietary BMPs

Many proprietary BMPs are available for construction site stormwater management. This manual does not provide a list of approved products; however, some local jurisdictions may require that proprietary products go through a formal approval process prior to use within their jurisdiction. Basic questions that local governments may want to consider asking when considering approval of proprietary construction BMPs include:

General

- Does the product provide equivalent or better function than the design details specified in this manual?
- What are the installation procedures?
- What are the maintenance requirements? Is special equipment required for maintenance?
- What are the consequences of failure of the product?
- Has the product been successfully implemented on other sites in the metropolitan Denver area?

Inlet Protection

- Does the inlet protection enable runoff to enter the inlet without excessive ponding in traffic areas?
- How does the BMP provide for overflow due to large storm events or blockages?
- How is the BMP secured to the street or curb? Will it result in damage to concrete or pavement? Is it secured in a manner that prevents short-circuiting or collapsing into the inlet?
- Does the BMP appear to be sturdy enough to withstand typical activities conducted at construction sites or traffic on public roadways?
- Is there potential for pollutant leaching from the BMP?

- For inlet inserts, is special equipment required to remove the insert? Is the insert material strong enough to withstand tearing and/or collapse into the inlet, even when maintenance is less than ideal?

Perimeter Controls

- How is the perimeter control installed (e.g., trenching, staking)? Perimeter controls that are not adequately secured may be subject to undercutting and washout.
- Is the material used in the perimeter control adequately durable for the life of the construction project?
- How are vehicle tracking and site access controlled where flexible perimeter controls allow vehicles to drive over the BMP?

Hydraulically Applied Products

- Does the product contain chemicals, pollutants, nutrients, or other materials that could adversely impact receiving waters or groundwater?
- Has the product been adequately field tested under local conditions to ensure that the service life is consistent with the manufacturer's representation?
- Does use of the product require special permits?

5.0 BMP Selection and Planning

Construction BMPs should be selected, designed, installed, and maintained based on site-specific conditions. BMPs should be selected based on the physical layout and site conditions that will exist during each stage of construction, because site conditions change through the various stages of construction. The number of stages that must be addressed in the SWMP depends on the type of construction activity and local jurisdiction requirements, but in general, three stages of erosion and sediment control plans can be considered. These stages include initial clearing and grading; utility, infrastructure and building construction; and final stabilization.

Effective construction site stormwater management planning involves the following:

- Collecting and analyzing site-specific information to identify needed erosion and sediment controls,
- Preparing a SWMP that specifies needed BMPs appropriate to each phase of construction, and
- Following the SWMP, maintaining BMPs and updating the SWMP as construction progresses.

This section focuses on important factors to consider in the development of a SWMP, including site-specific conditions, BMP functions, and other site-related plans.

5.1 Site Assessment

Early awareness of site-specific factors that make a site particularly prone to erosion problems can prevent serious problems later during the construction process. A site assessment should include attention to these factors, prior to selection of BMPs:

- **Slopes/Topography and Topographic Changes Due to Grading**: Slope length and steepness are two key factors in identifying the types and placement of both erosion and sediment control BMPs. Slopes will change throughout the phases of construction as grading is conducted. See Sections 5.2 and 5.3 for additional guidance.

- **Tributary Area/Catchment Size**: The overall size of sub-catchment areas prior to and following grading is a key factor in determining the types, sizes, spacing and other design requirements for sediment controls appropriate for each drainage area. The allowable tributary area for sediment controls varies, depending on the practice selected, as described in the BMP Fact Sheets.

- **Soils**: Regardless of soil type, all disturbed soils require erosion controls; however, NRCS soil maps and geotechnical reports for the development can be used to identify soil conditions where erosion may be particularly difficult to control. In such settings, additional layers of protection for both erosion and sediment controls may be needed and planned for proactively in the SWMP.

- **Vegetation**: Onsite vegetation that is to be left undisturbed must be clearly identified in the SWMP and/or the construction plans. Construction fence should be installed to avoid disturbance and compaction of these areas. This is particularly important for protection of mature trees, natural riparian buffers and wetlands, natural open space, or other areas specifically identified to be protected from compaction as part of Low Impact Development (LID) designs. Maintaining a vegetative buffer, in combination with other perimeter control BMPs, can be effective for minimizing transport of sediment off-site.

- **Drainage Infrastructure**: Understanding the hydrology of a site is important in the design of sediment controls. Offsite run-on as well as drainage patterns within the site should be thoroughly assessed. The configuration of hill slope areas and waterways, in the context of planned roads and buildings, will determine which erosion and sediment controls will be needed at each phase of construction.

- Sensitive Site Conditions: In cases where construction is occurring in areas of sensitive aquatic habitat, upstream of drinking water supplies, or near areas where threatened and endangered species are a concern, additional layers of protection may be specified by the local, state or federal government. These may include redundant BMPs or restrictions on times that construction activities are allowed.

5.2 Slope-Length and Runoff Considerations

Photograph 7-2. Diverting the upland slope drainage area may have avoided the rilling shown in this picture.

Cut-and-fill slopes should be designed and constructed to minimize erosion. This requires consideration of the length and steepness of the slope, the soil type, upslope drainage area, groundwater conditions and other applicable factors. Slopes found to be eroding excessively will require additional slope stabilization until the problem is corrected. The following guidelines should assist site planners and plan reviewers in developing an adequate design:

- Rough soil surfaces enhance infiltration and/or lengthen the travel path or runoff, reducing runoff velocity. See the Surface Roughening BMP Fact Sheet.

- Temporary diversion dikes should be constructed at the top of long or steep slopes. Diversion dikes or terraces reduce slope length within the disturbed area. See the Earth Dikes and Drainage Swales BMP Fact Sheet.

- Temporary diversion dikes should be provided whenever:

  $S^2L > 2.5$ for **undisturbed** tributary areas; Equation 7-1

  $S^2L > 1.0$ for disturbed tributary areas; Equation 7-2

  $S^2L > 0.25$ for paved tributary areas; Equation 7-3

  where:

  S = slope of the upstream tributary area (feet/foot)

  L = length of the upstream slope (feet)

  As an example, runoff from a developed area runs on to an area that will be disturbed. A diversion dike would be required if, for example, the length of the flow path was greater than 625 feet and the slope of the flow path was 2%.

- Concentrated stormwater (e.g., pipe outflow, channel, swale) should not be allowed to flow down cut or fill slopes unless contained within an adequately-sized temporary channel diversion, a permanent channel, or temporary slope drain. See the Temporary Slope Drain and Diversion Ditches/Channels BMP Fact Sheets.

- Wherever a slope face crosses a water seepage plane that endangers the stability of the slope, adequate drainage should be provided.

- Provide sediment basins or barriers (silt fence) at or near the toe of slopes to trap sediment or to reduce slope lengths. When flows are concentrated and conveyed down a slope using a slope drain or channel, energy dissipation measures will be required at the conveyance outlet at the toe of the slope. See the Sediment Control BMP Fact Sheets for several options for controlling sediment at the base of slopes.

5.3 Using the Revised Universal Soil Loss Equation

The Revised Universal Soil Loss Equation (RUSLE) is an erosion prediction method that has evolved over time, resulting from data collection and analysis efforts extending from the 1930s through the 1970s, ultimately published in *Agriculture Handbook 282* (Wischmeier and Smith, 1965), then *Agriculture Handbook 537* (Wischmeier and Smith, 1978) and *Agriculture Handbook 703* (Renard et al., 1997). Although originally developed for agricultural land use, it is also a useful method for estimating erosion potential on construction sites and adjusting BMPs to reduce the estimated erosion. The RUSLE is also incorporated into several modern erosion prediction models. The Modified Universal Soil Loss Equation (MUSLE) is similar to the RUSLE, but is differentiated by the fact that MUSLE is event-based while RUSLE is an annual method (with the option to calculate monthly or seasonal erosion). This section provides a brief overview of RUSLE and describes how it can be used to help select erosion control practices at construction sites.

$$A = RKLSCP \qquad \text{Equation 7-4}$$

where:

A = Computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. Typically, A is expressed in tons per acre per year.

R = Rainfall-runoff erosivity factor – the rainfall erosion index plus a factor for any significant runoff from snowmelt.

K = Soil erodibility factor – the soil-loss rate per erosion index unit for a specified soil.

L = Slope length factor – the ratio of soil loss from the field slope length to soil loss from a 72.6 ft length under identical conditions.

S = Slope steepness factor – the ratio of soil loss from the field slope gradient to soil loss from a 9 percent slope under otherwise identical conditions.

C = Cover-management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in a bare condition. Values range from 0.01 to 1.

P = Erosion control practice factor – the ratio of soil loss with a certain conservation practice (erosion control BMP) to that of no practice. Values range from 0.8 to 1.2.

The slope length, L, and steepness factor, S, are commonly combined as one variable, LS. Values for LS are quantified relative to a 72.6 ft slope length with a 9 percent slope. A slope with these two values will have an LS factor of 1.

A detailed discussion of RUSLE factors is beyond the scope of this manual; however, *Agriculture Handbook 703* can be obtained at no charge from the USDA publications website and used to develop or obtain values for the factors in the equation. Construction managers can use the RUSLE, either by hand or by using a variety of different software programs based on the equation, to evaluate how implementing various BMPs can help reduce surface erosion. Highly erosive sites or sites with sensitive receiving waters may benefit from more rigorous analysis using the RUSLE.

Although construction managers have no control over the *A* and *R* factors, factors *L, S, C* and *P* can be altered by implementing practices that reduce sediment loading. One technique to reduce the slope length and steepness is to terrace. For example, if a portion of a construction area has a slope length of 500 feet, it can be terraced into three or four equal sections to reduce the erosivity of the water coming down the slope. This factor can also be used to guide placement distances for silt fence, wattles and other practices that serve to break up the slope length. As another example, construction managers can vary cover management practices to decrease the *C* factor and reduce sediment loading. *C* values vary, depending on the type of cover implemented. Using the reference table for the *C* value, managers can select cover approaches to help reduce sediment loading. Finally, the practice factor *(P)* serves as an index of anticipated erosion reduction associated with various erosion control BMPs.

5.4 BMP Functions

Understanding the intended function of a BMP is critical to proper BMP selection. BMPs should be selected based on both the intended function of the BMP and consideration of whether the BMP can provide the desired function based on the site-specific conditions. It is also important to understand how BMP functions are related to maintenance. For example, when silt fence is initially installed, it provides a filtration function, but over time, the fabric can become clogged, leading to ponding and sedimentation behind the fence as the primary function rather than filtration.

Sediment control BMPs such as sediment basins can provide some settling of sediment from runoff, but must be combined with **erosion** controls throughout the site in order to be effective. Sediment basins, inlet protection, and other sediment control BMPs should not be solely relied upon as "end-of-pipe" treatment systems.

5.5 Consistency with Other Plans

Prior to selection of BMPs for the SWMP, it is important to cross-check other construction planning documents for consistency and/or opportunities for increased efficiencies and effectiveness. As an example, landscaping plans for a site should be consistent with final stabilization measures in the SWMP.

5.5.1 Drainage Plans

The SWMP should be prepared with due consideration of the final drainage plan for a development. As permanent drainage features are constructed, temporary sediment controls should be located and designed to both protect and complement these final drainage features. Temporary controls should be staged and removed at the appropriate time relative to the completion of permanent drainage features. Special care is necessary for permanent BMPs that rely on infiltration such as bioretention, permeable pavements, sand filters and others. These BMPs will clog if they are not adequately protected during construction (or constructed after tributary areas have been stabilized).

5.5.2 Post Construction Stormwater Management

Coordination of temporary and post-construction BMPs is important for several reasons. In some cases, post construction BMPs such as extended detention basins can be modified to serve as sedimentation basins during construction. In other cases, such as in the case of rain gardens or infiltration-oriented post-construction BMPs, it is critically important to protect the post-construction facilities from sediment loading during construction. Also, as previously noted, if an area is targeted for preservation in an uncompacted, natural condition under a LID design, it is critical to keep heavy equipment and staging out of this area.

5.5.3 Air Quality Plans

Properly implemented erosion and sediment control BMPs are beneficial in minimizing wind erosion. For example, surface stabilization measures that help to reduce precipitation-induced erosion help to reduce windborne dust and sediment. Additional controls, such as road watering (to moisten roads but not to the extent that runoff results) and/or soil binders may be necessary to fully comply with fugitive dust regulations at a construction site. Contact the appropriate local agency for air quality requirements during construction.

5.6 Guidelines for Integrating Site Conditions and BMPs into a SWMP

The following guidelines are recommended when combining BMPs into an effective SWMP:

- **Determine the limits of clearing and grading**: If the entire site will not undergo excavation and grading, or excavation and grading will occur in stages, the boundaries of each cut-and-fill operation should be defined. Buffer strips of natural vegetation may be utilized as a control measure. Adequate protection of both tree limbs and root systems is important when specifying limits of construction activity. Use construction fence or other barriers to protect areas that should not be compacted or disturbed.

- **Define the layout of buildings and roads**: Typically, this will have been decided previously as a part of the general development plan. If building layout is not final, the road areas stabilized with pavement and the drainage features related to roads should be defined as they relate to the plan.

- **Determine permanent drainage features**: The location of permanent channels, storm sewers, roadside swales and stormwater quality controls such as ponds, wetlands, grassed-lined swales, buffer strips and areas of porous pavement, if known, should be defined.

- **Determine extent of temporary channel diversions and crossings**: If permanent channel improvements are a part of the plan, the route, sizing and lining needed for temporary channel diversions should be determined. Location and type of temporary channel crossings can be assessed.

- **Determine the boundaries of watersheds**: The size of drainage catchments will determine the types of sediment controls to be used. Areas located offsite that contribute runoff must be assessed. Measures to limit the size of upland drainage areas, such as diversion dikes, should be considered at this stage. Routing offsite "clean" runoff around areas of disturbance in stabilized conveyances reduces the burden on onsite measures and can reduce liability of the permittee—once offsite runoff enters the permitted construction area, the permittee is responsible for erosion and sediment transport resulting from the offsite runoff.

- **Select erosion controls**: All areas of exposed soil will require erosion control measures based on factors including the duration of exposure, soil erosivity, slope steepness, and length, and others.

- **Select sediment controls**: Select the controls needed for each stage of the construction project. Each stage will have different demands for the control of erosion and sedimentation. For example, over-lot grading will require controls that may require different BMPs than when individual homes are being built and lots are disturbed after the streets and drainage systems are in place. Sediment basins are an essential part of the total plan when the tributary area exceeds one acre.

- **Determine sequencing of construction**: The schedule of construction will determine what areas must be disturbed at various stages throughout the development plan. The opportunity for phasing cut-and-fill operations to minimize the period of exposure of soils needs to be assessed and then incorporated into the SWMP.

- **Identify planned locations of topsoil stockpiles**: Areas for storing topsoil should be determined and proper measures to control erosion and sediment movement should be specified.

- **Identify planned location of temporary construction roads, vehicle tracking controls, portable toilets, waste disposal areas, and material storage areas**: These elements can be determined in the context of previously defined parts of the site construction management plan.

6.0 Construction Dewatering

Dewatering is typically necessary during construction activities that involve deep excavations, instream work, pumped surface diversions, and open trench operations in some cases. In Colorado, construction dewatering frequently requires a separate permit along with sample collection and the completion of Discharge Monitoring Reports (DMRs). When dewatering can be conducted without discharging surface runoff from the site, it may be possible to conduct such activities under the state Construction-phase Stormwater Permit. Some commonly used methods to handle the pumped water without surface discharge include land application to vegetated areas through a perforated discharge hose (i.e., the "sprinkler method") or dispersal from a water truck for dust control. Carefully check state and local permit requirements to determine when dewatering can be conducted without additional permitting.

Construction dewatering BMPs generally include practices to minimize turbidity in the pumped water. Representative practices that may help to reduce turbidity in various types of dewatering applications include:

- Using perimeter well points outside of the excavated area to draw down the water table rather than dewatering directly from the excavation;

- Placing a submersible pump in a perforated bucket filled with gravel for short-term pumping;

- Constructing a filtering sump pit for pumping groundwater below the excavation grade for multiple-day operations; or

- Using a flotation collar or other flotation device to pump from the surface of a sediment basin to avoid the silt that can accumulate on the bottom of the basin.

Guidance on BMPs for construction dewatering is provided on the Dewatering Operations Fact Sheet.

7.0 Construction in Waterways

Construction in waterways is often required for projects including bridge construction, utility construction, streambank stabilization and grade control, and temporary or permanent stream crossings. Construction in waterways requires a high standard of care in order to avoid and minimize damage to waterways, habitat, and aquatic life. In addition to the Construction Phase Permits already discussed, this work can also require a Clean Water Act Section 404 Permit from USACE, U.S. Fish and Wildlife

Service (USFWS) threatened and endangered species permitting, and/or other state and local permits. Some required permits may restrict construction to certain times of the year.

Many of the BMPs described in Section 4 of this chapter are used in waterway construction. This section provides guidance on factors to consider and plan for during construction in waterways, as well as guidance on specific BMPs that should be implemented, depending on site-specific conditions. Other UDFCD criteria and guidance that are closely related to in-stream work should also be referenced including:

- USDCM Volume 1 Major Drainage Chapter
- USDCM Volume 2 Revegetation Chapter
- USDCM Volume 2 Hydraulic Structures Chapter
- *Stormwater Management During Construction: Best Management Practices for Construction in Waterways Training Program Student Manual* (Altitude Training Associates 2008). This document is available for download on www.udfcd.org.

BMPs provided in this chapter that are commonly used when construction occurs in waterways include:

- EC-1 Surface Roughening (SR)
- EC-2 Temporary and Permanent Seeding (TS/PS)
- EC-3 Soil Binders (SB)
- EC-4 Mulching (MU)
- EC-6 Rolled Erosion Control Products (RECP)
- EC-10 Earth Dikes and Drainage Swale (ED/DS)
- EC-13 Streambank Stabilization (SS)
- SC-1 Silt Fence (SF)
- SM-1 Construction Phasing/Sequencing (CP)
- SM-8 Temporary Diversion Channel (TDC)
- SM-10 Dewatering Operations (DW)
- SM-11 Temporary Stream Crossing (TSC)

In addition to criteria specified for these BMPs, the following general principles should be followed:

- Construction vehicles should be kept out of a waterway to the maximum extent practicable.
- Where in-channel work is necessary, steps such as temporary channel diversions must be taken to stabilize the work area and control erosion during construction.
- When in-stream work has been completed, the channel must be stabilized using revegetation practices (often, including use of erosion control matting or turf reinforced mats), riprap, or other permanent stabilization measures as required by the SWMP.
- Where an actively-flowing watercourse must be crossed regularly by construction vehicles, a temporary crossing should be provided. Three primary methods are available: (1) a culvert crossing, (2) temporary bridge, and (3) a stream ford. See the Temporary Stream Crossing Fact Sheets.
- A permit is required for placement of fill in a waterway under Section 404 of the Clean Water Act.

The local office of the USACE should be contacted concerning the requirements for obtaining a 404 permit. In addition, a permit from USFWS may be needed if threatened or endangered species are of concern in the work area. Typically, the USFWS issues are addressed in conjunction with the 404 permit if one is required. A floodplain development permit and other local permits may also be required.

- When work takes place within a channel, a temporary water diversion to bypass the work area is typically required. See the Diversion Channel/Ditch BMP Fact Sheet for criteria and design details.
- To the extent practical, construction in a waterway should be sequenced to begin at the most downstream point and work progressively upstream installing required channel and grade control facilities.
- Complete work in small segments, exposing as little of the channel at a time as practical. Keep equipment operators contained in immediate work area and avoid excessive compacting of the soil surface because it inhibits revegetation.
- Where feasible, it is best to perform in-channel work between October 1 and March 31 in Colorado. This is the period when the chances of flash floods and flows higher than the 2-year flood peak flows are less likely.
- During the process of cut and fill, avoid letting side-cast or waste material enter waterways or placing it on unstable areas. Instead, efficiently move excavated material to areas needing fill or to a stockpile. For stream restoration/stabilization projects, consulting with a fluvial geomorphologist on stream stability issues may be prudent.

404 Permit Basics

Section 404 of the Federal Clean Water Act established a program to regulate the discharge of dredged and fill material into waters of the United States, including wetlands. Responsibility for administering and enforcing Section 404 is shared by the U.S. Army Corps of Engineers (USACE) and EPA. USACE administers the day-to-day program, including individual permit decisions and jurisdictional determinations; develops policy and guidance; and enforces Section 404 provisions. EPA develops and interprets environmental criteria used in evaluating permit applications, identifies activities that are exempt from permitting, reviews/comments on individual permit applications, enforces Section 404 provisions, and has authority to veto USACE permit decisions.

A Section 404 permit is typically required when the following activities are conducted in waters of the U.S., including wetlands:

- Construction of roads or paths
- Foundations or amenities for residential, commercial, or recreational developments
- Construction of ponds, dams, dikes or weirs
- Placement of riprap and channel protection
- Laying utility pipes or lines

When selecting BMPs for in-stream construction, a variety of factors should be considered such as:

- Hydrologic factors (tributary watershed size, length of the overland flow, roughness and slope characteristics, precipitation characteristics, imperviousness, etc.)
- Baseflow conditions
- Pollutants that may be delivered to the waterway from the surrounding area
- Extent of existing erosion, headcutting or bank sloughing
- Condition/type of vegetation and percent cover
- Sources of surface runoff
- Drainage pattern
- Historic events
- Flow regulation (ditch diversions, reservoir releases)

8.0 Considerations for Linear Construction Projects

Linear projects involving utilities, streets, highways, railways, and other transportation-related projects can pose some unique stormwater management challenges during construction. Section 8.1 identifies special considerations and approaches that may be beneficial to linear projects, and Section 8.2 provides criteria for trenching for underground utility lines.

8.1 General Considerations

General considerations for linear construction projects include:

- **Standard Details for Typical Activities**: Development of a set of standard BMP details for typical construction activities can promote consistent implementation of erosion and sediment control measures and more efficient SWMP preparation. For example, if a utility company frequently installs light poles, it may be beneficial to develop a standard detail showing the typical construction of a light pole and the associated BMPs. Typical details for construction activities can be used by contractors allowing them to know what BMPs must be used for specific construction activities. BMPs should be shown on the SWMP drawings when they are installed, or in some municipalities, it may be acceptable to reference the typical detail as an alternative to showing specific BMPs on the SWMP drawing. BMPs must be indicated on the site map if site-specific conditions vary from the conditions assumed for development of the typical construction activity BMP detail.

- **Construction Phasing**: By nature, linear construction activities are typically phased. Phasing often will be dictated by the extent of allowable traffic closures and typical requirements for closing trenches at the end of the workday in the right-of-way. For linear construction projects in the public right-of-way, stabilization often can be achieved rapidly as each segment or phase of the project is completed, often by paving or repairing and/or installing sod. For areas where revegetation is from seed, reaching final stabilization (and inactivating stormwater permit coverage) will be a lengthier process.

- **Weather and Climate**: Linear projects such as roadwork may need to consider seasonal weather patterns when scheduling construction. Bridgework over waterbodies should be planned during traditionally low water levels, October 1 to March 31 when possible. Utility projects should attempt to close trenches prior to inclement weather, if feasible, and at the end of each day when required by local requirements.

- **Space Constraints**: Select BMPs that work best under the space constraints of the project. Many utility and road construction projects in urban areas have BMPs that are located in active streets.

- **Durability**: Particularly in active traffic areas, durability of BMPs (i.e., ability to continue to function properly, even when run over by a vehicle) is an important consideration for BMP selection.

- **Potential for Ponding**: Creation of ponded water on roadways may also be a concern. It is important to keep in mind that inlet protection can function in two different ways: filtration and/or ponding. While both of these mechanisms can play a role in sediment removal, typically, inlet protection methods that encourage filtration and limit the amount of ponding are favorable, since ponding typically does not provide enough storage for significant residence time/settling and because ponding can impede travel in streets and highways. Ponding, which occurs to at least some degree with most types of inlet protection, can typically be addressed by selection of the appropriate type of inlet protection, frequent maintenance/sediment removal, and providing an overflow path that will not cause flooding in the event that excessive ponding occurs.

- **Temporary Access**: Unlike a typical residential or commercial development where there are access points that will be used throughout the duration of the project, for linear construction projects, it is often necessary to access the work area for limited periods of time at multiple locations throughout the corridor. For utility projects where access through vegetated areas is necessary at multiple locations, but generally only for a limited amount of time at each location, consider alternatives to standard geotextile and rock-lined vehicle tracking control pads such as construction mats or turf reinforced mats for temporary access to avoid disturbance to vegetation and soil that is typically associated with traditional vehicle tracking control pads.

- **Jurisdictional Considerations**: Linear projects are often multijurisdictional. In these cases, it is important to have upfront coordination with the municipalities that are involved to reduce the burden of permitting and SWMP preparation to the extent practical. For example, it may be possible to prepare a single SWMP that will satisfy the requirements of multiple municipalities rather than preparing separate SWMPs for work in each municipality.

- **Permitting Considerations**: Some municipalities require a stormwater permit for utility construction, maintenance and/or repair activities regardless of extent of the disturbed area. It is possible that even when coverage under the CDPHE Stormwater General Permit is not required (area of disturbance under 1.0 acre), coverage under the local jurisdiction is required. Check all local requirements prior to commencing work on linear construction projects.

8.2 Underground Utility Trenching Criteria

Specific criteria for trenching activities include:

- Minimize the length of trench open at one time to the extent practical. For most trenching projects, it should be feasible to phase construction so that no more than a few hundred feet of trench are open at any given time. Check local criteria, which may specify a maximum length of trench that may be open.

- Where consistent with safety and space considerations, place excavated material on the upgradient side of trenches.

- Trench dewatering devices must discharge in a manner that will not cause erosion or adversely affect flowing streams, wetlands, drainage systems, or off-site property. See the Dewatering Operations BMP Fact Sheet and Section 6 of this chapter for additional guidance.
- Provide storm sewer inlet protection whenever soil erosion from the excavated material has the potential to enter the storm drainage system. See Inlet Protection BMP Fact Sheet for specific guidance.
- Evaluate potential for sediment contributions to inlets or receiving waters that are not in the immediate vicinity of the work area and implement inlet protection and/or other BMPs as necessary. For example, if vehicles access the construction area to remove excavated material or to deliver materials, evaluate the potential for offsite sediment tracking and implement measures such as street sweeping, inlet protection, stabilized access to the construction area, and other BMPs to protect inlets or receiving waters that could be affected by tracked sediment. As another example, perimeter controls on the upgradient side of stockpiles and inlet protection on the opposite side of the crown of the street may be necessary if stockpile height or tracking from accessing stockpiles has the potential to contribute sediment to the opposite side of the street.

9.0 References

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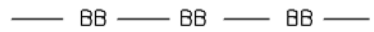
Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses: A guide to conservation planning. *Agriculture Handbook No. 537*, US Dept. of Agriculture. Washington, DC.

Construction BMP Plan Symbols

TITLE	KEY	SYMBOL
BRUSH BARRIER	BB	
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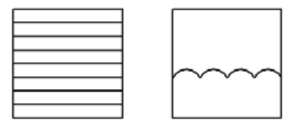
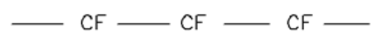
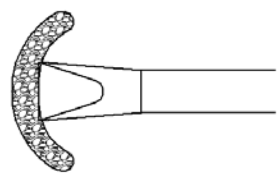
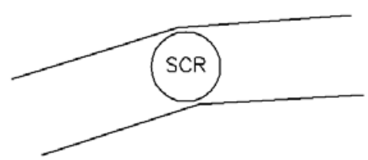
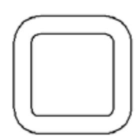
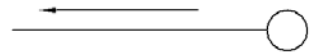
COMPOST BLANKET AND BERMS	CB	
CONSTRUCTION FENCE	CF	
CULVERT INLET PROTECTION	CIP	
STABILIZED CONSTRUCTION ROADWAY	SCR	
CONCRETE WASHOUT AREA	CWA	
DIVERSION DITCHES/CHANNELS	DD/DC	

TITLE	KEY	SYMBOL
DEWATERING OPERATIONS	DW	
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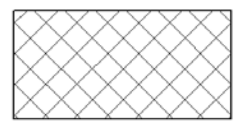
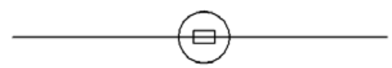
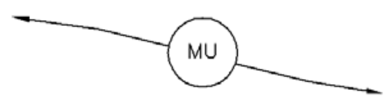
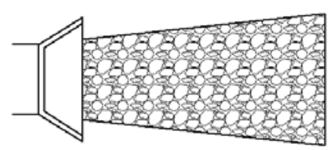
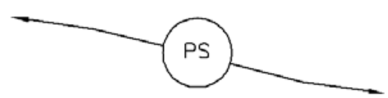
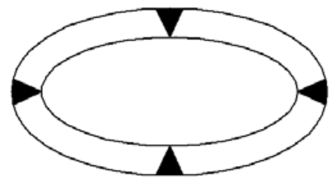
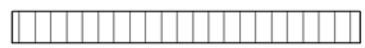
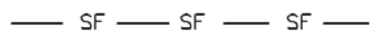
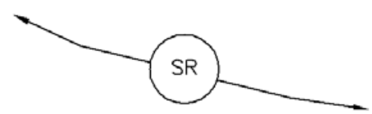
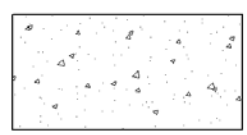
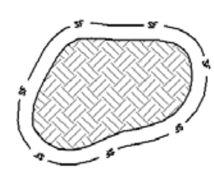
EROSION CONTROL BLANKET	ECB TRM	
INLET PROTECTION	IP	
MULCHING	MU	
OUTLET PROTECTION	OP	
PERMANENT SEEDING	PS	
REINFORCED CHECK DAM	RCD	

Construction BMP Plan Symbols

TITLE	KEY	SYMBOL
ROCK SOCKS	RS	
ROUGH CUT STREET CONTROL	RCS	
SEDIMENT BASIN	SB	
SEDIMENT CONTROL LOG	SCL	
SILT FENCE	SF	
SURFACE ROUGHENING	SR	
STABILIZED STAGING AREA	SSA	
STOCKPILE MANAGEMENT W/ PROTECTION	SP	

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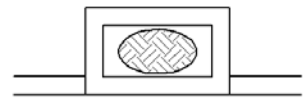
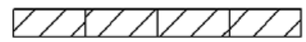
STOCKPILE MANAGEMENT W/ PROTECTION IN ROADWAY	SPR	
STRAW BALE BARRIER	SBB	
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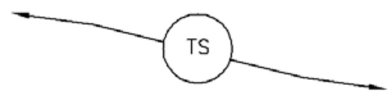
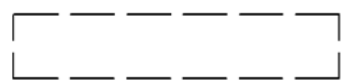
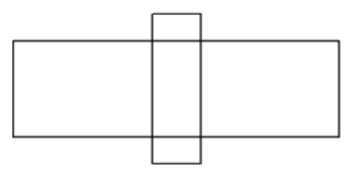
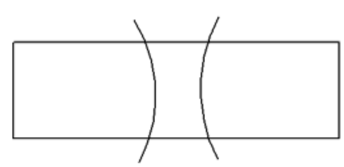
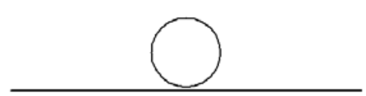
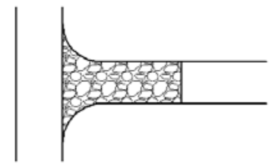
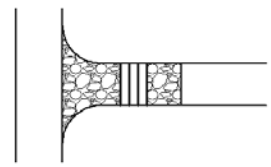
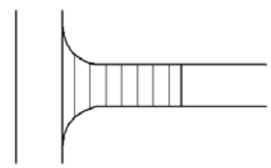
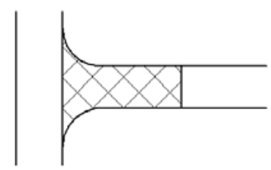
TEMPORARY SEEDING	TS	
TERRACING	TER	
TEMPORARY STREAM CROSSING W/CULVERT	TSCC	
TEMPORARY STREAM CROSSING W/FORD	TSCF	
TEMPORARY SLOPE DRAIN	TSD	

Construction BMP Plan Symbols

TITLE	KEY	SYMBOL
VEHICLE TRACKING CONTROL	VTC	
VEHICLE TRACKING CONTROL W/ WHEEL WASH	VTC/WW	
VEHICLE TRACKING CONTROL W/ CONSTRUCTION MAT	VTC/CM	
VEHICLE TRACKING CONTROL W/ TRM	VTC/TRM	

Description

Photograph SR-1. Surface roughening via imprinting for temporary stabilization.

Surface roughening is an erosion control practice that involves tracking, scarifying, imprinting, or tilling a disturbed area to provide temporary stabilization of disturbed areas. Surface roughening creates variations in the soil surface that help to minimize wind and water erosion. Depending on the technique used, surface roughening may also help establish conditions favorable to establishment of vegetation.

Appropriate Uses

Surface roughening can be used to provide temporary stabilization of disturbed areas, such as when revegetation cannot be immediately established due to seasonal planting limitations. Surface roughening is not a stand-alone BMP, and should be used in conjunction with other erosion and sediment controls.

Surface roughening is often implemented in conjunction with grading and is typically performed using heavy construction equipment to track the surface. Be aware that tracking with heavy equipment will also compact soils, which is not desirable in areas that will be revegetated. Scarifying, tilling, or ripping are better surface roughening techniques in locations where revegetation is planned. Roughening is not effective in very sandy soils and cannot be effectively performed in rocky soil.

Design and Installation

Typical design details for surfacing roughening on steep and mild slopes are provided in Details SR-1 and SR-2, respectively.

Surface roughening should be performed either after final grading or to temporarily stabilize an area during active construction that may be inactive for a short time period. Surface roughening should create depressions 2 to 6 inches deep and approximately 6 inches apart. The surface of exposed soil can be roughened by a number of techniques and equipment. Horizontal grooves (running parallel to the contours of the land) can be made using tracks from equipment treads, stair-step grading, ripping, or tilling.

Fill slopes can be constructed with a roughened surface. Cut slopes that have been smooth graded can be roughened as a subsequent operation. Roughening should follow along the contours of the slope. The tracks left by truck mounted equipment working perpendicular to the contour can leave acceptable horizontal depressions; however, the equipment will also compact the soil.

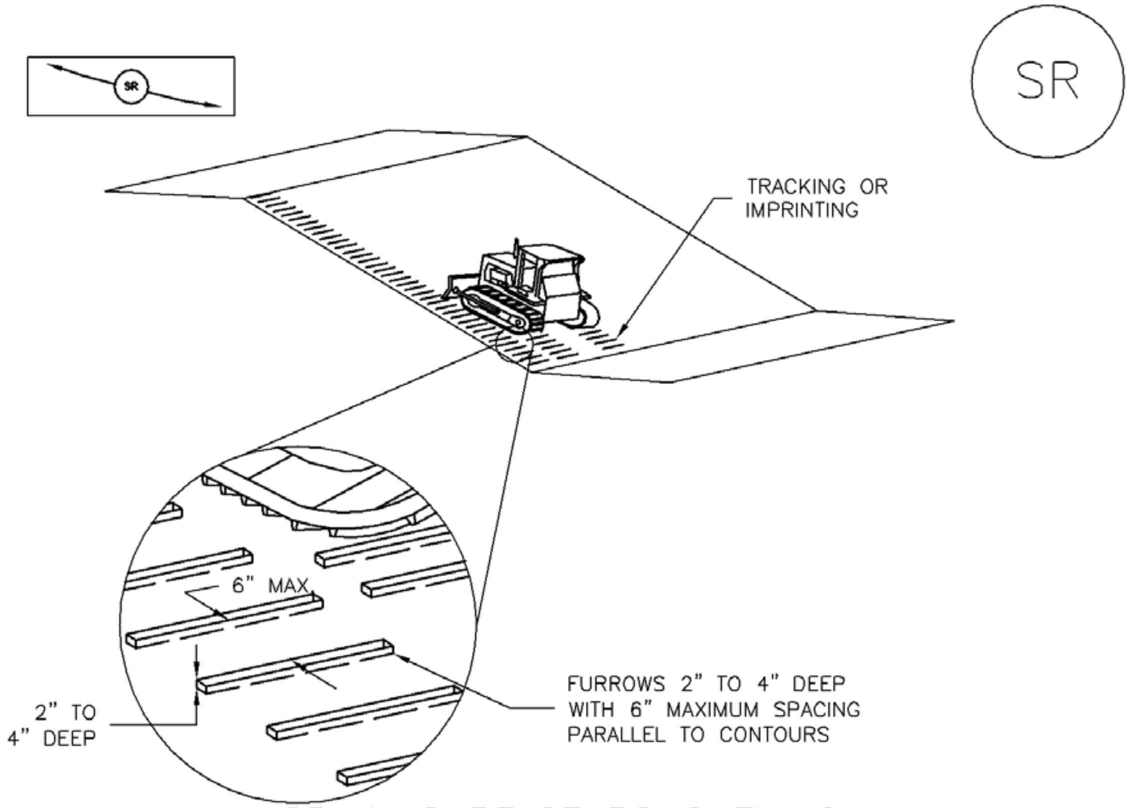
Surface Roughening	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

Maintenance and Removal

Care should be taken not to drive vehicles or equipment over areas that have been surface roughened. Tire tracks will smooth the roughened surface and may cause runoff to collect into rills and gullies.

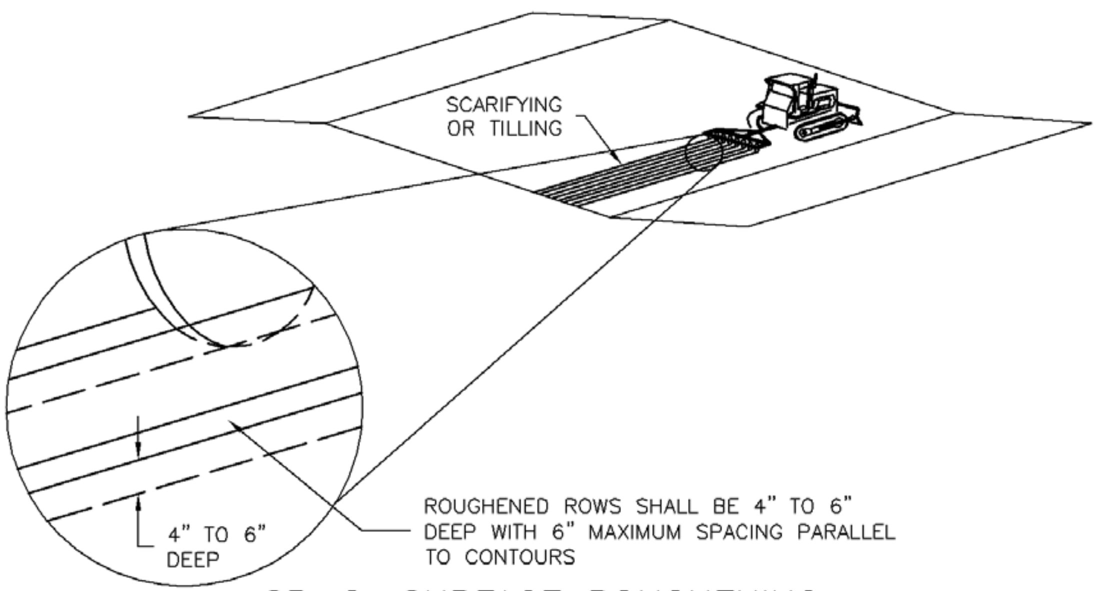
Because surface roughening is only a temporary control, additional treatments may be necessary to maintain the soil surface in a roughened condition.

Areas should be inspected for signs of erosion. Surface roughening is a temporary measure, and will not provide long-term erosion control.



SR–1. SURFACE ROUGHENING

FOR STEEP SLOPES (3:1 OR STEEPER)



SR–2. SURFACE ROUGHENING

FOR LOW SLOPES (LESS THAN 3:1)

SURFACE ROUGHENING INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   -LOCATION(S) OF SURFACE ROUGHENING.

2. SURFACE ROUGHENING SHALL BE PROVIDED PROMPTLY AFTER COMPLETION OF FINISHED GRADING (FOR AREAS NOT RECEIVING TOPSOIL) OR PRIOR TO TOPSOIL PLACEMENT OR ANY FORECASTED RAIN EVENT.

3. AREAS WHERE BUILDING FOUNDATIONS, PAVEMENT, OR SOD WILL BE PLACED WITHOUT DELAY IN THE CONSTRUCTION SEQUENCE, SURFACE ROUGHENING IS NOT REQUIRED.

4. DISTURBED SURFACES SHALL BE ROUGHENED USING RIPPING OR TILLING EQUIPMENT ON THE CONTOUR OR TRACKING UP AND DOWN A SLOPE USING EQUIPMENT TREADS.

5. A FARMING DISK SHALL NOT BE USED FOR SURFACE ROUGHENING.

SURFACE ROUGHENING MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACE UPON DISCOVERY OF THE FAILURE.

4. VEHICLES AND EQUIPMENT SHALL NOT BE DRIVEN OVER AREAS THAT HAVE BEEN SURFACE ROUGHENED.

5. IN NON-TURF GRASS FINISHED AREAS, SEEDING AND MULCHING SHALL TAKE PLACE DIRECTLY OVER SURFACE ROUGHENED AREAS WITHOUT FIRST SMOOTHING OUT THE SURFACE.

6. IN AREAS NOT SEEDED AND MULCHED AFTER SURFACE ROUGHENING, SURFACES SHALL BE RE-ROUGHENED AS NECESSARY TO MAINTAIN GROOVE DEPTH AND SMOOTH OVER RILL EROSION.

(DETAILS ADAPTED FROM TOWN OF PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Temporary seeding can be used to stabilize disturbed areas that will be inactive for an extended period. Permanent seeding should be used to stabilize areas at final grade that will not be otherwise stabilized. Effective seeding includes preparing a seedbed, selecting an appropriate seed mixture, using proper planting techniques, and protecting the seeded area with mulch, geotextiles, or other appropriate measures.

Photograph TS/PS -1. Equipment used to drill seed. Photo courtesy of Douglas County.

Appropriate Uses

When the soil surface is disturbed and will remain inactive for an extended period (typically determined by local government requirements), proactive stabilization measures, including planting a temporary seed mix, should be implemented. If the inactive period is short-lived (on the order of two weeks), techniques such as surface roughening may be appropriate. For longer periods of inactivity of up to one year, temporary seeding and mulching can provide effective erosion control. Permanent seeding should be used on finished areas that have not been otherwise stabilized.

The USDCM Volume 2 *Revegetation* Chapter contains suggested annual grains and native seed mixes to use for temporary seeding. Alternatively, local governments may have their own seed mixes and timelines for seeding. Check jurisdictional requirements for seeding and temporary stabilization.

Design and Installation

Effective seeding requires proper seedbed preparation, selecting an appropriate seed mixture, using appropriate seeding equipment to ensure proper coverage and density, and protecting seeded areas with mulch or fabric until plants are established.

The USDCM Volume 2 *Revegetation* Chapter contains detailed seed mixes, soil preparation practices, and seeding and mulching recommendations that should be referenced to supplement this Fact Sheet.

Drill seeding is the preferred seeding method. Hydroseeding is not recommended except in areas where steep slopes prevent use of drill seeding equipment, and even in these instances it is preferable to hand seed and mulch. Some jurisdictions do not allow hydroseeding or hydromulching.

Temporary and Permanent Seeding	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

Seedbed Preparation

Prior to seeding, ensure that areas to be revegetated have soil conditions capable of supporting vegetation. Overlot grading can result in loss of topsoil and compaction, resulting in poor quality subsoils at the ground surface that have low nutrient value, little organic matter content, few soil microorganisms, rooting restrictions, and conditions less conducive to infiltration of precipitation. As a result, it is typically necessary to provide stockpiled topsoil, compost, or other soil amendments and rototill them into the soil to a depth of 6 inches or more.

Topsoil should be salvaged during grading operations for use and spread on areas to be revegetated later. Topsoil should be viewed as an important resource to be utilized for vegetation establishment, due to its water-holding capacity, structure, texture, organic matter content, biological activity, and nutrient content. The rooting depth of most native grasses in the semi-arid Denver metropolitan area is 6 to 18 inches. If present, at a minimum of the upper 6 inches of topsoil should be stripped, stockpiled, and ultimately respread across areas that will be revegetated.

Where topsoil is not available, subsoils should be amended to provide an appropriate plant-growth medium. Organic matter, such as well digested compost, can be added to improve soil characteristics conducive to plant growth. Other treatments can be used to adjust soil pH conditions when needed. Soil testing, which is typically inexpensive, should be completed to determine and optimize the types and amounts of amendments that are required.

If the disturbed ground surface is compacted, rip or rototill the upper 12 inches of the surface prior to placing topsoil. If adding compost to the existing soil surface, rototilling is necessary. Surface roughening will assist in placing a stable topsoil layer on steeper slopes, and allow infiltration and root penetration to greater depth. Topsoil should not be placed when either the salvaged topsoil or receiving ground are frozen or snow covered.

Prior to seeding, the soil surface should be rough and the seedbed should be firm, but neither too loose nor compacted. The upper layer of soil should be in a condition suitable for seeding at the proper depth and conducive to plant growth. Seed-to-soil contact is the key to good germination.

Refer to MHFD's Topsoil Management Guidance for detailed information on topsoil assessment, design, and construction.

Temporary Vegetation

To provide temporary vegetative cover on disturbed areas which will not be paved, built upon, or fully landscaped or worked for an extended period (typically 30 days or more), plant an annual grass appropriate for the time of planting and mulch the planted areas. Temporary grain seed mixes suitable for the Denver metropolitan area are listed in Table TS/PS-1. Native temporary seed mixes are provided in USDCM Volume 2, Chapter 13, Appendix A. These are to be considered only as general recommendations when specific design guidance for a particular site is not available. Local governments typically specify seed mixes appropriate for their jurisdiction.

Permanent Revegetation

To provide vegetative cover on disturbed areas that have reached final grade, a perennial grass mix should be established. Permanent seeding should be performed promptly (typically within 14 days) after reaching final grade. Each site will have different characteristics and a landscape professional or the local jurisdiction should be contacted to determine the most suitable seed mix for a specific site. In lieu of a specific recommendation, one of the perennial grass mixes appropriate for site conditions and growth season listed in seed mix tables in the USDCM Volume 2 *Revegetation* Chapter can be used. The pure live seed (PLS) rates of application recommended in these tables are considered to be absolute minimum rates for seed applied using proper drill-seeding equipment. These are to be considered only as general recommendations when specific design guidance for a particular site is not available. Local governments typically specify seed mixes appropriate for their jurisdiction.

If desired for wildlife habitat or landscape diversity, shrubs such as rubber rabbitbrush (*Chrysothamnus nauseosus*), fourwing saltbush (*Atriplex canescens*) and skunkbrush sumac (*Rhus trilobata*) could be added to the upland seed mixes at 0.25, 0.5 and 1 pound PLS/acre, respectively. In riparian zones, planting root stock of such species as American plum (*Prunus americana*), woods rose (*Rosa woodsii*), plains cottonwood (*Populus sargentii*), and willow (*Salix spp.*) may be considered. On non-topsoiled upland sites, a legume such as Ladak alfalfa at 1 pound PLS/acre can be included as a source of nitrogen for perennial grasses.

Timing of seeding is an important aspect of the revegetation process. For upland and riparian areas on the Colorado Front Range, the suitable timing for seeding is from October through May. The most favorable time to plant non-irrigated areas is during the fall, so that seed can take advantage of winter and spring moisture. Seed should not be planted if the soil is frozen, snow covered, or wet.

Seeding dates for the highest success probability of perennial species along the Front Range are generally in the spring from April through early May and in the fall after the first of September until the ground freezes. If the area is irrigated, seeding may occur in summer months, as well. See Table TS/PS-2 for appropriate seeding dates.

Table TS/PS-1. Minimum Drill Seeding Rates for Various Temporary Annual Grasses

Species[a] (Common name)	Growth Season[b]	Pounds of Pure Live Seed (PLS)/acre[c]	Planting Depth (inches)
1. Oats	Cool	35 - 50	1 - 2
2. Spring wheat	Cool	25 - 35	1 - 2
3. Spring barley	Cool	25 - 35	1 - 2
4. Annual ryegrass	Cool	10 - 15	½
5. Millet	Warm	3 - 15	½ - ¾
6. Winter wheat	Cool	20–35	1 - 2
7. Winter barley	Cool	20–35	1 - 2
8. Winter rye	Cool	20–35	1 - 2
9. Triticale	Cool	25–40	1 - 2

[a] Successful seeding of annual grass resulting in adequate plant growth will usually produce enough dead-plant residue to provide protection from wind and water erosion for an additional year. This assumes that the cover is not disturbed or mowed closer than 8 inches.

Hydraulic seeding may be substituted for drilling only where slopes are steeper than 3:1 or where access limitations exist. When hydraulic seeding is used, hydraulic mulching should be applied as a separate operation, when practical, to prevent the seeds from being encapsulated in the mulch.

[b] See Table TS/PS-2 for seeding dates. Irrigation, if consistently applied, may extend the use of cool season species during the summer months.

[c] Seeding rates should be doubled if seed is broadcast, or increased by 50 percent if done using a Brillion Drill or by hydraulic seeding.

Table TS/PS-2. Seeding Dates for Annual and Perennial Grasses

	Annual Grasses (Numbers in table reference species in Table TS/PS-1)		Perennial Grasses	
Seeding Dates	**Warm**	**Cool**	**Warm**	**Cool**
January 1–March 15			✓	✓
March 16–April 30		1,2,3	✓	✓
May 1–May 15			✓	
May 16–June 30	5			
July 1–July 15	5			
July 16–August 31				
September 1–September 30		6, 7, 8, 9		
October 1–December 31			✓	✓

Mulch

Cover seeded areas with mulch or an appropriate rolled erosion control product to promote establishment of vegetation. Anchor mulch by crimping, netting or use of a non-toxic tackifier. See the USDCM Volume 2 *Revegetation* Chapter and Volume 3 Mulching BMP Fact Sheet (EC-04) for additional guidance.

Maintenance and Removal

Monitor and observe seeded areas to identify areas of poor growth or areas that fail to germinate. Reseed and mulch these areas, as needed.

If a temporary annual seed was planted, the area should be reseeded with the desired perennial mix when there will be no further work in the area. To minimize competition between annual and perennial species, the annual mix needs time to mature and die before seeding the perennial mix. To increase success of the perennial mix, it should be seeded during the appropriate seeding dates the second year after the temporary annual mix was seeded. Alternatively, if this timeline is not feasible, the annual mix seed heads should be removed and then the area seeded with the perennial mix.

An area that has been permanently seeded should have a good stand of vegetation within one growing season if irrigated and within three growing seasons without irrigation in Colorado. Reseed portions of the site that fail to germinate or remain bare after the first growing season.

Seeded areas may require irrigation, particularly during extended dry periods. Targeted weed control may also be necessary.

Protect seeded areas from construction equipment and vehicle access.

Description

Soil binders include a broad range of treatments that can be applied to exposed soils for temporary stabilization to reduce wind and water erosion. Soil binders may be applied alone or as tackifiers in conjunction with mulching and seeding applications.

Acknowledgement: This BMP Fact Sheet has been adapted from the 2003 California Stormwater Quality Association (CASQA) Stormwater BMP Handbook: Construction (www.cabmphandbooks.com).

Photograph SB-1. Tackifier being applied to provide temporary soil stabilization. Photo courtesy of Douglas County.

Appropriate Uses

Soil binders can be used for short-term, temporary stabilization of soils on both mild and steep slopes. Soil binders are often used in areas where work has temporarily stopped, but is expected to resume before revegetation can become established. Binders are also useful on stockpiled soils or where temporary or permanent seeding has occurred.

Prior to selecting a soil binder, check with the state and local jurisdiction to ensure that the chemicals used in the soil binders are allowed. The water quality impacts of some types of soil binders are relatively unknown and may not be allowed due to concerns about potential environmental impacts. Soil binders must be environmentally benign (non-toxic to plant and animal life), easy to apply, easy to maintain, economical, and should not stain paved or painted surfaces.

Soil binders should not be used in vehicle or pedestrian high traffic areas, due to loss in effectiveness under these conditions.

Site soil type will dictate appropriate soil binders to be used. Be aware that soil binders may not function effectively on silt or clay soils or highly compacted areas. Check manufacturer's recommendations for appropriateness with regard to soil conditions. Some binders may not be suitable for areas with existing vegetation.

Design and Installation

Properties of common soil binders used for erosion control are provided in Table SB-1. Design and installation guidance below are provided for general reference. Follow the manufacturer's instructions for application rates and procedures.

Soil Binders	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	Moderate

Table SB-1. Properties of Soil Binders for Erosion Control (Source: CASQA 2003)

Evaluation Criteria	Binder Type			
	Plant Material Based (short lived)	**Plant Material Based (long lived)**	**Polymeric Emulsion Blends**	**Cementitious-Based Binders**
Resistance to Leaching	High	High	Low to Moderate	Moderate
Resistance to Abrasion	Moderate	Low	Moderate to High	Moderate to High
Longevity	Short to Medium	Medium	Medium to Long	Medium
Minimum Curing Time before Rain	9 to 18 hours	19 to 24 hours	0 to 24 hours	4 to 8 hours
Compatibility with Existing Vegetation	Good	Poor	Poor	Poor
Mode of Degradation	Biodegradable	Biodegradable	Photodegradable/ Chemically Degradable	Photodegradable/ Chemically Degradable
Specialized Application Equipment	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher
Liquid/Powder	Powder	Liquid	Liquid/Powder	Powder
Surface Crusting	Yes, but dissolves on rewetting	Yes	Yes, but dissolves on rewetting	Yes
Clean Up	Water	Water	Water	Water
Erosion Control Application Rate	Varies	Varies	Varies	4,000 to 12,000 lbs/acre Typ.

Factors to consider when selecting a soil binder generally include:

- **Suitability to situation**: Consider where the soil binder will be applied, if it needs a high resistance to leaching or abrasion, and whether it needs to be compatible with existing vegetation. Determine the length of time soil stabilization will be needed, and if the soil binder will be placed in an area where it will degrade rapidly. In general, slope steepness is not a discriminating factor.

- **Soil types and surface materials**: Fines and moisture content are key properties of surface materials. Consider a soil binder's ability to penetrate, likelihood of leaching, and ability to form a surface crust on the surface materials.

- **Frequency of application**: The frequency of application can be affected by subgrade conditions, surface type, climate, and maintenance schedule. Frequent applications could lead to high costs. Application frequency may be minimized if the soil binder has good penetration, low evaporation, and good longevity. Consider also that frequent application will require frequent equipment clean up.

An overview of major categories of soil binders, corresponding to the types included in Table SB-1 follows.

Plant-Material Based (Short Lived) Binders

- **Guar**: A non-toxic, biodegradable, natural galactomannan-based hydrocolloid treated with dispersant agents for easy field mixing. It should be mixed with water at the rate of 11 to 15 lbs per 1,000 gallons. Recommended minimum application rates are provided in Table SB-2.

Table SB-2. Application Rates for Guar Soil Stabilizer

	Slope (H:V)				
	Flat	4:1	3:1	2:1	1:1
Application Rate (lb/acre)	40	45	50	60	70

- **Psyllium**: Composed of the finely ground muciloid coating of plantago seeds that is applied as a wet slurry to the surface of the soil. It dries to form a firm but rewettable membrane that binds soil particles together but permits germination and growth of seed. Psyllium requires 12 to 18 hours drying time. Application rates should be from 80 to 200 lbs/acre, with enough water in solution to allow for a uniform slurry flow.

- **Starch**: Non-ionic, cold-water soluble (pre-gelatinized) granular cornstarch. The material is mixed with water and applied at the rate of 150 lb/acre. Approximate drying time is 9 to 12 hours.

Plant-Material Based (Long Lived) Binders

- **Pitch and Rosin Emulsion**: Generally, a non-ionic pitch and rosin emulsion has a minimum solids content of 48 percent. The rosin should be a minimum of 26 percent of the total solids content. The soil stabilizer should be a non-corrosive, water dilutable emulsion that upon application cures to a water insoluble binding and cementing agent. For soil erosion control applications, the emulsion is diluted and should be applied as follows:

    - For clayey soil: 5 parts water to 1 part emulsion

- For sandy soil: 10 parts water to 1 part emulsion

Application can be by water truck or hydraulic seeder with the emulsion and product mixture applied at the rate specified by the manufacturer.

Polymeric Emulsion Blend Binders

- **Acrylic Copolymers and Polymers**: Polymeric soil stabilizers should consist of a liquid or solid polymer or copolymer with an acrylic base that contains a minimum of 55 percent solids. The polymeric compound should be handled and mixed in a manner that will not cause foaming or should contain an anti-foaming agent. The polymeric emulsion should not exceed its shelf life or expiration date; manufacturers should provide the expiration date. Polymeric soil stabilizer should be readily miscible in water, non-injurious to seed or animal life, non-flammable, should provide surface soil stabilization for various soil types without inhibiting water infiltration, and should not re-emulsify when cured. The applied compound should air cure within a maximum of 36 to 48 hours. Liquid copolymer should be diluted at a rate of 10 parts water to 1 part polymer and the mixture applied to soil at a rate of 1,175 gallons/acre.

- **Liquid Polymers of Methacrylates and Acrylates**: This material consists of a tackifier/sealer that is a liquid polymer of methacrylates and acrylates. It is an aqueous 100 percent acrylic emulsion blend of 40 percent solids by volume that is free from styrene, acetate, vinyl, ethoxylated surfactants or silicates. For soil stabilization applications, it is diluted with water in accordance with manufacturer's recommendations, and applied with a hydraulic seeder at the rate of 20 gallons/acre. Drying time is 12 to 18 hours after application.

- **Copolymers of Sodium Acrylates and Acrylamides**: These materials are non-toxic, dry powders that are copolymers of sodium acrylate and acrylamide. They are mixed with water and applied to the soil surface for erosion control at rates that are determined by slope gradient, as summarized in Table SB-3.

Table SB-3. Application Rates for Copolymers of Sodium Acrylates and Acrylamides

	Slope (H:V)		
	Flat to 5:1	5:1 to 3:1	2:2 to 1:1
Application Rate (lb/acre)	3.0-5.0	5.0-10.0	10.0-20.0

- **Polyacrylamide and Copolymer of Acrylamide**: Linear copolymer polyacrylamide is packaged as a dry flowable solid. When used as a stand-alone stabilizer, it is diluted at a rate of 11 lb/1,000 gal. of water and applied at the rate of 5.0 lb/acre.

- **Hydrocolloid Polymers**: Hydrocolloid Polymers are various combinations of dry flowable polyacrylamides, copolymers, and hydrocolloid polymers that are mixed with water and applied to the soil surface at rates of 55 to 60 lb/acre. Drying times are 0 to 4 hours.

Cementitious-Based Binders

- **Gypsum**: This formulated gypsum based product readily mixes with water and mulch to form a thin protective crust on the soil surface. It is composed of high purity gypsum that is ground, calcined and processed into calcium sulfate hemihydrate with a minimum purity of 86 percent. It is mixed in a hydraulic seeder and applied at rates 4,000 to 12,000 lb/acre. Drying time is 4 to 8 hours.

Installation

After selecting an appropriate soil binder, the untreated soil surface must be prepared before applying the soil binder. The untreated soil surface must contain sufficient moisture to assist the agent in achieving uniform distribution. In general, the following steps should be followed:

- Follow manufacturer's written recommendations for application rates, pre-wetting of application area, and cleaning of equipment after use.
- Prior to application, roughen embankment and fill areas.
- Consider the drying time for the selected soil binder and apply with sufficient time before anticipated rainfall. Soil binders should not be applied during or immediately before rainfall.
- Avoid over spray onto roads, sidewalks, drainage channels, sound walls, existing vegetation, etc.
- Soil binders should not be applied to frozen soil, areas with standing water, under freezing or rainy conditions, or when the temperature is below 40°F during the curing period.
- More than one treatment is often necessary, although the second treatment may be diluted or have a lower application rate.
- Generally, soil binders require a minimum curing time of 24 hours before they are fully effective. Refer to manufacturer's instructions for specific cure time.
- For liquid agents:
    - Crown or slope ground to avoid ponding.
    - Uniformly pre-wet ground at 0.03 to 0.3 gal/yd^2 or according to manufacturer's recommendations.
    - Apply solution under pressure. Overlap solution 6 to 12 in.
    - Allow treated area to cure for the time recommended by the manufacturer, typically at least 24 hours.
    - Apply second treatment before first treatment becomes ineffective, using 50 percent application rate.
    - In low humidity, reactivate chemicals by re-wetting with water at 0.1 to 0.2 gal/yd^2.

Maintenance and Removal

Soil binders tend to break down due to natural weathering. Weathering rates depend on a variety of site-specific and product characteristics. Consult the manufacturer for recommended reapplication rates and reapply the selected soil binder as needed to maintain effectiveness.

Soil binders can fail after heavy rainfall events and may require reapplication. In particular, soil binders will generally experience spot failures during heavy rainfall events. If runoff penetrates the soil at the top of a slope treated with a soil binder, it is likely that the runoff will undercut the stabilized soil layer and discharge at a point further down slope.

Areas where erosion is evident should be repaired and soil binder or other stabilization reapplied, as needed. Care should be exercised to minimize the damage to protected areas while making repairs.

Most binders biodegrade after exposure to sun, oxidation, heat and biological organisms; therefore, removal of the soil binder is not typically required.

Description

Mulching consists of evenly applying straw, hay, shredded wood mulch, rock, bark or compost to disturbed soils and securing the mulch by crimping, tackifiers, netting or other measures. Mulching helps reduce erosion by protecting bare soil from rainfall impact, increasing infiltration, and reducing runoff. Although often applied in conjunction with temporary or permanent seeding, it can also be used for temporary stabilization of areas that cannot be reseeded due to seasonal constraints.

Mulch can be applied either using standard mechanical dry application methods or using hydromulching equipment that hydraulically applies a slurry of water, wood fiber mulch, and often a tackifier.

Photograph MU-1. An area that was recently seeded, mulched, and crimped.

Appropriate Uses

Use mulch in conjunction with seeding to help protect the seedbed and stabilize the soil. Mulch can also be used as a temporary cover on low to mild slopes to help temporarily stabilize disturbed areas where growing season constraints prevent effective reseeding. Disturbed areas should be properly mulched and tacked, or seeded, mulched and tacked promptly after final grade is reached (typically within no longer than 14 days) on portions of the site not otherwise permanently stabilized.

Standard dry mulching is encouraged in most jurisdictions; however, hydromulching may not be allowed in certain jurisdictions or may not be allowed near waterways.

Do not apply mulch during windy conditions.

Design and Installation

Prior to mulching, surface-roughen areas by rolling with a crimping or punching type roller or by track walking. Track walking should only be used where other methods are impractical because track walking with heavy equipment typically compacts the soil.

A variety of mulches can be used effectively at construction sites. Consider the following:

Mulch	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No

- Clean, weed-free and seed-free cereal grain straw should be applied evenly at a rate of 2 tons per acre and must be tacked or fastened by a method suitable for the condition of the site. Straw mulch must be anchored (and not merely placed) on the surface. This can be accomplished mechanically by crimping or with the aid of tackifiers or nets. Anchoring with a crimping implement is preferred, and is the recommended method for areas flatter than 3:1. Mechanical crimpers must be capable of tucking the long mulch fibers into the soil to a depth of 3 inches without cutting them. An agricultural disk, while not an ideal substitute, may work if the disk blades are dull or blunted and set vertically; however, the frame may have to be weighted to afford proper soil penetration.

- Grass hay may be used in place of straw; however, because hay is comprised of the entire plant including seed, mulching with hay may seed the site with non-native grass species which might in turn out-compete the native seed. Alternatively, native species of grass hay may be purchased, but can be difficult to find and are more expensive than straw. Purchasing and utilizing a certified weed-free straw is an easier and less costly mulching method. When using grass hay, follow the same guidelines as for straw (provided above).

- On small areas sheltered from the wind and heavy runoff, spraying a tackifier on the mulch is satisfactory for holding it in place. For steep slopes and special situations where greater control is needed, erosion control blankets anchored with stakes should be used instead of mulch.

- Hydraulic mulching consists of wood cellulose fibers mixed with water and a tackifying agent and should be applied at a rate of no less than 1,500 pounds per acre (1,425 lbs of fibers mixed with at least 75 lbs of tackifier) with a hydraulic mulcher. For steeper slopes, up to 2000 pounds per acre may be required for effective hydroseeding. Hydromulch typically requires up to 24 hours to dry; therefore, it should not be applied immediately prior to inclement weather. Application to roads, waterways and existing vegetation should be avoided.

- Erosion control mats, blankets, or nets are recommended to help stabilize steep slopes (generally 3:1 and steeper) and waterways. Depending on the product, these may be used alone or in conjunction with grass or straw mulch. Normally, use of these products will be restricted to relatively small areas. Biodegradable mats made of straw and jute, straw-coconut, coconut fiber, or excelsior can be used instead of mulch. (See the ECM/TRM BMP for more information.)

- Some tackifiers or binders may be used to anchor mulch. Check with the local jurisdiction for allowed tackifiers. Manufacturer's recommendations should be followed at all times. (See the Soil Binder BMP for more information on general types of tackifiers.)

- Rock can also be used as mulch. It provides protection of exposed soils to wind and water erosion and allows infiltration of precipitation. An aggregate base course can be spread on disturbed areas for temporary or permanent stabilization. The rock mulch layer should be thick enough to provide full coverage of exposed soil on the area it is applied.

Maintenance and Removal

After mulching, the bare ground surface should not be more than 10 percent exposed. Reapply mulch, as needed, to cover bare areas.

Description

A compost blanket is a layer of compost uniformly applied to the soil in disturbed areas to control erosion, facilitate revegetation, and retain sediment resulting from sheet-flow runoff.

A compost filter berm is a dike of compost or a compost product that is placed perpendicular to runoff to control erosion in disturbed areas and retain sediment. Compost berms can be placed at regular intervals to help reduce the formation of rill and gully erosion when a compost blanket is stabilizing a slope.

Photograph CB-1. Application of a compost blanket to a disturbed area. Photo courtesy of Caltrans.

Appropriate Uses

Compost blankets can be used as an alternative to erosion control blankets and mulching to help stabilize disturbed areas where sheet flow conditions are present. Compost blankets should not be used in areas of concentrated flows. Compost provides an excellent source of nutrients for plant growth, and should be considered for use in areas that will be permanently vegetated.

Design and Installation

See Detail CB-1 for design details and notes.

Do not place compost in areas where it can easily be transported into drainage pathways or waterways. When using a compost blanket on a slope, berms should be installed periodically to reduce the potential for concentrated flow and rilling. Seeding should be completed before an area is composted or incorporated into the compost.

Compost quality is an important consideration when selecting compost blankets or berms. Representative compost quality factors include pH, salinity, moisture content, organic matter content, stability (maturity), and physical contaminants. The compost should meet all local, state, and federal quality requirements. Biosolids compost must meet the Standards for Class A biosolids outlined in 40 CFR Part 503. The U.S. Composting Council (USCC) certifies compost products under its Seal of Testing Assurance (STA) Program. Compost producers whose products have been certified through the STA Program provide customers with a standard product label that allows comparison between compost products. Only STA certified, Class I compost should be used.

Compost Blankets and Berms	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No

Maintenance and Removal

When rills or gullies develop in an area that has been composted, fill and cover the area with additional compost and install berms as necessary to help reduce erosion.

Weed control can be a maintenance challenge in areas using compost blankets. A weed control strategy may be necessary, including measures such as mechanical removal and spot application of targeted herbicides by licensed applicators.

For compost berms, accumulated sediments should be removed from behind the berm when the sediments reach approximately one third the height of the berm. Areas that have been washed away should be replaced. If the berm has experienced significant or repeated washouts, a compost berm may not be the appropriate BMP for this area.

Compost blankets and berms biodegrade and do not typically require removal following site stabilization.

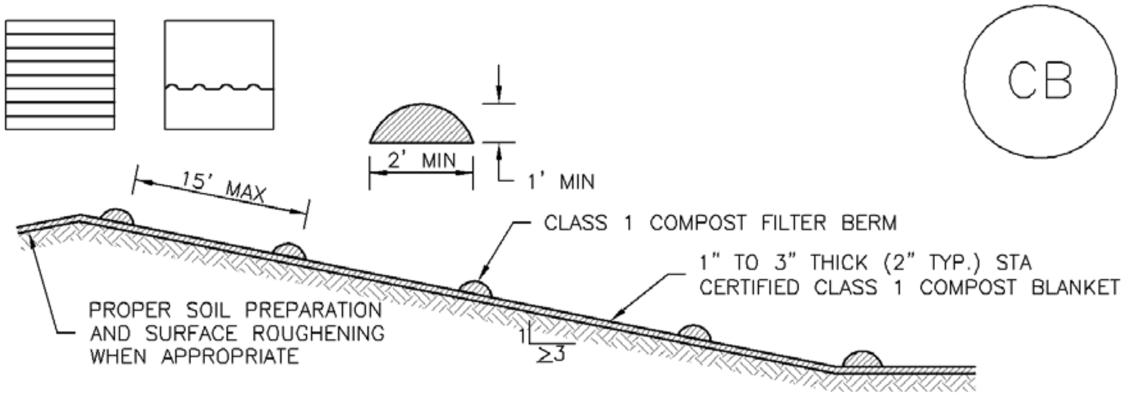


TABLE CB-1. CLASS 1 COMPOST	
PARAMETERS	CHARACTERISTIC
MINIMUM STABILITY INDICATOR	STABLE TO VERY STABLE
SOLUBLE SALTS	MAXIMUM 5 mmhos/cm
PH	6.0 – 8.0
AG INDEX	> 10
MATURITY INDICATOR EXPRESSED AS PERCENTAGE OF GERMINATION/VIGOR	80+/80+
MATURITY INDICATOR EXPRESSED AS AMMONIA N/ NITRATE N RATIO	< 4
MATURITY INDEX AS CARBON TO NITROGEN RATIO	20:1
TESTED FOR CLOPYRALID	YES/NEGATIVE RESULT
MOISTURE CONTENT	30–60%
ORGANIC MATTER CONTENT	25–45% OF DRY WEIGHT
PARTICLE SIZE DISTRIBUTION	3" (75mm) 100% PASSING
PRIMARY, SECONDARY NUTRIENTS; TRACE ELEMENTS	MUST BE REPORTED
TESTING AND TEST REPORT SUBMITTAL REQUIREMENTS	STA + CLOPYRALID
ORGANIC MATTER PER CUBIC YARD	MUST REPORT
CHEMICAL CONTAMINANTS	COMPLY WITH US EPA CLASS A STANDARD, 40 CFR 503.1 TABLES 1 & 3 LEVELS
MINIMUM MANUFACTURING/PRODUCTION REQUIREMENT	FULLY PERMITTED UNDER COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT, HAZARDOUS MATERIALS AND WASTE MANAGEMENT DIVISION
RISK FACTOR RELATING TO PLANT GERMINATION AND HEALTH	LOW

CB–1. COMPOST BLANKET AND COMPOST FILTER BERM

COMPOST FILTER BERM AND COMPOST BLANKET INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   - LOCATION OF COMPOST FILTER BERM(S).
   - LENGTH OF COMPOST FILTER BERM(S).

2. COMPOST BERMS AND BLANKETS MAY BE USED IN PLACE OF STRAW MULCH OR GEOTEXTILE FABRIC IN AREAS WHERE ACCESS TO LANDSCAPING IS DIFFICULT DUE TO LANDSCAPING OR OTHER OBJECTS OR IN AREAS WHERE A SMOOTH TURF GRASS FINISH IS DESIRED.

3. FILTER BERMS SHALL RUN PARALLEL TO THE CONTOUR.

4. FILTER BERMS SHALL BE A MINIMUM OF 1 FEET HIGH AND 2 FEET WIDE.

5. FILTER BERMS SHALL BE APPLIED BY PNEUMATIC BLOWER OR BY HAND.

6. FILTER BERMS SHALL ONLY BE UTILIZED IN AREAS WHERE SHEET FLOW CONDITIONS PREVAIL AND NOT IN AREAS OF CONCENTRATED FLOW.

7. COMPOST BLANKETS SHALL BE APPLIED AT A DEPTH OF 1 -3 INCHES (TYPICALLY 2 INCHES). FOR AREAS WITH EXISTING VEGETATION THAT ARE TO BE SUPPLEMENTED BY COMPOST, A THIN 0.5-INCH LAYER MAY BE USED.

8. SEEDING SHALL BE PERFORMED PRIOR TO THE APPLICATION OF COMPOST. ALTERNATIVELY, SEED MAY BE COMBINED WITH COMPOST AND BLOWN WITH THE PNEUMATIC BLOWER.

9. WHEN TURF GRASS FINISH IS NOT DESIRED, SURFACE ROUGHENING ON SLOPES SHALL TAKE PLACE PRIOR TO COMPOST APPLICATION.

10. COMPOST SHALL BE A CLASS 1 COMPOST AS DEFINED BY TABLE CB-1.

COMPOST FILTER BERM MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. COMPOST BERMS AND BLANKETS SHALL BE REAPPLIED OR REGRADED AS NECESSARY IF RILLING IN THE COMPOST SURFACE OCCURS.

(DETAILS ADAPTED FROM ARAPAHOE COUNTY, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Photograph RECP-1. Erosion control blanket protecting the slope from erosion and providing favorable conditions for revegetation.

Rolled Erosion Control Products (RECPs) include a variety of temporary or permanently installed manufactured products designed to control erosion and enhance vegetation establishment and survivability, particularly on slopes and in channels. For applications where natural vegetation alone will provide sufficient permanent erosion protection, temporary products such as netting, open weave textiles and a variety of erosion control blankets (ECBs) made of biodegradable natural materials (e.g., straw, coconut fiber) can be used. For applications where natural vegetation alone will not be sustainable under expected flow conditions, permanent rolled erosion control products such as turf reinforcement mats (TRMs) can be used. In particular, turf reinforcement mats are designed for discharges that exert velocities and sheer stresses that exceed the typical limits of mature natural vegetation.

Appropriate Uses

RECPs can be used to control erosion in conjunction with revegetation efforts, providing seedbed protection from wind and water erosion. These products are often used on disturbed areas on steep slopes, in areas with highly erosive soils, or as part of drainageway stabilization. In order to select the appropriate RECP for site conditions, it is important to have a general understanding of the general types of these products, their expected longevity, and general characteristics.

The Erosion Control Technology Council (ECTC 2005) characterizes rolled erosion control products according to these categories:

- **Mulch control netting**: A planar woven natural fiber or extruded geosynthetic mesh used as a temporary degradable rolled erosion control product to anchor loose fiber mulches.
- **Open weave textile**: A temporary degradable rolled erosion control product composed of processed natural or polymer yarns woven into a matrix, used to provide erosion control and facilitate vegetation establishment.
- **Erosion control blanket (ECB)**: A temporary degradable rolled erosion control product composed of processed natural or polymer fibers which are mechanically, structurally or chemically bound together to form a continuous matrix to provide erosion control and facilitate vegetation establishment. ECBs can be further differentiated into rapidly degrading single-net and double-net types or slowly degrading types.

Rolled Erosion Control Products	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

- **Turf Reinforcement Mat (TRM)**: A rolled erosion control product composed of non-degradable synthetic fibers, filaments, nets, wire mesh, and/or other elements, processed into a permanent, three-dimensional matrix of sufficient thickness. TRMs, which may be supplemented with degradable components, are designed to impart immediate erosion protection, enhance vegetation establishment and provide long-term functionality by permanently reinforcing vegetation during and after maturation. Note: TRMs are typically used in hydraulic applications, such as high flow ditches and channels, steep slopes, stream banks, and shorelines, where erosive forces may exceed the limits of natural, unreinforced vegetation or in areas where limited vegetation establishment is anticipated.

Tables RECP-1 and RECP-2 provide guidelines for selecting rolled erosion control products appropriate to site conditions and desired longevity. Table RECP-1 is for conditions where natural vegetation alone will provide permanent erosion control, whereas Table RECP-2 is for conditions where vegetation alone will not be adequately stable to provide long-term erosion protection due to flow or other conditions.

Table RECP-1. ECTC Standard Specification for Temporary Rolled Erosion Control Products
(Adapted from Erosion Control Technology Council 2005)

Product Description	Slope Applications*		Channel Applications*	Minimum Tensile Strength[1]	Expected Longevity
	Maximum Gradient	C Factor[2,5]	Max. Shear Stress[3,4,6]		
Mulch Control Nets	5:1 (H:V)	≤0.10 @ 5:1	0.25 lbs/ft^2 (12 Pa)	5 lbs/ft (0.073 kN/m)	Up to 12 months
Netless Rolled Erosion Control Blankets	4:1 (H:V)	≤0.10 @ 4:1	0.5 lbs/ft^2 (24 Pa)	5 lbs/ft (0.073 kN/m)	
Single-net Erosion Control Blankets & Open Weave Textiles	3:1 (H:V)	≤0.15 @ 3:1	1.5 lbs/ft^2 (72 Pa)	50 lbs/ft (0.73 kN/m)	
Double-net Erosion Control Blankets	2:1 (H:V)	≤0.20 @ 2:1	1.75 lbs/ft^2 (84 Pa)	75 lbs/ft (1.09 kN/m)	
Mulch Control Nets	5:1 (H:V)	≤0.10 @ 5:1	0.25 lbs/ft^2 (12 Pa)	25 lbs/ft (0.36 kN/m)	24 months
Erosion Control Blankets & Open Weave Textiles (slowly degrading)	1.5:1 (H:V)	≤0.25 @ 1.5:1	2.00 lbs/ft^2 (96 Pa)	100 lbs/ft (1.45 kN/m)	24 months
Erosion Control Blankets & Open Weave Textiles	1:1 (H:V)	≤0.25 @ 1:1	2.25 lbs/ft^2 (108 Pa)	125 lbs/ft (1.82 kN/m)	36 months

* C Factor and shear stress for mulch control nettings must be obtained with netting used in conjunction with pre-applied mulch material. (*See Section 5.3 of Chapter 7 Construction BMPs for more information on the C Factor*.)

[1] Minimum Average Roll Values, Machine direction using ECTC Mod. ASTM D 5035.

[2] C Factor calculated as ratio of soil loss from RECP protected slope (tested at specified or greater gradient, H:V) to ratio of soil loss from unprotected (control) plot in large-scale testing.

[3] Required minimum shear stress RECP (unvegetated) can sustain without physical damage or excess erosion (> 12.7 mm (0.5 in) soil loss) during a 30-minute flow event in large-scale testing.

[4] The permissible shear stress levels established for each performance category are based on historical experience with products characterized by Manning's roughness coefficients in the range of 0.01 - 0.05.

[5] Acceptable large-scale test methods may include ASTM D 6459, or other independent testing deemed acceptable by the engineer.

[6] Per the engineer’s discretion. Recommended acceptable large-scale testing protocol may include ASTM D 6460, or other independent testing deemed acceptable by the engineer.

Table RECP-2. ECTC Standard Specification for Permanent[1] Rolled Erosion Control Products
(Adapted from: Erosion Control Technology Council 2005)

Product Type	Slope Applications	Channel Applications	
	Maximum Gradient	Maximum Shear Stress[4,5]	Minimum Tensile Strength[2,3]
TRMs with a minimum thickness of 0.25 inches (6.35 mm) per ASTM D 6525 and UV stability of 80% per ASTM D 4355 (500 hours exposure).	0.5:1 (H:V)	6.0 lbs/ft^2 (288 Pa)	125 lbs/ft (1.82 kN/m)
	0.5:1 (H:V)	8.0 lbs/ft^2 (384 Pa)	150 lbs/ft (2.19 kN/m)
	0.5:1 (H:V)	10.0 lbs/ft^2 (480 Pa)	175 lbs/ft (2.55 kN/m)

[1] For TRMs containing degradable components, all property values must be obtained on the non-degradable portion of the matting alone.

[2] Minimum Average Roll Values, machine direction only for tensile strength determination using ASTM D 6818 (Supersedes Mod. ASTM D 5035 for RECPs)

[3] Field conditions with high loading and/or high survivability requirements may warrant the use of a TRM with a tensile strength of 44 kN/m (3,000 lb/ft) or greater.

[4] Required minimum shear stress TRM (fully vegetated) can sustain without physical damage or excess erosion (> 12.7 mm (0.5 in.) soil loss) during a 30-minute flow event in large scale testing.

[5] Acceptable large-scale testing protocols may include ASTM D 6460, or other independent testing deemed acceptable by the engineer.

Design and Installation

RECPs should be installed according to manufacturer's specifications and guidelines. Regardless of the type of product used, it is important to ensure no gaps or voids exist under the material and that all corners of the material are secured using stakes and trenching. Continuous contact between the product and the soil is necessary to avoid failure. Never use metal stakes to secure temporary erosion control products. Often wooden stakes are used to anchor RECPs; however, wood stakes may present installation and maintenance challenges and generally take a long time to biodegrade. Some local jurisdictions have had favorable experiences using biodegradable stakes.

This BMP Fact Sheet provides design details for several commonly used ECB applications, including:

ECB-1 Pipe Outlet to Drainageway

ECB-2 Small Ditch or Drainageway

ECB-3 Outside of Drainageway

Staking patterns are also provided in the design details according to these factors:

- ECB type
- Slope or channel type

For other types of RECPs including TRMs, these design details are intended to serve as general guidelines for design and installation; however, engineers should adhere to manufacturer's installation recommendations.

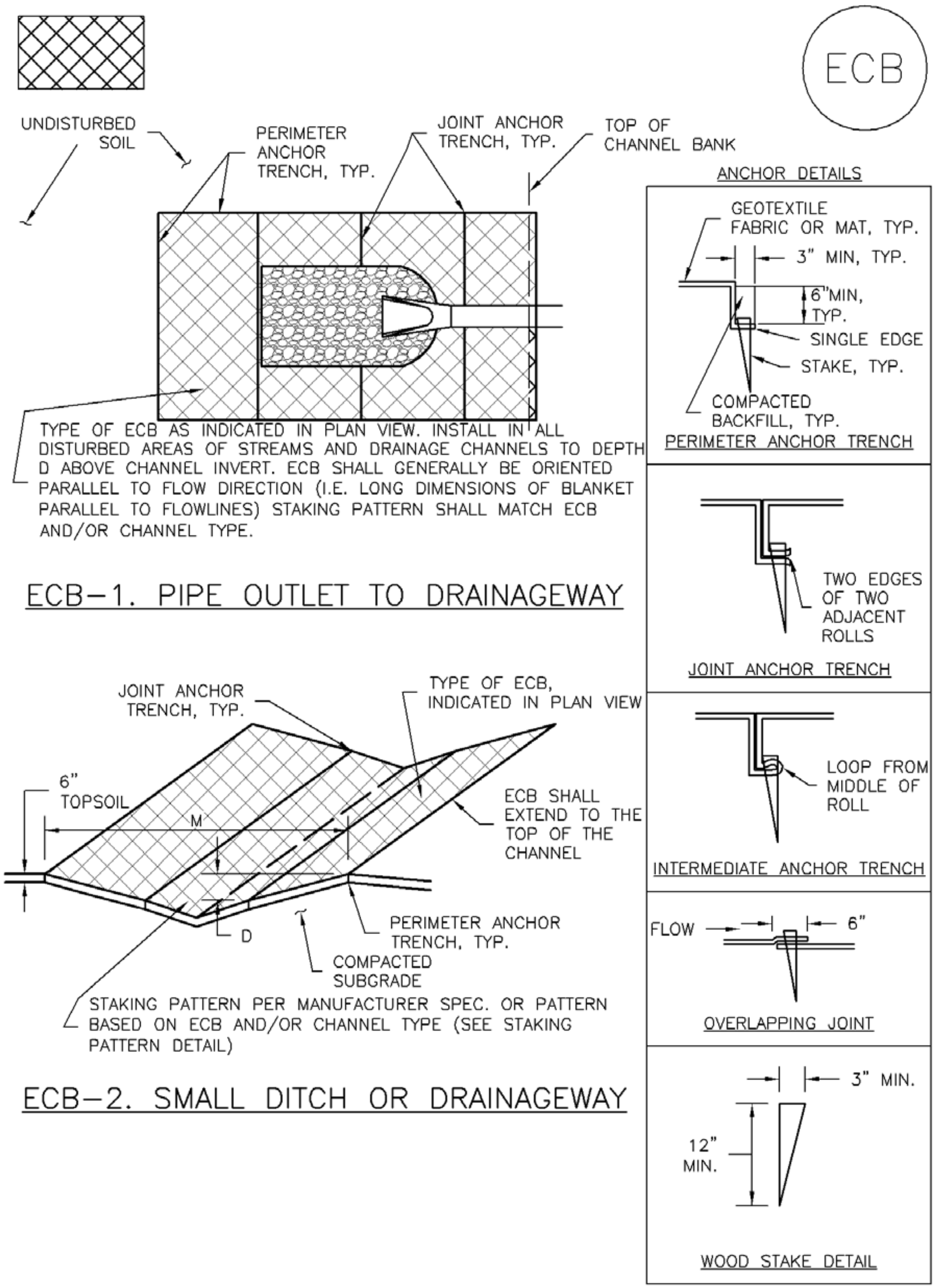
Maintenance and Removal

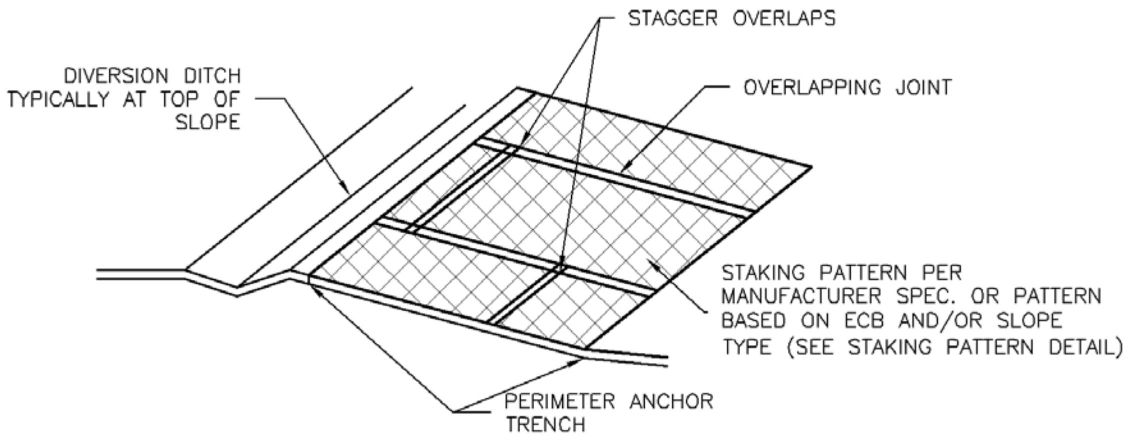
Inspection of erosion control blankets and other RECPs includes:

- Check for general signs of erosion, including voids beneath the mat. If voids are apparent, fill the void with suitable soil and replace the erosion control blanket, following the appropriate staking pattern.
- Check for damaged or loose stakes and secure loose portions of the blanket.

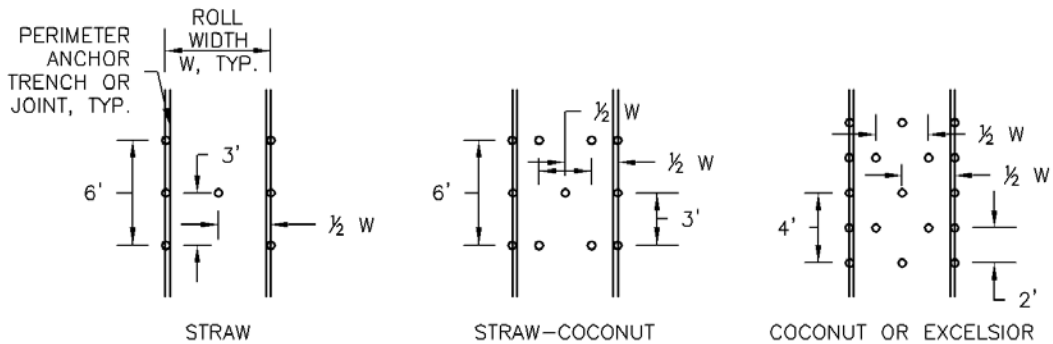
Erosion control blankets and other RECPs that are biodegradable typically do not need to be removed after construction. If they must be removed, then an alternate soil stabilization method should be installed promptly following removal.

Turf reinforcement mats, although generally resistant to biodegradation, are typically left in place as a dense vegetated cover grows in through the mat matrix. The turf reinforcement mat provides long-term stability and helps the established vegetation resist erosive forces.

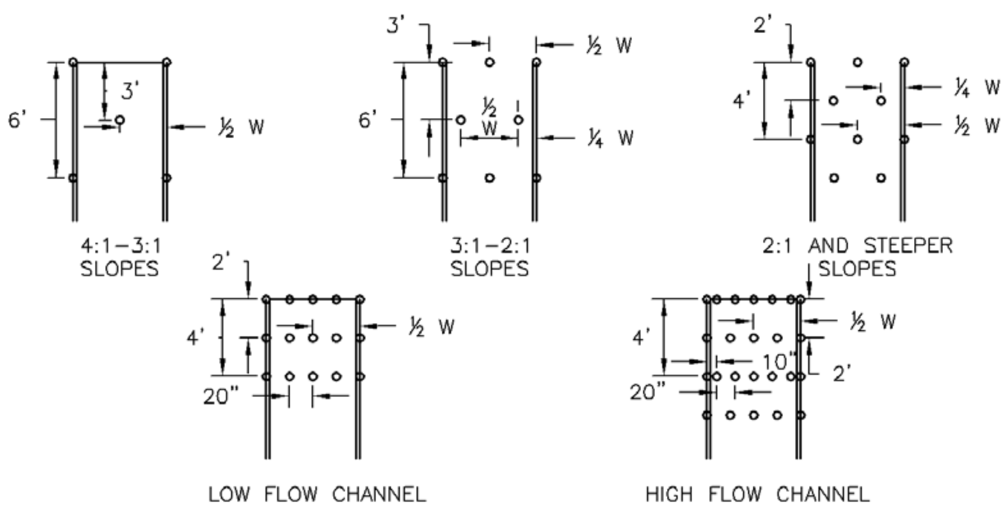

ECB
UNDISTURBED SOIL
PERIMETER ANCHOR TRENCH, TYP.
JOINT ANCHOR TRENCH, TYP.
TOP OF CHANNEL BANK
TYPE OF ECB AS INDICATED IN PLAN VIEW. INSTALL IN ALL DISTURBED AREAS OF STREAMS AND DRAINAGE CHANNELS TO DEPTH D ABOVE CHANNEL INVERT. ECB SHALL GENERALLY BE ORIENTED PARALLEL TO FLOW DIRECTION (I.E. LONG DIMENSIONS OF BLANKET PARALLEL TO FLOWLINES) STAKING PATTERN SHALL MATCH ECB AND/OR CHANNEL TYPE.
ECB-1. PIPE OUTLET TO DRAINAGEWAY
JOINT ANCHOR TRENCH, TYP.
TYPE OF ECB, INDICATED IN PLAN VIEW
6" TOPSOIL
M
ECB SHALL EXTEND TO THE TOP OF THE CHANNEL
D
PERIMETER ANCHOR TRENCH, TYP.
COMPACTED SUBGRADE
STAKING PATTERN PER MANUFACTURER SPEC. OR PATTERN BASED ON ECB AND/OR CHANNEL TYPE (SEE STAKING PATTERN DETAIL)
ECB-2. SMALL DITCH OR DRAINAGEWAY
ANCHOR DETAILS
GEOTEXTILE FABRIC OR MAT, TYP.
3" MIN, TYP.
6" MIN, TYP.
SINGLE EDGE
STAKE, TYP.
COMPACTED BACKFILL, TYP.
PERIMETER ANCHOR TRENCH
TWO EDGES OF TWO ADJACENT ROLLS
JOINT ANCHOR TRENCH
LOOP FROM MIDDLE OF ROLL
INTERMEDIATE ANCHOR TRENCH
FLOW
6"
OVERLAPPING JOINT
3" MIN.
12" MIN.
WOOD STAKE DETAIL



ECB–3. OUTSIDE OF DRAINAGEWAY



STAKING PATTERNS BY ECB TYPE



STAKING PATTERNS BY SLOPE OR CHANNEL TYPE

EROSION CONTROL BLANKET INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - LOCATION OF ECB.
   - TYPE OF ECB (STRAW, STRAW–COCONUT, COCONUT, OR EXCELSIOR).
   - AREA, A, IN SQUARE YARDS OF EACH TYPE OF ECB.

2. 100% NATURAL AND BIODEGRADABLE MATERIALS ARE PREFERRED FOR RECPs, ALTHOUGH SOME JURISDICTIONS MAY ALLOW OTHER MATERIALS IN SOME APPLICATIONS.

3. IN AREAS WHERE ECBs ARE SHOWN ON THE PLANS, THE PERMITTEE SHALL PLACE TOPSOIL AND PERFORM FINAL GRADING, SURFACE PREPARATION, AND SEEDING AND MULCHING. SUBGRADE SHALL BE SMOOTH AND MOIST PRIOR TO ECB INSTALLATION AND THE ECB SHALL BE IN FULL CONTACT WITH SUBGRADE. NO GAPS OR VOIDS SHALL EXIST UNDER THE BLANKET.

4. PERIMETER ANCHOR TRENCH SHALL BE USED ALONG THE OUTSIDE PERIMETER OF ALL BLANKET AREAS.

5. JOINT ANCHOR TRENCH SHALL BE USED TO JOIN ROLLS OF ECBs TOGETHER (LONGITUDINALLY AND TRANSVERSELY) FOR ALL ECBs EXCEPT STRAW WHICH MAY USE AN OVERLAPPING JOINT.

6. INTERMEDIATE ANCHOR TRENCH SHALL BE USED AT SPACING OF ONE–HALF ROLL LENGTH FOR COCONUT AND EXCELSIOR ECBs.

7. OVERLAPPING JOINT DETAIL SHALL BE USED TO JOIN ROLLS OF ECBs TOGETHER FOR ECBs ON SLOPES.

8. MATERIAL SPECIFICATIONS OF ECBs SHALL CONFORM TO TABLE ECB–1.

9. ANY AREAS OF SEEDING AND MULCHING DISTURBED IN THE PROCESS OF INSTALLING ECBS SHALL BE RESEEDED AND MULCHED.

10. DETAILS ON DESIGN PLANS FOR MAJOR DRAINAGEWAY STABILIZATION WILL GOVERN IF DIFFERENT FROM THOSE SHOWN HERE.

TABLE ECB–1. ECB MATERIAL SPECIFICATIONS

TYPE	COCONUT CONTENT	STRAW CONTENT	EXCELSIOR CONTENT	RECOMMENDED NETTING**
STRAW*	–	100%	–	DOUBLE/ NATURAL
STRAW–COCONUT	30% MIN	70% MAX	–	DOUBLE/ NATURAL
COCONUT	100%	–	–	DOUBLE/ NATURAL
EXCELSIOR	–	–	100%	DOUBLE/ NATURAL

*STRAW ECBs MAY ONLY BE USED OUTSIDE OF STREAMS AND DRAINAGE CHANNEL.
**ALTERNATE NETTING MAY BE ACCEPTABLE IN SOME JURISDICTIONS

EROSION CONTROL BLANKET MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. ECBs SHALL BE LEFT IN PLACE TO EVENTUALLY BIODEGRADE, UNLESS REQUESTED TO BE REMOVED BY THE LOCAL JURISDICTION.

5. ANY ECB PULLED OUT, TORN, OR OTHERWISE DAMAGED SHALL BE REPAIRED OR REINSTALLED. ANY SUBGRADE AREAS BELOW THE GEOTEXTILE THAT HAVE ERODED TO CREATED A VOID UNDER THE BLANKET, OR THAT REMAIN DEVOID OF GRASS SHALL BE REPAIRED, RESEEDED AND MULCHED AND THE ECB REINSTALLED.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO AND TOWN OF PARKER COLORADO, NOT AVAILABLE IN AUTOCAD)

Description

A temporary slope drain is a pipe or culvert used to convey water down a slope where there is a high potential for erosion. A drainage channel or swale at the top of the slope typically directs upgradient runoff to the pipe entrance for conveyance down the slope. The pipe outlet must be equipped with outlet protection.

Photograph TSD-1. A temporary slope drain installed to convey runoff down a slope during construction. Photo courtesy of the City of Aurora.

Appropriate Uses

Use on long, steep slopes when there is a high potential of flow concentration or rill development.

Design and Installation

Effective use of temporary slope drains involves design of an effective collection system to direct flows to the pipe, proper sizing and anchoring of the pipe, and outlet protection. Upgradient of the temporary slope drain, a temporary drainage ditch or swale should be constructed to collect surface runoff from the drainage area and convey it to the drain entrance. The temporary slope drain must be sized to safely convey the desired flow volume. At a minimum, it should be sized to convey the 2-year, 24-hour storm.

Temporary slope drains may be constructed of flexible or rigid pipe, riprap, or heavy (30 mil) plastic lining. When piping is used, it must be properly anchored by burying it with adequate cover or by using an anchor system to secure it to the ground.

The discharge from the slope drain must be directed to a stabilized outlet, temporary or permanent channel, and/or sedimentation basin.

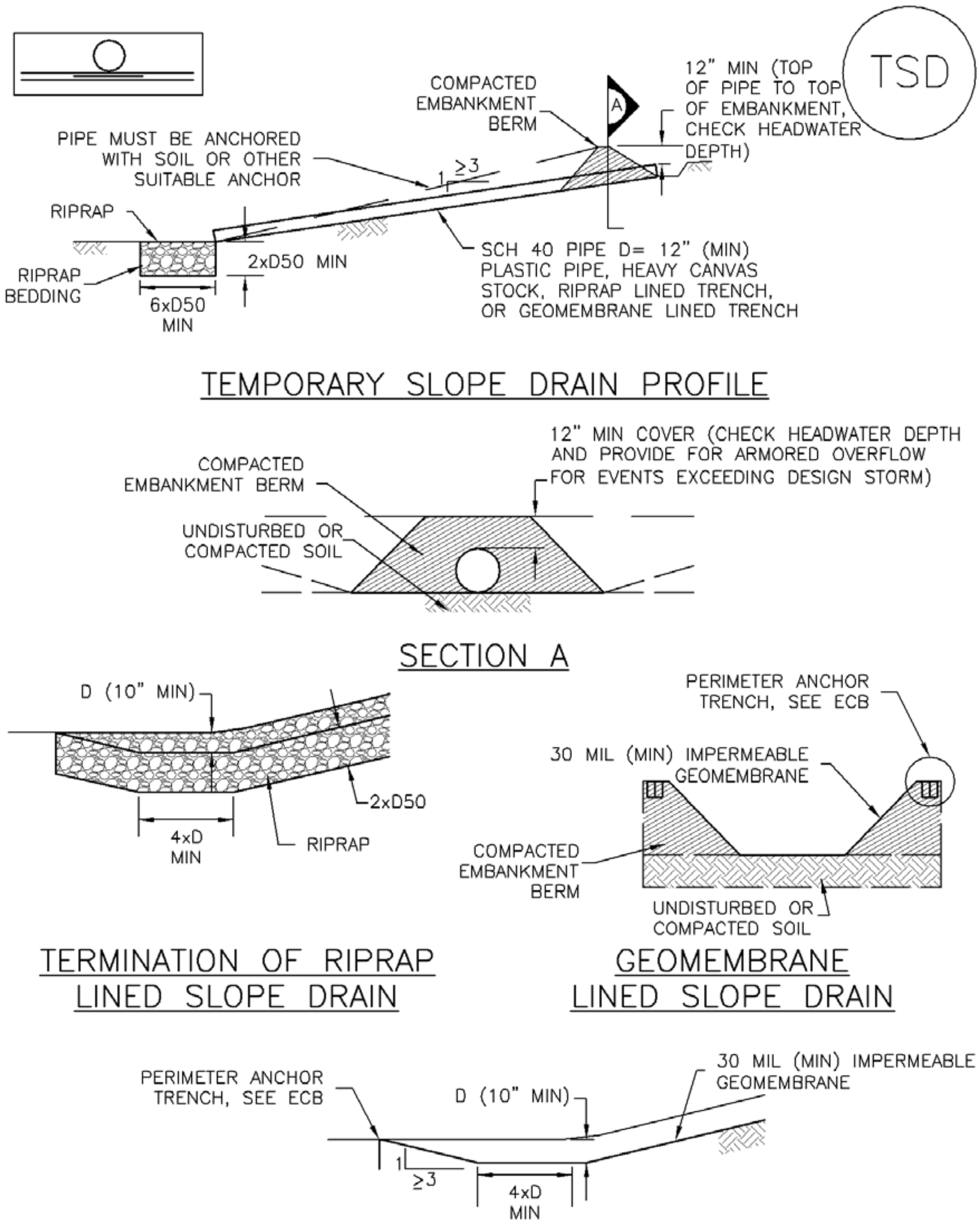
See Detail TSD-1 for additional sizing and design information.

Temporary Slope Drains	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

Maintenance and Removal

Inspect the entrance for sediment accumulation and remove, as needed. Clogging as a result of sediment deposition at the entrance can lead to ponding upstream causing flooding or overtopping of the slope drain. Inspect the downstream outlet for signs of erosion and stabilize, as needed. It may also be necessary to remove accumulated sediment at the outfall. Inspect pipe anchors to ensure that they are secure. If the pipe is secured by ground cover, ensure erosion has not compromised the depth of cover.

Slope drains should be removed when no longer needed or just prior to installation of permanent slope stabilization measures that cannot be installed with the slope drain in place. When slope drains are removed, the disturbed areas should be covered with topsoil, seeded, mulched or otherwise stabilized as required by the local jurisdiction.



TSD–1. TEMPORARY SLOPE DRAIN PROFILE

SLOPE DRAIN INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   -LOCATION AND LENGTH OF SLOPE DRAIN
   -PIPE DIAMETER, D, AND RIPRAP SIZE, D50.

2. SLOPE DRAIN SHALL BE DESIGNED TO CONVEY PEAK RUNOFF FOR 2-YEAR 24-HOUR STORM AT A MINIMUM. FOR LONGER DURATION PROJECTS, LARGER MAY BE APPROPRIATE.

3. SLOPE DRAIN DIMENSIONS SHALL BE CONSIDERED MINIMUM DIMENSIONS; CONTRACTOR MAY ELECT TO INSTALL LARGER FACILITIES.

4. SLOPE DRAINS INDICATED SHALL BE INSTALLED PRIOR TO UPGRADIENT LAND-DISTURBING ACTIVITIES.

5. CHECK HEADWATER DEPTHS FOR TEMPORARY AND PERMANENT SLOPE DRAINS. DETAILS SHOW MINIMUM COVER; INCREASE AS NECESSARY FOR DESIGN HEADWATER DEPTH.

6. RIPRAP PAD SHALL BE PLACED AT SLOPE DRAIN OUTFALL.

7. ANCHOR PIPE BY COVERING WITH SOIL OR AN ALTERNATE SUITABLE ANCHOR MATERIAL.

SLOPE DRAIN MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. INSPECT INLET AND OUTLET POINTS AFTER STORMS FOR CLOGGING OR EVIDENCE OF OVERTOPPING. BREACHES IN PIPE OR OTHER CONVEYANCE SHALL BE REPAIRED AS SOON AS PRACTICABLE IF OBSERVED.

5. INSPECT RIPRAP PAD AT OUTLET FOR SIGNS OF EROSION. IF SIGNS OF EROSION EXIST, ADDITIONAL ARMORING SHALL BE INSTALLED.

6. TEMPORARY SLOPE DRAINS ARE TO REMAIN IN PLACE UNTIL NO LONGER NEEDED, BUT SHALL BE REMOVED PRIOR TO THE END OF CONSTRUCTION. WHEN SLOPE DRAINS ARE REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOP SOIL, SEEDED, MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND THE CITY OF COLORADO SPRINGS, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Photograph TOP-1. Riprap outlet protection.

Outlet protection helps to reduce erosion immediately downstream of a pipe, culvert, slope drain, rundown or other conveyance with concentrated, high-velocity flows. Typical outlet protection consists of riprap or rock aprons at the conveyance outlet.

Appropriate Uses

Outlet protection should be used when a conveyance discharges onto a disturbed area where there is potential for accelerated erosion due to concentrated flow. Outlet protection should be provided where the velocity at the culvert outlet exceeds the maximum permissible velocity of the material in the receiving channel.

Note**:** This Fact Sheet and detail are for temporary outlet protection, outlets that are intended to be used for less than 2 years. For permanent, long-term outlet protection, see the *Major Drainage* chapter of Volume 1.

Design and Installation

Design outlet protection to handle runoff from the largest drainage area that may be contributing runoff during construction (the drainage area may change as a result of grading). Key in rock, around the entire perimeter of the apron, to a minimum depth of 6 inches for stability. Extend riprap to the height of the culvert or the normal flow depth of the downstream channel, whichever is less. Additional erosion control measures such as vegetative lining, turf reinforcement mat and/or other channel lining methods may be required downstream of the outlet protection if the channel is susceptible to erosion. See Design Detail OP-1 for additional information.

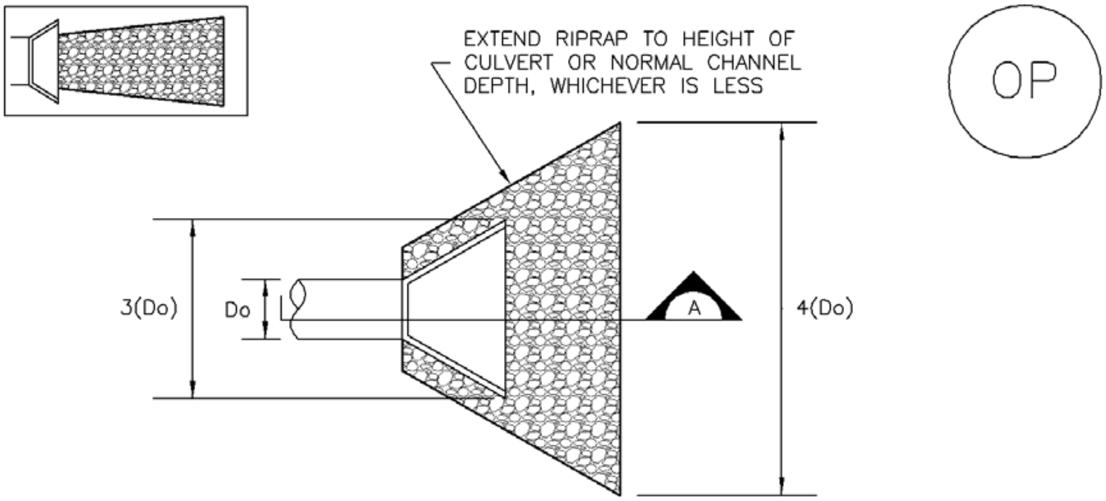
Maintenance and Removal

Inspect apron for damage and displaced rocks. If rocks are missing or significantly displaced, repair or replace as necessary. If rocks are continuously missing or displaced, consider increasing the size of the riprap or deeper keying of the perimeter.

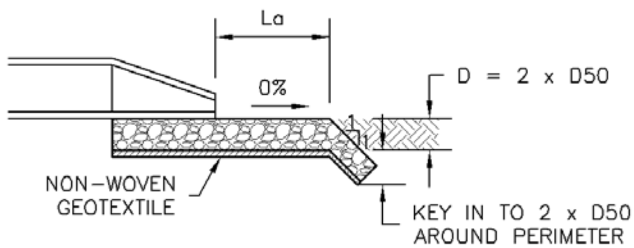
Remove sediment accumulated at the outlet before the outlet protection becomes buried and ineffective. When sediment accumulation is noted, check that upgradient BMPs, including inlet protection, are in effective operating condition.

Outlet protection may be removed once the pipe is no longer draining an upstream area, or once the downstream area has been sufficiently stabilized. If the drainage pipe is permanent, outlet protection can be left in place; however, permanent outlet protection should be designed and constructed in accordance with the requirements of the *Major Drainage* chapter of Volume 2.

Outlet Protection	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No



TEMPORARY OUTLET PROTECTION PLAN



SECTION A

TABLE OP-1. TEMPORARY OUTLET PROTECTION SIZING TABLE

PIPE DIAMETER, Do (INCHES)	DISCHARGE, Q (CFS)	APRON LENGTH, La (FT)	RIPRAP D50 DIAMETER MIN (INCHES)
8	2.5 5	5 10	4 6
12	5 10	10 13	4 6
18	10 20 30 40	10 16 23 26	6 9 12 16
24	30 40 50 60	16 26 26 30	9 9 12 16

OP-1. TEMPORARY OUTLET PROTECTION

TEMPORARY OUTLET PROTECTION INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   - –LOCATION OF OUTLET PROTECTION.
   - –DIMENSIONS OF OUTLET PROTECTION.

2. DETAIL IS INTENDED FOR PIPES WITH SLOPE ≤ 10%. ADDITIONAL EVALUATION OF RIPRAP SIZING AND OUTLET PROTECTION DIMENSIONS REQUIRED FOR STEEPER SLOPES.

3. TEMPORARY OUTLET PROTECTION INFORMATION IS FOR OUTLETS INTENDED TO BE UTILIZED LESS THAN 2 YEARS.

TEMPORARY OUTLET PROTECTION INSPECTION AND MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM AURORA, COLORADO AND PREVIOUS VERSION OF VOLUME 3, NOT AVAILABLE IN AUTOCAD)

Photograph RCS-1. Rough cut street controls.

Description

Rough cut street controls are rock or earthen berms placed along dirt roadways that are under construction or used for construction access. These temporary berms intercept sheet flow and divert runoff from the roadway, and control erosion by minimizing concentration of flow and reducing runoff velocity.

Appropriate Uses

Appropriate uses include:

- Temporary dirt construction roadways that have not received roadbase.
- Roadways under construction that will not be paved within 14 days of final grading, and that have not yet received roadbase.

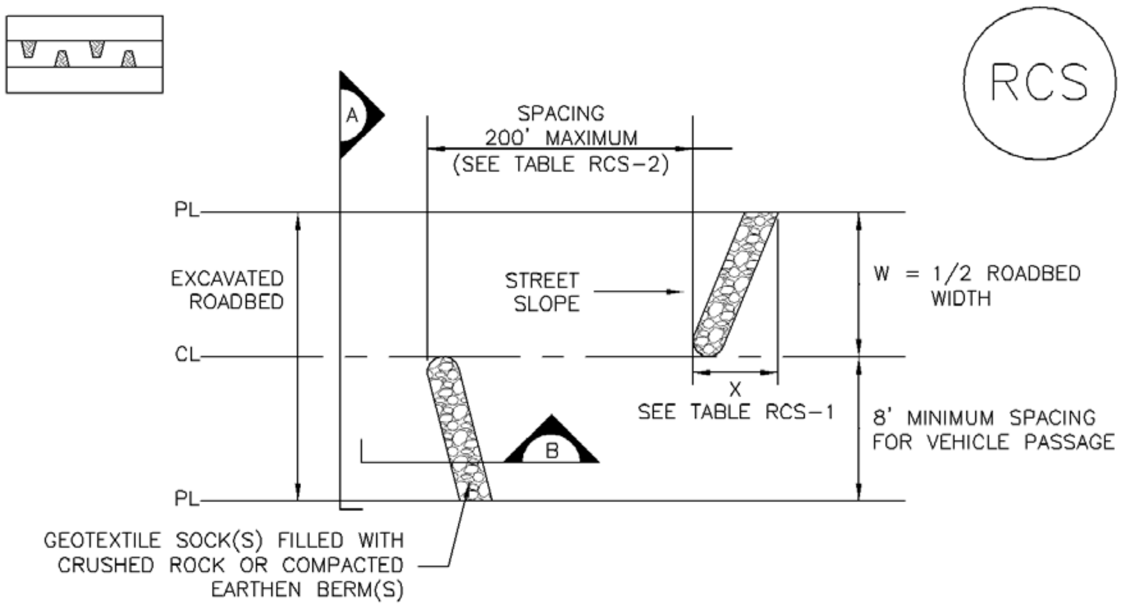
Design and Installation

Rough cut street controls are designed to redirect sheet flow off the dirt roadway to prevent water from concentrating and eroding the soil. These controls consist of runoff barriers that are constructed at intervals along the road. These barriers are installed perpendicular to the longitudinal slope from the outer edge of the roadside swale to the crown of the road. The barriers are positioned alternately from the right and left side of the road to allow construction traffic to pass in the lane not barred. If construction traffic is expected to be congested and a vehicle tracking control has been constructed, rough-cut street controls may be omitted for 400 feet from the entrance. Runoff from the controls should be directed to another stormwater BMP such as a roadside swale with check dams once removed from the roadway. See Detail RCS-1 for additional information.

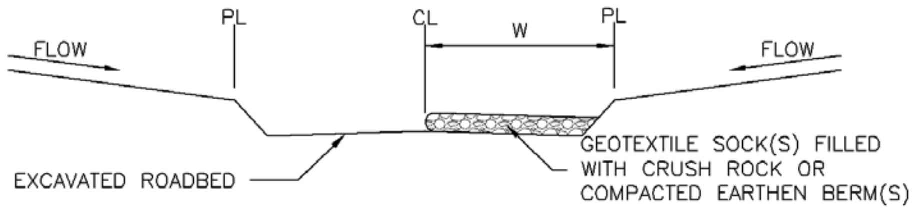
Maintenance and Removal

Inspect street controls for erosion and stability. If rills are forming in the roadway or cutting through the control berms, place the street controls at shorter intervals. If earthen berms are used, periodic recompaction may be necessary. When rock berms are used, repair and/or replace as necessary when damaged. Street controls may be removed 14 days prior to road surfacing and paving.

Rough Cut Street Control	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No



ROUGH CUT STREET CONTROL PLAN



SECTION A

SECTION B

TABLE RCS-1

W (FT)	X (FT)
20–30	5
31–40	7
41–50	9
51–60	10.5
61–70	12

TABLE RCS-2

LONGITUDINAL STREET SLOPE (%)	SPACING (FT)
<2 2	NOT TYPICALLY NEEDED 200
3 4	200 150
5 6	100 50
7 8	25 25

RCS–1. ROUGH CUT STREET CONTROL

ROUGH CUT STREET CONTROL INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   -LOCATION OF ROUGH CUT STREET CONTROL MEASURES.

2. ROUGH CUT STREET CONTROL SHALL BE INSTALLED AFTER A ROAD HAS BEEN CUT IN, AND WILL NOT BE PAVED FOR MORE THAN 14 DAYS OR FOR TEMPORARY CONSTRUCTION ROADS THAT HAVE NOT RECEIVED ROAD BASE.

ROUGH CUT STREET CONTROL INSPECTION AND MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

(DETAILS ADAPTED FROM AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Earth dikes and drainage swales are temporary storm conveyance channels constructed either to divert runoff around slopes or to convey runoff to additional sediment control BMPs prior to discharge of runoff from a site. Drainage swales may be lined or unlined, but if an unlined swale is used, it must be well compacted and capable of resisting erosive velocities.

Photograph ED/DS-1. Example of an earth dike used to divert flows at a construction site. Photo courtesy of CDOT.

Appropriate Uses

Earth dikes and drainage swales are typically used to control the flow path of runoff at a construction site by diverting runoff around areas prone to erosion, such as steep slopes. Earth dikes and drainage swales may also be constructed as temporary conveyance features. This will direct runoff to additional sediment control treatment BMPs, such as sediment traps or basins.

Design and Installation

When earth dikes are used to divert water for slope protection, the earth dike typically consists of a horizontal ridge of soil placed perpendicular to the slope and angled slightly to provide drainage along the contour. The dike is used in conjunction with a swale or a small channel upslope of the berm to convey the diverted water. Temporary diversion dikes can be constructed by excavation of a V-shaped trench or ditch and placement of the fill on the downslope side of the cut. There are two types of placement for temporary slope diversion dikes:

- A dike located at the top of a slope to divert upland runoff away from the disturbed area and convey it in a temporary or permanent channel.
- A diversion dike located at the base or mid-slope of a disturbed area to intercept runoff and reduce the effective slope length.

Depending on the project, either an earth dike or drainage swale may be more appropriate. If there is a need for cut on the project, then an excavated drainage swale may be better suited. When the project is primarily fill, then a conveyance constructed using a berm may be the better option.

All dikes or swales receiving runoff from a disturbed area should direct stormwater to a sediment control BMP such as a sediment trap or basin.

Earth Dikes and Drainage Swales	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No

Unlined dikes or swales should only be used for intercepting sheet flow runoff and are not intended for diversion of concentrated flows.

Details with notes are provided for several design variations, including:

ED-1. Unlined Earth Dike formed by Berm

DS-1. Unlined Excavated Swale

DS-2. Unlined Swale Formed by Cut and Fill

DS-3. ECB-lined Swale

DS-4. Synthetic-lined Swale

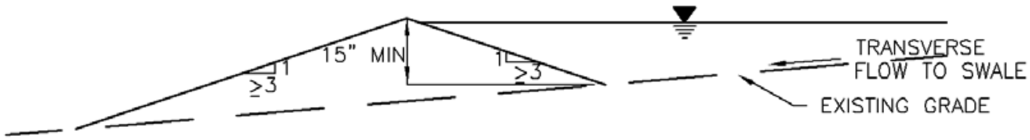
DS-5. Riprap-lined Swale

The details also include guidance on permissible velocities for cohesive channels if unlined approaches will be used.

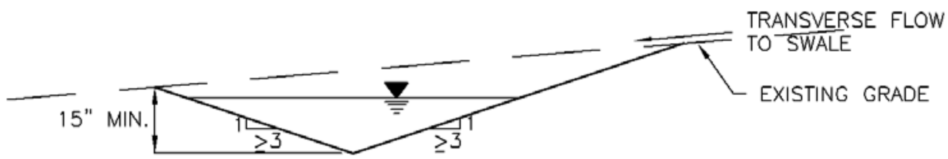
Maintenance and Removal

Inspect earth dikes for stability, compaction, and signs of erosion and repair. Inspect side slopes for erosion and damage to erosion control fabric. Stabilize slopes and repair fabric as necessary. If there is reoccurring extensive damage, consider installing rock check dams or lining the channel with riprap.

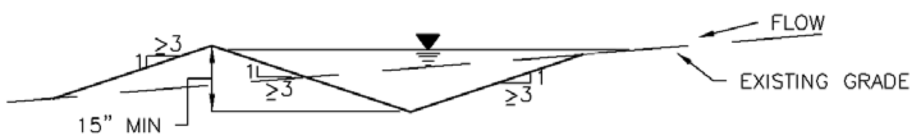
If drainage swales are not permanent, remove dikes and fill channels when the upstream area is stabilized. Stabilize the fill or disturbed area immediately following removal by revegetation or other permanent stabilization method approved by the local jurisdiction.



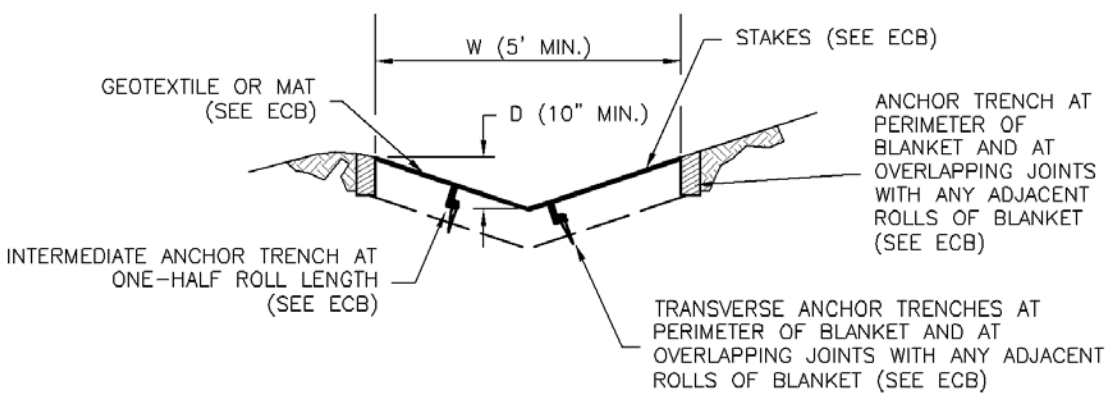
ED–1. COMPACTED UNLINED EARTH DIKE FORMED BY BERM



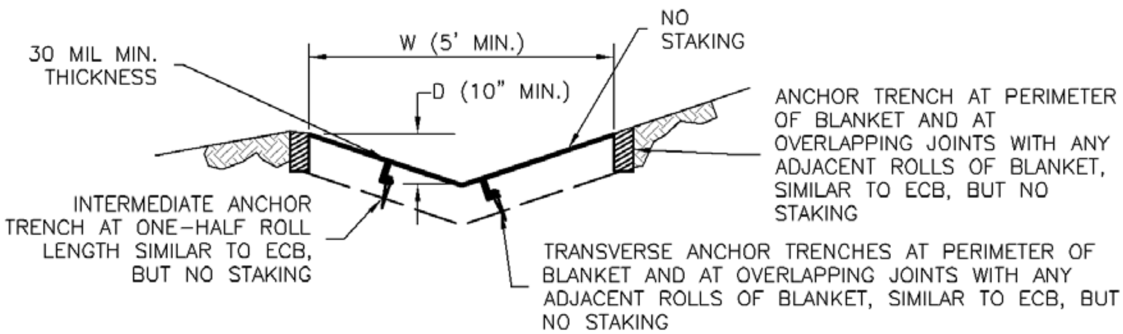
DS–1. COMPACTED UNLINED EXCAVATED SWALE



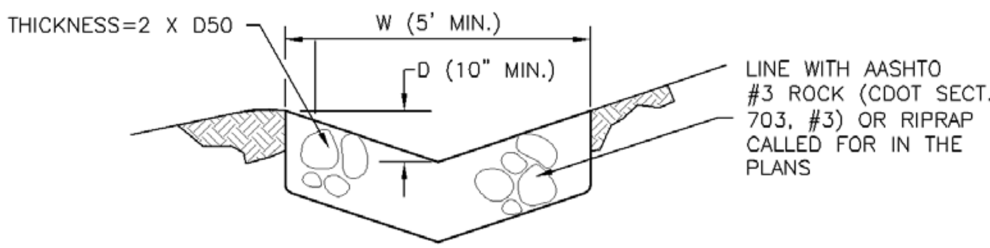
DS–2. COMPACTED UNLINED SWALE FORMED BY CUT AND FILL



DS–3. ECB LINED SWALE (CUT AND FILL OR BERM)



DS-4. SYNTHETIC LINED SWALE



DS-5. RIPRAP LINED SWALE

EARTH DIKE AND DRAINAGE SWALE INSTALLATION NOTES

1. SEE SITE PLAN FOR:
   - LOCATION OF DIVERSION SWALE
   - TYPE OF SWALE (UNLINED, COMPACTED AND/OR LINED).
   - LENGTH OF EACH SWALE.
   - DEPTH, D, AND WIDTH, W DIMENSIONS.
   - FOR ECB/TRM LINED DITCH, SEE ECB DETAIL.
   - FOR RIPRAP LINED DITCH, SIZE OF RIPRAP, D50.

2. SEE DRAINAGE PLANS FOR DETAILS OF PERMANENT CONVEYANCE FACILITIES AND/OR DIVERSION SWALES EXCEEDING 2-YEAR FLOW RATE OR 10 CFS.

3. EARTH DIKES AND SWALES INDICATED ON SWMP PLAN SHALL BE INSTALLED PRIOR TO LAND-DISTURBING ACTIVITIES IN PROXIMITY.

4. EMBANKMENT IS TO BE COMPACTED TO 90% OF MAXIMUM DENSITY AND WITHIN 2% OF OPTIMUM MOISTURE CONTENT ACCORDING TO ASTM D698.

5. SWALES ARE TO DRAIN TO A SEDIMENT CONTROL BMP.

6. FOR LINED DITCHES, INSTALLATION OF ECB/TRM SHALL CONFORM TO THE REQUIREMENTS OF THE ECB DETAIL.

7. WHEN CONSTRUCTION TRAFFIC MUST CROSS A DIVERSION SWALE, INSTALL A TEMPORARY CULVERT WITH A MINIMUM DIAMETER OF 12 INCHES.

EARTH DIKE AND DRAINAGE SWALE MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SWALES SHALL REMAIN IN PLACE UNTIL THE END OF CONSTRUCTION; IF APPROVED BY LOCAL JURISDICTION, SWALES MAY BE LEFT IN PLACE.

5. WHEN A SWALE IS REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY LOCAL JURISDICTION.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND THE CITY OF COLORADO SPRINGS, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Terracing involves grading steep slopes into a series of relatively flat sections, or terraces, separated at intervals by steep slope segments. Terraces shorten the uninterrupted flow lengths on steep slopes, helping to reduce the development of rills and gullies. Retaining walls, gabions, cribbing, deadman anchors, rock-filled slope mattresses, and other types of soil retention systems can be used in terracing.

Photograph TER-1. Use of a terrace to reduce erosion by controlling slope length on a long, steep slope. Photo courtesy of Douglas County.

Appropriate Uses

Terracing techniques are most typically used to control erosion on slopes that are steeper than 4:1.

Design and Installation

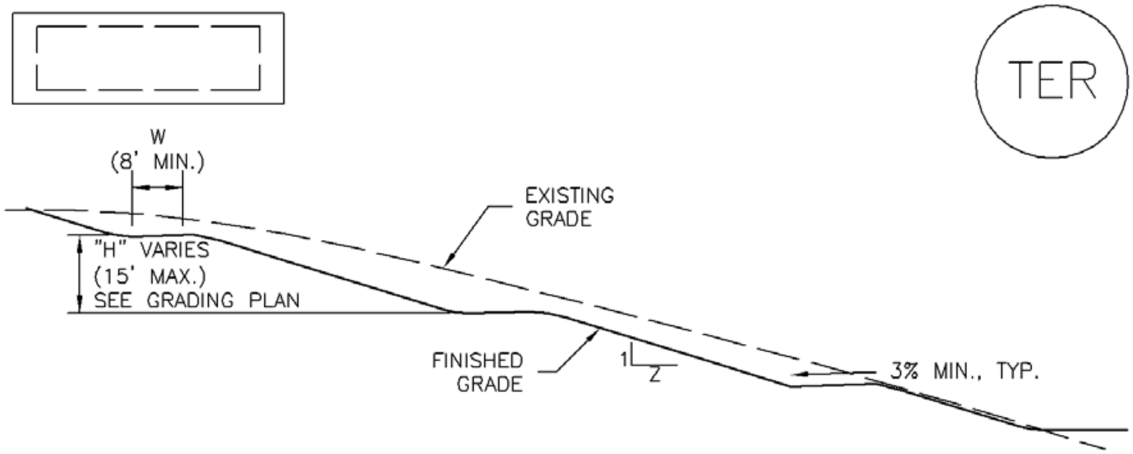
Design details with notes are provided in Detail TER-1.

The type, number, and spacing of terraces will depend on the slope, slope length, and other factors. The Revised Universal Soil Loss Equation (RUSLE) may be helpful in determining spacing of terraces on slopes. Terracing should be used in combination with other stabilization measures that provide cover for exposed soils such as mulching, seeding, surface roughening, or other measures.

Maintenance and Removal

Repair rill erosion on slopes and remove accumulated sediment, as needed. Terracing may be temporary or permanent. If terracing is temporary, the slope should be topsoiled, seeded, and mulched when the slope is graded to its final configuration and terraces are removed. Due to the steepness of the slope, once terraces are graded, erosion control blankets or other stabilization measures are typically required. If terraces are permanent, vegetation should be established on slopes and terraces as soon as practical.

Terracing	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No



TER–1. TERRACING

TERRACING INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - –LOCATION OF TERRACING
   - –WIDTH (W), AND SLOPE (Z).

2. TERRACING IS TYPICALLY NOT REQUIRED FOR SLOPES OF 4:1 OR FLATTER.

3. GRADE TERRACES TO DRAIN BACK TO SLOPE AT A MINIMUM OF 3% GRADE.

TERRACING MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. RILL EROSION OCCURRING ON TERRACED SLOPES SHALL BE REPAIRED, RESEEDED, MULCHED OR STABILIZED IN A MANNER APPROVED BY LOCAL JURISDICTION.

5. TERRACING MAY NEED TO BE RE–GRADED TO RETURN THE SLOPE TO THE FINAL DESIGN GRADE. THE SLOPE SHALL THEN BE COVERED WITH TOPSOIL, SEEDED AND MULCHED, OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND TOWN OF PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Check dams are temporary grade control structures placed in drainage channels to limit the erosivity of stormwater by reducing flow velocity. Check dams are typically constructed from rock, gravel bags, sand bags, or sometimes, proprietary devices. Reinforced check dams are typically constructed from rock and wire gabion. Although the primary function of check dams is to reduce the velocity of concentrated flows, a secondary benefit is sediment trapping upstream of the structure.

Photograph CD-1. Rock check dams in a roadside ditch. Photo courtesy of WWE.

Appropriate Uses

Use as a grade control for temporary drainage ditches or swales until final soil stabilization measures are established upstream and downstream. Check dams can be used on mild or moderately steep slopes. Check dams may be used under the following conditions:

- As temporary grade control facilities along waterways until final stabilization is established.
- Along permanent swales that need protection prior to installation of a non-erodible lining.
- Along temporary channels, ditches or swales that need protection where construction of a non-erodible lining is not practicable.
- Reinforced check dams should be used in areas subject to high flow velocities.

Design and Installation

Place check dams at regularly spaced intervals along the drainage swale or ditch. Check dams heights should allow for pools to develop upstream of each check dam, extending to the downstream toe of the check dam immediately upstream.

When rock is used for the check dam, place rock mechanically or by hand. Do not dump rocks into the drainage channel. Where multiple check dams are used, the top of the lower dam should be at the same elevation as the toe of the upper dam.

When reinforced check dams are used, install erosion control fabric under and around the check dam to prevent erosion on the upstream and downstream sides. Each section of the dam should be keyed in to reduce the potential for washout or undermining. A rock apron upstream and downstream of the dam may be necessary to further control erosion.

Check Dams	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	No

Design details with notes are provided for the following types of check dams:

- Rock Check Dams (CD-1)
- Reinforced Check Dams (CD-2)

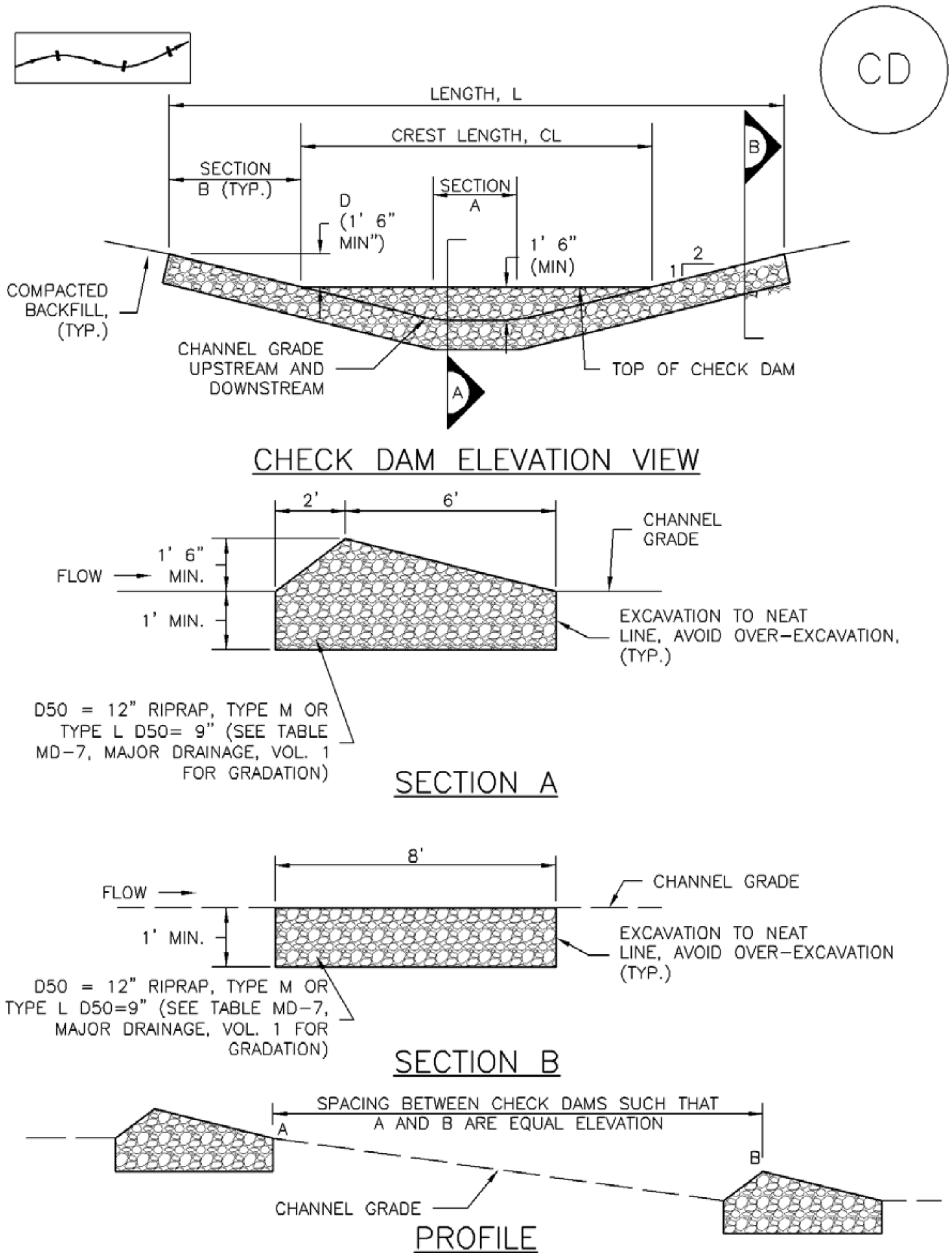
Sediment control logs may also be used as check dams; however, silt fence is not appropriate for use as a check dam. Many jurisdictions also prohibit or discourage use of straw bales for this purpose.

Maintenance and Removal

Replace missing rocks causing voids in the check dam. If gravel bags or sandbags are used, replace or repair torn or displaced bags.

Remove accumulated sediment, as needed to maintain BMP effectiveness, typically before the sediment depth upstream of the check dam is within ½ of the crest height. Remove accumulated sediment prior to mulching, seeding, or chemical soil stabilization. Removed sediment can be incorporated into the earthwork with approval from the Project Engineer, or disposed of at an alternate location in accordance with the standard specifications.

Check dams constructed in permanent swales should be removed when perennial grasses have become established, or immediately prior to installation of a non-erodible lining. All of the rock and accumulated sediment should be removed, and the area seeded and mulched, or otherwise stabilized.



CD-1. CHECK DAM

CHECK DAM INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - LOCATION OF CHECK DAMS.
   - CHECK DAM TYPE (CHECK DAM OR REINFORCED CHECK DAM).
   - LENGTH (L), CREST LENGTH (CL), AND DEPTH (D).

2. CHECK DAMS INDICATED ON INITIAL SWMP SHALL BE INSTALLED AFTER CONSTRUCTION FENCE, BUT PRIOR TO ANY UPSTREAM LAND DISTURBING ACTIVITIES.

3. RIPRAP UTILIZED FOR CHECK DAMS SHOULD BE OF APPROPRIATE SIZE FOR THE APPLICATION. TYPICAL TYPES OF RIPRAP USED FOR CHECK DAMS ARE TYPE M (D50 12") OR TYPE L (D50 9").

4. RIPRAP PAD SHALL BE TRENCHED INTO THE GROUND A MINIMUM OF 1'.

5. THE ENDS OF THE CHECK DAM SHALL BE A MINIMUM OF 1' 6" HIGHER THAN THE CENTER OF THE CHECK DAM.

CHECK DAM MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

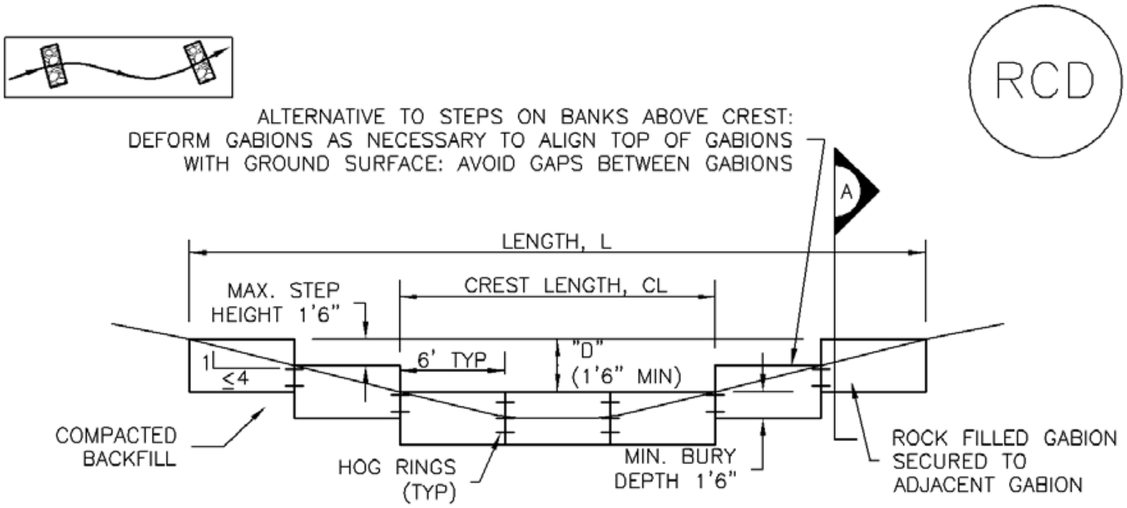
4. SEDIMENT ACCUMULATED UPSTREAM OF THE CHECK DAMS SHALL BE REMOVED WHEN THE SEDIMENT DEPTH IS WITHIN ½ OF THE HEIGHT OF THE CREST.

5. CHECK DAMS ARE TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

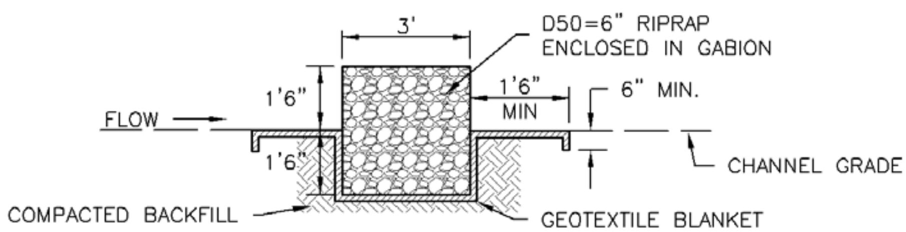
6. WHEN CHECK DAMS ARE REMOVED, EXCAVATIONS SHALL BE FILLED WITH SUITABLE COMPACTED BACKFILL. DISTURBED AREA SHALL BE SEEDED AND MULCHED AND COVERED WITH GEOTEXTILE OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.



REINFORCED CHECK DAM ELEVATION VIEW



SECTION A

REINFORCED CHECK DAM INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - LOCATIONS OF CHECK DAMS.
   - CHECK DAM TYPE (CHECK DAM OR REINFORCED CHECK DAM).
   - LENGTH (L), CREST LENGTH (CL), AND DEPTH (D).

2. CHECK DAMS INDICATED ON THE SWMP SHALL BE INSTALLED PRIOR TO AN UPSTREAM LAND–DISTURBING ACTIVITIES.

3. REINFORCED CHECK DAMS, GABIONS SHALL HAVE GALVANIZED TWISTED WIRE NETTING WITH A MAXIMUM OPENING DIMENSION OF 4½" AND A MINIMUM WIRE THICKNESS OF 0.10". WIRE "HOG RINGS" AT 4" SPACING OR OTHER APPROVED MEANS SHALL BE USED AT ALL GABION SEAMS AND TO SECURE THE GABION TO THE ADJACENT SECTION.

4. THE CHECK DAM SHALL BE TRENCHED INTO THE GROUND A MINIMUM OF 1' 6".

5. GEOTEXTILE BLANKET SHALL BE PLACED IN THE REINFORCED CHECK DAM TRENCH EXTENDING A MINIMUM OF 1' 6" ON BOTH THE UPSTREAM AND DOWNSTREAM SIDES OF THE REINFORCED CHECK DAM.

CD–2. REINFORCED CHECK DAM

REINFORCED CHECK DAM MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED UPSTREAM OF REINFORCED CHECK DAMS SHALL BE REMOVED AS NEEDED TO MAINTAIN THE EFFECTIVENESS OF BMP, TYPICALLY WHEN THE UPSTREAM SEDIMENT DEPTH IS WITHIN ½ THE HEIGHT OF THE CREST.

5. REPAIR OR REPLACE REINFORCED CHECK DAMS WHEN THERE ARE SIGNS OF DAMAGE SUCH AS HOLES IN THE GABION OR UNDERCUTTING.

6. REINFORCED CHECK DAMS ARE TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

7. WHEN REINFORCED CHECK DAMS ARE REMOVED, ALL DISTURBED AREAS SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED, AND COVERED WITH A GEOTEXTILE BLANKET, OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND CITY OF AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Photograph SS-1. Streambank stabilization using geotextiles following installation of a permanent in-stream grade control structure.

Streambank stabilization involves a combination of erosion and sediment control practices to protect streams, banks, and in-stream habitat from accelerated erosion. BMPs associated with streambank stabilization may include protection of existing vegetation, check dams/grade control, temporary and permanent seeding, outlet protection, rolled erosion control products, temporary diversions, dewatering operations and bioengineering practices such as brush layering, live staking and fascines.

Appropriate Uses

Streambank stabilization may be a construction activity in and of itself, or it may be in conjunction with a broader construction project that discharges to a waterway that is susceptible to accelerated erosion due to increases in the rate and volume of stormwater runoff. Depending on the health of the stream, water quality sampling and testing may be advisable prior to and/or during construction to evaluate health and stability of the stream and potential effects from adjacent construction activities.

Design and Installation

Streambank stabilization consists of protecting the stream in a variety of ways to minimize negative effects to the stream environment. The following lists the minimum requirements necessary for construction streambank stabilization:

- Protect existing vegetation along the stream bank in accordance with the Vegetated Buffers and Protection of Existing Vegetation Fact Sheets. Preserving a riparian buffer along the streambank will help to remove sediment and decrease runoff rates from the disturbed area.
- Outside the riparian buffer, provide sediment control in the form of a silt fence or equivalent sediment control practice along the entire length of the stream that will receive runoff from the area of disturbance. In some cases, a double-layered perimeter control may be justified adjacent to sensitive receiving waters and wetlands to provide additional protection.
- Stabilize all areas that will be draining to the stream. Use rolled erosion control products, temporary or permanent seeding, or other appropriate measures.
- Ensure all point discharges entering the stream are adequately armored with a velocity dissipation device and appropriate outlet protection.

See individual design details and notes for the various BMPs referenced in this practice. Additional information on bioengineering techniques for stream stabilization can be

Streambank Stabilization	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

found in the *Major Drainage* chapter of Volume 1 and additional guidance on BMPs for working in waterways can be found in UDFCD's *Best Management Practices for Construction in Waterways Training Manual*.

Maintenance and Removal

Inspect BMPs protecting the stream for damage on a daily basis. Maintain, repair, or replace damaged BMPs following the guidance provided in individual BMP Fact Sheets for practices that are implemented. Some streambank stabilization BMPs are intended to remain in place as vegetation matures (e.g. erosion control blankets protecting seeded stream banks and turf reinforcement mats).

For BMPs that are not to remain in place as a part of final stabilization such as silt fence and other temporary measures, BMPs should be removed when all land disturbing activities have ceased and areas have been permanently stabilized.

Description

Wind erosion and dust control BMPs help to keep soil particles from entering the air as a result of land disturbing construction activities. These BMPs include a variety of practices generally focused on either graded disturbed areas or construction roadways. For graded areas, practices such as seeding and mulching, use of soil binders, site watering, or other practices that provide prompt surface cover should be used. For construction roadways, road watering and stabilized surfaces should be considered.

Photograph DC-1. Water truck used for dust suppression. Photo courtesy of Douglas County.

Appropriate Uses

Dust control measures should be used on any site where dust poses a problem to air quality. Dust control is important to control for the health of construction workers and surrounding waterbodies.

Design and Installation

The following construction BMPs can be used for dust control:

- An irrigation/sprinkler system can be used to wet the top layer of disturbed soil to help keep dry soil particles from becoming airborne.
- Seeding and mulching can be used to stabilize disturbed surfaces and reduce dust emissions.
- Protecting existing vegetation can help to slow wind velocities across the ground surface, thereby limiting the likelihood of soil particles to become airborne.
- Spray-on soil binders form a bond between soil particles keeping them grounded. Chemical treatments may require additional permitting requirements. Potential impacts to surrounding waterways and habitat must be considered prior to use.
- Placing rock on construction roadways and entrances will help keep dust to a minimum across the construction site.
- Wind fences can be installed on site to reduce wind speeds. Install fences perpendicular to the prevailing wind direction for maximum effectiveness.

Wind Erosion Control/ Dust Control	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	Moderate

Maintenance and Removal

When using an irrigation/sprinkler control system to aid in dust control, be careful not to overwater. Overwatering will cause construction vehicles to track mud off-site.

Description

Concrete waste management involves designating and properly managing a specific area of the construction site as a concrete washout area. A concrete washout area can be created using one of several approaches designed to receive wash water from washing of tools and concrete mixer chutes, liquid concrete waste from dump trucks, mobile batch mixers, or pump trucks. Three basic approaches are available: excavation of a pit in the ground, use of an above ground storage area, or use of prefabricated haul-away concrete washout containers. Surface discharges of concrete washout water from construction sites are prohibited.

Photograph CWA-1. Example of concrete washout area. Note gravel tracking pad for access and sign.

Appropriate Uses

Concrete washout areas must be designated on all sites that will generate concrete wash water or liquid concrete waste from onsite concrete mixing or concrete delivery.

Because pH is a pollutant of concern for washout activities, when unlined pits are used for concrete washout, the soil must have adequate buffering capacity to result in protection of state groundwater standards; otherwise, a liner/containment must be used. The following management practices are recommended to prevent an impact from unlined pits to groundwater:

- The use of the washout site should be temporary (less than 1 year), and
- The washout site should be not be located in an area where shallow groundwater may be present, such as near natural drainages, springs, or wetlands.

Design and Installation

Concrete washout activities must be conducted in a manner that does not contribute pollutants to surface waters or stormwater runoff. Concrete washout areas may be lined or unlined excavated pits in the ground, commercially manufactured prefabricated washout containers, or aboveground holding areas constructed of berms, sandbags or straw bales with a plastic liner.

Although unlined washout areas may be used, lined pits may be required to protect groundwater under certain conditions.

Do not locate an unlined washout area within 400 feet of any natural drainage pathway or waterbody or within 1,000 feet of any wells or drinking water sources. Even for lined concrete washouts, it is advisable to locate the facility away from waterbodies and drainage paths. If site constraints make these

Concrete Washout Area	
Functions	
Erosion Control	No
Sediment Control	No
Site/Material Management	Yes

setbacks infeasible or if highly permeable soils exist in the area, then the pit must be installed with an impermeable liner (16 mil minimum thickness) or surface storage alternatives using prefabricated concrete washout devices or a lined aboveground storage area should be used.

Design details with notes are provided in Detail CWA-1 for pits and CWA-2 for aboveground storage areas. Pre-fabricated concrete washout container information can be obtained from vendors.

Maintenance and Removal

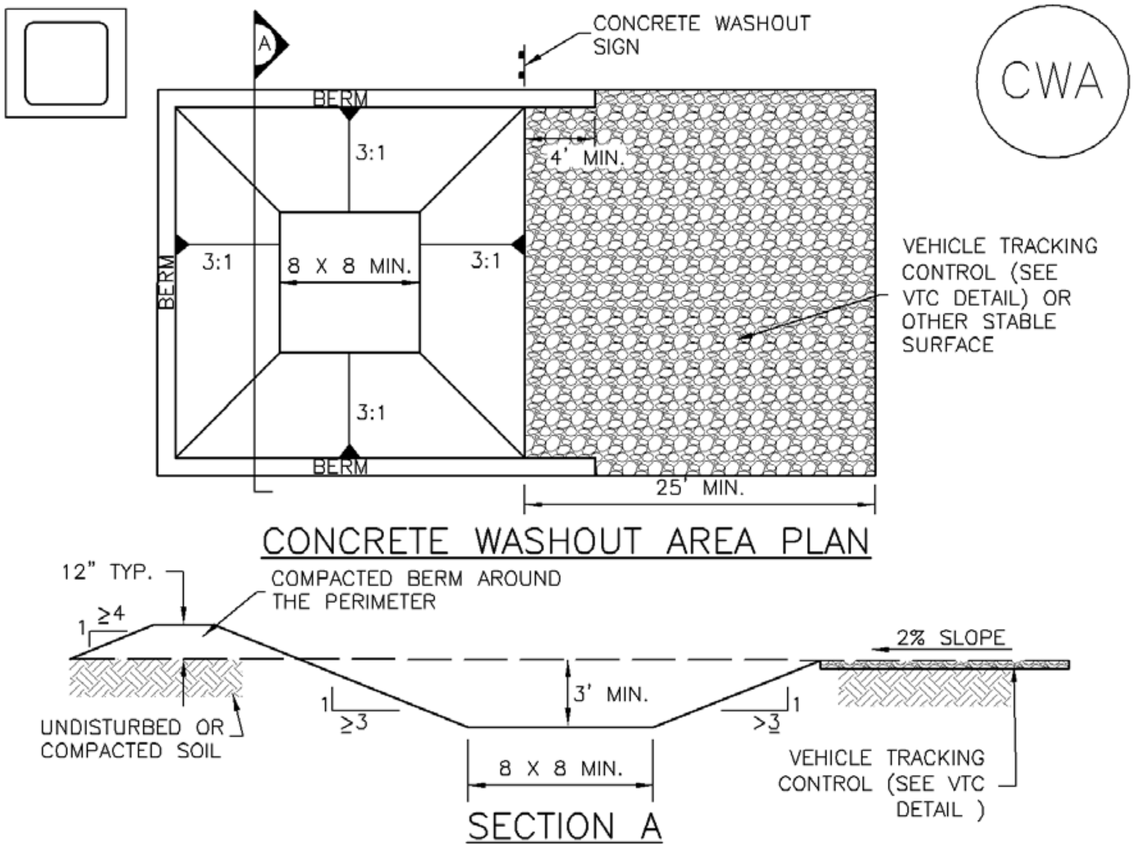
A key consideration for concrete washout areas is to ensure that adequate signage is in place identifying the location of the washout area. Part of inspecting and maintaining washout areas is ensuring that adequate signage is provided and in good repair and that the washout area is being used, as opposed to washout in non-designated areas of the site.

Remove concrete waste in the washout area, as needed to maintain BMP function (typically when filled to about two-thirds of its capacity). Collect concrete waste and deliver offsite to a designated disposal location.

Upon termination of use of the washout site, accumulated solid waste, including concrete waste and any contaminated soils, must be removed from the site to prevent on-site disposal of solid waste. If the wash water is allowed to evaporate and the concrete hardens, it may be recycled.

Photograph CWA-2. Prefabricated concrete washout. Photo courtesy of CDOT**.**

Photograph CWA-3. Earthen concrete washout. Photo courtesy of CDOT**.**



CWA–1. CONCRETE WASHOUT AREA

CWA INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –CWA INSTALLATION LOCATION.

2. DO NOT LOCATE AN UNLINED CWA WITHIN 400' OF ANY NATURAL DRAINAGE PATHWAY OR WATERBODY. DO NOT LOCATE WITHIN 1,000' OF ANY WELLS OR DRINKING WATER SOURCES. IF SITE CONSTRAINTS MAKE THIS INFEASIBLE, OR IF HIGHLY PERMEABLE SOILS EXIST ON SITE, THE CWA MUST BE INSTALLED WITH AN IMPERMEABLE LINER (16 MIL MIN. THICKNESS) OR SURFACE STORAGE ALTERNATIVES USING PREFABRICATED CONCRETE WASHOUT DEVICES OR A LINED ABOVE GROUND STORAGE ARE SHOULD BE USED.

3. THE CWA SHALL BE INSTALLED PRIOR TO CONCRETE PLACEMENT ON SITE.

4. CWA SHALL INCLUDE A FLAT SUBSURFACE PIT THAT IS AT LEAST 8' BY 8' SLOPES LEADING OUT OF THE SUBSURFACE PIT SHALL BE 3:1 OR FLATTER. THE PIT SHALL BE AT LEAST 3' DEEP.

5. BERM SURROUNDING SIDES AND BACK OF THE CWA SHALL HAVE MINIMUM HEIGHT OF 1'.

6. VEHICLE TRACKING PAD SHALL BE SLOPED 2% TOWARDS THE CWA.

7. SIGNS SHALL BE PLACED AT THE CONSTRUCTION ENTRANCE, AT THE CWA, AND ELSEWHERE AS NECESSARY TO CLEARLY INDICATE THE LOCATION OF THE CWA TO OPERATORS OF CONCRETE TRUCKS AND PUMP RIGS.

8. USE EXCAVATED MATERIAL FOR PERIMETER BERM CONSTRUCTION.

CWA MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. THE CWA SHALL BE REPAIRED, CLEANED, OR ENLARGED AS NECESSARY TO MAINTAIN CAPACITY FOR CONCRETE WASTE. CONCRETE MATERIALS, ACCUMULATED IN PIT, SHALL BE REMOVED ONCE THE MATERIALS HAVE REACHED A DEPTH OF 2'.

5. CONCRETE WASHOUT WATER, WASTED PIECES OF CONCRETE AND ALL OTHER DEBRIS IN THE SUBSURFACE PIT SHALL BE TRANSPORTED FROM THE JOB SITE IN A WATER-TIGHT CONTAINER AND DISPOSED OF PROPERLY.

6. THE CWA SHALL REMAIN IN PLACE UNTIL ALL CONCRETE FOR THE PROJECT IS PLACED.

7. WHEN THE CWA IS REMOVED, COVER THE DISTURBED AREA WITH TOP SOIL, SEED AND MULCH OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND THE CITY OF PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD).

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Photograph SP-1. A topsoil stockpile that has been partially revegetated and is protected by silt fence perimeter control.

Description

Stockpile management includes measures to minimize erosion and sediment transport from soil stockpiles.

Appropriate Uses

Stockpile management should be used when soils or other erodible materials are stored at the construction site. Special attention should be given to stockpiles in close proximity to natural or manmade storm systems.

Design and Installation

Locate stockpiles away from all drainage system components including storm sewer inlets. Where practical, choose stockpile locations that that will remain undisturbed for the longest period of time as the phases of construction progress. Place sediment control BMPs around the perimeter of the stockpile, such as sediment control logs, rock socks, silt fence, straw bales and sand bags. See Detail SP-1 for guidance on proper establishment of perimeter controls around a stockpile. For stockpiles in active use, provide a stabilized designated access point on the upgradient side of the stockpile.

Stabilize the stockpile surface with surface roughening, temporary seeding and mulching, erosion control blankets, or soil binders. Soils stockpiled for an extended period (typically for more than 60 days) should be seeded and mulched with a temporary grass cover once the stockpile is placed (typically within 14 days). Use of mulch only or a soil binder is acceptable if the stockpile will be in place for a more limited time period (typically 30-60 days). Timeframes for stabilization of stockpiles noted in this fact sheet are "typical" guidelines. Check permit requirements for specific federal, state, and/or local requirements that may be more prescriptive.

Stockpiles should not be placed in streets or paved areas unless no other practical alternative exists. See the Stabilized Staging Area Fact Sheet for guidance when staging in roadways is unavoidable due to space or right-of-way constraints. For paved areas, rock socks must be used for perimeter control and all inlets with the potential to receive sediment from the stockpile (even from vehicle tracking) must be protected.

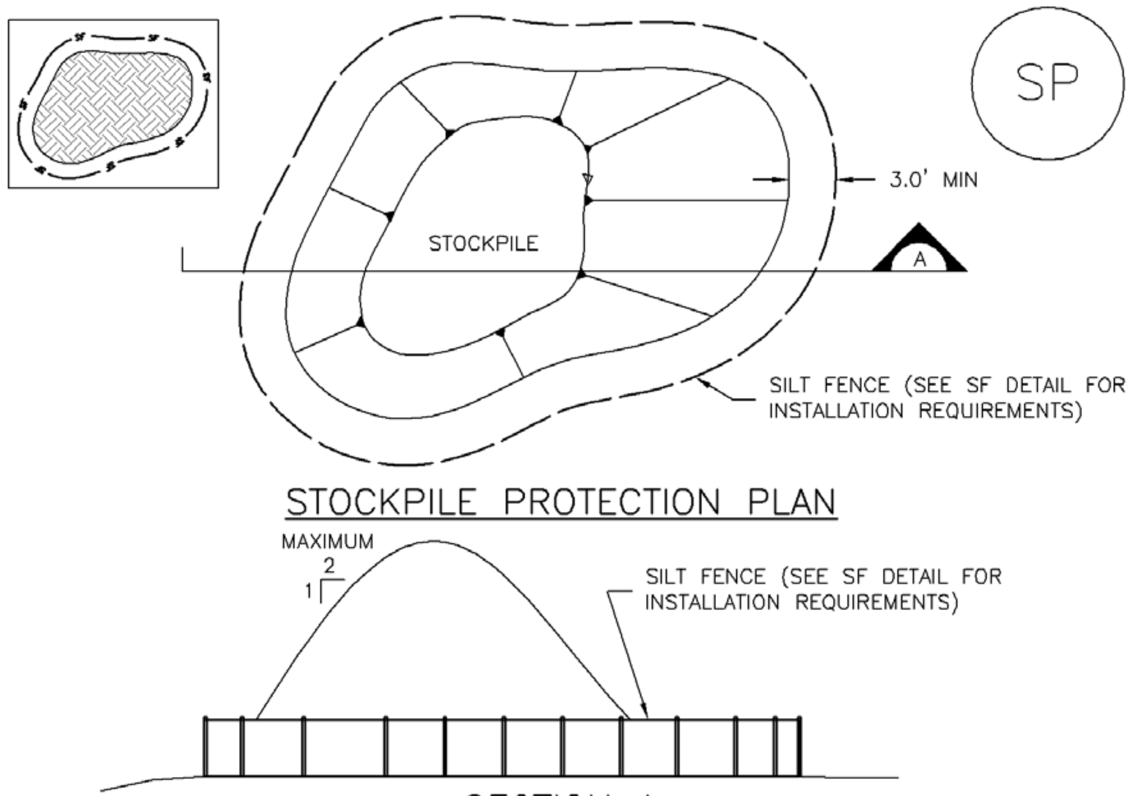
Maintenance and Removal

Inspect perimeter controls and inlet protection in accordance with their respective BMP Fact Sheets. Where seeding, mulch and/or soil binders are used, reseeding or reapplication of soil binder may be necessary.

When temporary removal of a perimeter BMP is necessary to access a stockpile, ensure BMPs are reinstalled in accordance with their respective design detail section.

Stockpile Management	
Functions	
Erosion Control	Yes
Sediment Control	Yes
Site/Material Management	Yes

When the stockpile is no longer needed, properly dispose of excess materials and revegetate or otherwise stabilize the ground surface where the stockpile was located.



SP–1. STOCKPILE PROTECTION

STOCKPILE PROTECTION INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION OF STOCKPILES.
   –TYPE OF STOCKPILE PROTECTION.

2. INSTALL PERIMETER CONTROLS IN ACCORDANCE WITH THEIR RESPECTIVE DESIGN DETAILS. SILT FENCE IS SHOWN IN THE STOCKPILE PROTECTION DETAILS; HOWEVER, OTHER TYPES OF PERIMETER CONTROLS INCLUDING SEDIMENT CONTROL LOGS OR ROCK SOCKS MAY BE SUITABLE IN SOME CIRCUMSTANCES. CONSIDERATIONS FOR DETERMINING THE APPROPRIATE TYPE OF PERIMETER CONTROL FOR A STOCKPILE INCLUDE WHETHER THE STOCKPILE IS LOCATED ON A PERVIOUS OR IMPERVIOUS SURFACE, THE RELATIVE HEIGHTS OF THE PERIMETER CONTROL AND STOCKPILE, THE ABILITY OF THE PERIMETER CONTROL TO CONTAIN THE STOCKPILE WITHOUT FAILING IN THE EVENT THAT MATERIAL FROM THE STOCKPILE SHIFTS OR SLUMPS AGAINST THE PERIMETER, AND OTHER FACTORS.

3. STABILIZE THE STOCKPILE SURFACE WITH SURFACE ROUGHENING, TEMPORARY SEEDING AND MULCHING, EROSION CONTROL BLANKETS, OR SOIL BINDERS. SOILS STOCKPILED FOR AN EXTENDED PERIOD (TYPICALLY FOR MORE THAN 60 DAYS) SHOULD BE SEEDED AND MULCHED WITH A TEMPORARY GRASS COVER ONCE THE STOCKPILE IS PLACED (TYPICALLY WITHIN 14 DAYS). USE OF MULCH ONLY OR A SOIL BINDER IS ACCEPTABLE IF THE STOCKPILE WILL BE IN PLACE FOR A MORE LIMITED TIME PERIOD (TYPICALLY 30–60 DAYS).

4. FOR TEMPORARY STOCKPILES ON THE INTERIOR PORTION OF A CONSTRUCTION SITE, WHERE OTHER DOWNGRADIENT CONTROLS, INCLUDING PERIMETER CONTROL, ARE IN PLACE, STOCKPILE PERIMETER CONTROLS MAY NOT BE REQUIRED.

STOCKPILE PROTECTION MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

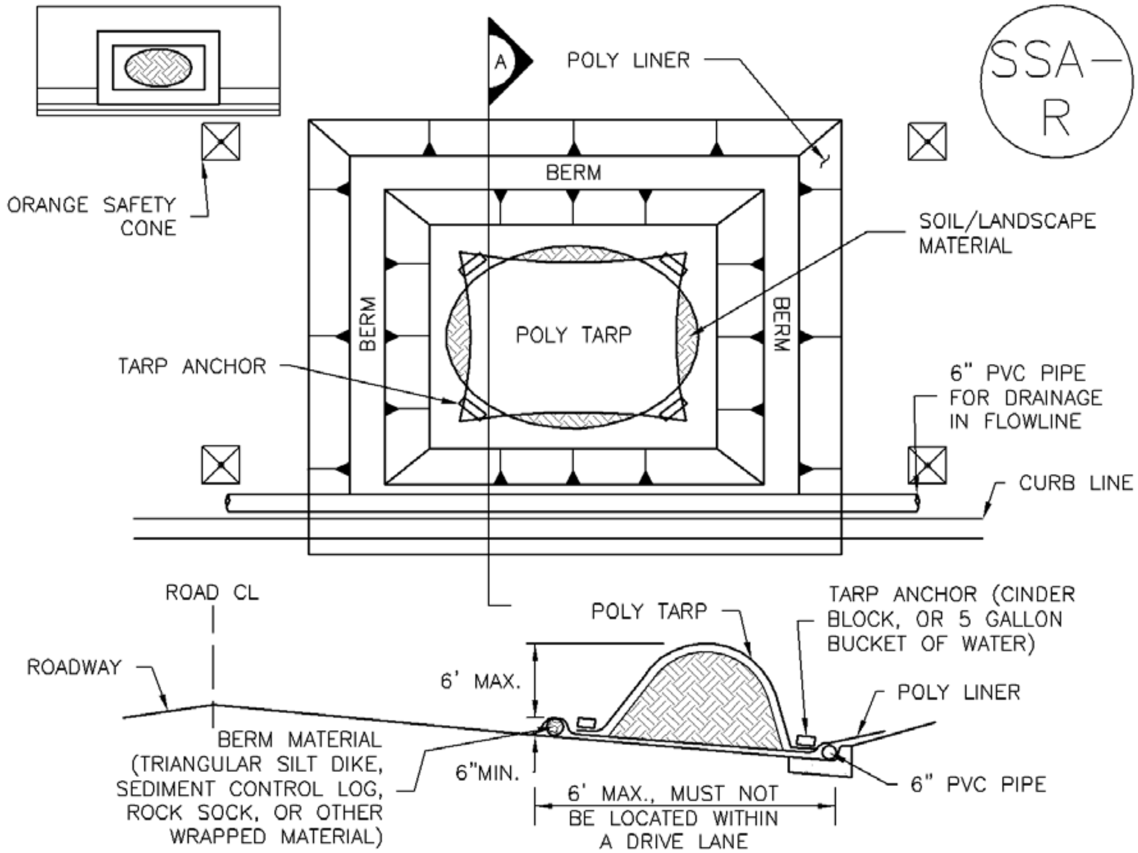
STOCKPILE PROTECTION MAINTENANCE NOTES

4. IF PERIMETER PROTECTION MUST BE MOVED TO ACCESS SOIL STOCKPILE, REPLACE PERIMETER CONTROLS BY THE END OF THE WORKDAY.

5. STOCKPILE PERIMETER CONTROLS CAN BE REMOVED ONCE ALL THE MATERIAL FROM THE STOCKPILE HAS BEEN USED.

(DETAILS ADAPTED FROM PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.



SP-2. MATERIALS STAGING IN ROADWAY

MATERIALS STAGING IN ROADWAYS INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   - LOCATION OF MATERIAL STAGING AREA(S).
   - CONTRACTOR MAY ADJUST LOCATION AND SIZE OF STAGING AREA WITH APPROVAL FROM THE LOCAL JURISDICTION.

2. FEATURE MUST BE INSTALLED PRIOR TO EXCAVATION, EARTHWORK OR DELIVERY OF MATERIALS.

3. MATERIALS MUST BE STATIONED ON THE POLY LINER. ANY INCIDENTAL MATERIALS DEPOSITED ON PAVED SECTION OR ALONG CURB LINE MUST BE CLEANED UP PROMPTLY.

4. POLY LINER AND TARP COVER SHOULD BE OF SIGNIFICANT THICKNESS TO PREVENT DAMAGE OR LOSS OF INTEGRITY.

5. SAND BAGS MAY BE SUBSTITUTED TO ANCHOR THE COVER TARP OR PROVIDE BERMING UNDER THE BASE LINER.

6. FEATURE IS NOT INTENDED FOR USE WITH WET MATERIAL THAT WILL BE DRAINING AND/OR SPREADING OUT ON THE POLY LINER OR FOR DEMOLITION MATERIALS.

7. THIS FEATURE CAN BE USED FOR:
   - UTILITY REPAIRS.
   - WHEN OTHER STAGING LOCATIONS AND OPTIONS ARE LIMITED.
   - OTHER LIMITED APPLICATION AND SHORT DURATION STAGING.

MATERIALS STAGING IN ROADWAY MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. INSPECT PVC PIPE ALONG CURB LINE FOR CLOGGING AND DEBRIS. REMOVE OBSTRUCTIONS PROMPTLY.

5. CLEAN MATERIAL FROM PAVED SURFACES BY SWEEPING OR VACUUMING.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM AURORA, COLORADO)

Description

Implement construction site good housekeeping practices to prevent pollution associated with solid, liquid and hazardous construction-related materials and wastes. Stormwater Management Plans (SWMPs) should clearly specify BMPs including these good housekeeping practices:

- Provide for waste management.
- Establish proper building material staging areas.
- Designate paint and concrete washout areas.
- Establish proper equipment/vehicle fueling and maintenance practices.
- Control equipment/vehicle washing and allowable non-stormwater discharges.
- Develop a spill prevention and response plan.

Acknowledgement: This Fact Sheet is based directly on EPA guidance provided in *Developing Your Stormwater Pollution Prevent Plan* (EPA 2007).

Photographs GH-1 and GH-2. Proper materials storage and secondary containment for fuel tanks are important good housekeeping practices. Photos courtesy of CDOT and City of Aurora.

Appropriate Uses

Good housekeeping practices are necessary at all construction sites.

Design and Installation

The following principles and actions should be addressed in SWMPs:

- **Provide for Waste Management.** Implement management procedures and practices to prevent or reduce the exposure and transport of pollutants in stormwater from solid, liquid and sanitary wastes that will be generated at the site. Practices such as trash disposal, recycling, proper material handling, and cleanup measures can reduce the potential for stormwater runoff to pick up construction site wastes and discharge them to surface waters. Implement a comprehensive set of waste-management practices for hazardous or toxic materials, such as paints, solvents, petroleum products, pesticides, wood preservatives, acids, roofing tar, and other materials. Practices should include storage, handling, inventory, and cleanup procedures, in case of spills. Specific practices that should be considered include:

Solid or Construction Waste

- o Designate trash and bulk waste-collection areas on-site.

Good Housekeeping	
Functions	
Erosion Control	No
Sediment Control	No
Site/Material Management	Yes

- Recycle materials whenever possible (e.g., paper, wood, concrete, oil).
- Segregate and provide proper disposal options for hazardous material wastes.
- Clean up litter and debris from the construction site daily.
- Locate waste-collection areas away from streets, gutters, watercourses, and storm drains. Waste-collection areas (dumpsters, and such) are often best located near construction site entrances to minimize traffic on disturbed soils. Consider secondary containment around waste collection areas to minimize the likelihood of contaminated discharges.
- Empty waste containers before they are full and overflowing.

Sanitary and Septic Waste

- Provide convenient, well-maintained, and properly located toilet facilities on-site.
- Locate toilet facilities away from storm drain inlets and waterways to prevent accidental spills and contamination of stormwater.
- Maintain clean restroom facilities and empty portable toilets regularly.
- Where possible, provide secondary containment pans under portable toilets.
- Provide tie-downs or stake-downs for portable toilets.
- Educate employees, subcontractors, and suppliers on locations of facilities.
- Treat or dispose of sanitary and septic waste in accordance with state or local regulations. Do not discharge or bury wastewater at the construction site.
- Inspect facilities for leaks. If found, repair or replace immediately.
- Special care is necessary during maintenance (pump out) to ensure that waste and/or biocide are not spilled on the ground.

Hazardous Materials and Wastes

- Develop and implement employee and subcontractor education, as needed, on hazardous and toxic waste handling, storage, disposal, and cleanup.
- Designate hazardous waste-collection areas on-site.
- Place all hazardous and toxic material wastes in secondary containment.

Photograph GH-3. Locate portable toilet facilities on level surfaces away from waterways and storm drains. Photo courtesy of WWE.

- Hazardous waste containers should be inspected to ensure that all containers are labeled properly and that no leaks are present.

- **Establish Proper Building Material Handling and Staging Areas**. The SWMP should include comprehensive handling and management procedures for building materials, especially those that are hazardous or toxic. Paints, solvents, pesticides, fuels and oils, other hazardous materials or building materials that have the potential to contaminate stormwater should be stored indoors or under cover whenever possible or in areas with secondary containment. Secondary containment measures prevent a spill from spreading across the site and may include dikes, berms, curbing, or other containment methods. Secondary containment techniques should also ensure the protection of groundwater. Designate staging areas for activities such as fueling vehicles, mixing paints, plaster, mortar, and other potential pollutants. Designated staging areas enable easier monitoring of the use of materials and clean up of spills. Training employees and subcontractors is essential to the success of this pollution prevention principle. Consider the following specific materials handling and staging practices:

    - Train employees and subcontractors in proper handling and storage practices.

    - Clearly designate site areas for staging and storage with signs and on construction drawings. Staging areas should be located in areas central to the construction site. Segment the staging area into sub-areas designated for vehicles, equipment, or stockpiles. Construction entrances and exits should be clearly marked so that delivery vehicles enter/exit through stabilized areas with vehicle tracking controls (See Vehicle Tracking Control Fact Sheet).

    - Provide storage in accordance with Spill Protection, Control and Countermeasures (SPCC) requirements and plans and provide cover and impermeable perimeter control, as necessary, for hazardous materials and contaminated soils that must be stored on site.

    - Ensure that storage containers are regularly inspected for leaks, corrosion, support or foundation failure, or other signs of deterioration and tested for soundness.

    - Reuse and recycle construction materials when possible.

- **Designate Concrete Washout Areas**. Concrete contractors should be encouraged to use the washout facilities at their own plants or dispatch facilities when feasible; however, concrete washout commonly occurs on construction sites. If it is necessary to provide for concrete washout areas on-site, designate specific washout areas and design facilities to handle anticipated washout water. Washout areas should also be provided for paint and stucco operations. Because washout areas can be a source of pollutants from leaks or spills, care must be taken with regard to their placement and proper use. See the Concrete Washout Area Fact Sheet for detailed guidance.

    Both self-constructed and prefabricated washout containers can fill up quickly when concrete, paint, and stucco work are occurring on large portions of the site. Be sure to check for evidence that contractors are using the washout areas and not dumping materials onto the ground or into drainage facilities. If the washout areas are not being used regularly, consider posting additional signage, relocating the facilities to more convenient locations, or providing training to workers and contractors.

    When concrete, paint, or stucco is part of the construction process, consider these practices which will help prevent contamination of stormwater. Include the locations of these areas and the maintenance and inspection procedures in the SWMP.

  - Do not washout concrete trucks or equipment into storm drains, streets, gutters, uncontained areas, or streams. Only use designated washout areas.
  - Establish washout areas and advertise their locations with signs. Ensure that signage remains in good repair.
  - Provide adequate containment for the amount of wash water that will be used.
  - Inspect washout structures daily to detect leaks or tears and to identify when materials need to be removed.
  - Dispose of materials properly. The preferred method is to allow the water to evaporate and to recycle the hardened concrete. Full service companies may provide dewatering services and should dispose of wastewater properly. Concrete wash water can be highly polluted. It should not be discharged to any surface water, storm sewer system, or allowed to infiltrate into the ground in the vicinity of waterbodies. Washwater should not be discharged to a sanitary sewer system without first receiving written permission from the system operator.

- **Establish Proper Equipment/Vehicle Fueling and Maintenance Practices**. Create a clearly designated on-site fueling and maintenance area that is clean and dry. The on-site fueling area should have a spill kit, and staff should know how to use it. If possible, conduct vehicle fueling and maintenance activities in a covered area. Consider the following practices to help prevent the discharge of pollutants to stormwater from equipment/vehicle fueling and maintenance. Include the locations of designated fueling and maintenance areas and inspection and maintenance procedures in the SWMP.
  - Train employees and subcontractors in proper fueling procedures (stay with vehicles during fueling, proper use of pumps, emergency shutoff valves, etc.).
  - Inspect on-site vehicles and equipment regularly for leaks, equipment damage, and other service problems.
  - Clearly designate vehicle/equipment service areas away from drainage facilities and watercourses to prevent stormwater run-on and runoff.
  - Use drip pans, drip cloths, or absorbent pads when replacing spent fluids.
  - Collect all spent fluids, store in appropriate labeled containers in the proper storage areas, and recycle fluids whenever possible.

- **Control Equipment/Vehicle Washing and Allowable Non-Stormwater Discharges.** Implement practices to prevent contamination of surface and groundwater from equipment and vehicle wash water. Representative practices include:
  - Educate employees and subcontractors on proper washing procedures.
  - Use off-site washing facilities, when available.
  - Clearly mark the washing areas and inform workers that all washing must occur in this area.
  - Contain wash water and treat it using BMPs. Infiltrate washwater when possible, but maintain separation from drainage paths and waterbodies.

- Use high-pressure water spray at vehicle washing facilities without detergents. Water alone can remove most dirt adequately.
- Do not conduct other activities, such as vehicle repairs, in the wash area.
- Include the location of the washing facilities and the inspection and maintenance procedures in the SWMP.

- **Develop a Spill Prevention and Response Plan.** Spill prevention and response procedures must be identified in the SWMP. Representative procedures include identifying ways to reduce the chance of spills, stop the source of spills, contain and clean up spills, dispose of materials contaminated by spills, and train personnel responsible for spill prevention and response. The plan should also specify material handling procedures and storage requirements and ensure that clear and concise spill cleanup procedures are provided and posted for areas in which spills may potentially occur. When developing a spill prevention plan, include the following:
    - Note the locations of chemical storage areas, storm drains, tributary drainage areas, surface waterbodies on or near the site, and measures to stop spills from leaving the site.
    - Provide proper handling and safety procedures for each type of waste. Keep Material Safety Data Sheets (MSDSs) for chemical used on site with the SWMP.
    - Establish an education program for employees and subcontractors on the potential hazards to humans and the environment from spills and leaks.
    - Specify how to notify appropriate authorities, such as police and fire departments, hospitals, or municipal sewage treatment facilities to request assistance. Emergency procedures and contact numbers should be provided in the SWMP and posted at storage locations.
    - Describe the procedures, equipment and materials for immediate cleanup of spills and proper disposal.
    - Identify personnel responsible for implementing the plan in the event of a spill. Update the spill prevention plan and clean up materials as changes occur to the types of chemicals stored and used at the facility.

Spill Prevention, Control, and Countermeasure (SPCC) Plan

Construction sites may be subject to 40 CFR Part 112 regulations that require the preparation and implementation of a SPCC Plan to prevent oil spills from aboveground and underground storage tanks. The facility is subject to this rule if it is a non-transportation-related facility that:

- Has a total storage capacity greater than 1,320 gallons or a completely buried storage capacity greater than 42,000 gallons.
- Could reasonably be expected to discharge oil in quantities that may be harmful to navigable waters of the United States and adjoining shorelines.

Furthermore, if the facility is subject to 40 CFR Part 112, the SWMP should reference the SPCC Plan. To find out more about SPCC Plans, see EPA's website on SPPC at www.epa.gov/oilspill/spcc.htm.

Reporting Oil Spills

In the event of an oil spill, contact the National Response Center toll free at 1-800-424- 8802 for assistance, or for more details, visit their website: www.nrc.uscg.mil.

Maintenance and Removal

Effective implementation of good housekeeping practices is dependent on clear designation of personnel responsible for supervising and implementing good housekeeping programs, such as site cleanup and disposal of trash and debris, hazardous material management and disposal, vehicle and equipment maintenance, and other practices. Emergency response "drills" may aid in emergency preparedness.

Checklists may be helpful in good housekeeping efforts.

Staging and storage areas require permanent stabilization when the areas are no longer being used for construction-related activities.

Construction-related materials, debris and waste must be removed from the construction site once construction is complete.

Design Details

See the following Fact Sheets for related Design Details:

MM-1 Concrete Washout Area

MM-2 Stockpile Management

SM-4 Vehicle Tracking Control

Design details are not necessary for other good housekeeping practices; however, be sure to designate where specific practices will occur on the appropriate construction drawings.

Description

A silt fence is a woven geotextile fabric attached to wooden posts and trenched into the ground. It is designed as a sediment barrier to intercept sheet flow runoff from disturbed areas.

Photograph SF-1. Silt fence creates a sediment barrier, forcing sheet flow runoff to evaporate or infiltrate.

Appropriate Uses

A silt fence can be used where runoff is conveyed from a disturbed area as sheet flow. Silt fence is not designed to receive concentrated flow or to be used as a filter fabric. Typical uses include:

- Down slope of a disturbed area to accept sheet flow.
- Along the perimeter of a receiving water such as a stream, pond or wetland.
- At the perimeter of a construction site.

Design and Installation

Silt fence should be installed along the contour of slopes so that it intercepts sheet flow. The maximum recommended tributary drainage area per 100 lineal feet of silt fence, installed along the contour, is approximately 0.25 acres with a disturbed slope length of up to 150 feet and a tributary slope gradient no steeper than 3:1. Longer and steeper slopes require additional measures. This recommendation only applies to silt fence installed along the contour. Silt fence installed for other uses, such as perimeter control, should be installed in a way that will not produce concentrated flows. For example, a "J-hook" installation may be appropriate to force runoff to pond and evaporate or infiltrate in multiple areas rather than concentrate and cause erosive conditions parallel to the silt fence.

See Detail SF-1 for proper silt fence installation, which involves proper trenching, staking, securing the fabric to the stakes, and backfilling the silt fence. Properly installed silt fence should not be easily pulled out by hand and there should be no gaps between the ground and the fabric.

Silt fence must meet the minimum allowable strength requirements, depth of installation requirement, and other specifications in the design details. Improper installation of silt fence is a common reason for silt fence failure; however, when properly installed and used for the appropriate purposes, it can be highly effective.

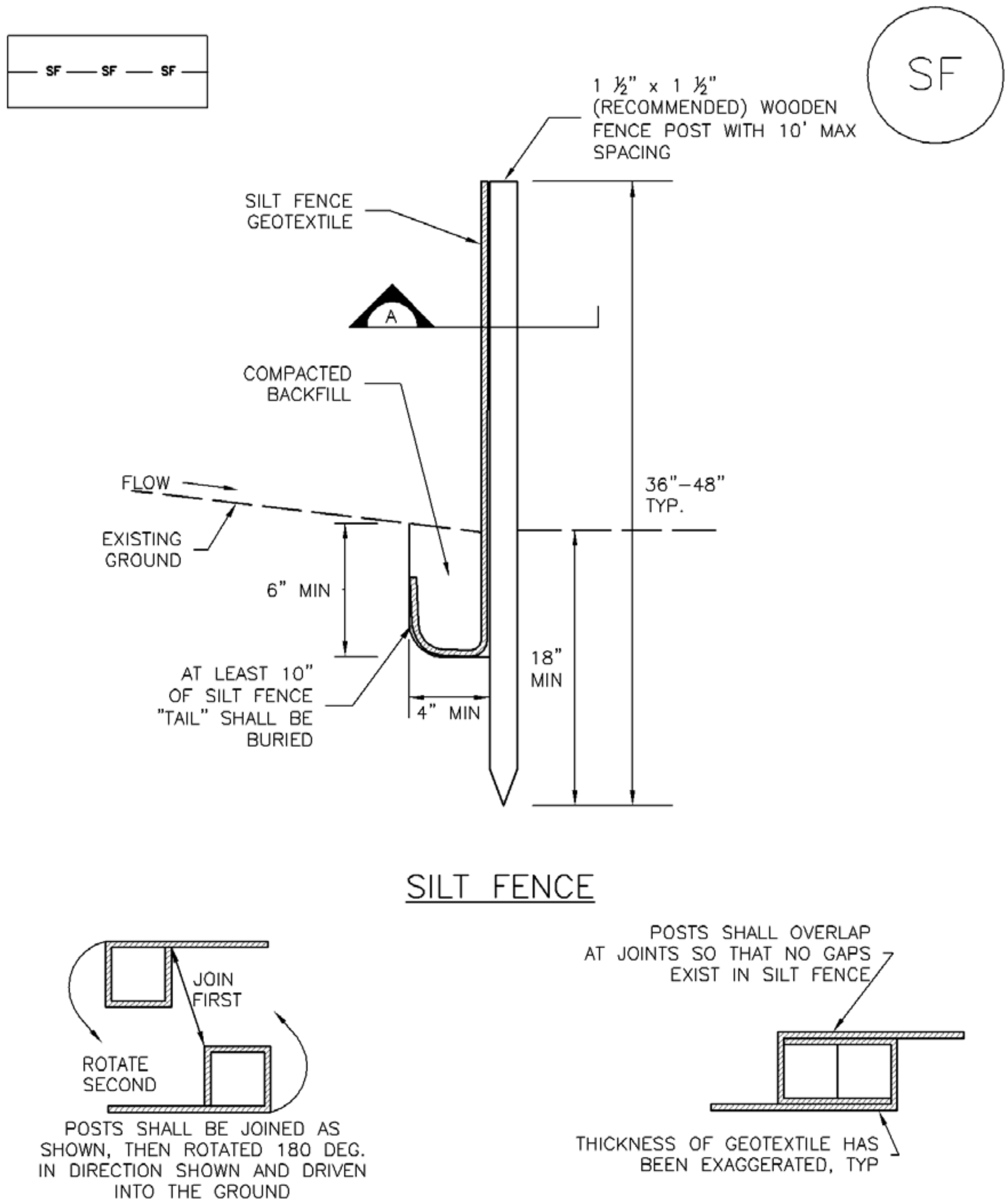
Silt Fence	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	No

Maintenance and Removal

Inspection of silt fence includes observing the material for tears or holes and checking for slumping fence and undercut areas bypassing flows. Repair of silt fence typically involves replacing the damaged section with a new section. Sediment accumulated behind silt fence should be removed, as needed to maintain BMP effectiveness, typically before it reaches a depth of 6 inches.

Silt fence may be removed when the upstream area has reached final stabilization.

Photograph SF-2. When silt fence is not installed along the contour, a "J-hook" installation may be appropriate to ensure that the BMP does not create concentrated flow parallel to the silt fence. Photo courtesy of Tom Gore.



SF–1. SILT FENCE

SILT FENCE INSTALLATION NOTES

1. SILT FENCE MUST BE PLACED AWAY FROM THE TOE OF THE SLOPE TO ALLOW FOR WATER PONDING. SILT FENCE AT THE TOE OF A SLOPE SHOULD BE INSTALLED IN A FLAT LOCATION AT LEAST SEVERAL FEET (2–5 FT) FROM THE TOE OF THE SLOPE TO ALLOW ROOM FOR PONDING AND DEPOSITION.

2. A UNIFORM 6" X 4" ANCHOR TRENCH SHALL BE EXCAVATED USING TRENCHER OR SILT FENCE INSTALLATION DEVICE. NO ROAD GRADERS, BACKHOES, OR SIMILAR EQUIPMENT SHALL BE USED.

3. COMPACT ANCHOR TRENCH BY HAND WITH A "JUMPING JACK" OR BY WHEEL ROLLING. COMPACTION SHALL BE SUCH THAT SILT FENCE RESISTS BEING PULLED OUT OF ANCHOR TRENCH BY HAND.

4. SILT FENCE SHALL BE PULLED TIGHT AS IT IS ANCHORED TO THE STAKES. THERE SHOULD BE NO NOTICEABLE SAG BETWEEN STAKES AFTER IT HAS BEEN ANCHORED TO THE STAKES.

5. SILT FENCE FABRIC SHALL BE ANCHORED TO THE STAKES USING 1" HEAVY DUTY STAPLES OR NAILS WITH 1" HEADS. STAPLES AND NAILS SHOULD BE PLACED 3" ALONG THE FABRIC DOWN THE STAKE.

6. AT THE END OF A RUN OF SILT FENCE ALONG A CONTOUR, THE SILT FENCE SHOULD BE TURNED PERPENDICULAR TO THE CONTOUR TO CREATE A "J–HOOK." THE "J–HOOK" EXTENDING PERPENDICULAR TO THE CONTOUR SHOULD BE OF SUFFICIENT LENGTH TO KEEP RUNOFF FROM FLOWING AROUND THE END OF THE SILT FENCE (TYPICALLY 10' – 20').

7. SILT FENCE SHALL BE INSTALLED PRIOR TO ANY LAND DISTURBING ACTIVITIES.

SILT FENCE MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED UPSTREAM OF THE SILT FENCE SHALL BE REMOVED AS NEEDED TO MAINTAIN THE FUNCTIONALITY OF THE BMP, TYPICALLY WHEN DEPTH OF ACCUMULATED SEDIMENTS IS APPROXIMATELY 6".

5. REPAIR OR REPLACE SILT FENCE WHEN THERE ARE SIGNS OF WEAR, SUCH AS SAGGING, TEARING, OR COLLAPSE.

6. SILT FENCE IS TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION, OR IS REPLACED BY AN EQUIVALENT PERIMETER SEDIMENT CONTROL BMP.

7. WHEN SILT FENCE IS REMOVED, ALL DISTURBED AREAS SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAIL ADAPTED FROM TOWN OF PARKER, COLORADO AND CITY OF AURORA, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

A sediment control log is a linear roll made of natural materials such as straw, coconut fiber, or compost. The most common type of sediment control log has straw filling and is often referred to as a "straw wattle." All sediment control logs are used as a sediment barrier to intercept sheet flow runoff from disturbed areas.

Photographs SCL-1 and SCL-2. Sediment control logs used as 1) a perimeter control around a soil stockpile; and, 2) as a "J-hook" perimeter control at the corner of a construction site.

Appropriate Uses

Sediment control logs can be used in the following applications to trap sediment:

- As perimeter control for stockpiles and the site.
- As part of inlet protection designs.
- As check dams in small drainage ditches. (Sediment control logs are not intended for use in channels with high flow velocities.)
- On disturbed slopes to shorten flow lengths (as an erosion control).
- As part of multi-layered perimeter control along a receiving water such as a stream, pond or wetland.

Sediment control logs work well in combination with other layers of erosion and sediment controls.

Design and Installation

Sediment control logs should be installed along the contour to avoid concentrating flows. The maximum allowable tributary drainage area per 100 lineal feet of sediment control log, installed along the contour, is approximately 0.25 acres with a disturbed slope length of up to 150 feet and a tributary slope gradient no steeper than 3:1. Longer and steeper slopes require additional measures. This recommendation only applies to sediment control logs installed along the contour. When installed for other uses, such as perimeter control, it should be installed in a way that will not produce concentrated flows. For example, a "J-hook" installation may be appropriate to force runoff to pond and evaporate or infiltrate in multiple areas rather than concentrate and cause erosive conditions parallel to the BMP.

Sediment Control Log	
Functions	
Erosion Control	Moderate
Sediment Control	Yes
Site/Material Management	No

Although sediment control logs initially allow runoff to flow through the BMP, they can quickly become a barrier and should be installed as if they are impermeable.

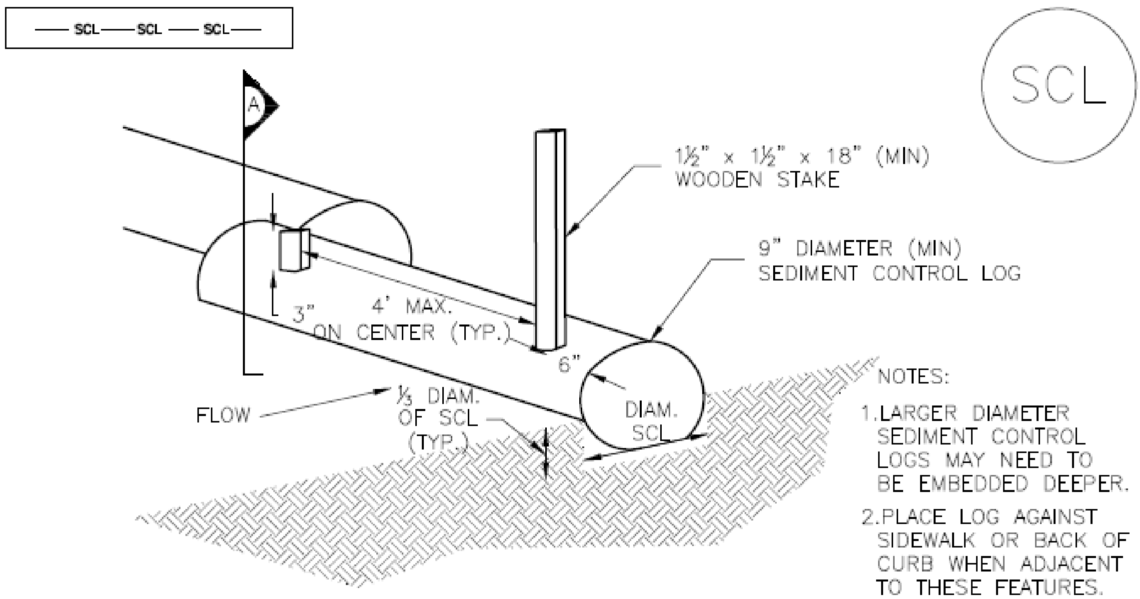
Design details and notes for sediment control logs are provided in the following details. Sediment logs must be properly installed per the detail to prevent undercutting, bypassing and displacement. When installed on slopes, sediment control logs should be installed along the contours (i.e., perpendicular to flow).

Improper installation can lead to poor performance. Be sure that sediment control logs are properly trenched (if lighter than 8 lb/foot), anchored and tightly jointed.

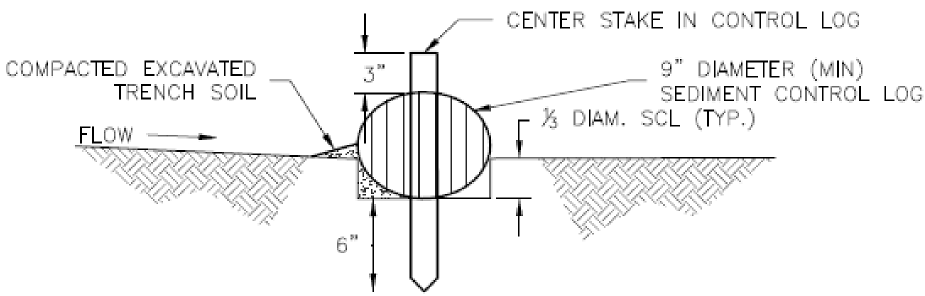
Maintenance and Removal

Be aware that sediment control logs will eventually degrade. Remove accumulated sediment before the depth is one-half the height of the sediment log and repair damage to the sediment log, typically by replacing the damaged section.

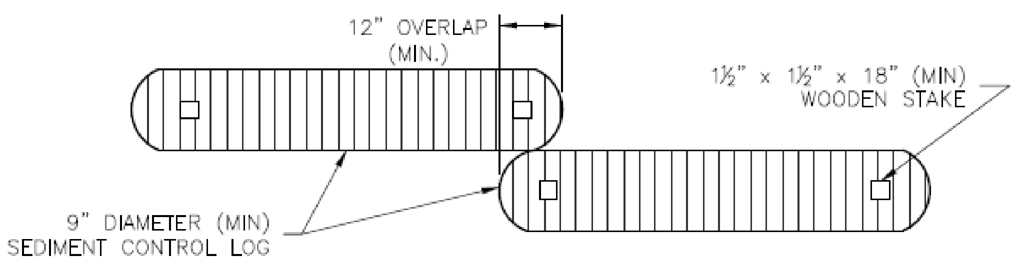
Once the upstream area is stabilized, remove and properly dispose of the logs. Areas disturbed beneath the logs may need to be seeded and mulched. Sediment control logs that are biodegradable may occasionally be left in place (e.g., when logs are used in conjunction with erosion control blankets as permanent slope breaks). However, removal of sediment control logs after final stabilization is typically appropriate when used in perimeter control, inlet protection and check dam applications. Compost from compost sediment control logs may be spread over the area and seeded as long as this does not cover newly established vegetation.



TRENCHED SEDIMENT CONTROL LOG

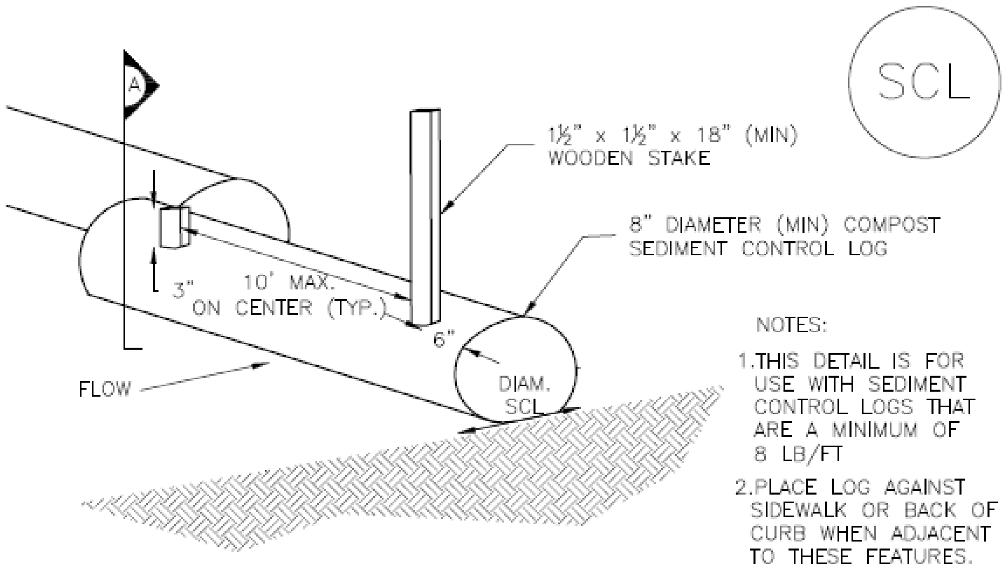


SECTION (A)
TRENCHED SEDIMENT CONTROL LOG

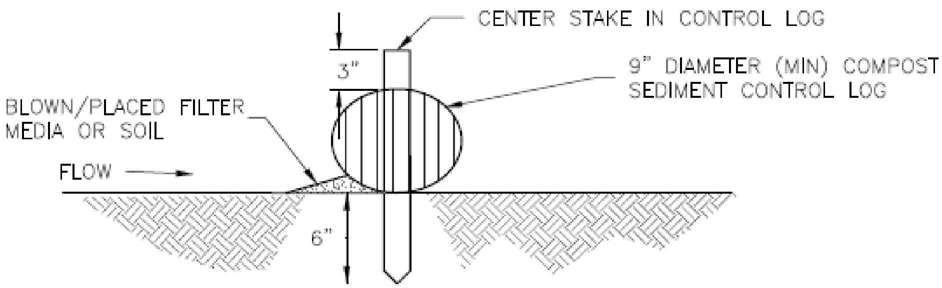


LOG JOINTS

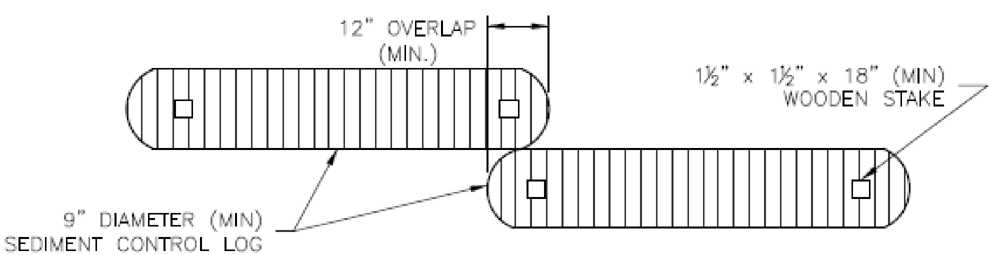
SCL–1. TRENCHED SEDIMENT CONTROL LOG



COMPOST SEDIMENT CONTROL LOG (WEIGHTED)

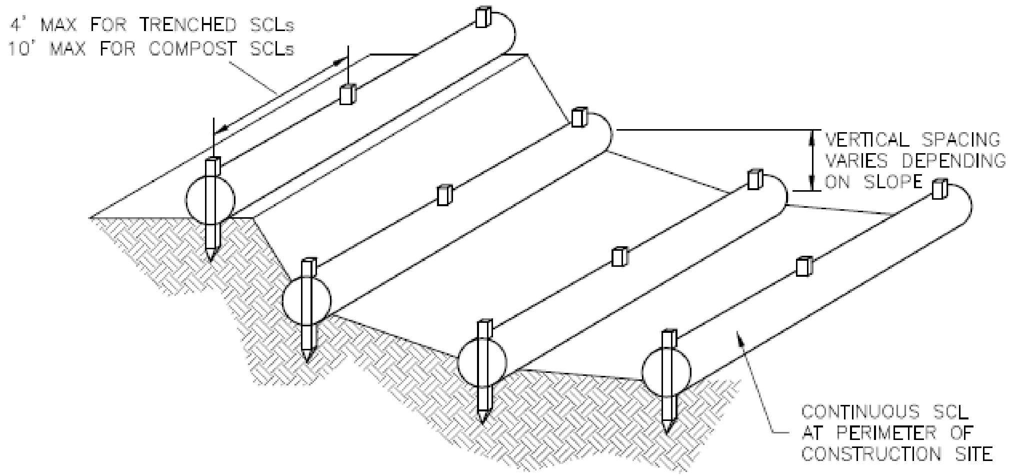


SECTION (A)
COMPOST SEDIMENT CONTROL LOG



LOG JOINTS

SCL-2. COMPOST SEDIMENT CONTROL LOG (WEIGHTED)



SCL-3. SEDIMENT CONTROL LOGS TO CONTROL SLOPE LENGTH

SEDIMENT CONTROL LOG INSTALLATION NOTES

1. SEE PLAN VIEW FOR LOCATION AND LENGTH OF SEDIMENT CONTROL LOGS.

2. SEDIMENT CONTROL LOGS THAT ACT AS A PERIMETER CONTROL SHALL BE INSTALLED PRIOR TO ANY UPGRADIENT LAND–DISTURBING ACTIVITIES.

3. SEDIMENT CONTROL LOGS SHALL CONSIST OF STRAW, COMPOST, EXCELSIOR OR COCONUT FIBER, AND SHALL BE FREE OF ANY NOXIOUS WEED SEEDS OR DEFECTS INCLUDING RIPS, HOLES AND OBVIOUS WEAR.

4. SEDIMENT CONTROL LOGS MAY BE USED AS SMALL CHECK DAMS IN DITCHES AND SWALES. HOWEVER, THEY SHOULD NOT BE USED IN PERENNIAL STREAMS.

5. IT IS RECOMMENDED THAT SEDIMENT CONTROL LOGS BE TRENCHED INTO THE GROUND TO A DEPTH OF APPROXIMATELY ⅓ OF THE DIAMETER OF THE LOG. IF TRENCHING TO THIS DEPTH IS NOT FEASIBLE AND/OR DESIRABLE (SHORT TERM INSTALLATION WITH DESIRE NOT TO DAMAGE LANDSCAPE) A LESSER TRENCHING DEPTH MAY BE ACCEPTABLE WITH MORE ROBUST STAKING. COMPOST LOGS THAT ARE 8 LB/FT DO NOT NEED TO BE TRENCHED.

6. THE UPHILL SIDE OF THE SEDIMENT CONTROL LOG SHALL BE BACKFILLED WITH SOIL OR FILTER MATERIAL THAT IS FREE OF ROCKS AND DEBRIS. THE SOIL SHALL BE TIGHTLY COMPACTED INTO THE SHAPE OF A RIGHT TRIANGLE USING A SHOVEL OR WEIGHTED LAWN ROLLER OR BLOWN IN PLACE.

7. FOLLOW MANUFACTURERS' GUIDANCE FOR STAKING. IF MANUFACTURERS' INSTRUCTIONS DO NOT SPECIFY SPACING, STAKES SHALL BE PLACED ON 4' CENTERS AND EMBEDDED A MINIMUM OF 6" INTO THE GROUND. 3" OF THE STAKE SHALL PROTRUDE FROM THE TOP OF THE LOG. STAKES THAT ARE BROKEN PRIOR TO INSTALLATION SHALL BE REPLACED. COMPOST LOGS SHOULD BE STAKED 10' ON CENTER.

SEDIMENT CONTROL LOG MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED UPSTREAM OF SEDIMENT CONTROL LOG SHALL BE REMOVED AS NEEDED TO MAINTAIN FUNCTIONALITY OF THE BMP, TYPICALLY WHEN DEPTH OF ACCUMULATED SEDIMENTS IS APPROXIMATELY ½ OF THE HEIGHT OF THE SEDIMENT CONTROL LOG.

5. SEDIMENT CONTROL LOG SHALL BE REMOVED AT THE END OF CONSTRUCTION.COMPOST FROM COMPOST LOGS MAY BE LEFT IN PLACE AS LONG AS BAGS ARE REMOVED AND THE AREA SEEDED. IF DISTURBED AREAS EXIST AFTER REMOVAL, THEY SHALL BE COVERED WITH TOP SOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAILS ADAPTED FROM TOWN OF PARKER, COLORADO, JEFFERSON COUNTY, COLORADO, DOUGLAS COUNTY, COLORADO, AND CITY OF AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

A straw bale barrier is a linear wall of straw bales designed to intercept sheet flow and trap sediment before runoff exits a disturbed area.

Photograph SBB-1. Straw bale barrier used for perimeter control. Photo courtesy of Tom Gore.

Appropriate Uses

Appropriate uses of properly installed straw bale barriers may include:

- As a perimeter control for a site or soil stockpile.
- As a sediment control at the toe of an erodible slope.
- Along the edge of a stream or drainage pathway to reduce sediment laden runoff from entering the waterway.
- As part of an inlet protection design in sump conditions (See Inlet Protection BMP).

Do not use straw bale barriers in areas of concentrated flow or in areas where ponding is not desirable. Straw bales tend to degrade quickly, so they should generally not be used in areas where longer term disturbance is expected.

Due to a history of inappropriate placement, poor installation, and short effective lifespan, the use of straw bales is discouraged or prohibited by some communities.

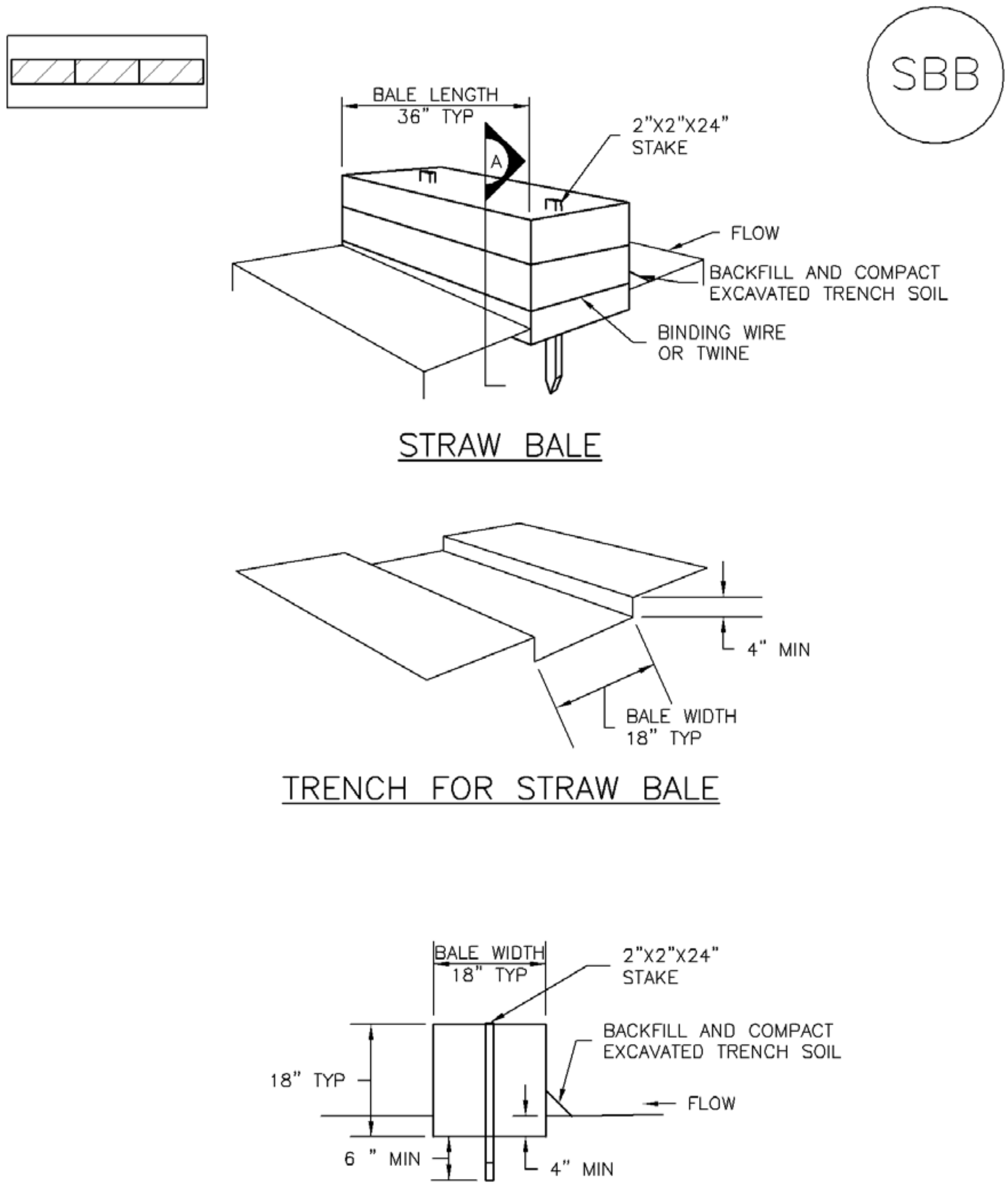
Design and Installation

The maximum recommended tributary drainage area per 100 lineal feet of straw bale barrier is 0.25 acres with a disturbed slope length of up to 150 feet and a tributary slope gradient no steeper than 3:1; longer and steeper slopes require additional measures. Design details with notes are provided in Detail SBB-1. To be effective, bales must be installed in accordance with the design details with proper trenching, staking, and binding. Jute and cotton string must not be used to bind the straw bale. The bales should be certified weed-free prior to use.

Maintenance and Removal

Check bales for rotting and replace as necessary. Straw bales degrade, and rotting bales require replacement on a regular basis (as often as every three months) depending on environmental conditions. Check for undercutting, bypassed flows, and displacement. Repair by properly re-installing the straw bale barrier and repairing washouts around the bales. Remove sediment accumulated behind the bale when it reaches one-quarter of the bale height. Remove and properly dispose of the straw bale once the upstream area has been stabilized. Areas of disturbance beneath the bale should be seeded and mulched when the bale is removed.

Straw Bale Barrier	
Functions	
Erosion Control	No
Sediment Control	Moderate
Site/Material Management	No



SBB–1. STRAW BALE

STRAW BALE INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   -LOCATION(S) OF STRAW BALES.

2. STRAW BALES SHALL CONSIST OF CERTIFIED WEED FREE STRAW OR HAY. LOCAL JURISDICTIONS MAY REQUIRE PROOF THAT BALES ARE WEED FREE.

3. STRAW BALES SHALL CONSIST OF APPROXIMATELY 5 CUBIC FEET OF STRAW OR HAY AND WEIGH NOT LESS THAN 35 POUNDS.

4. WHEN STRAW BALES ARE USED IN SERIES AS A BARRIER, THE END OF EACH BALE SHALL BE TIGHTLY ABUTTING ONE ANOTHER.

5. STRAW BALE DIMENSIONS SHALL BE APPROXIMATELY 36"X18"X18".

6. A UNIFORM ANCHOR TRENCH SHALL BE EXCAVATED TO A DEPTH OF 4". STRAW BALES SHALL BE PLACED SO THAT BINDING TWINE IS ENCOMPASSING THE VERTICAL SIDES OF THE BALE(S). ALL EXCAVATED SOIL SHALL BE PLACED ON THE UPHILL SIDE OF THE STRAW BALE(S) AND COMPACTED.

7. TWO (2) WOODEN STAKES SHALL BE USED TO HOLD EACH BALE IN PLACE. WOODEN STAKES SHALL BE 2"X2"X24". WOODEN STAKES SHALL BE DRIVEN 6" INTO THE GROUND.

STRAW BALE MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. STRAW BALES SHALL BE REPLACED IF THEY BECOME HEAVILY SOILED, ROTTEN, OR DAMAGED BEYOND REPAIR.

5. SEDIMENT ACCUMULATED UPSTREAM OF STRAW BALE BARRIER SHALL BE REMOVED AS NEEDED TO MAINTAIN FUNCTIONALITY OF THE BMP, TYPICALLY WHEN DEPTH OF ACCUMULATED SEDIMENTS IS APPROXIMATELY ¼ OF THE HEIGHT OF THE STRAW BALE BARRIER.

6. STRAW BALES ARE TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

7. WHEN STRAW BALES ARE REMOVED, ALL DISTURBED AREAS SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAILS ADAPTED FROM TOWN OF PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

A brush barrier is a perimeter sediment control constructed with stacked shrubs, tree limbs, and bushy vegetation that has been cleared from a construction area. Brush barriers reduce sediment loads by intercepting and slowing sheet flow from disturbed areas.

Photograph BB-1. Brush barrier constructed with chipped wood. Photo courtesy of EPA.

Appropriate Uses

A brush barrier is an appropriate BMP at sites where there is adequate brush from the clearing and grubbing of the construction site to construct an effective brush barrier. Brush barriers are typically used at the toe of slopes and should be implemented in combination with other BMPs such as surface roughening and reseeding. Brush barriers should be considered short-term, supplemental BMPs because they are constructed of materials that naturally decompose. Brush barriers are not acceptable as a sole means of perimeter control, but they may be used internally within a site to reduce slope length or at the site perimeter in combination with other perimeter control BMPs for multi-layered protection.

Brush barriers are not appropriate for high-velocity flow areas. A large amount of material is needed to construct a useful brush barrier; therefore, alternative perimeter controls such as a fabric silt fence may be more appropriate for sites with little material from clearing.

Design and Installation

The drainage area for brush barriers should be no greater than 0.25 acre per 100 feet of barrier length. Additionally, the drainage slope leading down to a brush barrier must be no greater than 3:1 and no longer than 150 feet.

To construct an effective brush barrier, use only small shrubs and limbs with diameters of 6 inches or less. Larger materials (such as a tree stump) can create void spaces in the barrier, making it ineffective. The brush barrier mound should be at least 3 feet high and 5 feet wide at its base.

In order to avoid significant movement of the brush and improve effectiveness, a filter fabric can be placed over the top of the brush pile, keyed in on the upstream side, and anchored on the downstream side. On the upgradient side, the filter fabric cover should be buried in a trench 4 inches deep and 6 inches wide.

Brush Barrier	
Functions	
Erosion Control	Moderate
Sediment Control	Moderate
Site/Material	No

Maintenance and Removal

Inspect the brush barrier for voids where concentrated flow or erosion is occurring. Voids in the brush barrier should be filled with additional brush. Accumulated sediment should be removed from the uphill side of the barrier when sediment height reaches one-third of the height of the barrier.

If filter fabric is used, inspect the filter fabric for damage; replace and properly secure it, as needed.

Once the upstream area has been vegetated or stabilized, the brush barrier should be removed and the underlying area revegetated.

Description

Photograph RS-1. Rock socks placed at regular intervals in a curb line can help reduce sediment loading to storm sewer inlets. Rock socks can also be used as perimeter controls.

A rock sock is constructed of gravel that has been wrapped by wire mesh or a geotextile to form an elongated cylindrical filter. Rock socks are typically used either as a perimeter control or as part of inlet protection. When placed at angles in the curb line, rock socks are typically referred to as curb socks. Rock socks are intended to trap sediment from stormwater runoff that flows onto roadways as a result of construction activities.

Appropriate Uses

Rock socks can be used at the perimeter of a disturbed area to control localized sediment loading. A benefit of rock socks as opposed to other perimeter controls is that they do not have to be trenched or staked into the ground; therefore, they are often used on roadway construction projects where paved surfaces are present.

Use rock socks in inlet protection applications when the construction of a roadway is substantially complete and the roadway has been directly connected to a receiving storm system.

Design and Installation

When rock socks are used as perimeter controls, the maximum recommended tributary drainage area per 100 lineal feet of rock socks is approximately 0.25 acres with disturbed slope length of up to 150 feet and a tributary slope gradient no steeper than 3:1. A rock sock design detail and notes are provided in Detail RS-1. Also see the Inlet Protection Fact Sheet for design and installation guidance when rock socks are used for inlet protection and in the curb line.

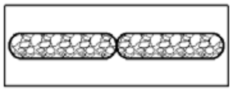
When placed in the gutter adjacent to a curb, rock socks should protrude no more than two feet from the curb in order for traffic to pass safely. If located in a high traffic area, place construction markers to alert drivers and street maintenance workers of their presence.

Maintenance and Removal

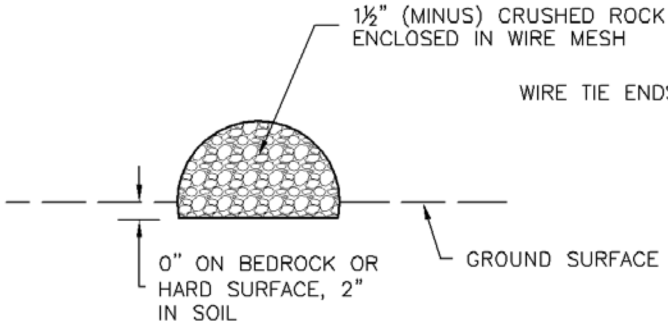
Rock socks are susceptible to displacement and breaking due to vehicle traffic. Inspect rock socks for damage and repair or replace as necessary. Remove sediment by sweeping or vacuuming as needed to maintain the functionality of the BMP, typically when sediment has accumulated behind the rock sock to one-half of the sock's height.

Once upstream stabilization is complete, rock socks and accumulated sediment should be removed and properly disposed.

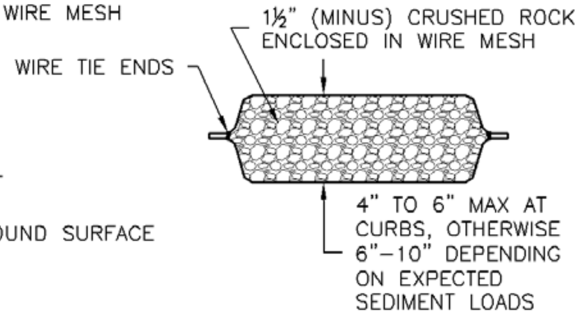
Rock Sock	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	No



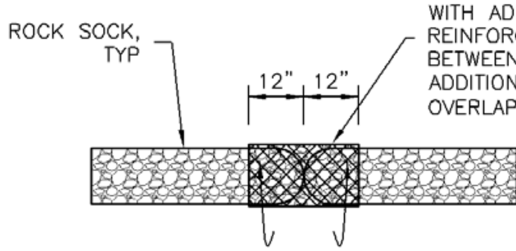
RS



ROCK SOCK SECTION



ROCK SOCK PLAN



ROCK SOCK JOINTING

GRADATION TABLE	
SIEVE SIZE	MASS PERCENT PASSING SQUARE MESH SIEVES
	NO. 4
2"	100
1½"	90 – 100
1"	20 – 55
¾"	0 – 15
⅜"	0 – 5
MATCHES SPECIFICATIONS FOR NO. 4 COARSE AGGREGATE FOR CONCRETE PER AASHTO M43. ALL ROCK SHALL BE FRACTURED FACE, ALL SIDES.	

ROCK SOCK INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   -LOCATION(S) OF ROCK SOCKS.

2. CRUSHED ROCK SHALL BE 1½" (MINUS) IN SIZE WITH A FRACTURED FACE (ALL SIDES) AND SHALL COMPLY WITH GRADATION SHOWN ON THIS SHEET (1½" MINUS).

3. WIRE MESH SHALL BE FABRICATED OF 10 GAGE POULTRY MESH, OR EQUIVALENT, WITH A MAXIMUM OPENING OF ½", RECOMMENDED MINIMUM ROLL WIDTH OF 48"

4. WIRE MESH SHALL BE SECURED USING "HOG RINGS" OR WIRE TIES AT 6" CENTERS ALONG ALL JOINTS AND AT 2" CENTERS ON ENDS OF SOCKS.

5. SOME MUNICIPALITIES MAY ALLOW THE USE OF FILTER FABRIC AS AN ALTERNATIVE TO WIRE MESH FOR THE ROCK ENCLOSURE.

RS-1. ROCK SOCK PERIMETER CONTROL

ROCK SOCK MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. ROCK SOCKS SHALL BE REPLACED IF THEY BECOME HEAVILY SOILED, OR DAMAGED BEYOND REPAIR.

5. SEDIMENT ACCUMULATED UPSTREAM OF ROCK SOCKS SHALL BE REMOVED AS NEEDED TO MAINTAIN FUNCTIONALITY OF THE BMP, TYPICALLY WHEN DEPTH OF ACCUMULATED SEDIMENTS IS APPROXIMATELY ½ OF THE HEIGHT OF THE ROCK SOCK.

6. ROCK SOCKS ARE TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

7. WHEN ROCK SOCKS ARE REMOVED, ALL DISTURBED AREAS SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAIL ADAPTED FROM TOWN OF PARKER, COLORADO AND CITY OF AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

NOTE: THE DETAILS INCLUDED WITH THIS FACT SHEET SHOW COMMONLY USED, CONVENTIONAL METHODS OF ROCK SOCK INSTALLATION IN THE DENVER METROPOLITAN AREA. THERE ARE MANY OTHER SIMILAR PROPRIETARY PRODUCTS ON THE MARKET. UDFCD NEITHER NDORSES NOR DISCOURAGES USE OF PROPRIETARY PROTECTION PRODUCTS; HOWEVER, IN THE EVENT PROPRIETARY METHODS ARE USED, THE APPROPRIATE DETAIL FROM THE MANUFACTURER MUST BE INCLUDED IN THE SWMP AND THE BMP MUST BE INSTALLED AND MAINTAINED AS SHOWN IN THE MANUFACTURER'S DETAILS.

Description

Inlet protection consists of permeable barriers installed around an inlet to filter runoff and remove sediment prior to entering a storm drain inlet. Inlet protection can be constructed from rock socks, sediment control logs, silt fence, block and rock socks, or other materials approved by the local jurisdiction. Area inlets can also be protected by over-excavating around the inlet to form a sediment trap.

Photograph IP-1. Inlet protection for a curb opening inlet.

Appropriate Uses

Install protection at storm sewer inlets that are operable during construction. Consider the potential for tracked-out sediment or temporary stockpile areas to contribute sediment to inlets when determining which inlets must be protected. This may include inlets in the general proximity of the construction area, not limited to downgradient inlets. Inlet protection is not a stand-alone BMP and should be used in conjunction with other upgradient BMPs.

Design and Installation

To function effectively, inlet protection measures must be installed to ensure that flows do not bypass the inlet protection and enter the storm drain without treatment. However, designs must also enable the inlet to function without completely blocking flows into the inlet in a manner that causes localized flooding. When selecting the type of inlet protection, consider factors such as type of inlet (e.g., curb or area, sump or on-grade conditions), traffic, anticipated flows, ability to secure the BMP properly, safety and other site-specific conditions. For example, block and rock socks will be better suited to a curb and gutter along a roadway, as opposed to silt fence or sediment control logs, which cannot be properly secured in a curb and gutter setting, but are effective area inlet protection measures.

Several inlet protection designs are provided in the Design Details. Additionally, a variety of proprietary products are available for inlet protection that may be approved for use by local governments. If proprietary products are used, design details and installation procedures from the manufacturer must be followed. Regardless of the type of inlet protection selected, inlet protection is most effective when combined with other BMPs such as curb socks and check dams. Inlet protection is often the last barrier before runoff enters the storm sewer or receiving water.

Design details with notes are provided for these forms of inlet protection:

IP-1. Block and Rock Sock Inlet Protection for Sump or On-grade Inlets

IP-2. Curb (Rock) Socks Upstream of Inlet Protection, On-grade Inlets

Inlet Protection (various forms)	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	No

IP-3. Rock Sock Inlet Protection for Sump/Area Inlet

IP-4. Silt Fence Inlet Protection for Sump/Area Inlet

IP-5. Over-excavation Inlet Protection

IP-6. Straw Bale Inlet Protection for Sump/Area Inlet

CIP-1. Culvert Inlet Protection

Propriety inlet protection devices should be installed in accordance with manufacturer specifications.

More information is provided below on selecting inlet protection for sump and on-grade locations.

Inlets Located in a Sump

When applying inlet protection in sump conditions, it is important that the inlet continue to function during larger runoff events. For curb inlets, the maximum height of the protective barrier should be lower than the top of the curb opening to allow overflow into the inlet during larger storms without excessive localized flooding. If the inlet protection height is greater than the curb elevation, particularly if the filter becomes clogged with sediment, runoff will not enter the inlet and may bypass it, possibly causing localized flooding, public safety issues, and downstream erosion and damage from bypassed flows.

Area inlets located in a sump setting can be protected through the use of silt fence, concrete block and rock socks (on paved surfaces), sediment control logs/straw wattles embedded in the adjacent soil and stacked around the area inlet (on pervious surfaces), over-excavation around the inlet, and proprietary products providing equivalent functions.

Inlets Located on a Slope

For curb and gutter inlets on paved sloping streets, block and rock sock inlet protection is recommended in conjunction with curb socks in the gutter leading to the inlet. For inlets located along unpaved roads, also see the Check Dam Fact Sheet.

Maintenance and Removal

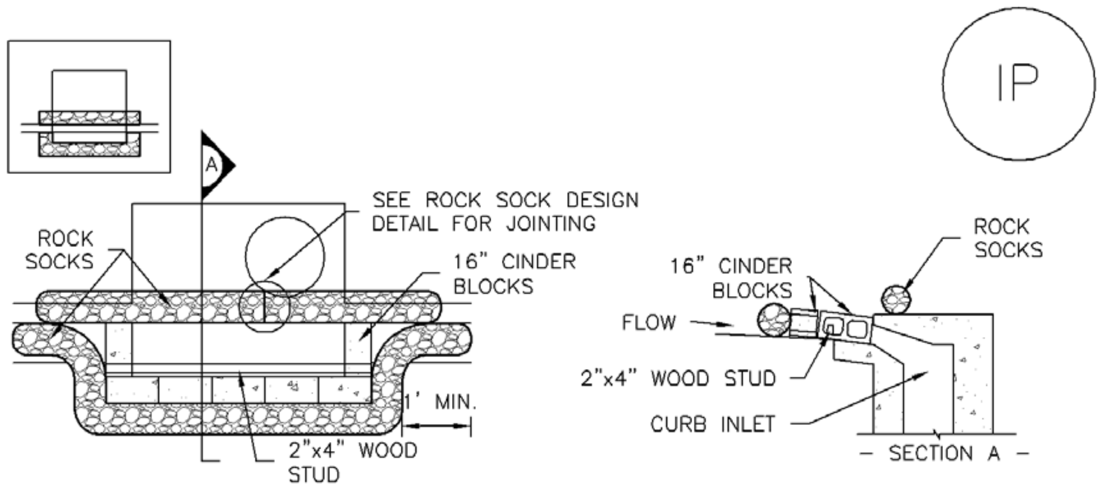
Inspect inlet protection frequently. Inspection and maintenance guidance includes:

- Inspect for tears that can result in sediment directly entering the inlet, as well as result in the contents of the BMP (e.g., gravel) washing into the inlet.
- Check for improper installation resulting in untreated flows bypassing the BMP and directly entering the inlet or bypassing to an unprotected downstream inlet. For example, silt fence that has not been properly trenched around the inlet can result in flows under the silt fence and directly into the inlet.
- Look for displaced BMPs that are no longer protecting the inlet. Displacement may occur following larger storm events that wash away or reposition the inlet protection. Traffic or equipment may also crush or displace the BMP.
- Monitor sediment accumulation upgradient of the inlet protection.

- Remove sediment accumulation from the area upstream of the inlet protection, as needed to maintain BMP effectiveness, typically when it reaches no more than half the storage capacity of the inlet protection. For silt fence, remove sediment when it accumulates to a depth of no more than 6 inches. Remove sediment accumulation from the area upstream of the inlet protection as needed to maintain the functionality of the BMP.

- Propriety inlet protection devices should be inspected and maintained in accordance with manufacturer specifications. If proprietary inlet insert devices are used, sediment should be removed in a timely manner to prevent devices from breaking and spilling sediment into the storm drain.

Inlet protection must be removed and properly disposed of when the drainage area for the inlet has reached final stabilization.



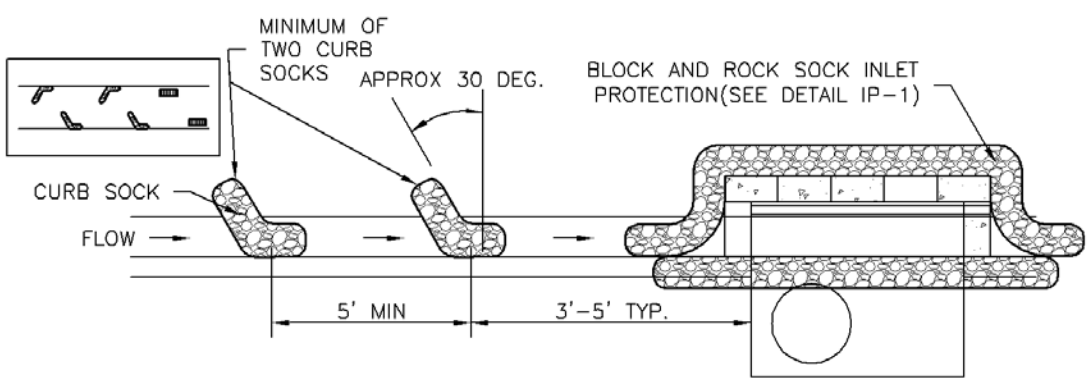
IP–1. BLOCK AND ROCK SOCK SUMP OR ON GRADE INLET PROTECTION

BLOCK AND CURB SOCK INLET PROTECTION INSTALLATION NOTES

1. SEE ROCK SOCK DESIGN DETAIL FOR INSTALLATION REQUIREMENTS.

2. CONCRETE "CINDER" BLOCKS SHALL BE LAID ON THEIR SIDES AROUND THE INLET IN A SINGLE ROW, ABUTTING ONE ANOTHER WITH THE OPEN END FACING AWAY FROM THE CURB.

3. GRAVEL BAGS SHALL BE PLACED AROUND CONCRETE BLOCKS, CLOSELY ABUTTING ONE ANOTHER AND JOINTED TOGETHER IN ACCORDANCE WITH ROCK SOCK DESIGN DETAIL.



IP–2. CURB ROCK SOCKS UPSTREAM OF INLET PROTECTION

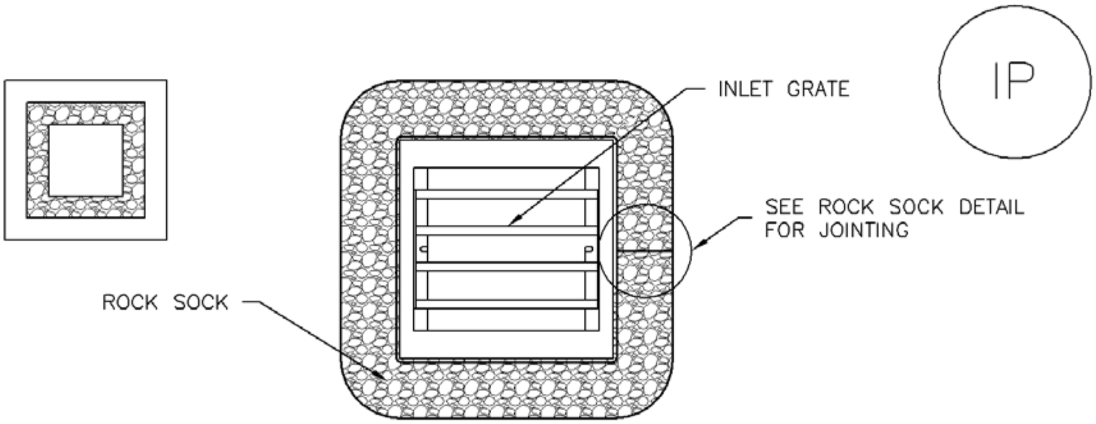
CURB ROCK SOCK INLET PROTECTION INSTALLATION NOTES

1. SEE ROCK SOCK DESIGN DETAIL INSTALLATION REQUIREMENTS.

2. PLACEMENT OF THE SOCK SHALL BE APPROXIMATELY 30 DEGREES FROM PERPENDICULAR IN THE OPPOSITE DIRECTION OF FLOW.

3. SOCKS ARE TO BE FLUSH WITH THE CURB AND SPACED A MINIMUM OF 5 FEET APART.

4. AT LEAST TWO CURB SOCKS IN SERIES ARE REQUIRED UPSTREAM OF ON–GRADE INLETS.

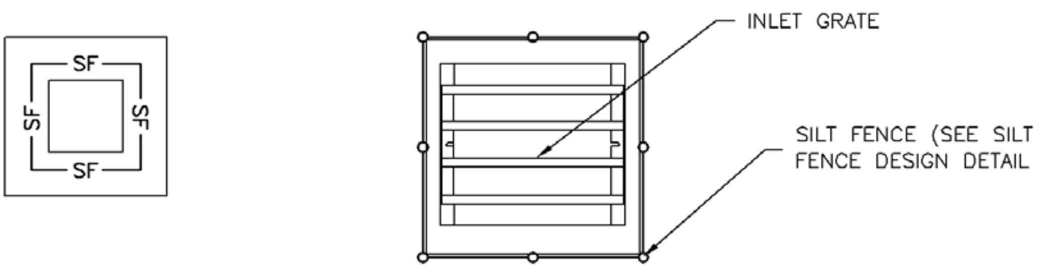


IP–3. ROCK SOCK SUMP/AREA INLET PROTECTION

ROCK SOCK SUMP/AREA INLET PROTECTION INSTALLATION NOTES

1. SEE ROCK SOCK DESIGN DETAIL FOR INSTALLATION REQUIREMENTS.

2. STRAW WATTLES/SEDIMENT CONTROL LOGS MAY BE USED IN PLACE OF ROCK SOCKS FOR INLETS IN PERVIOUS AREAS. INSTALL PER SEDIMENT CONTROL LOG DETAIL.



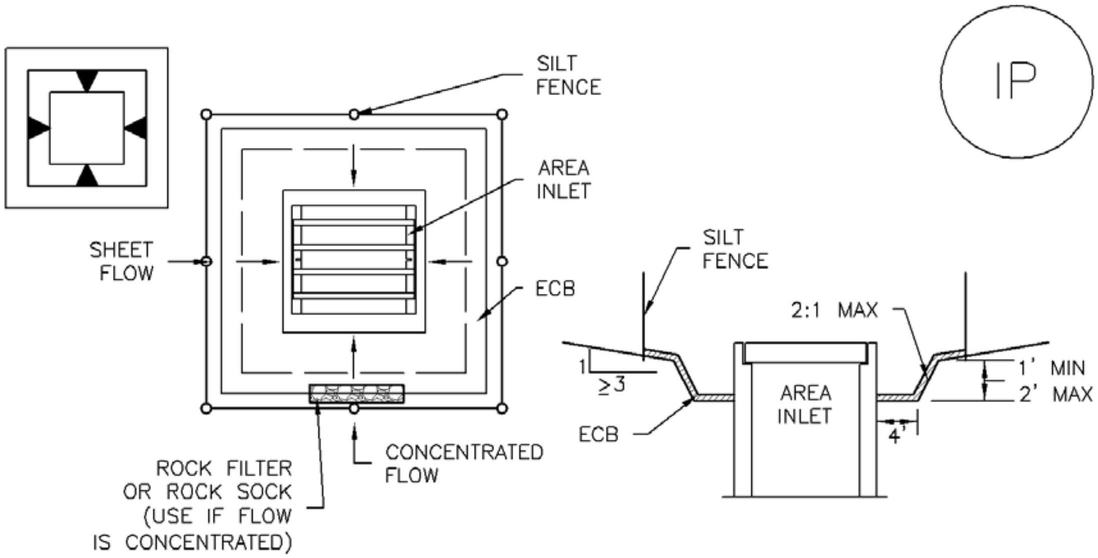
IP–4. SILT FENCE FOR SUMP INLET PROTECTION

SILT FENCE INLET PROTECTION INSTALLATION NOTES

1. SEE SILT FENCE DESIGN DETAIL FOR INSTALLATION REQUIREMENTS.

2. POSTS SHALL BE PLACED AT EACH CORNER OF THE INLET AND AROUND THE EDGES AT A MAXIMUM SPACING OF 3 FEET.

3. STRAW WATTLES/SEDIMENT CONTROL LOGS MAY BE USED IN PLACE OF SILT FENCE FOR INLETS IN PERVIOUS AREAS. INSTALL PER SEDIMENT CONTROL LOG DETAIL.



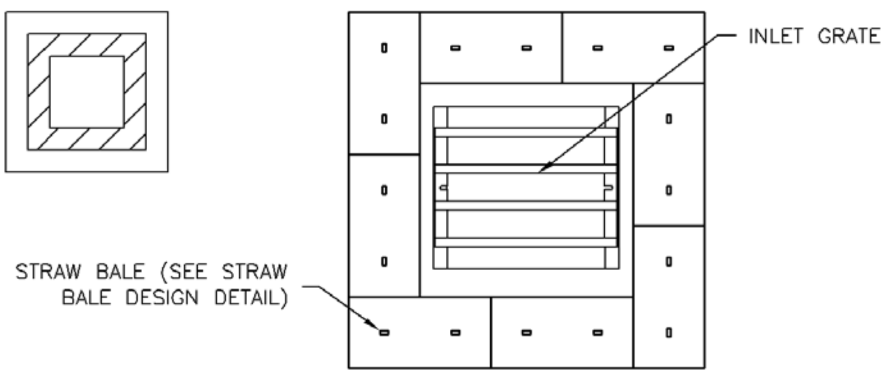
IP-5. OVEREXCAVATION INLET PROTECTION

OVEREXCAVATION INLET PROTECTION INSTALLATION NOTES

1. THIS FORM OF INLET PROTECTION IS PRIMARILY APPLICABLE FOR SITES THAT HAVE NOT YET REACHED FINAL GRADE AND SHOULD BE USED ONLY FOR INLETS WITH A RELATIVELY SMALL CONTRIBUTING DRAINAGE AREA.

2. WHEN USING FOR CONCENTRATED FLOWS, SHAPE BASIN IN 2:1 RATIO WITH LENGTH ORIENTED TOWARDS DIRECTION OF FLOW.

3. SEDIMENT MUST BE PERIODICALLY REMOVED FROM THE OVEREXCAVATED AREA.

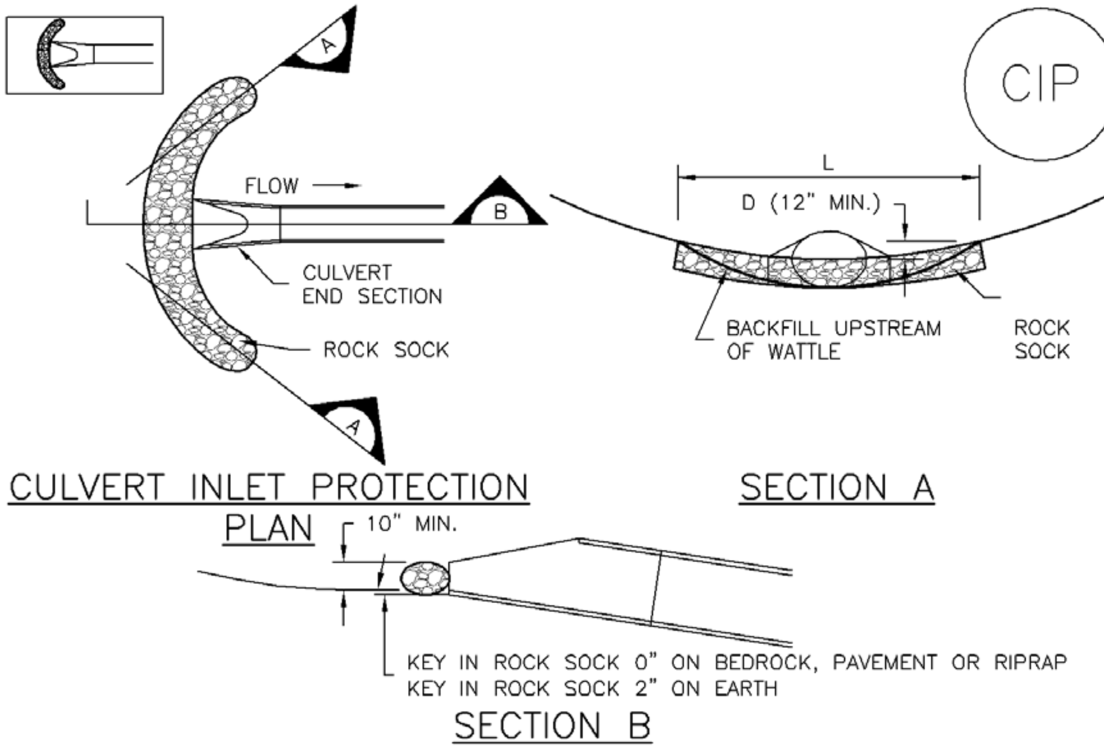


IP-6. STRAW BALE FOR SUMP INLET PROTECTION

STRAW BALE BARRIER INLET PROTECTION INSTALLATION NOTES

1. SEE STRAW BALE DESIGN DETAIL FOR INSTALLATION REQUIREMENTS.

2. BALES SHALL BE PLACED IN A SINGLE ROW AROUND THE INLET WITH ENDS OF BALES TIGHTLY ABUTTING ONE ANOTHER.



CIP-1. CULVERT INLET PROTECTION

CULVERT INLET PROTECTION INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   -LOCATION OF CULVERT INLET PROTECTION.

2. SEE ROCK SOCK DESIGN DETAIL FOR ROCK GRADATION REQUIREMENTS AND JOINTING DETAIL.

CULVERT INLET PROTECTION MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED UPSTREAM OF THE CULVERT SHALL BE REMOVED WHEN THE SEDIMENT DEPTH IS ½ THE HEIGHT OF THE ROCK SOCK.

5. CULVERT INLET PROTECTION SHALL REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS PERMANENTLY STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

(DETAILS ADAPTED FROM AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

GENERAL INLET PROTECTION INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - -LOCATION OF INLET PROTECTION.
   - -TYPE OF INLET PROTECTION (IP.1, IP.2, IP.3, IP.4, IP.5, IP.6)

2. INLET PROTECTION SHALL BE INSTALLED PROMPTLY AFTER INLET CONSTRUCTION OR PAVING IS COMPLETE (TYPICALLY WITHIN 48 HOURS). IF A RAINFALL/RUNOFF EVENT IS FORECAST, INSTALL INLET PROTECTION PRIOR TO ONSET OF EVENT.

3. MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

INLET PROTECTION MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED UPSTREAM OF INLET PROTECTION SHALL BE REMOVED AS NECESSARY TO MAINTAIN BMP EFFECTIVENESS, TYPICALLY WHEN STORAGE VOLUME REACHES 50% OF CAPACITY, A DEPTH OF 6" WHEN SILT FENCE IS USED, OR ¼ OF THE HEIGHT FOR STRAW BALES.

5. INLET PROTECTION IS TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS PERMANENTLY STABILIZED, UNLESS THE LOCAL JURISDICTION APPROVES EARLIER REMOVAL OF INLET PROTECTION IN STREETS.

6. WHEN INLET PROTECTION AT AREA INLETS IS REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOP SOIL, SEEDED AND MULCHED, OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAIL ADAPTED FROM TOWN OF PARKER, COLORADO AND CITY OF AURORA, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

NOTE: THE DETAILS INCLUDED WITH THIS FACT SHEET SHOW COMMONLY USED, CONVENTIONAL METHODS OF INLET PROTECTION IN THE DENVER METROPOLITAN AREA. THERE ARE MANY PROPRIETARY INLET PROTECTION METHODS ON THE MARKET. UDFCD NEITHER ENDORSES NOR DISCOURAGES USE OF PROPRIETARY INLET PROTECTION; HOWEVER, IN THE EVENT PROPRIETARY METHODS ARE USED, THE APPROPRIATE DETAIL FROM THE MANUFACTURER MUST BE INCLUDED IN THE SWMP AND THE BMP MUST BE INSTALLED AND MAINTAINED AS SHOWN IN THE MANUFACTURER'S DETAILS.

NOTE: SOME MUNICIPALITIES DISCOURAGE OR PROHIBIT THE USE OF STRAW BALES FOR INLET PROTECTION. CHECK WITH LOCAL JURISDICTION TO DETERMINE IF STRAW BALE INLET PROTECTION IS ACCEPTABLE.

Description

Photograph SB-1. Sediment basin at the toe of a slope. Photo courtesy of WWE.

A sediment basin is a temporary pond built on a construction site to capture eroded or disturbed soil transported in storm runoff prior to discharge from the site. Sediment basins are designed to capture site runoff and slowly release it to allow time for settling of sediment prior to discharge. Sediment basins are often constructed in locations that will later be modified to serve as post-construction stormwater basins.

Appropriate Uses

Most large construction sites (typically greater than 2 acres) will require one or more sediment basins for effective management of construction site runoff. On linear construction projects, sediment basins may be impractical; instead, sediment traps or other combinations of BMPs may be more appropriate.

Sediment basins should not be used as stand-alone sediment controls. Erosion and other sediment controls should also be implemented upstream.

When feasible, the sediment basin should be installed in the same location where a permanent post-construction detention pond will be located.

Design and Installation

The design procedure for a sediment basin includes these steps:

- **Basin Storage Volume**: Provide a storage volume of at least 3,600 cubic feet per acre of drainage area. To the extent practical, undisturbed and/or off-site areas should be diverted around sediment basins to prevent "clean" runoff from mixing with runoff from disturbed areas. For undisturbed areas (both on-site and off-site) that cannot be diverted around the sediment basin, provide a minimum of 500 ft^3/acre of storage for undeveloped (but stable) off-site areas in addition to the 3,600 ft^3/acre for disturbed areas. For stable, developed areas that cannot be diverted around the sediment basin, storage volume requirements are summarized in Table SB-1.
- **Basin Geometry:** Design basin with a minimum length-to-width ratio of 2:1 (L:W). If this cannot be achieved because of site space constraints, baffling may be required to extend the effective distance between the inflow point(s) and the outlet to minimize short-circuiting.
- **Dam Embankment**: It is recommended that embankment slopes be 4:1 (H:V) or flatter and no steeper than 3:1 (H:V) in any location.

Sediment Basins	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	No

- **Inflow Structure**: For concentrated flow entering the basin, provide energy dissipation at the point of inflow.

Table SB-1. Additional Volume Requirements for Undisturbed and Developed Tributary Areas Draining through Sediment Basins

Imperviousness (%)	Additional Storage Volume (ft^3) Per Acre of Tributary Area
Undeveloped	500
10	800
20	1230
30	1600
40	2030
50	2470
60	2980
70	3560
80	4360
90	5300
100	6460

- **Outlet Works**: The outlet pipe shall extend through the embankment at a minimum slope of 0.5 percent. Outlet works can be designed using one of the following approaches:
  - **Riser Pipe (Simplified Detail):** Detail SB-1 provides a simplified design for basins treating no more than 15 acres.
  - **Orifice Plate or Riser Pipe**: Follow the design criteria for Full Spectrum Detention outlets in the EDB Fact Sheet provided in Chapter 4 of this manual for sizing of outlet perforations with an emptying time of approximately 72 hours. In lieu of the trash rack, pack uniformly sized 1½ - to 2-inch gravel in front of the plate or surrounding the riser pipe. This gravel will need to be cleaned out frequently during the construction period as sediment accumulates within it. The gravel pack will need to be removed and disposed of following construction to reclaim the basin for use as a permanent detention facility. If the basin will be used as a permanent extended detention basin for the site, a trash rack will need to be installed once contributing drainage areas have been stabilized and the gravel pack and accumulated sediment have been removed.
  - **Floating Skimmer**: If a floating skimmer is used, install it using manufacturer's recommendations. Illustration SB-1 provides an illustration of a Faircloth Skimmer Floating Outlet™, one of the more commonly used floating skimmer outlets. A skimmer should be designed to release the design volume in no less than 48 hours. The use of a floating skimmer outlet can increase the sediment capture efficiency of a basin significantly. A floating outlet continually decants cleanest water off the surface of the pond and releases cleaner water than would discharge from a perforated riser pipe or plate.

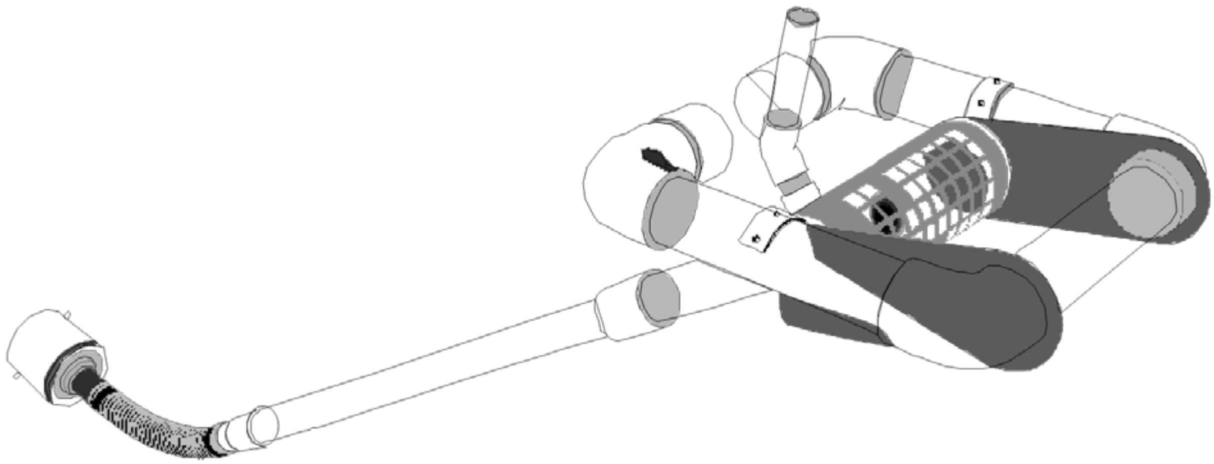


Illustration SB-1. Outlet structure for a temporary sediment basin - Faircloth Skimmer Floating Outlet. Illustration courtesy of J. W. Faircloth & Sons, Inc., FairclothSkimmer.com.

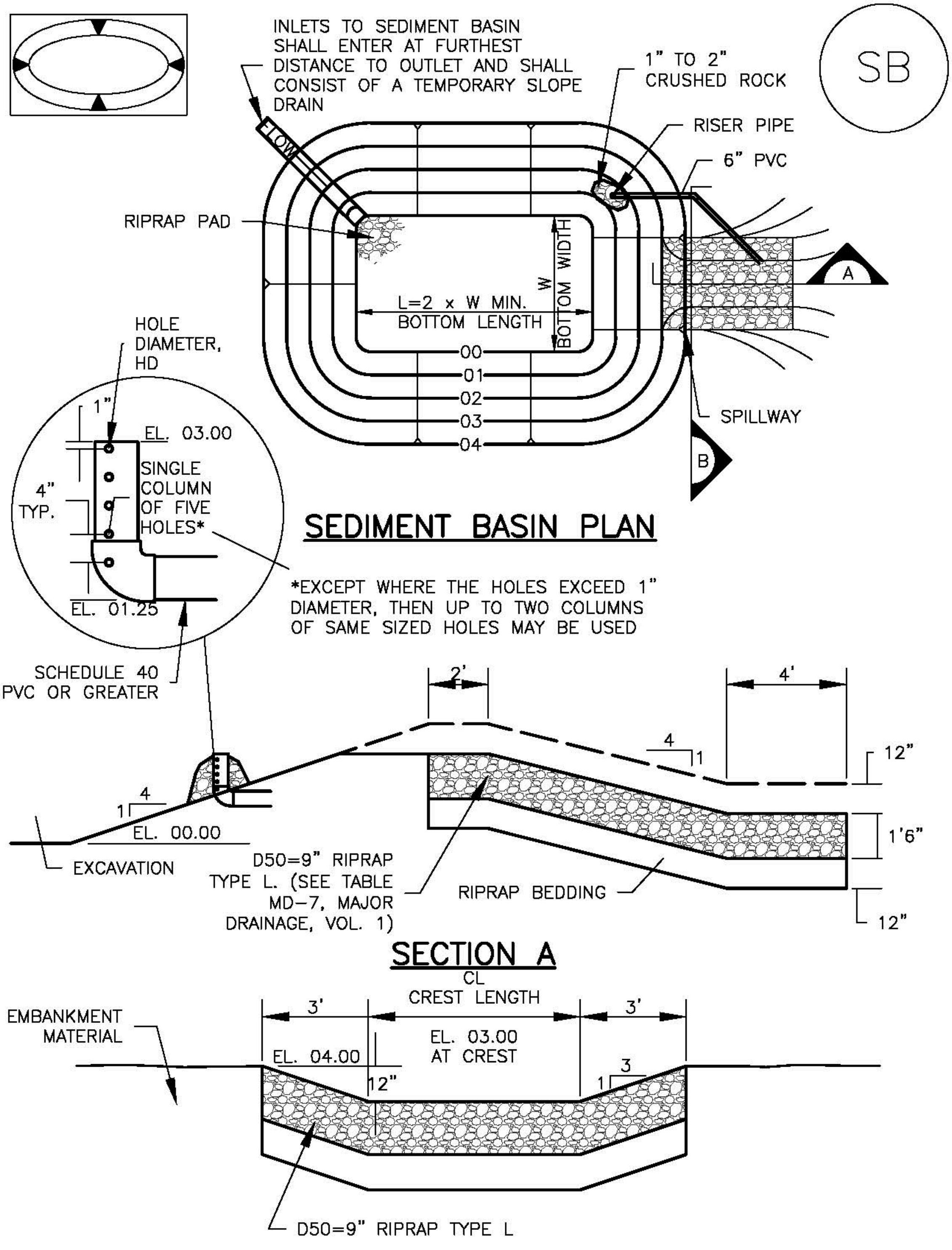
- **Outlet Protection and Spillway:** Consider all flow paths for runoff leaving the basin, including protection at the typical point of discharge as well as overtopping.
  - **Outlet Protection:** Outlet protection should be provided where the velocity of flow will exceed the maximum permissible velocity of the material of the waterway into which discharge occurs. This may require the use of a riprap apron at the outlet location and/or other measures to keep the waterway from eroding.
  - **Emergency Spillway:** Provide a stabilized emergency overflow spillway for rainstorms that exceed the capacity of the sediment basin volume and its outlet. Protect basin embankments from erosion and overtopping. If the sediment basin will be converted to a permanent detention basin, design and construct the emergency spillway(s) as required for the permanent facility. If the sediment basin will not become a permanent detention basin, it may be possible to substitute a heavy polyvinyl membrane or properly bedded rock cover to line the spillway and downstream embankment, depending on the height, slope, and width of the embankments.

Maintenance and Removal

Maintenance activities include the following:

- Dredge sediment from the basin, as needed to maintain BMP effectiveness, typically when the design storage volume is no more than one-third filled with sediment.
- Inspect the sediment basin embankments for stability and seepage.
- Inspect the inlet and outlet of the basin, repair damage, and remove debris. Remove, clean and replace the gravel around the outlet on a regular basis to remove the accumulated sediment within it and keep the outlet functioning.
- Be aware that removal of a sediment basin may require dewatering and associated permit requirements.
- Do not remove a sediment basin until the upstream area has been stabilized with vegetation.

Final disposition of the sediment basin depends on whether the basin will be converted to a permanent post-construction stormwater basin or whether the basin area will be returned to grade. For basins being converted to permanent detention basins, remove accumulated sediment and reconfigure the basin and outlet to meet the requirements of the final design for the detention facility. If the sediment basin is not to be used as a permanent detention facility, fill the excavated area with soil and stabilize with vegetation.



SB
INLETS TO SEDIMENT BASIN SHALL ENTER AT FURTHEST DISTANCE TO OUTLET AND SHALL CONSIST OF A TEMPORARY SLOPE DRAIN
FLOW
1" TO 2" CRUSHED ROCK
RISER PIPE
6" PVC
RIPRAP PAD
L=2 x W MIN. BOTTOM LENGTH
W BOTTOM WIDTH
00
01
02
03
04
A
SPILLWAY
B
HOLE DIAMETER, HD
1"
EL. 03.00
SINGLE COLUMN OF FIVE HOLES*
4" TYP.
EL. 01.25
SEDIMENT BASIN PLAN
*EXCEPT WHERE THE HOLES EXCEED 1" DIAMETER, THEN UP TO TWO COLUMNS OF SAME SIZED HOLES MAY BE USED
SCHEDULE 40 PVC OR GREATER
2'
4'
4
1
12"
1'6"
EL. 00.00
EXCAVATION
D50=9" RIPRAP TYPE L. (SEE TABLE MD-7, MAJOR DRAINAGE, VOL. 1)
RIPRAP BEDDING
SECTION A
CL
CREST LENGTH
3'
EMBANKMENT MATERIAL
EL. 04.00
EL. 03.00 AT CREST
3
D50=9" RIPRAP TYPE L

TABLE SB-1. SIZING INFORMATION FOR STANDARD SEDIMENT BASIN			
Upstream Drainage Area (rounded to nearest acre), (ac)	Basin Bottom Width (W), (ft)	Spillway Crest Length (CL), (ft)	Hole Diameter (HD), (in)
1	12 1/2	2	9/32
2	21	3	13/16
3	28	5	1/2
4	33 1/2	6	9/16
5	38 1/2	8	21/32
6	43	9	21/32
7	47 1/4	11	25/32
8	51	12	27/32
9	55	13	7/8
10	58 1/4	15	15/16
11	61	16	31/32
12	64	18	1
13	67 1/2	19	1 1/16
14	70 1/2	21	1 1/8
15	73 1/4	22	1 3/16

SEDIMENT BASIN INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - -LOCATION OF SEDIMENT BASIN.
   - -TYPE OF BASIN (STANDARD BASIN OR NONSTANDARD BASIN).
   - -FOR STANDARD BASIN, BOTTOM WIDTH W, CREST LENGTH CL, AND HOLE DIAMETER, HD.
   - -FOR NONSTANDARD BASIN, SEE CONSTRUCTION DRAWINGS FOR DESIGN OF BASIN INCLUDING RISER HEIGHT H, NUMBER OF COLUMNS N, HOLE DIAMETER HD AND PIPE DIAMETER D.

2. FOR STANDARD BASIN, BOTTOM DIMENSION MAY BE MODIFIED AS LONG AS BOTTOM AREA IS NOT REDUCED.

3. SEDIMENT BASINS SHALL BE INSTALLED PRIOR TO ANY OTHER LAND-DISTURBING ACTIVITY THAT RELIES ON ON BASINS AS AS A STORMWATER CONTROL.

4. EMBANKMENT MATERIAL SHALL CONSIST OF SOIL FREE OF DEBRIS, ORGANIC MATERIAL, AND ROCKS OR CONCRETE GREATER THAN 3 INCHES AND SHALL HAVE A MINIMUM OF 15 PERCENT BY WEIGHT PASSING THE NO. 200 SIEVE.

5. EMBANKMENT MATERIAL SHALL BE COMPACTED TO AT LEAST 95 PERCENT OF MAXIMUM DENSITY IN ACCORDANCE WITH ASTM D698.

6. PIPE SCH 40 OR GREATER SHALL BE USED.

7. THE DETAILS SHOWN ON THESE SHEETS PERTAIN TO STANDARD SEDIMENT BASIN(S) FOR DRAINAGE AREAS LESS THAN 15 ACRES. SEE CONSTRUCTION DRAWINGS FOR EMBANKMENT, STORAGE VOLUME, SPILLWAY, OUTLET, AND OUTLET PROTECTION DETAILS FOR ANY SEDIMENT BASIN(S) THAT HAVE BEEN INDIVIDUALLY DESIGNED FOR DRAINAGE AREAS LARGER THAN 15 ACRES.

SEDIMENT BASIN MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. SEDIMENT ACCUMULATED IN BASIN SHALL BE REMOVED AS NEEDED TO MAINTAIN BMP EFFECTIVENESS, TYPICALLY WHEN SEDIMENT DEPTH REACHES ONE FOOT (I.E., TWO FEET BELOW THE SPILLWAY CREST).

5. SEDIMENT BASINS ARE TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND GRASS COVER IS ACCEPTED BY THE LOCAL JURISDICTION.

6. WHEN SEDIMENT BASINS ARE REMOVED, ALL DISTURBED AREAS SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Photograph ST-1. Sediment traps are used to collect sediment-laden runoff from disturbed area. Photo courtesy of EPA Menu of BMPs.

Sediment traps are formed by excavating an area or by placing an earthen embankment across a low area or drainage swale. Sediment traps are designed to capture drainage from disturbed areas less than one acre and allow settling of sediment.

Appropriate Uses

Sediment traps can be used in combination with other layers of erosion and sediment controls to trap sediment from small drainage areas (less than one acre) or areas with localized high sediment loading. For example, sediment traps are often provided in conjunction with vehicle tracking controls and wheel wash facilities.

Design and Installation

A sediment trap consists of a small excavated basin with an earthen berm and a riprap outlet. The berm of the sediment trap may be constructed from the excavated material and must be compacted to 95 percent of the maximum density in accordance with ASTM D698. An overflow outlet must be provided at an elevation at least 6 inches below the top of the berm. See Detail ST-1 for additional design and installation information.

Maintenance and Removal

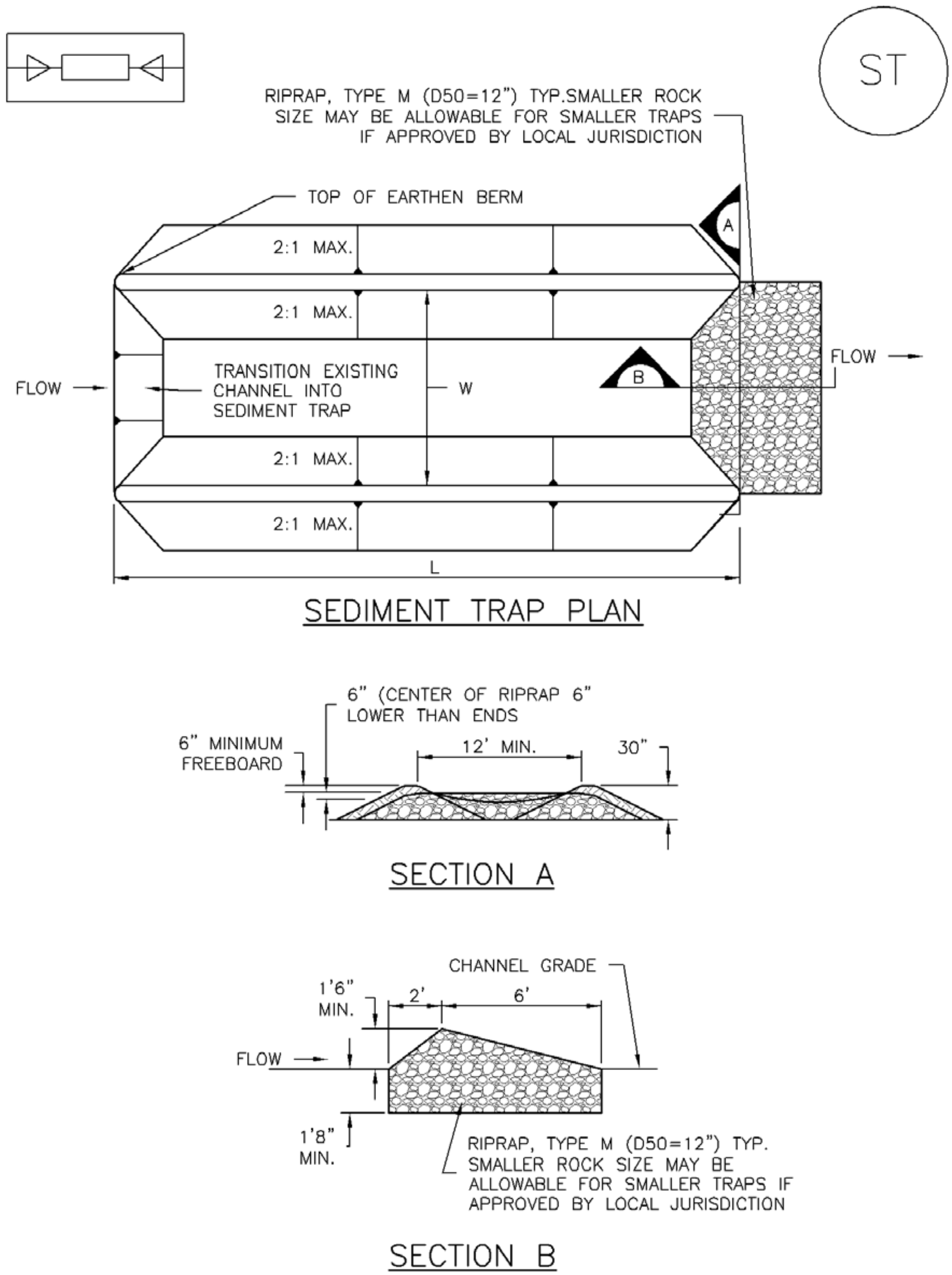
Inspect the sediment trap embankments for stability and seepage.

Remove accumulated sediment as needed to maintain the effectiveness of the sediment trap, typically when the sediment depth is approximately one-half the height of the outflow embankment.

Inspect the outlet for debris and damage. Repair damage to the outlet, and remove all obstructions.

A sediment trap should not be removed until the upstream area is sufficiently stabilized. Upon removal of the trap, the disturbed area should be covered with topsoil and stabilized.

Sediment Trap	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	No



ST–1. SEDIMENT TRAP

SEDIMENT TRAP INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   -LOCATION, LENGTH AND WIDTH OF SEDIMENT TRAP.

2. ONLY USE FOR DRAINAGE AREAS LESS THAN 1 ACRE.

3. SEDIMENT TRAPS SHALL BE INSTALLED PRIOR TO ANY UPGRADIENT LAND-DISTURBING ACTIVITIES.

4. SEDIMENT TRAP BERM SHALL BE CONSTRUCTED FROM MATERIAL FROM EXCAVATION. THE BERM SHALL BE COMPACTED TO 95% OF THE MAXIMUM DENSITY IN ACCORDANCE WITH ASTM D698.

5. SEDIMENT TRAP OUTLET TO BE CONSTRUCTED OF RIPRAP, TYPE M (D50=12") TYP.SMALLER ROCK SIZE MAY BE ALLOWABLE FOR SMALLER TRAPS IF APPROVED BY LOCAL JURISDICTION.

6. THE TOP OF THE EARTHEN BERM SHALL BE A MINIMUM OF 6" HIGHER THAN THE TOP OF THE RIPRAP OUTLET STRUCTURE.

7. THE ENDS OF THE RIPRAP OUTLET STRUCTURE SHALL BE A MINIMUM OF 6" HIGHER THAN THE CENTER OF THE OUTLET STRUCTURE.

SEDIMENT TRAP MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. REMOVE SEDIMENT ACCUMULATED IN TRAP AS NEEDED TO MAINTAIN THE FUNCTIONALITY OF THE BMP, TYPICALLY WHEN THE SEDIMENT DEPTH REACHES ½ THE HEIGHT OF THE RIPRAP OUTLET.

5. SEDIMENT TRAPS SHALL REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

6. WHEN SEDIMENT TRAPS ARE REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO, NOT AVAILABLE IN AUTOCAD)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Buffer strips of preserved natural vegetation or grass help protect waterways and wetlands from land disturbing activities. Vegetated buffers improve stormwater runoff quality by straining sediment, promoting infiltration, and slowing runoff velocities.

Photograph VB-1. A vegetated buffer is maintained between the area of active construction and the drainage swale. Photo courtesy of WWE.

Appropriate Uses

Vegetated buffers can be used to separate land disturbing activities and natural surface waters or conveyances. In many jurisdictions, local governments require some type of setback from natural waterways. Concentrated flow should not be directed through a buffer; instead, runoff should be in the form of sheet flow. Vegetated buffers are typically used in combination with other perimeter control BMPs such as sediment control logs or silt fence for multi-layered protection.

Design and Installation

Minimum buffer widths may vary based on local regulations. Clearly delineate the boundary of the natural buffer area using construction fencing, silt fence, or a comparable technique. In areas that have been cleared and graded, vegetated buffers such as sod can also be installed to create or restore a vegetated buffer around the perimeter of the site.

Maintenance and Removal

Inspect buffer areas for signs of erosion such as gullies or rills. Stabilize eroding areas, as needed. If erosion is due to concentrated flow conditions, it may be necessary to install a level spreader or other technique to restore sheet flow conditions. Inspect perimeter controls delineating the vegetative buffer and repair or replace as needed.

Vegetated Buffers	
Functions	
Erosion Control	Moderate
Sediment Control	Yes
Site/Material Management	Yes

Description

Photograph CT-1. Proprietary chemical treatment system being used on a construction site with sensitive receiving waters. Photo courtesy of WWE.

Chemical treatment for erosion and sediment control can take several forms:

1. Applying chemicals to disturbed surfaces to reduce erosion (these uses are discussed in the Soil Binders Fact Sheet).
2. Adding flocculants to sedimentation ponds or tanks to enhance sediment removal prior.
3. Using proprietary barriers or flow-through devices containing flocculants (e.g., "floc logs").

The use of flocculants as described in No. 2 and No. 3 above will likely require special permitting. Check with the state permitting agency. See the Soil Binder BMP Fact Sheet for information on surface application of chemical treatments, as described in No. 1.

Appropriate Uses

At sites with fine-grained materials such as clays, chemical addition to sedimentation ponds or tanks can enhance settling of suspended materials through flocculation.

Prior to selecting and using chemical treatments, it is important to check state and local permit requirements related to their use.

Design and Installation

Due to variations among proprietary chemical treatment methods, design details are not provided for this BMP. Chemical feed systems for sedimentation ponds, settling tanks and dewatering bags should be installed and operated in accordance with manufacturer's recommendations and applicable regulations. Alum and chitosan are two common chemicals used as flocculants. Because the potential long-term impact of these chemicals to natural drainageways is not yet fully understood, the state does not currently allow chemical addition under the CDPS General Stormwater Construction Discharge Permit. Additional permitting may be necessary, which may include sampling requirements and numeric discharge limits.

Any devices or barriers containing chemicals should be installed following manufacturer's guidelines. Check for state and local jurisdiction usage restrictions and requirements before including these practices in the SWMP and implementing them onsite.

Chemical Treatment	
Functions	
Erosion Control	Moderate
Sediment Control	Yes
Site/Material Management	No

Maintenance and Removal

Chemical feed systems for sedimentation ponds or tanks should be maintained in accordance with manufacturer's recommendations and removed when the systems are no longer being used. Accumulated sediment should be dried and disposed of either at a landfill or in accordance with applicable regulations.

Barriers and devices containing chemicals should be removed and replaced when tears or other damage to the devices are observed. These barriers should be removed and properly disposed of when the site has been stabilized.

Description

Photograph CP-1. Construction phasing to avoid disturbing the entire area at one time. Photo courtesy of WWE.

Effective construction site management to minimize erosion and sediment transport includes attention to construction phasing, scheduling, and sequencing of land disturbing activities. On most construction projects, erosion and sediment controls will need to be adjusted as the project progresses and should be documented in the SWMP.

Construction phasing refers to disturbing only part of a site at a time to limit the potential for erosion from dormant parts of a site. Grading activities and construction are completed and soils are effectively stabilized on one part of a site before grading and construction begins on another portion of the site.

Construction sequencing or scheduling refers to a specified work schedule that coordinates the timing of land disturbing activities and the installation of erosion and sediment control practices.

Appropriate Uses

All construction projects can benefit from upfront planning to phase and sequence construction activities to minimize the extent and duration of disturbance. Larger projects and linear construction projects may benefit most from construction sequencing or phasing, but even small projects can benefit from construction sequencing that minimizes the duration of disturbance.

Typically, erosion and sediment controls needed at a site will change as a site progresses through the major phases of construction. Erosion and sediment control practices corresponding to each phase of construction must be documented in the SWMP.

Design and Installation

BMPs appropriate to the major phases of development should be identified on construction drawings. In some cases, it will be necessary to provide several drawings showing construction-phase BMPs placed according to stages of development (e.g., clearing and grading, utility installation, active construction, final stabilization). Some municipalities in the Denver area set maximum sizes for disturbed area associated with phases of a construction project. Additionally, requirements for phased construction drawings vary among local governments within the UDFCD boundary. Some local governments require separate erosion and sediment control drawings for initial BMPs, interim conditions (in active construction), and final stabilization.

Construction Scheduling	
Functions	
Erosion Control	Moderate
Sediment Control	Moderate
Site/Material Management	Yes

Typical construction phasing BMPs include:

- Limit the amount of disturbed area at any given time on a site to the extent practical. For example, a 100-acre subdivision might be constructed in five phases of 20 acres each.
- If there is carryover of stockpiled material from one phase to the next, position carryover material in a location easily accessible for the pending phase that will not require disturbance of stabilized areas to access the stockpile. Particularly with regard to efforts to balance cut and fill at a site, careful planning for location of stockpiles is important.

Typical construction sequencing BMPs include:

- Sequence construction activities to minimize duration of soil disturbance and exposure. For example, when multiple utilities will occupy the same trench, schedule installation so that the trench does not have to be closed and opened multiple times.
- Schedule site stabilization activities (e.g., landscaping, seeding and mulching, installation of erosion control blankets) as soon as feasible following grading.
- Install initial erosion and sediment control practices before construction begins. Promptly install additional BMPs for inlet protection, stabilization, etc., as construction activities are completed.

Table CP-1 provides typical sequencing of construction activities and associated BMPs.

Maintenance and Removal

When the construction schedule is altered, erosion and sediment control measures in the SWMP and construction drawings should be appropriately adjusted to reflect actual "on the ground" conditions at the construction site. Be aware that changes in construction schedules can have significant implications for site stabilization, particularly with regard to establishment of vegetative cover.

Table CP-1. Typical Phased BMP Installation for Construction Projects

Project Phase	BMPs
Pre-disturbance, Site Access	▪ Install sediment controls downgradient of access point (on paved streets this may consist of inlet protection). ▪ Establish vehicle tracking control at entrances to paved streets. Fence as needed. ▪ Use construction fencing to define the boundaries of the project and limit access to areas of the site that are not to be disturbed. **Note: it may be necessary to protect inlets in the general vicinity of the site, even if not downgradient, if there is a possibility that sediment tracked from the site could contribute to the inlets.**
Site Clearing and Grubbing	▪ Install perimeter controls as needed on downgradient perimeter of site (silt fence, wattles, etc). ▪ Limit disturbance to those areas planned for disturbance and protect undisturbed areas within the site (construction fence, flagging, etc). ▪ Preserve vegetative buffer at site perimeter. ▪ Create stabilized staging area. ▪ Locate portable toilets on flat surfaces away from drainage paths. Stake in areas susceptible to high winds. ▪ Construct concrete washout area and provide signage. ▪ Establish waste disposal areas. ▪ Install sediment basins. ▪ Create dirt perimeter berms and/or brush barriers during grubbing and clearing. ▪ Separate and stockpile topsoil, leave roughened and/or cover. ▪ Protect stockpiles with perimeter control BMPs. Stockpiles should be located away from drainage paths and should be accessed from the upgradient side so that perimeter controls can remain in place on the downgradient side. Use erosion control blankets, temporary seeding, and/or mulch for stockpiles that will be inactive for an extended period. ▪ Leave disturbed area of site in a roughened condition to limit erosion. Consider temporary revegetation for areas of the site that have been disturbed but that will be inactive for an extended period. ▪ Water to minimize dust but not to the point that watering creates runoff.

Project Phase	BMPs
Utility And Infrastructure Installation	**In Addition to the Above BMPs:** ▪ Close trench as soon as possible (generally at the end of the day). ▪ Use rough-cut street control or apply road base for streets that will not be promptly paved. ▪ Provide inlet protection as streets are paved and inlets are constructed. ▪ Protect and repair BMPs, as necessary. ▪ Perform street sweeping as needed.
Building Construction	**In Addition to the Above BMPs:** ▪ Implement materials management and good housekeeping practices for home building activities. ▪ Use perimeter controls for temporary stockpiles from foundation excavations. ▪ For lots adjacent to streets, lot-line perimeter controls may be necessary at the back of curb.
Final Grading	**In Addition to the Above BMPs:** ▪ Remove excess or waste materials. ▪ Remove stored materials.
Final Stabilization	**In Addition to the Above BMPs:** ▪ Seed and mulch/tackify. ▪ Seed and install blankets on steep slopes. ▪ Remove all temporary BMPs when site has reached final stabilization.

Description

Protection of existing vegetation on a construction site can be accomplished through installation of a construction fence around the area requiring protection. In cases where upgradient areas are disturbed, it may also be necessary to install perimeter controls to minimize sediment loading to sensitive areas such as wetlands. Existing vegetation may be designated for protection to maintain a stable surface cover as part of construction phasing, or vegetation may be protected in areas designated to remain in natural condition under post-development conditions (e.g., wetlands, mature trees, riparian areas, open space).

Photograph PV-1. Protection of existing vegetation and a sensitive area. Photo courtesy of CDOT.

Appropriate Uses

Existing vegetation should be preserved for the maximum practical duration on a construction site through the use of effective construction phasing. Preserving vegetation helps to minimize erosion and can reduce revegetation costs following construction.

Protection of wetland areas is required under the Clean Water Act, unless a permit has been obtained from the U.S. Army Corps of Engineers (USACE) allowing impacts in limited areas.

If trees are to be protected as part of post-development landscaping, care must be taken to avoid several types of damage, some of which may not be apparent at the time of injury. Potential sources of injury include soil compaction during grading or due to construction traffic, direct equipment-related injury such as bark removal, branch breakage, surface grading and trenching, and soil cut and fill. In order to minimize injuries that may lead to immediate or later death of the tree, tree protection zones should be developed during site design, implemented at the beginning of a construction project, as well as continued during active construction.

Design and Installation

General

Once an area has been designated as a preservation area, there should be no construction activity allowed within a set distance of the area. Clearly mark the area with construction fencing. Do not allow stockpiles, equipment, trailers or parking within the protected area. Guidelines to protect various types of existing vegetation follow.

Protection of Existing Vegetation	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	Yes

Surface Cover During Phased Construction

Install construction fencing or other perimeter controls around areas to be protected from clearing and grading as part of construction phasing.

Maintaining surface cover on steep slopes for the maximum practical duration during construction is recommended.

Open Space Preservation

Where natural open space areas will be preserved as part of a development, it is important to install construction fencing around these areas to protect them from compaction. This is particularly important when areas with soils with high infiltration rates are preserved as part of LID designs. Preserved open space areas should not be used for staging and equipment storage.

Wetlands and Riparian Areas

Install a construction fence around the perimeter of the wetland or riparian (streamside vegetation) area to prevent access by equipment. In areas downgradient of disturbed areas, install a perimeter control such as silt fence, sediment control logs, or similar measure to minimize sediment loading to the wetland.

Tree Protection[1]

- Before beginning construction operations, establish a tree protection zone around trees to be preserved by installing construction fences. Allow enough space from the trunk to protect the root zone from soil compaction and mechanical damage, and the branches from mechanical damage (see Table PV-1). If low branches will be kept, place the fence outside of the drip line. Where this is not possible, place fencing as far away from the trunk as possible. In order to maintain a healthy tree, be aware that about 60 percent of the tree's root zone extends beyond the drip line.

Table PV-1
Guidelines for Determining the Tree Protection Zone
(Source: Matheny and Clark, 1998; as cited in GreenCO and WWE 2008)

	Distance from Trunk (ft) per inch of DBH		
Species Tolerance to Damage	*Young*	*Mature*	*Over mature*
Good	0.5'	0.75'	1.0'
Moderate	0.75'	1.0'	1.25'
Poor	1.0'	1.25'	1.5'
Notes: DBH = diameter at breast height (4.5 ft above grade); Young = <20% of life expectancy; Mature = 20%-80% of life expectancy; Over mature =>80% of life expectancy			

- Most tree roots grow within the top 12 to 18 inches of soil. Grade changes within the tree protection zone should be avoided where possible because seemingly minor grade changes can either smother

[1] Tree Protection guidelines adapted from GreenCO and WWE (2008). *Green Industry Best Management Practices (BMPs) for the Conservation and Protection of Water Resources in Colorado: Moving Toward Sustainability, Third Release.* See www.greenco.org for more detailed guidance on tree preservation.

roots (in fill situations) or damage roots (in cut situations). Consider small walls where needed to avoid grade changes in the tree protection zone.

- Place and maintain a layer of mulch 4 to 6-inch thick from the tree trunk to the fencing, keeping a 6-inch space between the mulch and the trunk. Mulch helps to preserve moisture and decrease soil compaction if construction traffic is unavoidable. When planting operations are completed, the mulch may be reused throughout planting areas.

- Limit access, if needed at all, and appoint one route as the main entrance and exit to the tree protection zone. Within the tree protection zone, do not allow any equipment to be stored, chemicals to be dumped, or construction activities to take place except fine grading, irrigation system installation, and planting operations. These activities should be conducted in consultation with a landscaping professional, following Green Industry BMPs.

- Be aware that soil compaction can cause extreme damage to tree health that may appear gradually over a period of years. Soil compaction is easier to prevent than repair.

Maintenance and Removal

Repair or replace damaged or displaced fencing or other protective barriers around the vegetated area.

If damage occurs to a tree, consult an arborist for guidance on how to care for the tree. If a tree in a designated preservation area is damaged beyond repair, remove and replace with a 2-inch diameter tree of the same or similar species.

Construction equipment must not enter a wetland area, except as permitted by the U.S. Army Corps of Engineers (USACE). Inadvertent placement of fill in a wetland is a 404 permit violation and will require notification of the USACE.

If damage to vegetation occurs in a protected area, reseed the area with the same or similar species, following the recommendations in the USDCM *Revegetation* chapter.

Photograph CF-1. A construction fence helps delineate areas where existing vegetation is being protected. Photo courtesy of Douglas County.

Description

A construction fence restricts site access to designated entrances and exits, delineates construction site boundaries, and keeps construction out of sensitive areas such as natural areas to be preserved as open space, wetlands and riparian areas.

Appropriate Uses

A construction fence can be used to delineate the site perimeter and locations within the site where access is restricted to protect natural resources such as wetlands, waterbodies, trees, and other natural areas of the site that should not be disturbed.

If natural resource protection is an objective, then the construction fencing should be used in combination with other perimeter control BMPs such as silt fence, sediment control logs or similar measures.

Design and Installation

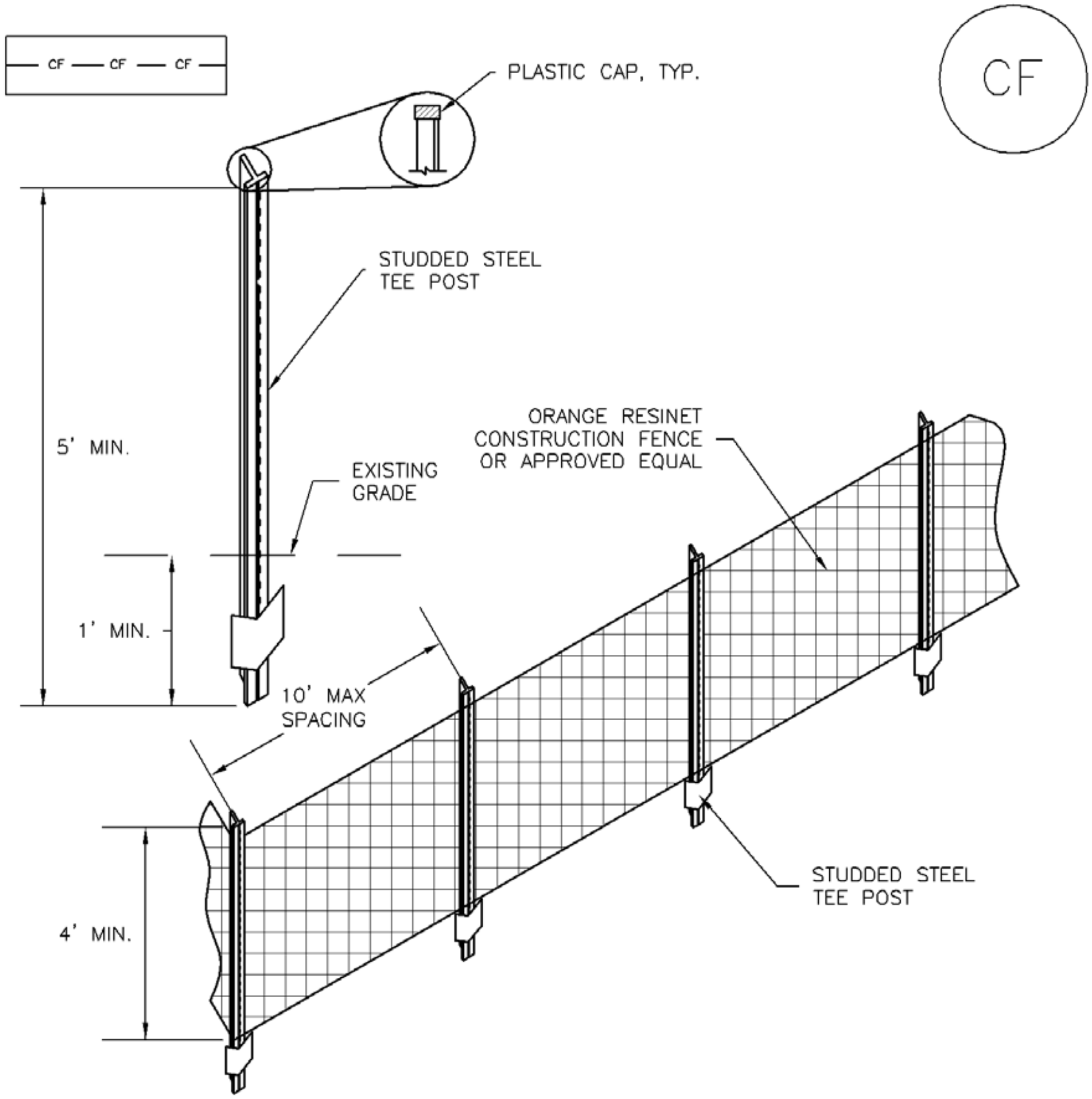
Construction fencing may be chain link or plastic mesh and should be installed following manufacturer's recommendations. See Detail CF-1 for typical installations.

Do not place construction fencing in areas within work limits of machinery.

Maintenance and Removal

- Inspect fences for damage; repair or replace as necessary.
- Fencing should be tight and any areas with slumping or fallen posts should be reinstalled.
- Fencing should be removed once construction is complete.

Construction Fence	
Functions	
Erosion Control	No
Sediment Control	No
Site/Material Management	Yes



CF–1. PLASTIC MESH CONSTRUCTION FENCE

CONSTRUCTION FENCE INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   –LOCATION OF CONSTRUCTION FENCE.

2. CONSTRUCTION FENCE SHOWN SHALL BE INSTALLED PRIOR TO ANY LAND DISTURBING ACTIVITIES.

3. CONSTRUCTION FENCE SHALL BE COMPOSED OF ORANGE, CONTRACTOR–GRADE MATERIAL THAT IS AT LEAST 4' HIGH. METAL POSTS SHOULD HAVE A PLASTIC CAP FOR SAFETY.

4. STUDDED STEEL TEE POSTS SHALL BE UTILIZED TO SUPPORT THE CONSTRUCTION FENCE. MAXIMUM SPACING FOR STEEL TEE POSTS SHALL BE 10'.

5. CONSTRUCTION FENCE SHALL BE SECURELY FASTENED TO THE TOP, MIDDLE, AND BOTTOM OF EACH POST.

CONSTRUCTION FENCE MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. CONSTRUCTION FENCE SHALL BE REPAIRED OR REPLACED WHEN THERE ARE SIGNS OF DAMAGE SUCH AS RIPS OR SAGS. CONSTRUCTION FENCE IS TO REMAIN IN PLACE UNTIL THE UPSTREAM DISTURBED AREA IS STABILIZED AND APPROVED BY THE LOCAL JURISDICTION.

5. WHEN CONSTRUCTION FENCES ARE REMOVED, ALL DISTURBED AREAS ASSOCIATED WITH THE INSTALLATION, MAINTENANCE, AND/OR REMOVAL OF THE FENCE SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED, OR OTHERWISE STABILIZED AS APPROVED BY LOCAL JURISDICTION.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAIL ADAPTED FROM TOWN OF PARKER, COLORADO, NOT AVAILABLE IN AUTOCAD)

Description

Vehicle tracking controls provide stabilized construction site access where vehicles exit the site onto paved public roads. An effective vehicle tracking control helps remove sediment (mud or dirt) from vehicles, reducing tracking onto the paved surface.

Photograph VTC-1. A vehicle tracking control pad constructed with properly sized rock reduces off-site sediment tracking.

Appropriate Uses

Implement a stabilized construction entrance or vehicle tracking control where frequent heavy vehicle traffic exits the construction site onto a paved roadway. An effective vehicle tracking control is particularly important during the following conditions:

- Wet weather periods when mud is easily tracked off site.
- During dry weather periods where dust is a concern.
- When poorly drained, clayey soils are present on site.

Although wheel washes are not required in designs of vehicle tracking controls, they may be needed at particularly muddy sites.

Design and Installation

Construct the vehicle tracking control on a level surface. Where feasible, grade the tracking control towards the construction site to reduce off-site runoff. Place signage, as needed, to direct construction vehicles to the designated exit through the vehicle tracking control. There are several different types of stabilized construction entrances including:

VTC-1. Aggregate Vehicle Tracking Control. This is a coarse-aggregate surfaced pad underlain by a geotextile. This is the most common vehicle tracking control, and when properly maintained can be effective at removing sediment from vehicle tires.

VTC-2. Vehicle Tracking Control with Construction Mat or Turf Reinforcement Mat. This type of control may be appropriate for site access at very small construction sites with low traffic volume over vegetated areas. Although this application does not typically remove sediment from vehicles, it helps protect existing vegetation and provides a stabilized entrance.

Vehicle Tracking Control	
Functions	
Erosion Control	Moderate
Sediment Control	Yes
Site/Material Management	Yes

VTC-3. Stabilized Construction Entrance/Exit with Wheel Wash. This is an aggregate pad, similar to VTC-1, but includes equipment for tire washing. The wheel wash equipment may be as simple as hand-held power washing equipment to more advance proprietary systems. When a wheel wash is provided, it is important to direct wash water to a sediment trap prior to discharge from the site.

Vehicle tracking controls are sometimes installed in combination with a sediment trap to treat runoff.

Maintenance and Removal

Inspect the area for degradation and replace aggregate or material used for a stabilized entrance/exit as needed. If the area becomes clogged and ponds water, remove and dispose of excess sediment or replace material with a fresh layer of aggregate as necessary.

Photograph VTC-2. A vehicle tracking control pad with wheel wash facility. Photo courtesy of Tom Gore.

With aggregate vehicle tracking controls, ensure rock and debris from this area do not enter the public right-of-way.

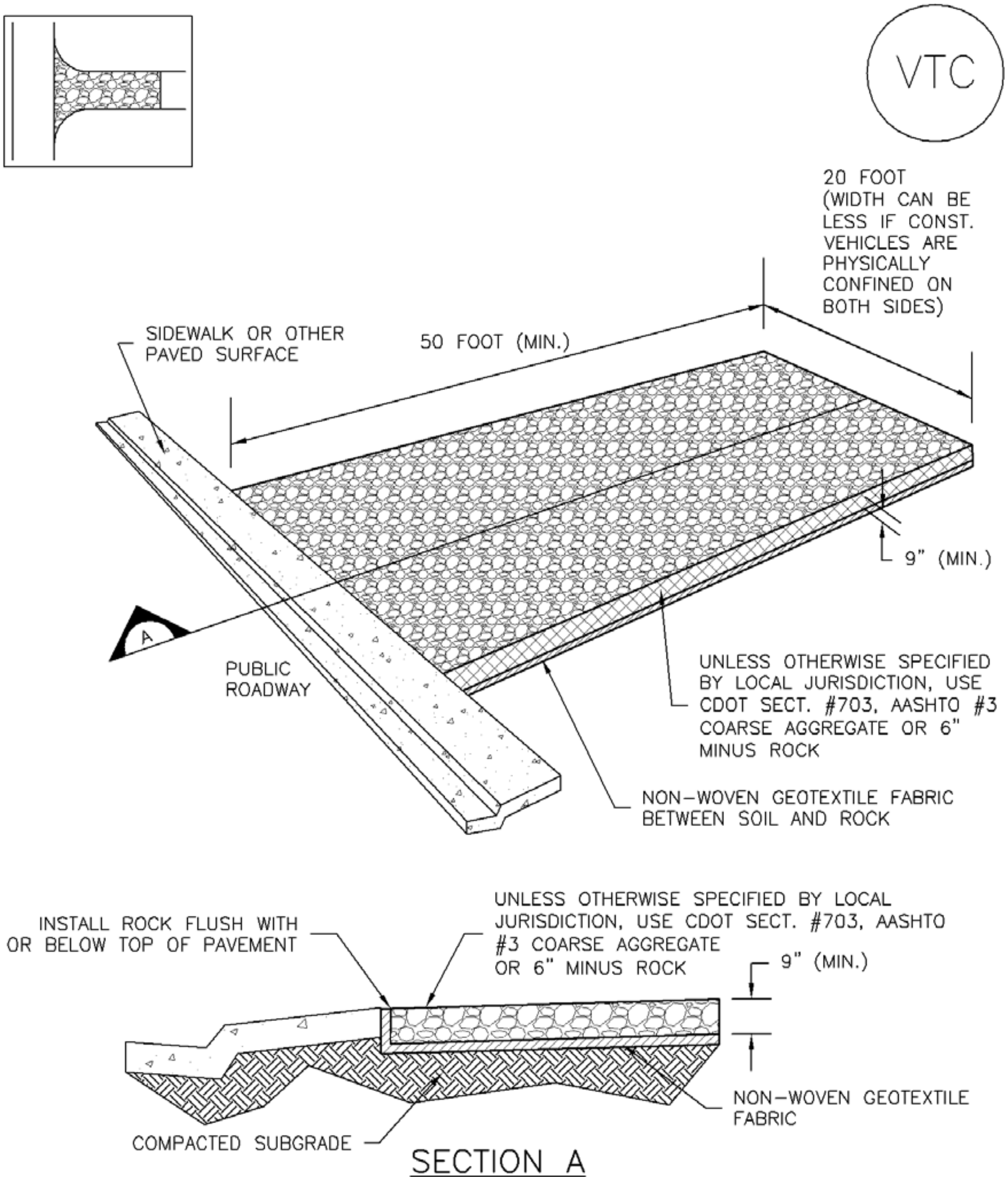
Remove sediment that is tracked onto the public right of way daily or more frequently as needed. Excess sediment in the roadway indicates that the stabilized construction entrance needs maintenance.

Ensure that drainage ditches at the entrance/exit area remain clear.

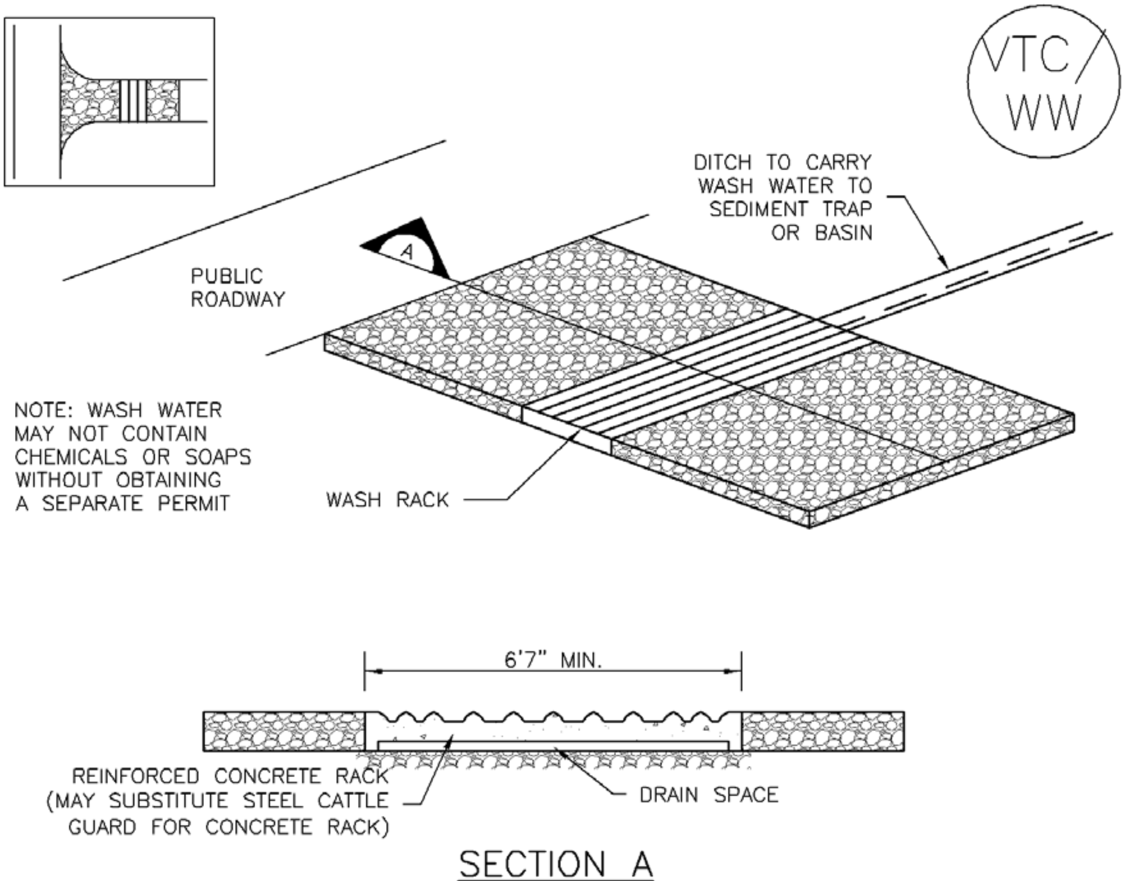
A stabilized entrance should be removed only when there is no longer the potential for vehicle tracking to occur. This is typically after the site has been stabilized.

When wheel wash equipment is used, be sure that the wash water is discharged to a sediment trap prior to discharge. Also inspect channels conveying the water from the wash area to the sediment trap and stabilize areas that may be eroding.

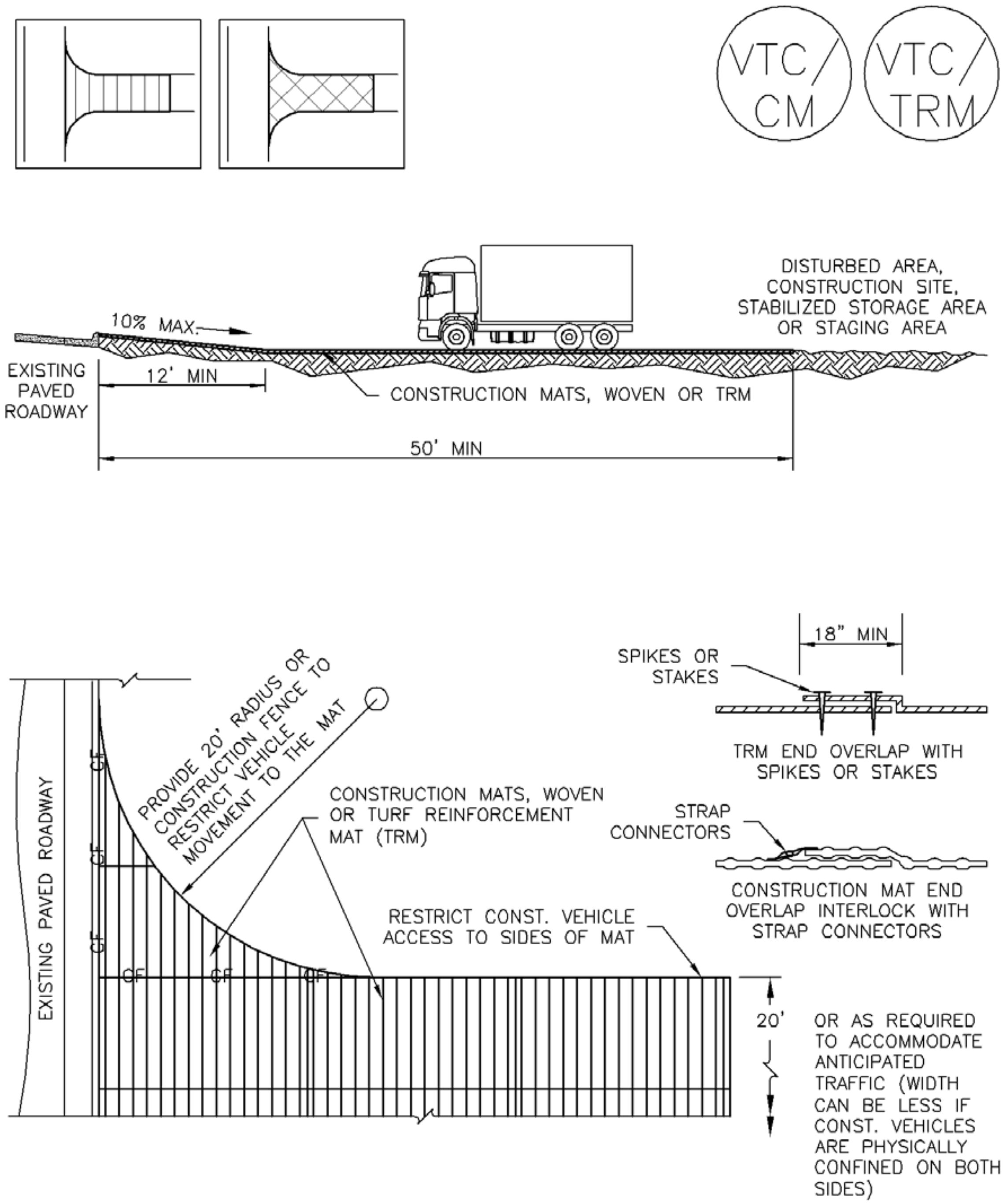
When a construction entrance/exit is removed, excess sediment from the aggregate should be removed and disposed of appropriately. The entrance should be promptly stabilized with a permanent surface following removal, typically by paving.



VTC-1. AGGREGATE VEHICLE TRACKING CONTROL



VTC–2. AGGREGATE VEHICLE TRACKING CONTROL WITH WASH RACK



VTC-3. VEHICLE TRACKING CONTROL W/ CONSTRUCTION MAT OR TURF REINFORCEMENT MAT (TRM)

STABILIZED CONSTRUCTION ENTRANCE/EXIT INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   -LOCATION OF CONSTRUCTION ENTRANCE(S)/EXIT(S).
   -TYPE OF CONSTRUCTION ENTRANCE(S)/EXITS(S) (WITH/WITHOUT WHEEL WASH, CONSTRUCTION MAT OR TRM).

2. CONSTRUCTION MAT OR TRM STABILIZED CONSTRUCTION ENTRANCES ARE ONLY TO BE USED ON SHORT DURATION PROJECTS (TYPICALLY RANGING FROM A WEEK TO A MONTH) WHERE THERE WILL BE LIMITED VEHICULAR ACCESS.

3. A STABILIZED CONSTRUCTION ENTRANCE/EXIT SHALL BE LOCATED AT ALL ACCESS POINTS WHERE VEHICLES ACCESS THE CONSTRUCTION SITE FROM PAVED RIGHT-OF-WAYS.

4. STABILIZED CONSTRUCTION ENTRANCE/EXIT SHALL BE INSTALLED PRIOR TO ANY LAND DISTURBING ACTIVITIES.

5. A NON-WOVEN GEOTEXTILE FABRIC SHALL BE PLACED UNDER THE STABILIZED CONSTRUCTION ENTRANCE/EXIT PRIOR TO THE PLACEMENT OF ROCK.

6. UNLESS OTHERWISE SPECIFIED BY LOCAL JURISDICTION, ROCK SHALL CONSIST OF DOT SECT. #703, AASHTO #3 COARSE AGGREGATE OR 6" (MINUS) ROCK.

STABILIZED CONSTRUCTION ENTRANCE/EXIT MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. ROCK SHALL BE REAPPLIED OR REGRADED AS NECESSARY TO THE STABILIZED ENTRANCE/EXIT TO MAINTAIN A CONSISTENT DEPTH.

5. SEDIMENT TRACKED ONTO PAVED ROADS IS TO BE REMOVED THROUGHOUT THE DAY AND AT THE END OF THE DAY BY SHOVELING OR SWEEPING. SEDIMENT MAY NOT BE WASHED DOWN STORM SEWER DRAINS.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM CITY OF BROOMFIELD, COLORADO, NOT AVAILABLE IN AUTOCAD)

Description

A stabilized construction roadway is a temporary method to control sediment runoff, vehicle tracking, and dust from roads during construction activities.

Photograph SCR-1. Stabilized construction roadway.

Appropriate Uses

Use on high traffic construction roads to minimize dust and erosion.

Stabilized construction roadways are used instead of rough-cut street controls on roadways with frequent construction traffic.

Design and Installation

Stabilized construction roadways typically involve two key components: 1) stabilizing the road surface with an aggregate base course of 3-inch-diameter granular material and 2) stabilizing roadside ditches, if applicable. Early application of road base is generally suitable where a layer of coarse aggregate is specified for final road construction.

Maintenance and Removal

Apply additional gravel as necessary to ensure roadway integrity.

Inspect drainage ditches along the roadway for erosion and stabilize, as needed, through the use of check dams or rolled erosion control products.

Gravel may be removed once the road is ready to be paved. Prior to paving, the road should be inspected for grade changes and damage. Regrade and repair as necessary.

Stabilized Construction Roadway	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material Management	Yes

Stabilized Staging Area (SSA) SM-6

Photograph SSA-1. Example of a staging area with a gravel surface to prevent mud tracking and reduce runoff. Photo courtesy of Douglas County.

Description

A stabilized staging area is a clearly designated area where construction equipment and vehicles, stockpiles, waste bins, and other construction-related materials are stored. The contractor office trailer may also be located in this area. Depending on the size of the construction site, more than one staging area may be necessary.

Appropriate Uses

Most construction sites will require a staging area, which should be clearly designated in SWMP drawings. The layout of the staging area may vary depending on the type of construction activity. Staging areas located in roadways due to space constraints require special measures to avoid materials being washed into storm inlets.

Design and Installation

Stabilized staging areas should be completed prior to other construction activities beginning on the site. Major components of a stabilized staging area include:

- Appropriate space to contain storage and provide for loading/unloading operations, as well as parking if necessary.
- A stabilized surface, either paved or covered, with 3-inch diameter aggregate or larger.
- Perimeter controls such as silt fence, sediment control logs, or other measures.
- Construction fencing to prevent unauthorized access to construction materials.
- Provisions for Good Housekeeping practices related to materials storage and disposal, as described in the Good Housekeeping BMP Fact Sheet.
- A stabilized construction entrance/exit, as described in the Vehicle Tracking Control BMP Fact Sheet, to accommodate traffic associated with material delivery and waste disposal vehicles.

Over-sizing the stabilized staging area may result in disturbance of existing vegetation in excess of that required for the project. This increases costs, as well as requirements for long-term stabilization following the construction period. When designing the stabilized staging area, minimize the area of disturbance to the extent practical.

Stabilized Staging Area	
Functions	
Erosion Control	Yes
Sediment Control	Moderate
Site/Material	Yes

Minimizing Long-Term Stabilization Requirements

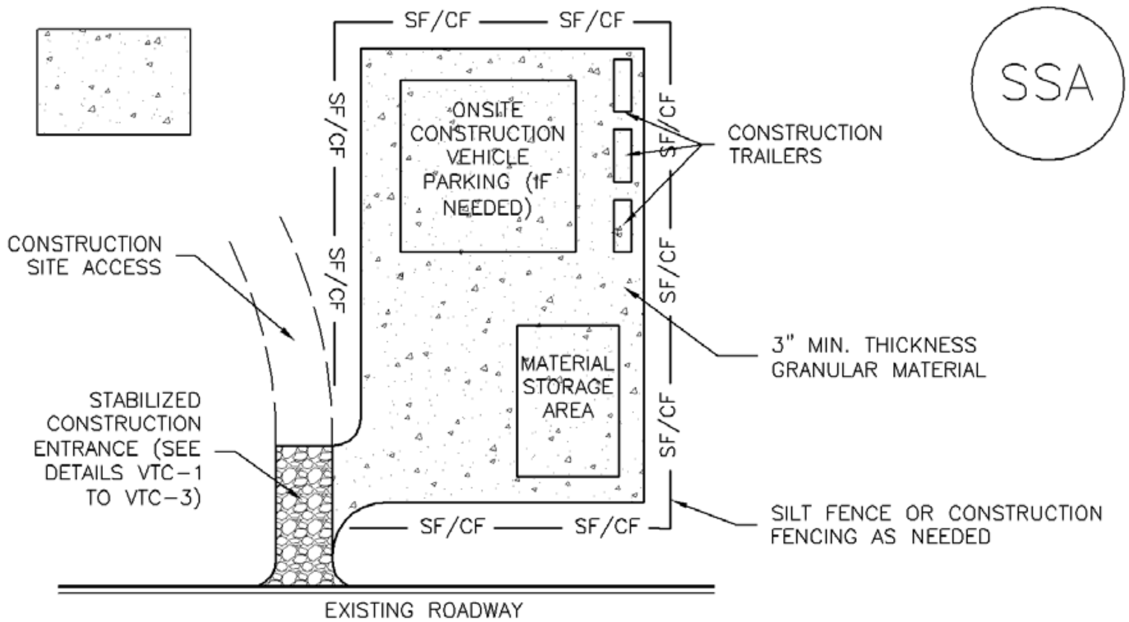
- Utilize off-site parking and restrict vehicle access to the site.
- Use construction mats in lieu of rock when staging is provided in an area that will not be disturbed otherwise.
- Consider use of a bermed contained area for materials and equipment that do not require a stabilized surface.
- Consider phasing of staging areas to avoid disturbance in an area that will not be otherwise disturbed.

See Detail SSA-1 for a typical stabilized staging area and SSA-2 for a stabilized staging area when materials staging in roadways is required.

Maintenance and Removal

Maintenance of stabilized staging areas includes maintaining a stable surface cover of gravel, repairing perimeter controls, and following good housekeeping practices.

When construction is complete, debris, unused stockpiles and materials should be recycled or properly disposed. In some cases, this will require disposal of contaminated soil from equipment leaks in an appropriate landfill. Staging areas should then be permanently stabilized with vegetation or other surface cover planned for the development.



SSA-1. STABILIZED STAGING AREA

STABILIZED STAGING AREA INSTALLATION NOTES

1. SEE PLAN VIEW FOR
   - -LOCATION OF STAGING AREA(S).
   - -CONTRACTOR MAY ADJUST LOCATION AND SIZE OF STAGING AREA WITH APPROVAL FROM THE LOCAL JURISDICTION.

2. STABILIZED STAGING AREA SHOULD BE APPROPRIATE FOR THE NEEDS OF THE SITE. OVERSIZING RESULTS IN A LARGER AREA TO STABILIZE FOLLOWING CONSTRUCTION.

3. STAGING AREA SHALL BE STABILIZED PRIOR TO OTHER OPERATIONS ON THE SITE.

4. THE STABILIZED STAGING AREA SHALL CONSIST OF A MINIMUM 3" THICK GRANULAR MATERIAL.

5. UNLESS OTHERWISE SPECIFIED BY LOCAL JURISDICTION, ROCK SHALL CONSIST OF DOT SECT. #703, AASHTO #3 COARSE AGGREGATE OR 6" (MINUS) ROCK.

6. ADDITIONAL PERIMETER BMPs MAY BE REQUIRED INCLUDING BUT NOT LIMITED TO SILT FENCE AND CONSTRUCTION FENCING.

STABILIZED STAGING AREA MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. ROCK SHALL BE REAPPLIED OR REGRADED AS NECESSARY IF RUTTING OCCURS OR UNDERLYING SUBGRADE BECOMES EXPOSED.

STABILIZED STAGING AREA MAINTENANCE NOTES

5. STABILIZED STAGING AREA SHALL BE ENLARGED IF NECESSARY TO CONTAIN PARKING, STORAGE, AND UNLOADING/LOADING OPERATIONS.

6. THE STABILIZED STAGING AREA SHALL BE REMOVED AT THE END OF CONSTRUCTION. THE GRANULAR MATERIAL SHALL BE REMOVED OR, IF APPROVED BY THE LOCAL JURISDICTION, USED ON SITE, AND THE AREA COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY LOCAL JURISDICTION.

NOTE: MANY MUNICIPALITIES PROHIBIT THE USE OF RECYCLED CONCRETE AS GRANULAR MATERIAL FOR STABILIZED STAGING AREAS DUE TO DIFFICULTIES WITH RE-ESTABLISHMENT OF VEGETATION IN AREAS WHERE RECYCLED CONCRETE WAS PLACED.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO, NOT AVAILABLE IN AUTOCAD)

Description

Street sweeping and vacuuming remove sediment that has been tracked onto roadways to reduce sediment transport into storm drain systems or a surface waterway.

Photograph SS-1. A street sweeper removes sediment and potential pollutants along the curb line at a construction site. Photo courtesy of Tom Gore.

Appropriate Uses

Use this practice at construction sites where vehicles may track sediment offsite onto paved roadways.

Design and Installation

Street sweeping or vacuuming should be conducted when there is noticeable sediment accumulation on roadways adjacent to the construction site. Typically, this will be concentrated at the entrance/exit to the construction site. Well-maintained stabilized construction entrances, vehicle tracking controls and tire wash facilities can help reduce the necessary frequency of street sweeping and vacuuming.

On smaller construction sites, street sweeping can be conducted manually using a shovel and broom. Never wash accumulated sediment on roadways into storm drains.

Maintenance and Removal

- Inspect paved roads around the perimeter of the construction site on a daily basis and more frequently, as needed. Remove accumulated sediment, as needed.
- Following street sweeping, check inlet protection that may have been displaced during street sweeping.
- Inspect area to be swept for materials that may be hazardous prior to beginning sweeping operations.

Street Sweeping/ Vacuuming	
Functions	
Erosion Control	No
Sediment Control	Yes
Site/Material Management	Yes

Description

Temporary diversion methods are used to reroute water from a stream or restrict flows to a designated portion of the stream channel to allow for construction activities to take place in the stream, along the banks or beneath the active channel. Temporary diversion methods are often required during the construction of detention ponds, dams, in-stream grade control structures, utility installation and other activities, including maintenance, that require working in waterways. Temporary diversion methods include temporary diversion channels, pump-arounds, piped diversions, coffer dams and other similar practices. The primary purpose of all temporary diversion methods is to protect water quality by passing upstream flows around the active construction zone.

Photograph TDM-1. This coffer dam, installed to allow grading and stabilization of the stream bank, consists of concrete blocks covered by an impermeable linear held in place by sand bags.

Appropriate Uses

Temporary diversion methods are appropriate in situations when it is necessary to divert the flow around the area where work is being conducted. Temporary diversion methods vary with the size of the waterway that is being diverted.

Temporary Diversion Channel	
Functions	
Erosion Control	Yes
Sediment Control	No
Site/Material Management	No

For large streams, a temporary diversion may consist of berms or coffer dams constructed within the stream to confine flow to one side of the stream while work progresses on the "dry" side of the berm. For smaller streams and often for construction of dams and detention basins, a temporary diversion method may divert the entire waterway. For short duration projects (typically less than a month of active construction) with low baseflows, a pump and/or bypass pipe may serve as a temporary diversion. Whenever a temporary diversion is used, construction should be scheduled during drier times of the year (November through March) to the extent feasible, and construction in the waterway should progress as quickly as practical to reduce the risk of exceeding the temporary diversion capacity. Timing and duration of construction are primary considerations for determining the design flow most appropriate for a diversion. A sizing method that does not consider these variables is overly simplistic and can result in inflated project costs and land disturbances that provide little to no water quality benefit. Additionally, disturbing more area than necessary can result in increased erosion.

Temporary diversion method section and approach should occur on a project- and site-specific basis. For short duration projects (typically associated with maintenance of utilities and stream crossings and minor repairs to outfalls and eroded banks) constructed during dry times of the year, diversion construction can create greater disturbance and mobilization of sediment than all of the other earth disturbing activities of the project combined, and the cost of the diversion could be a significant percentage of the overall project cost. If it can be reasonably determined, based on area and duration of disturbance, that channel work will result in less disturbance and movement of sediment than would occur through installation of a temporary diversion, it is reasonable to exempt these activities from the requirement to construct a temporary diversion.

On the other end of the spectrum, a basis of design for a temporary diversion in excess of the methodology presented in this Fact Sheet may be appropriate for longer duration projects and/or projects where the consequences of exceeding diversion capacity are significant in terms of public safety, damage to infrastructure and property, environmental impacts, damage or delay to the project and other factors. In short, engineers should recognize that temporary diversions must be thoughtfully analyzed on a case-by-case basis, considering site-specific circumstances.

Design Considerations

Selection and design of temporary diversion methods should consider many factors, including:

- Will construction of a temporary diversion cause greater environmental impacts than if the project is constructed without a temporary diversion? This frequently applies to short duration, small scale projects associated with maintenance activities such as bank erosion repair, drop structure and pond maintenance, outfall improvements/repair and other limited construction activities.

- Size of stream, tributary watershed area and anticipated flow rates during construction. Special consideration should be given to large streams with large tributary areas with higher flow rates since the sizing methodology presented in this Fact Sheet is based on data from watersheds less than 20 square miles.

- Any special water quality or aquatic life conditions the waterway.

- Nature of surrounding land use, property ownership, and easements in the project area are important considerations in determining feasibility and methods for temporary diversions. For example, in a highly urbanized setting or an area with limited right-of-way, there may not be adequate space to construct a diversion channel.

- Seasonal variations in stream hydrology (baseflow vs. peak flow).
  - Irrigation flows: If an irrigation ditch enters the stream, it is recommended that the ditch company be contacted to confirm when flows from the ditch may be expected.
  - Weather (storm runoff): If diversions are constructed in summer months when thunderstorms and flash flooding can occur, contractors will need to track weather forecasts closely and provide additional protection when higher flows from runoff are anticipated. The UDFCD Alert System can be used for daily forecasts and to provide warnings for severe weather.

- Probability of flood flows exceeding diversion capacity and/or diversion failure. Consider the consequences of exceedance or failure such as:
  - Public safety
  - Environmental
  - Legal
  - Regulatory
  - Economic
  - Project disruption/delay

- Realistic estimation of project duration and time of year during which construction will occur.

- Comparison of the overall project costs to the temporary diversion costs (design and construction) and determining the costs and benefits of different diversion strategies relative to the protection that they provide.

- Permitting requirements for overall project and for diversion methods (United States Army Corps of Engineers, United States Fish and Wildlife Service, Colorado Department of Public Health and Environment, Federal Emergency Management Agency, Division of Water Resources, local governments, and others). Permit requirements and existing vegetative cover may limit the allowable area disturbance.

- Public safety aspects. For example, if a pipeline is being used, consideration should be given to public access and inlet protection.

- Legal considerations, which are a function of many different factors such as property ownership, history of localized flooding, or parties that will have interest in project.

Design and Installation

1. Determine if a diversion is appropriate based on appropriate uses and design considerations stated earlier. As noted, in some cases, constructing a project under wet conditions is preferable to constructing a temporary diversion to create dry conditions, especially if construction of the temporary diversion will require a significant amount of disturbance relative to the overall project.

2. Determine project duration.

   - "Long duration" projects are projects that last <u>longer than three months</u> and in many cases are Capital Improvement Projects or traditional land development projects.

   - "Short duration" projects are projects that are completed within <u>one month or less</u> and generally are associated with maintenance and repair activities.

   - "Interim duration" projects are projects that will last <u>longer than one month but up to three months</u>.

3. Determine the time of year in which construction will occur.

4. Gather necessary temporary diversion sizing parameters that may include tributary area, imperviousness, project duration safety factor, and seasonal sizing coefficient.

5. Apply applicable sizing methodology and perform necessary calculations (provided following this section). Use engineering judgment to determine if the temporary diversion design flow is adequate for the specific project.

6. Determine appropriate method of diversion. Follow the design steps for the selected method discussed below.

   - <u>Channel Diversion</u> – For smaller streams, construction of dams and detention basins, or as the site allows, a channel diversion may divert the entire waterway as illustrated in Figure TDM-1.

- Berm or Coffer Dam – A berm or coffer dam is appropriate for streams of all sizes to confine flow to one side of the stream.

- Piped Diversion – A bypass pipe is generally appropriate for short duration projects with low baseflows.

- Pumped Diversion – A pumped diversion may be appropriate for short duration projects with low baseflows. It may also be the only option where space for the diversion is limited as shown in photograph TDM-2.

Selecting a Diversion Method

Selection of the appropriate diversion type is largely site specific. The best choice represents the most efficient method while keeping disturbance to a minimum.

7. Consider developing an emergency action plan, as a precaution, for rapidly removing equipment and materials with potential to contribute pollutants to runoff from the waterway in advance of imminent runoff with the potential to exceed diversion capacity. The emergency action plan should designate an individual who will be on the site throughout most of the construction project with the authority to order that work be halted and equipment and materials with potential to contribute to stormwater pollution be moved to high ground outside of the active channel. The emergency action plan should identify where equipment and materials removed from the channel will be stored temporarily during a runoff event that is expected to exceed temporary diversion capacity. The UDFCD Alert System and warnings of the potential for severe weather issued by UDFCD should be consulted daily during construction.

Channel Diversion

1. Use sizing methodology to determine temporary diversion design flow rate.

2. Determine channel slope based on existing and proposed site conditions.

   Perform initial channel sizing calculations using Manning's Equation. Determine maximum permissible velocities based on lining material. Pay particular attention to diversion channel entrance, bends, transitions and downstream return to stream where scour forces may require greater protection. Unlined channels should not be used. Table TDM-1 gives Manning's "n" values for the most commonly used lining materials.

   Because temporary diversion channels typically are not in service long enough to establish adequate vegetative lining, they must be designed to be stable for the design flow with the channel shear stress less than the critical tractive shear stress for the channel lining material.

3. Determine the channel geometry and check the capacity using Manning's Equation and the "n" value given in Table TDM-1. The steepest side slope allowable is two horizontal to one vertical (2:1), unless vertical walls are installed using sheet piling, concrete or stacked stone. Consideration for public access and safety should be accounted for when determining channel geometry.

4. Determine depth of flow. A maximum depth of 1-foot is allowed for flows less than 20 cfs and a maximum of 3 feet for flows less than 100 cfs. (Flows in excess of 100 cfs should be designed in accordance with the *Major Drainage* chapter in Volume 1). Provide a minimum of 0.5 feet of freeboard above the design water surface elevation.

Table TDM-1. Manning's n Values for Temporary Diversion Channel Design

Lining Material	Manning's n Depth = 0 to 1.0 ft	Manning's n Depth = 1.0 to 3.0 ft	Manning's n Depth = 3.0 to 5.0 ft
Plastic Membrane	0.011	0.010	0.009
Straw/Curled Wood Mats	0.035	0.025	0.020
Riprap, Type VL	0.070	0.045	0.035
Riprap, Type L	0.100	0.070	0.040
Riprap, Type M	0.125	0.075	0.045

Note: Use manufacturer's Manning's n when available. See the *Major Drainage* chapter of the USDCM for riprap gradation. Erosion protection should extend a minimum of 0.5 feet above the design water depth.

Berm or Coffer Dam

For coffer dams or berms that are intended to isolate a portion of the stream from the work area steps 1-4 should be applied to the "wet" side of the coffer dam or berm.

1. Use sizing methodology to determine temporary diversion design flow rate.

2. Determine channel slope based on existing and proposed site conditions.

3. Perform initial channel sizing calculations using Manning's Equation. Determine maximum permissible velocities based on lining material. Because temporary diversion measures typically are not in service long enough to establish adequate vegetative lining, they must be designed to be stable for the design flow with the channel shear stress less than the critical tractive shear stress for the channel lining material. This stability criterion applies to the stream-side of berms when berms are used to isolate a work area within a stream.

4. Determine the channel geometry and check the capacity using Manning's Equation and the "n" value given in Table TDM-1. The steepest side slope allowable is two horizontal to one vertical (2:1), unless vertical walls are installed using sheet piling, concrete or stacked stone. Provide a minimum of 0.5 feet of freeboard above the design water surface elevation.

Piped Diversion

1. Use sizing methodology to determine temporary diversion design flow rate.

2. Size the pipe to accommodate the design flow using no more than 80 percent of the pipe full flow capacity. Select a Manning's n value based on the type of pipe material that will be used (concrete n = 0.013 [typ.], corrugated metal pipe n = 0.024 [typ.]).

Pumped Diversion

1. Use sizing methodology to determine temporary diversion design flow rate.

2. A backup pump (or pumps) with capacity equal to or greater than the diversion design flow rate should be on site and in good working order at all times.

Photograph TDM-2. Despite a relatively significant baseflow, a pumped diversion was selected for this Lakewood Gulch project due to a lack of space crossing Federal Boulevard. Photo courtesy of City and County of Denver.

Sizing Methodology

The methodology for sizing of temporary diversion methods was developed using baseflow observations and Crest Stage Indicator (CSI) peak flow data collected from 21 watersheds within the UDFCD boundary. These data were collected over extended periods of time (up to 31 years) and, as a result, provide a sound statistical basis for the sizing methodology.

Determine sizing procedure to use based on the project duration.

- "Long duration" projects last longer than three months and in many cases are Capital Improvement Projects or traditional land development projects.

- "Short duration" projects are completed within one month or less and generally are associated with maintenance and repair activities. For these projects, it is recommended that the temporary diversion be sized based on the statistics identified for baseflows (i.e., vs. peak flows) and be of sufficient size to convey a flow that has a less than 50% chance of being exceeded between November – March, including a project duration safety factor.

"Long duration" projects last longer than three months.

"Short duration" projects are completed within one month or less.

"Interim duration" projects last longer than one month and up to three months.

- "Interim duration" projects will last longer than one month but up to three months. In these projects, engineering judgment must be applied, drawing on sizing methods for "short duration" and "long duration" project criteria and the time of year of construction to develop a basis of design for the temporary diversion method that is appropriate for the project.

It is highly recommended that projects involving temporary diversions be constructed between November and March. If a short duration project requiring a temporary diversion must be conducted between April and October, the extended weather forecast should be evaluated to avoid periods of anticipated precipitation and a conservative safety factor should be applied. Additional protection may need to be provided for the site if higher flows from runoff are anticipated.

Sizing Procedure for Long Duration Projects (duration greater than three months)

1. Determine the tributary drainage area, *A*, in square miles.

2. Determine the watershed imperviousness (adjusted as appropriate for disconnected impervious area, see Chapter 3).

3. Determine the design peak flow rate according to Figure TDM-2. Note: For long duration projects, or where the consequences of diversion failure warrant, a larger design flow may be necessary, and/or a more detailed, site-specific hydrologic analysis.

Figure TDM-2 may be used to estimate the design discharge for the sizing of temporary diversion methods for projects exceeding three months in duration. The curves in this figure were originally developed using annual peak flow data collected from 17 watersheds within the UDFCD boundary and then updated in 2012 using annual peak flow data from 21 watersheds with CSI gages. These data were collected over extended periods of time (up to 31 years) and, as a result, provide a sound statistical basis for the figure. The data supporting Figure TDM-2 were taken during the high flood potential period of April through September.

Figure TDM-2 provides estimated 2-year peak flow rates with the upper 5% and lower 95% confidence limits shown and is based on watershed imperviousness for small waterways (25 square miles or less).[1] Because Figure TDM-2 was developed using data from small watersheds, it is not appropriate to extrapolate from this figure for larger, more complex watersheds. For larger waterways (e.g., South Platte River, Sand Creek, Bear Creek, etc.), including ones controlled by flood control reservoirs (e.g., Chatfield Dam, Cherry Creek Dam, etc.), site-specific hydrologic analysis and risk assessment will be necessary to evaluate the appropriate level of protection to be provided by the temporary diversion. For any size watershed, it is important that the designer understand watershed characteristics to determine applicability of the simplified method and how these characteristics influence the choice of diversion method. It is also important to recognize that larger floods can and do occur. It is the responsibility of the designer and the contractor to assess their risk of having the temporary diversion being exceeded and to evaluate the damages such an event may cause to the project, adjacent properties and others.

[1] There are a multitude of factors affecting rainfall-runoff response of a watershed in addition to impervious area. Other factors include soil types, total area, fraction of connected/disconnected impervious area, watershed shape, topography and many other factors). Figure TDM-2 provides a simplified design tool based on watershed imperviousness but should not be blindly relied upon without due consideration of other factors including those listed above and others.

Sizing Procedure for Short Duration Projects (one month or less of active construction)

1. Determine the tributary drainage area, *A*, in square miles.

2. Select a safety factor, *S*, based on project duration from Table TDM-2. Short duration projects have been broken down further into projects less than two weeks and projects from two weeks up to one month.

3. Select the sizing coefficient, *K*, corresponding to the month in which the project will occur (see Table TDM-2). For projects that span two months with different *K* values, use the greater of the two *K* values. For short duration projects that will occur during the traditionally dry period of the year (November through March) a *K* value of 0.2 is recommended. For short duration projects that will occur April through October, and wet weather is not predicted, a *K* value of 0.5 is recommended.

When a diversion is determined to be appropriate, safety factors and *K* values in Table TDM-2 are **minimum** recommended values. Depending on the many factors to consider in selecting and sizing a temporary diversion listed above, higher values for *K* and *S* may be appropriate.

Table TDM-2.Temporary Diversion Sizing Coefficients and Safety Factors for Short Duration Projects

Time of Year	Project Duration	Safety Factor, S	Temporary Diversion Sizing Coefficient, K
November - March	Less than 2 weeks	1.0	0.2
November - March	2 weeks to 1 month	1.5	0.2
April - October	Less than 2 weeks (during dry weather conditions)	1.0	0.5
April - October	2 weeks to 1 month	1.5	0.5

Note: K coefficients were developed from regression analysis of baseflow data from USGS Crest Stage Indicator (CSI) data to approximate flows that have a less than 50% chance of being exceeded between November - March.

4. Calculate the recommended temporary diversion design flow rate using equation TDM-1:

$$Q = S \ K \ A \quad \text{(Equation TDM-1)}$$

In which,

Q = temporary diversion design flow rate for short-duration projects (cfs).

S = safety factor coefficient from Table TDM-2 based on duration.

K = diversion sizing coefficient from Table TDM-2 based on seasonality.

A = tributary area (square miles).

Of course, if the observed condition at the construction site suggests a higher flow, this should be estimated and used instead.

<u>Example of Short-Duration Temporary Diversion Sizing Methodology</u>

Project Location: Goldsmith Gulch Downstream (north) of E. Cornell Avenue

Planned project will involve approximately 0.12 acres of disturbance for bank stabilization, which will be completed within two weeks during the November to March time period. Using StreamStats, the gross contributing watershed area was determined to be approximately 6.2 mi^2. Based on project duration and seasonal timing, Table TDM-2 yields S = 1.0, K = 0.2. Equation TDM-1 can be used to calculate the recommended diversion flow:

$$Q = S\ K\ A$$

$$Q = 1.0 \bullet 0.2 \bullet 6.2\ mi^2 = 1.2\ cfs$$

Had this been a larger restorative maintenance project that will last 4 weeks, but will be started and completed within the November through March period, application of Equation TDM-1 and the recommended safety factor suggest the following diversion design flow:

$$Q = S\ K\ A$$

$$Q = 1.5 \bullet 0.2 \bullet 6.2\ mi^2 = 1.9\ cfs$$

Sizing Procedure for Interim Duration Projects (longer than one month and up to three months)

When projects last <u>longer than one month but up to three months</u>, a combination of sizing methods should be applied. The recommended temporary diversion flow rate should be evaluated using both the sizing procedure for short duration projects as well as the sizing procedure for long duration projects. These calculated flow rates should be weighed in combination with site-specific factors to determine an appropriate design flow rate. Each site should be evaluated individually to determine factors that may affect the design flow choice. For example, the designer may select to use the more conservative design flow for an interim duration project occurring in July and August where a chance for wet weather is forecast and flooding or damage to the area surrounding the project is unacceptable.

Maintenance and Removal

Because temporary diversions are one of the most critical BMPs for work in waterways, they must be inspected and maintained frequently to remain in effective operating condition. Flow barriers should be inspected at the start and end of each workday and at any time that excess water is noted in dry work areas. For diversion channels, the diversion channel itself should be inspected for signs of erosion, and the lining should be repaired or replaced if there are signs of failure. Check armoring at the diversion return point to the waterway, and add additional armoring if erosion is noted.

Water should not be allowed to flow back through the natural stream until all construction is completed. After redirecting the flow through the natural channel, temporary diversion measures should be removed. For temporary diversion channels, lining materials should be removed, and the diversion channel should then be backfilled and stabilized. Points of tie-in to the natural channel should be protected with riprap sized in accordance with the *Major Drainage* chapter in Volume 1.

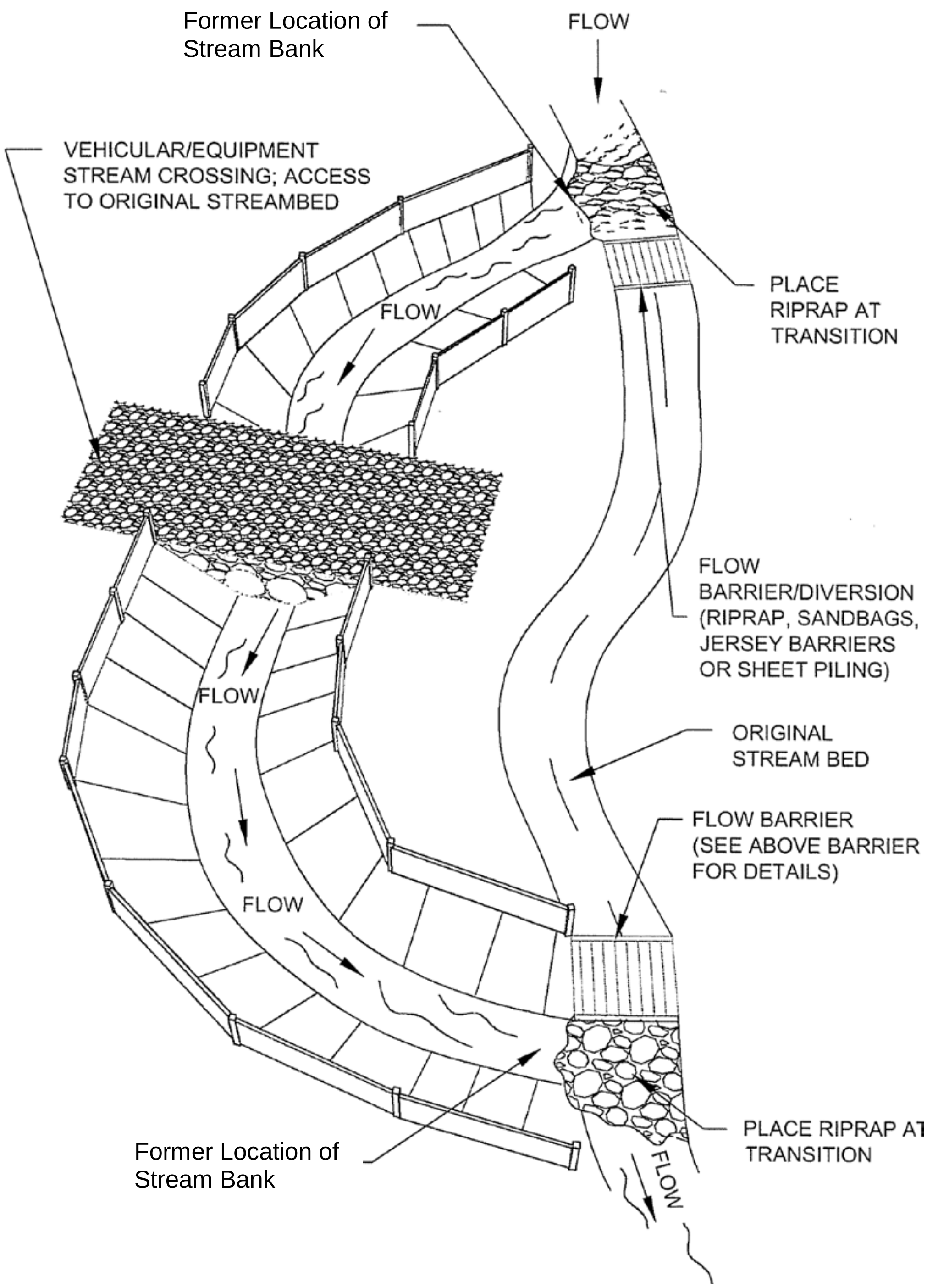


Figure TDM-1. Typical Temporary Diversion Channel

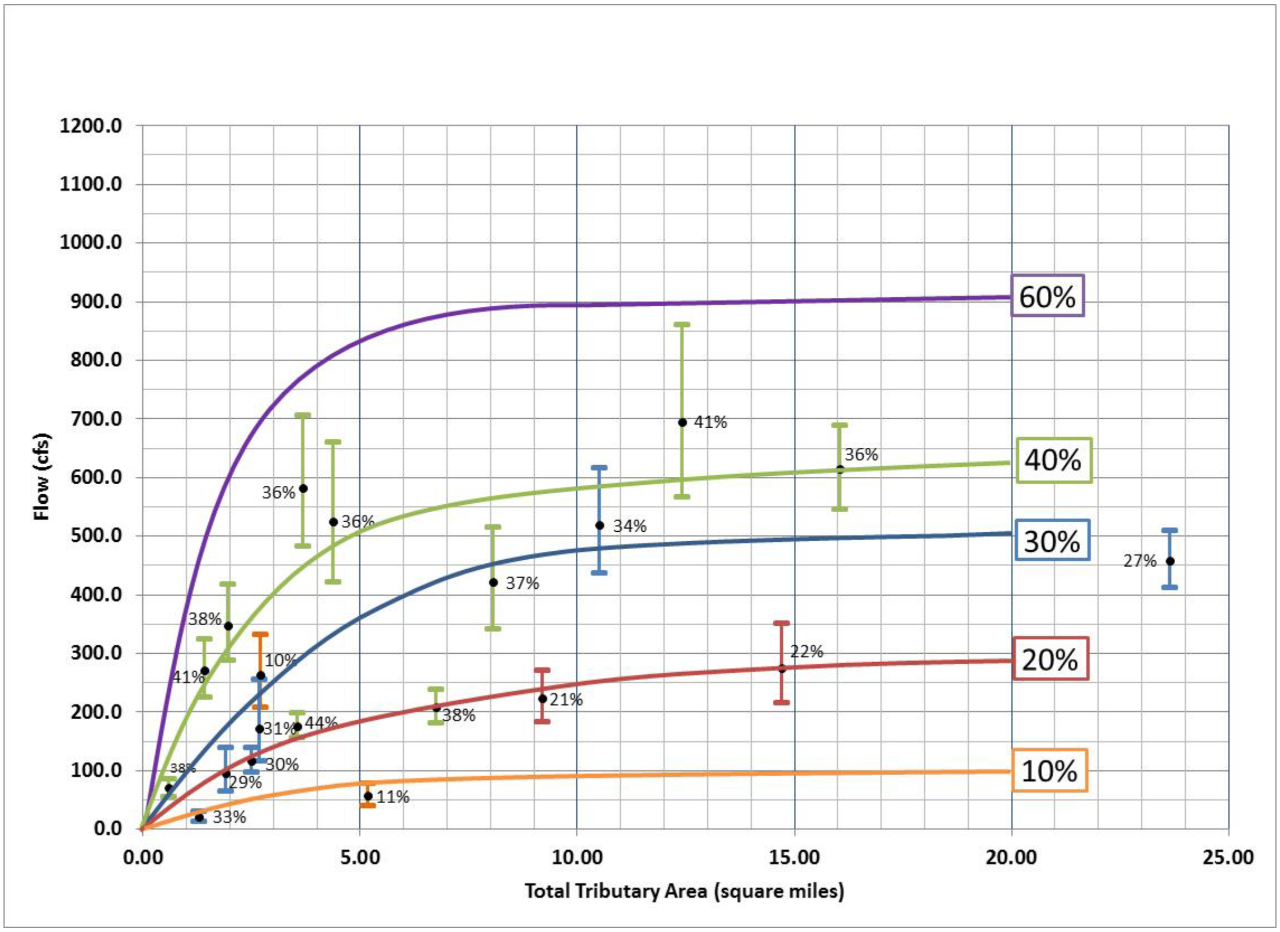
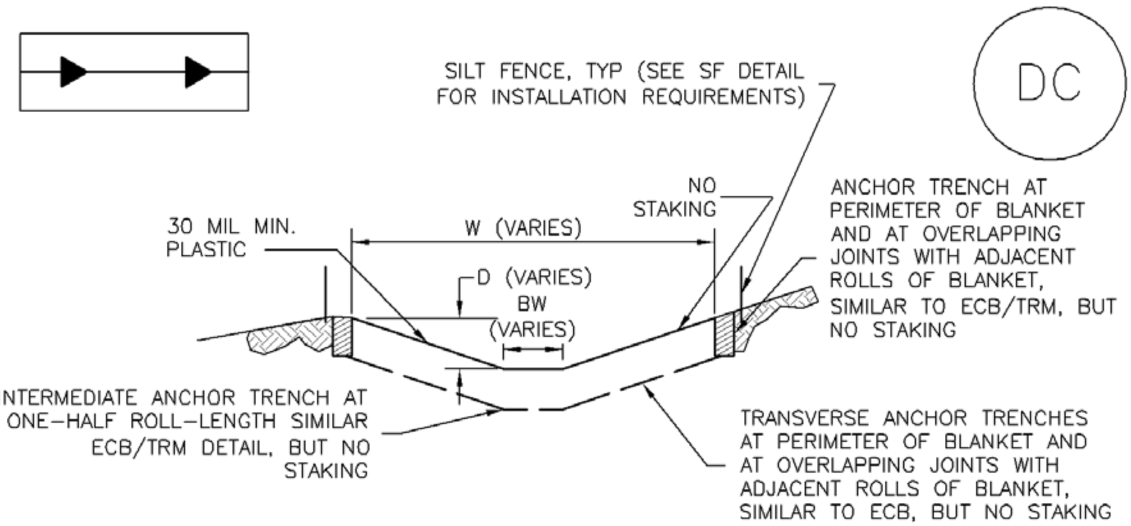
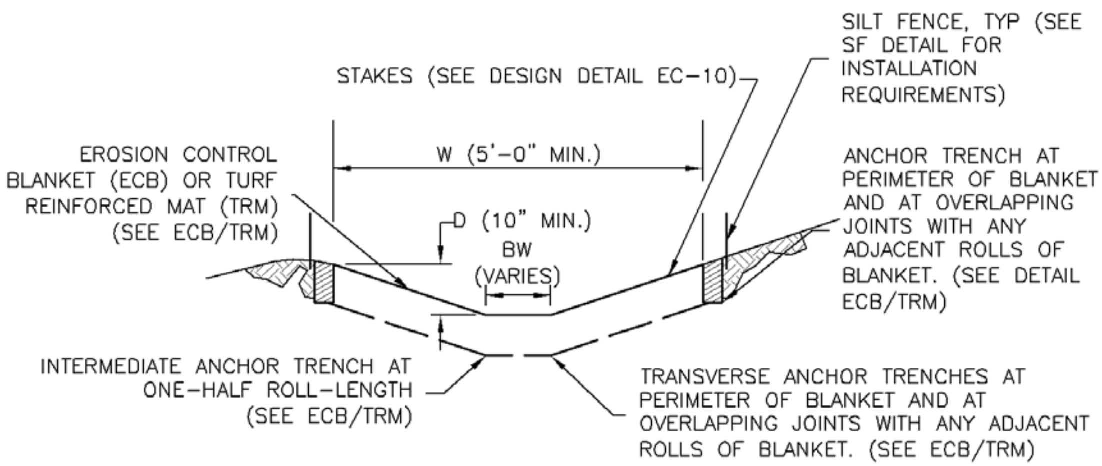


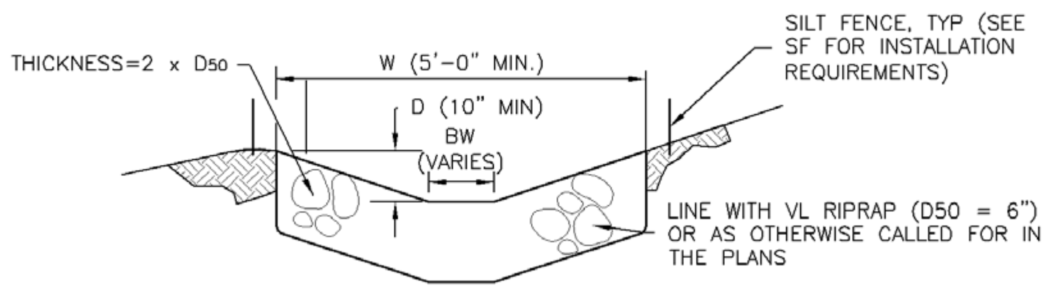
Figure TDM-2. Temporary Diversion Facility Sizing Nomograph for Long Duration Projects (Duration in excess of three months) Based on 2-year Peak Flows - Denver Metropolitan and Adjacent Areas, Updated April 2012



DC–1. PLASTIC LINED DIVERSION CHANNEL



DC–2. GEOTEXTILE OR MAT LINED DIVERSION CHANNEL



DC–3. RIPRAP LINED DIVERSION CHANNEL

CHANNEL DIVERSION INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - –LOCATION OF DIVERSION CHANNEL
   - –TYPE OF CHANNEL (UNLINED, GEOTEXTILE OR MAT LINED, PLASTIC LINE, OR RIPRAP LINED).
   - –LENGTH OF EACH TYPE OF CHANNEL.
   - –DEPTH, D, WIDTH, W, AND BOTTOM WIDTH, BW.
   - –FOR RIPRAP LINED CHANNEL, SIZE OF RIPRAP, D50, SHALL BE SHOWN ON PLANS.

2. SEE DRAINAGE PLANS FOR DETAILS OF PERMANENT CONVEYANCE FACILITIES.

3. DIVERSION CHANNELS INDICATED ON THE SWMP PLAN SHALL BE INSTALLED PRIOR TO WORK IN DOWNGRADIENT AREAS OR NATURAL CHANNELS.

4. FOR GEOTEXTILE OR MAT LINED CHANNELS, INSTALLATION OF GEOTEXTILE OR MAT SHALL CONFORM TO THE REQUIREMENTS OF DETAIL ECB, FOR PLASTIC LINED CHANNELS, INSTALLATION OF ANCHOR TRENCHES SHALL CONFORM TO THE REQUIREMENTS OF DETAIL ECB.

5. WHERE CONSTRUCTION TRAFFIC MUST CROSS A DIVERSION CHANNEL, THE PERMITTEE SHALL INSTALL A TEMPORARY STREAM CROSSING CONFORMING TO THE REQUIREMENTS OF DETAIL TSC.

DIVERSION CHANNEL MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. DIVERSION CHANNELS ARE TO REMAIN IN PLACE UNTIL WORK IN THE DOWNGRADIENT AREA OR NATURAL CHANNEL IS NO LONGER REQUIRED. IF APPROVED BY LOCAL JURISDICTION DIVERSION CHANNEL MAY BE LEFT IN PLACE.

5. IF DIVERSION CHANNELS ARE REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY LOCAL JURISDICTION.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO)

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

Description

Photograph DW-1. A relatively small dewatering operation using straw bales and a dewatering bag.

The BMPs selected for construction dewatering vary depending on site-specific features such as soils, topography, anticipated discharge quantities, and discharge location. Dewatering typically involves pumping water from an inundated area to a BMP, and then downstream to a receiving waterway, sediment basin, or well-vegetated area. Dewatering typically involves use of several BMPs in sequence.

Appropriate Uses

Dewatering operations are used when an area of the construction site needs to be dewatered as the result of a large storm event, groundwater, or existing ponding conditions. This can occur during deep excavation, utility trenching, and wetland or pond excavation.

Photograph DW-2. Dewatering bags used for a relatively large dewatering operation.

Design and Installation

Dewatering techniques will vary depending on site conditions. However, all dewatering discharges must be treated to remove sediment before discharging from the construction site. Discharging water into a sediment trap or basin is an acceptable treatment option. Water may also be treated using a dewatering filter bag, and a series of straw bales or sediment logs. If these previous options are not feasible due to space or the ability to passively treat the discharge to remove sediment, then a settling tank or an active treatment system may need to be utilized. Settling tanks are manufactured tanks with a series of baffles to promote settling. Flocculants can also be added to the tank to induce more rapid settling. This is an approach sometimes used on highly urbanized construction sites. Contact the state agency for special requirements prior to using flocculents and land application techniques.

Some commonly used methods to handle the pumped water without surface discharge include land application to vegetated areas through a perforated discharge hose (i.e., the "sprinkler method") or dispersal from a water truck for dust control.

Dewatering Operations	
Functions	
Erosion Control	Moderate
Sediment Control	Yes
Site/Material Management	Yes

Dewatering discharges to non-paved areas must minimize the potential for scour at the discharge point either using a velocity dissipation device or dewatering filter bag.

Design Details are provided for these types of dewatering situations:

DW-1. Dewatering for Pond Already Filled with Water

DW-2 Dewatering Sump for Submersed Pump

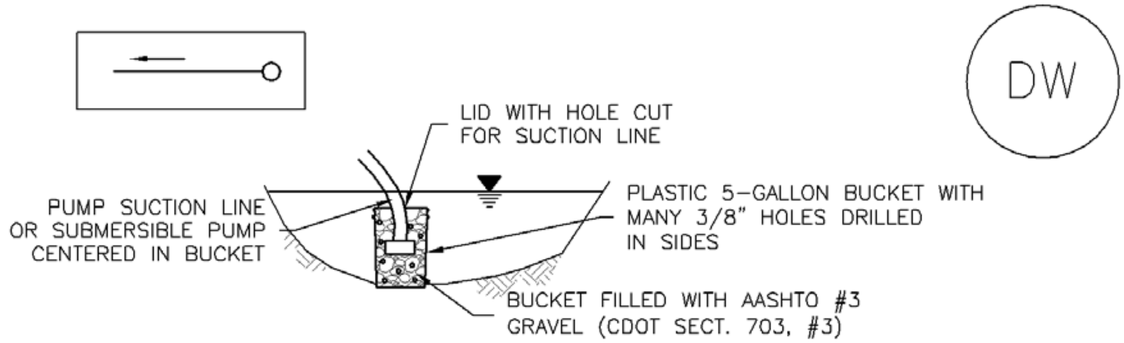
DW-3 Sump Discharge Settling Basin

DW-4 Dewatering Filter Bag

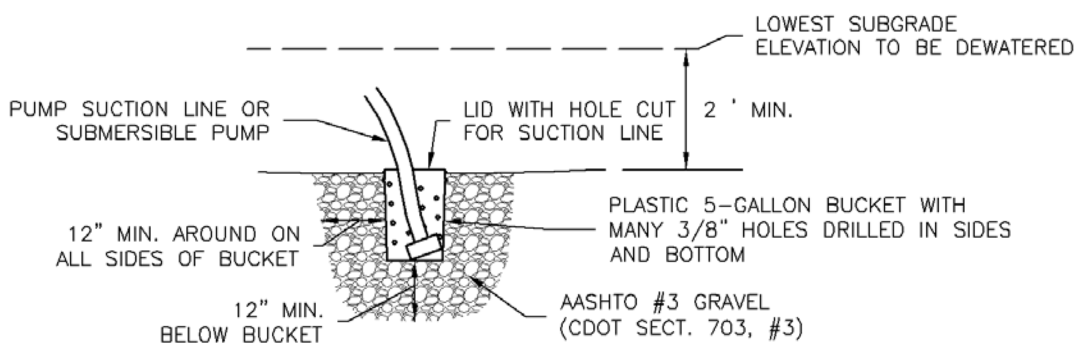
Maintenance and Removal

When a sediment basin or trap is used to enable settling of sediment from construction dewatering discharges, inspect the basin for sediment accumulation. Remove sediment prior to the basin or trap reaching half full. Inspect treatment facilities prior to any dewatering activity. If using a sediment control practice such as a sediment trap or basin, complete all maintenance requirements as described in the fact sheets prior to dewatering.

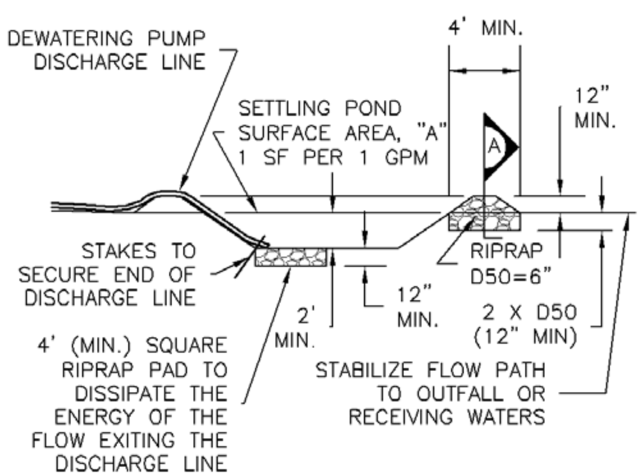
Properly dispose of used dewatering bags, as well as sediment removed from the dewatering BMPs. Depending on the size of the dewatering operation, it may also be necessary to revegetate or otherwise stabilize the area where the dewatering operation was occurring.



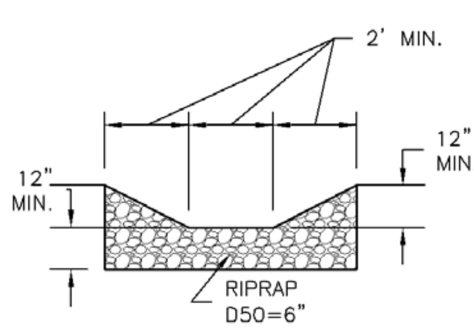
DW-1. DEWATERING POND ALREADY FILLED WITH WATER



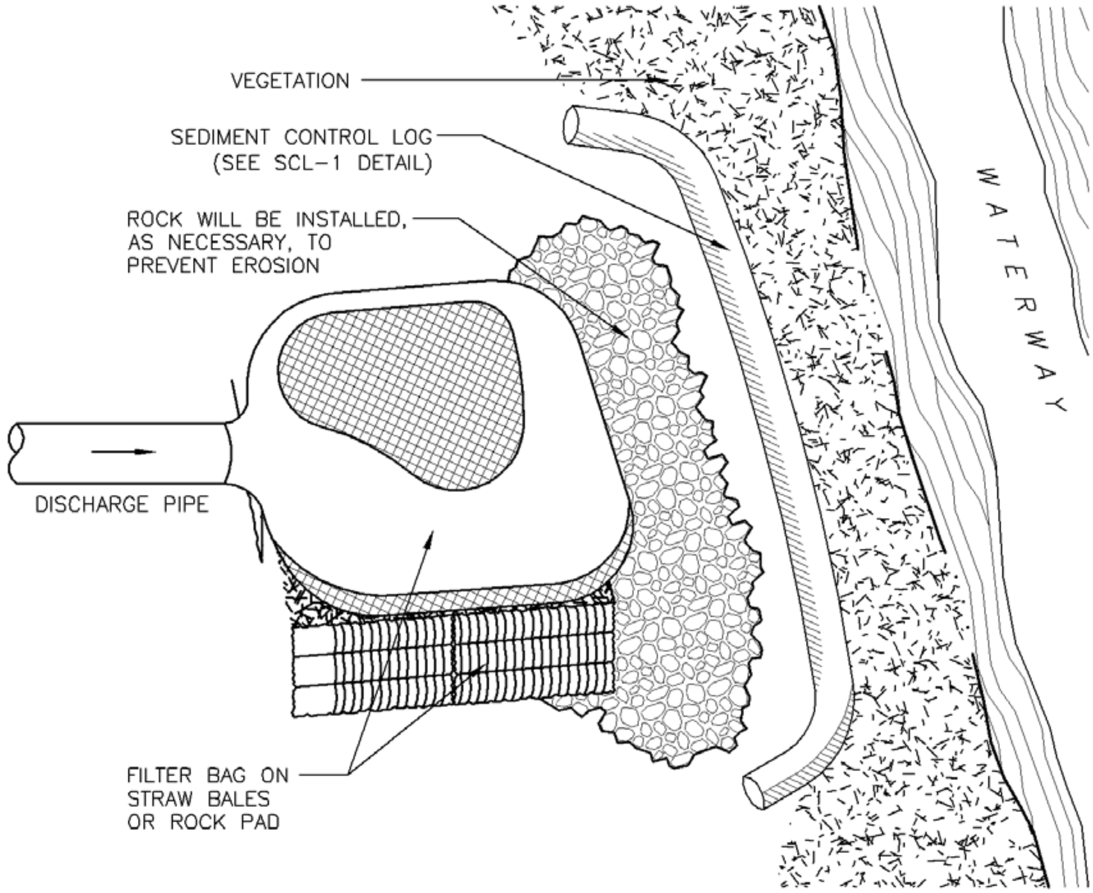
DW-2. DEWATERING SUMP FOR SUBMERSED PUMP



DW-3. SUMP DISCHARGE
SETTLING BASIN



SETTLING BASIN
SECTION A



DW-4. DEWATERING FILTER BAG

DEWATERING INSTALLATION NOTES

1. SEE PLAN VIEW FOR;
   - LOCATION OF DEWATERING EQUIPMENT.
   - TYPE OF DEWATERING OPERATION (DW-1 TO DW-4).

2. THE OWNER OR CONTRACTOR SHALL OBTAIN A CONSTRUCTION DISCHARGE (DEWATERING) PERMIT FROM THE STATE PRIOR TO ANY DEWATERING OPERATIONS DISCHARGING FROM THE SITE. ALL DEWATERING SHALL BE IN ACCORDANCE WITH THE REQUIREMENTS OF THE PERMIT.

3. THE OWNER OR OPERATOR SHALL PROVIDE, OPERATE, AND MAINTAIN DEWATERING SYSTEMS OF SUFFICIENT SIZE AND CAPACITY TO PERMIT EXCAVATION AND SUBSEQUENT CONSTRUCTION IN DRY CONDITIONS AND TO LOWER AND MAINTAIN THE GROUNDWATER LEVEL A MINIMUM OF 2-FEET BELOW THE LOWEST POINT OF EXCAVATION AND CONTINUOUSLY MAINTAIN EXCAVATIONS FREE OF WATER UNTIL BACK-FILLED TO FINAL GRADE.

DEWATERING INSTALLATION NOTES

4. DEWATERING OPERATIONS SHALL USE ONE OR MORE OF THE DEWATERING SUMPS SHOWN ABOVE, WELL POINTS, OR OTHER MEANS APPROVED BY THE LOCAL JURISDICTION TO REDUCE THE PUMPING OF SEDIMENT, AND SHALL PROVIDE A TEMPORARY SEDIMENT BASIN OR FILTRATION BMP TO REDUCE SEDIMENT TO ALLOWABLE LEVELS PRIOR TO RELEASE OFF SITE OR TO A RECEIVING WATER. A SEDIMENT BASIN MAY BE USED IN LIEU OF SUMP DISCHARGE SETTLING BASIN SHOWN ABOVE IF A 4-FOOT-SQUARE RIPRAP PAD IS PLACED AT THE DISCHARGE POINT AND THE DISCHARGE END OF THE LINE IS STAKED IN PLACE TO PREVENT MOVEMENT OF THE LINE.

DEWATERING MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. DEWATERING BMPs ARE REQUIRED IN ADDITION TO ALL OTHER PERMIT REQUIREMENTS.

5. TEMPORARY SETTLING BASINS SHALL BE REMOVED WHEN NO LONGER NEEDED FOR DEWATERING OPERATIONS. ANY DISTURBED AREA SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAILS ADAPTED FROM DOUGLAS COUNTY, COLORADO, NOT AVAILABLE IN AUTOCAD)

Description

Where an actively flowing watercourse must be crossed regularly by construction vehicles, a temporary crossing should be provided. Three primary methods are available:

- Culvert crossing
- Stream ford
- Temporary bridge

Culvert crossings and fords are the most commonly used methods. Due to the expense associated with a temporary bridge, these are used primarily on long-term projects.

Photograph TSC-1. A temporary stream crossing using culverts. Photo courtesy of Tom Gore.

Appropriate Uses

Construction vehicles shall be kept out of waterways to the maximum extent practicable. Use a temporary stream crossing when it is absolutely necessary to cross a stream on a construction site. Construct a temporary crossing even if the stream or drainageway is typically dry. Multiple stream crossings should be avoided to minimize environmental impacts.

A permit is required for placement of fill in a waterway under Section 404 of the Clean Water Act. The local office of the U.S. Army Corps of Engineers (USACE) should be contacted concerning the requirements for obtaining a 404 permit. In addition, a permit from the U.S. Fish and Wildlife Service (USFWS) may be needed if endangered species are of concern in the work area. Typically, the USFWS issues are addressed by a 404 permit, if one is required. The municipality of jurisdiction should also be consulted, and can provide assistance. Other permits to be obtained may include a floodplain development permit from the local jurisdiction.

Design and Installation

Design details are provided for these types of stream crossings:

TSC-1. Culvert Crossing

TSC-2. Ford Crossing

TSC-3. Flume Crossing

Temporary Stream Crossing	
Functions	
Erosion Control	Yes
Sediment Control	Yes
Site/Material Management	No

A culvert crossing should be sized appropriately with consideration for the duration of construction and seasonal variation of flows. The sizing methodology provided in the Temporary Diversion Methods Fact Sheet is also appropriate for determining the design flow for temporary stream crossings. Culvert sizing must account for the headwater and tailwater controls to properly size the culvert. For additional discussion on design of box culverts and pipes, see the *Major Drainage* chapter in Volume 1. The designer also needs to confirm that the riprap selected is appropriate for the conditions in the channel being crossed.

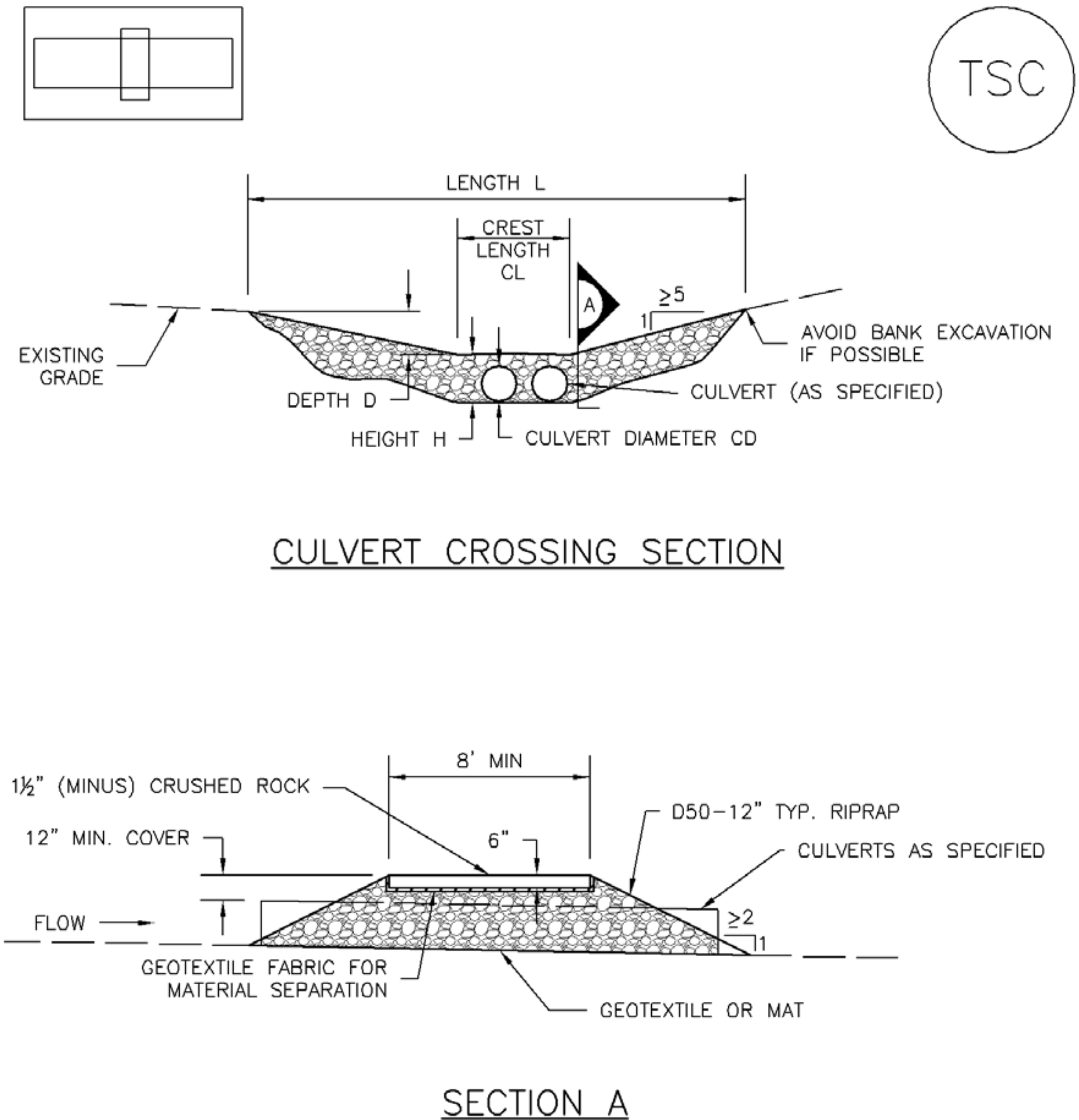
When a ford must be used, namely when a culvert is not practical or the best solution, the ford should be lined with at least a 12-inch thick layer of Type VL (D_{50} = 6 inches) or Type L (D_{50} = 9 inches) riprap with void spaces filed with 1-1/2 inch diameter rock. Ford crossings are recommended primarily for crossings of ephemeral (i.e. intermittently, briefly flowing) streams.

For a temporary bridge crossing, consult with a structural and/or geotechnical engineer for temporary bridge design or consider pre-fabricated alternatives.

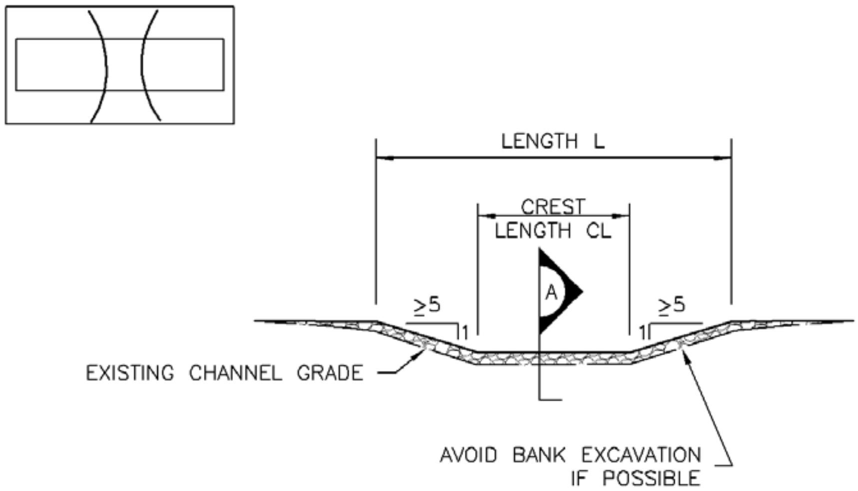
Maintenance and Removal

Inspect stream for bank erosion and in-stream degradation. If bank erosion is occurring, stabilize banks using erosion control practices such as erosion control blankets. If in-stream degradation is occurring, armor the culvert outlet(s) with riprap to dissipate energy. If sediment is accumulating upstream of the crossing, remove excess sediment as needed to maintain the functionality of the crossing.

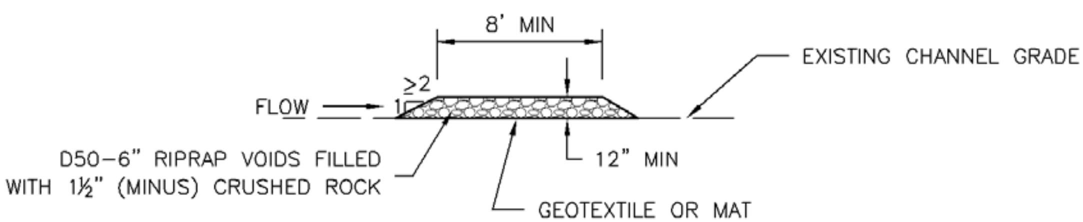
Remove the temporary crossing when it is no longer needed for construction. Take care to minimize the amount of sediment lost into the stream upon removal. Once the crossing has been removed, stabilize the stream banks with seed and erosion control blankets.



TSC-1. CULVERT CROSSING

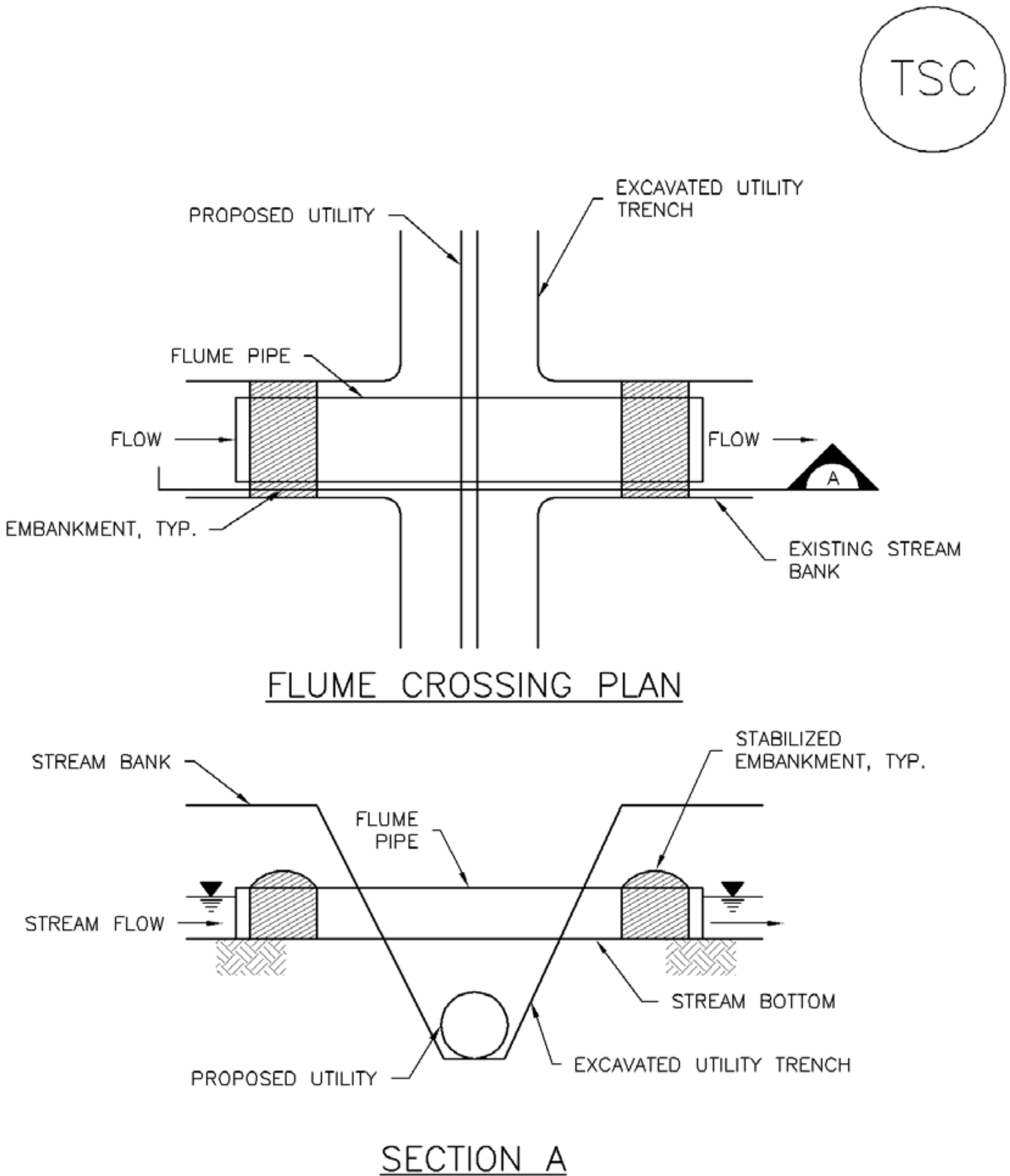


FORD CROSSING SECTION



SECTION A

TSC–2. FORD CROSSING



TSC–3. FLUME CROSSING

TEMPORARY STREAM CROSSING INSTALLATION NOTES

1. SEE PLAN VIEW FOR:
   - LOCATIONS OF TEMPORARY STREAM CROSSINGS.
   - STREAM CROSSING TYPE (FORD, CULVERT, OR FLUME).
   - FOR FORD CROSSING: LENGTH (L), CREST LENGTH (CL), AND DEPTH (D).
   - FOR CULVERT CROSSING: LENGTH (L), CREST LENGTH (CL), CROSSING HEIGHT (H), DEPTH (D), CULVERT DIAMETER (CD), AND NUMBER, TYPE AND CLASS OR GAUGE OF CULVERTS.

2. TEMPORARY STREAM CROSSING DIMENSIONS, D50, AND NUMBER OF CULVERTS INDICATED (FOR CULVERT CROSSING) SHALL BE CONSIDERED MINIMUM DIMENSIONS; ENGINEER MAY ELECT TO INSTALL LARGER FACILITIES. ANY DAMAGE TO STREAM CROSSING OR EXISTING STREAM CHANNEL DURING BASEFLOW OR FLOOD EVENTS SHALL BE PROMPTLY REPAIRED.

3. SEE MAJOR DRAINAGE CHAPTER FOR RIPRAP GRADATIONS.

4. WHERE FAILURE OF A STREAM CROSSING CAN RESULT IN SIGNIFICANT DAMAGE OR HARM IT MUST BE DESIGNED BY A STRUCTURAL ENGINEER.

TEMPORARY STREAM CROSSING MAINTENANCE NOTES

1. INSPECT BMPs EACH WORKDAY, AND MAINTAIN THEM IN EFFECTIVE OPERATING CONDITION. MAINTENANCE OF BMPs SHOULD BE PROACTIVE, NOT REACTIVE. INSPECT BMPs AS SOON AS POSSIBLE (AND ALWAYS WITHIN 24 HOURS) FOLLOWING A STORM THAT CAUSES SURFACE EROSION, AND PERFORM NECESSARY MAINTENANCE.

2. FREQUENT OBSERVATIONS AND MAINTENANCE ARE NECESSARY TO MAINTAIN BMPs IN EFFECTIVE OPERATING CONDITION. INSPECTIONS AND CORRECTIVE MEASURES SHOULD BE DOCUMENTED THOROUGHLY.

3. WHERE BMPs HAVE FAILED, REPAIR OR REPLACEMENT SHOULD BE INITIATED UPON DISCOVERY OF THE FAILURE.

4. REMOVE SEDIMENT ACCUMULATED UPSTREAM OF CROSSING AS NEEDED TO MAINTAIN THE FUNCTIONALITY OF THE CROSSING.

5. STREAM CROSSINGS ARE TO REMAIN IN PLACE UNTIL NO LONGER NEEDED AND SHALL BE REMOVED PRIOR TO THE END OF CONSTRUCTION.

6. WHEN STREAM CROSSINGS ARE REMOVED, THE DISTURBED AREA SHALL BE COVERED WITH TOPSOIL, SEEDED AND MULCHED AND COVERED WITH GEOTEXTILE OR OTHERWISE STABILIZED IN A MANNER APPROVED BY THE LOCAL JURISDICTION.

NOTE: MANY JURISDICTIONS HAVE BMP DETAILS THAT VARY FROM UDFCD STANDARD DETAILS. CONSULT WITH LOCAL JURISDICTIONS AS TO WHICH DETAIL SHOULD BE USED WHEN DIFFERENCES ARE NOTED.

(DETAIL ADAPTED FROM DOUGLAS COUNTY, COLORADO AND CITY OF AURORA, COLORADO (Va. DSWC), NOT AVAILABLE IN AUTOCAD)

Description

Temporary batch plant management includes implementing multiple BMPs such as perimeter controls, concrete washout area, stabilized construction access, good housekeeping, and other practices designed to reduce polluted runoff from the batch plant area.

Photograph TBP-1. Effective stormwater management at temporary batch plants requires implementation of multiple BMPs. Photo courtesy of California Stormwater BMP Handbook.

Appropriate Uses

Implement this BMP at temporary batch plants and identify the location of the batch plant in the SWMP.

Additional permitting may be required for the operation of batch plants depending on their duration and location.

Design and Installation

The following lists temporary management strategies to mitigate runoff from batch plant operations:

- When stockpiling materials, follow the Stockpile Management BMP.
- Locate batch plants away from storm drains and natural surface waters.
- A perimeter control should be installed around the temporary batch plant.
- Install run-on controls where feasible.
- A designated concrete washout should be located within the perimeter of the site following the procedures in the Concrete Washout Area BMP.
- Follow the Good Housekeeping BMP, including proper spill containment measures, materials storage, and waste storage practices.
- A stabilized construction entrance or vehicle tracking control pad should be installed at the plant entrance, in accordance with the Vehicle Tracking Control BMP.

Maintenance and Removal

Inspect the batch plant for proper functioning of the BMPs, with attention to material and waste storage areas, integrity of perimeter BMPs, and an effective stabilized construction entrance.

Temporary Batch Plants	
Functions	
Erosion Control	No
Sediment Control	No
Site/Material Management	Yes

After the temporary batch plant is no longer needed, remove stockpiled materials and equipment, regrade the site as needed, and revegetate or otherwise stabilize the area.

Paving and Grinding Operations (PGO) SM-12

Description

Manage runoff from paving and grinding operations to reduce pollutants entering storm drainage systems and natural drainageways.

Appropriate Uses

Use runoff management practices during all paving and grinding operations such as surfacing, resurfacing, and saw cutting.

Photograph PGO-1. Paving operations on a Colorado highway. Photo courtesy of CDOT.

Design and Installation

There are a variety of management strategies that can be used to manage runoff from paving and grinding operations:

- Establish inlet protection for all inlets that could potentially receive runoff.
- Schedule paving operations when dry weather is forecasted.
- Keep spill kits onsite for equipment spills and keep drip pans onsite for stored equipment.
- Install perimeter controls when asphalt material is used on embankments or shoulders near waterways, drainages, or inlets.
- Do not wash any paved surface into receiving storm drain inlets or natural drainageways. Instead, loose material should be swept or vacuumed following paving and grinding operations.
- Store materials away from drainages or waterways.
- Recycle asphalt and pavement material when feasible. Material that cannot be recycled must be disposed of in accordance with applicable regulations.

See BMP Fact Sheets for Inlet Protection, Silt Fence and other perimeter controls selected for use during paving and grinding operations.

Maintenance and Removal

Perform maintenance and removal of inlet protection and perimeter controls in accordance with their respective fact sheets.

Promptly respond to spills in accordance with the spill prevention and control plan.

Paving and Grinding Operations	
Functions	
Erosion Control	No
Sediment Control	No
Site/Material Management	Yes

Glossary[1]

Note: This glossary is not intended to provide regulatory or legal definitions of terms. Instead, it is intended to provide users of Volume 3 with a basic understanding of terms used in this manual.

303(d) List: Section 303(d) of federal Clean Water Act requires states to list those waterbodies that are not attaining water quality standards, including designated uses, and identify relative priorities among the impaired waterbodies. Once a stream is listed on the state 303(d) list, a Total Maximum Daily Load (TMDL) is typically required to assign allowable pollutant loads to various sources to enable the waterbody to attain designated uses in the future.

404 Permit: A federal discharge permit authorized under Section 404 of the Clean Water Act, which regulates the discharge of dredged, excavated, or fill material into wetlands, streams, rivers, and other Waters of the U.S. The U.S. Army Corps of Engineers is the federal agency authorized to issue Section 404 Permits for certain activities conducted in wetlands or other U.S. waters. When working in or around waterways or wetlands, 404 Permits are often required.

Best Management Practice (BMP): A technique, process, activity, or structure used to reduce pollutant discharges in stormwater. BMPs include source control practices (non-structural BMPs) and engineered structures designed to treat runoff. BMPs are most effective when used in combination and selected and designed based on site-specific characteristics.

Biofilter: Dense vegetation designed to filter pollutants from stormwater runoff. (Also see definition of Grass Buffer and Grass Swale.)

Bioretention: A method of stormwater quality treatment that relies on soils and vegetation for reduction of the quantity (volume) of stormwater runoff and removal/retention of stormwater pollutants. Bioretention facilities reduce runoff volume discharged downstream by infiltration and evapotranspiration. Bioretention facilities may be designed for infiltration to subsoils or with underdrains, depending on site-specific conditions. Pollutant removal processes include filtration, biological uptake, sorption and sedimentation (in the temporary surface pool during an event). Bioretention facilities are also known as rain gardens and porous landscape detention.

Buffer Zone: A designated transitional area around a stream, lake, or wetland left in a natural, usually vegetated state so as to protect the waterbody from runoff pollution. Development is often restricted or prohibited in a buffer zone.

Catch Basin: A depressed entryway to the storm drain system, usually located at a street corner.

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[1] Definitions in this glossary have been compiled from several key references and websites including: Denver Water Quality Management Plan Glossary, Denver Wastewater Management Division Rules and Regulations http://www.denvergov.org/admin/template3/forms/Sewer%20charges.PDF, CWQCD http://www.cdphe.state.co.us/wq/, Utah APWA http://www.ulct.org/apwa/Glossary.htm, EPA website glossaries http://www.epa.gov/ednnrmrl/main/gloss.htm and http://cfpub.epa.gov/npdes/glossary.cfm?program_id=0, the Low Impact Development website: http://www.lowimpactdevelopment.org/school/glossary.html, the Maryland website http://www.mde.state.md.us/assets/document/sedimentstormwater/Glossary.pdf, and the NRDC website http://www.nrdc.org/water/pollution/storm/gloss.asp.

Clean Water Act: Federal legislation that provides statutory authority for the National Pollutant Discharge Elimination System (NPDES) program and other water quality protection requirements; Public law 92-500; 33 U.S.C. 1251 et seq. Also known as the Federal Water Pollution Control Act. Under the Clean Water Act stormwater requirements, most urban areas must meet requirements of Municipal Separate Storm Sewer System (MS4) permits, and many industries and institutions such as state departments of transportation must also meet NPDES stormwater permit requirements. Operators of regulated MS4s are required to develop a Stormwater Management Plan (SWMP) that includes measurable goals and to implement needed stormwater management controls (BMPs). MS4s are also required to assess controls and the effectiveness of their stormwater programs and reduce the discharge of pollutants to the "maximum extent practicable."

Colorado Discharge Permit System (CDPS): The State of Colorado's system of permitting discharges (e.g., stormwater, wastewater) to Waters of the State that corresponds to the federal NPDES permits under the federal Clean Water Act.

Constructed Wetland Basin: An engineered stormwater BMP designed with a permanent shallow water surface and hydrophytic vegetation such as rushes, willows, cattails, and reeds. Constructed wetland basins included outlet structures to control peak flows and treat the WQCV through settling of pollutants and biological uptake. A perennial supply of water is necessary for constructed wetland basins.

Design Storm: A rainfall event of specific duration, intensity, and return frequency (e.g., the 1-year, 24-hour storm) that is used to calculate runoff volume and peak discharge rate for the purpose of designing stormwater facilities.

Detention: The storage and slow release of stormwater from an excavated pond, enclosed depression, or tank. Detention is used for pollutant removal, stormwater storage, and peak flow reduction. Both wet and dry detention methods can be applied.

Directly Connected Impervious Area (DCIA): The impervious portion of a site that drains directly to the storm sewer system. DCIA is a key component of the conceptual model used in the volume reduction calculations in Chapter 3 of this manual.

Distributed Controls: Use of multiple BMPs distributed throughout a development site to control and treat stormwater close to it source, as opposed to routing flows to a larger, centralized stormwater facility. Use of distributed stormwater controls is key component of Low Impact Development.

Dry Pond: See definition of Extended Detention Basin (EDB).

Dry Weather Flows: Flows from municipal storm sewer systems that are not due to rain or snow-generated urban runoff.

Effective Imperviousness: Impervious areas that contribute surface runoff to the drainage system. For the purposes of this manual, Effective Imperviousness includes Directly Connected Impervious Area and portions of the Unconnected Impervious Area that also contribute to runoff from a site. For small, frequently occurring events, the Effective Imperviousness may be equivalent to Directly Connected Impervious Area since runoff from Unconnected Impervious Areas may infiltrate into Receiving Pervious Areas; however, for larger events, the Effective Imperviousness is increased to account for runoff from Unconnected Impervious Areas that exceeds the infiltration capacity of the Receiving Pervious Area. *Note: Users should be aware that some national engineering literature defines the Effective Impervious Area more narrowly to include only Directly Connected Impervious Area.*

Effluent Limitation Guidelines (ELGs): EPA-published guidelines in the Federal Register (Volume 74, Number 229, pages 62997-63057) establishing technology-based effluent limitation guidelines and new source performance standards for the construction and development industry. This rule requires construction site owners and operators to implement a range of erosion and sediment control measures and pollution prevention practices to control pollutants in discharges from construction sites. Additionally, the rule will eventually require monitoring and sampling of stormwater discharges and compliance with a numeric standard for turbidity in these discharges for larger construction sites (i.e., 10 acres or more).

Endangered Species Act: The Endangered Species Act of 1973 protects animal and plant species currently in danger of extinction (endangered) and those that may become endangered in the foreseeable future (threatened). It provides for the conservation of ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend, both through federal action and by encouraging the establishment of state programs.

Erosion Control Measures: Source controls used to limit erosion of soil at construction sites and other erosion-prone areas. Representative measures include surface treatments that stabilize soil that has been exposed due to excavation or grading and flow controls that redirect flows or reduce velocities of concentrated flow.

Erosion: Process by which soil particles are detached and transported by wind, water, and gravity to a downslope or downstream location

Eutrophication: An increase in the concentration of chemical nutrients (e.g., phosphorus, nitrogen) in an ecosystem to an extent that increases the primary productivity (e.g., algal growth) of the ecosystem, resulting in decreased oxygen levels and deteriorated water quality.

Event Mean Concentration (EMC): Pollutant concentration based on a composite of multiple samples (aliquots) collected during the course of a storm. Because EMCs represent conditions at multiple points on a storm hydrograph, they are most representative of average pollutant concentrations over an entire runoff event. EMCs are contrasted with single "grab" samples, which reflect storm conditions at a particular point in time.

Excess Urban Runoff Volume (EURV): The difference between urban and pre-development runoff volumes. The EURV is the basis of design for Full Spectrum Detention facilities.

Extended Detention Basin (EDB): An engineered basin with an outlet structure designed to slowly release urban runoff over an extended time period to provide water quality benefits and control peak flows for frequently occurring storm events. The basins are sometimes called "dry ponds" because they are designed not to have a significant permanent pool of water remaining between storm runoff events. Outlet structures for extended detention basins are sized to control more frequently occurring storm events, whereas flood control detention facilities are designed to control less frequent, larger storm events. Outlet structures can be designed to integrate water quality and flood control into a single detention facility. Also see Full Spectrum Detention.

Extensive Green Roof: A shallow green roof, typically 6 inches or shallower, that is designed to satisfy specific engineering and performance goals such as water quality treatment. An extensive green roof has low lying plants designed to provide maximum groundcover, water retention, erosion resistance, and respirative transpiration of moisture. Extensive green roofs usually use plants with foliage from 2 to 6 inches and provide 2 to 4 inches of soil/growing media.

Forebay: Storage space located near a stormwater BMP inlet designed to trap incoming coarse sediments and other gross solids before they accumulate in the main treatment area of the BMP.

Full Spectrum Detention: A stormwater detention facility design to provide water quality and flood control benefits and reduced impacts on downstream channels by detaining the Excess Urban Runoff Volume (EURV) and releasing it over a 72 hour period. The EURV is approximately

Geographic Information System (GIS): A database of digital information and data on land-use, land cover, ecological characteristics, and other geographic attributes that can be overlaid, statistically analyzed, mathematically manipulated, and graphically displayed using maps, charts, and graphs.

Grass Buffer: Uniformly graded and densely vegetated area, typically turfgrass. This BMP requires sheet flow to promote filtration, infiltration, and settling to reduce runoff pollutants.

Grass Swale: Densely vegetated drainageway with low-pitched side slopes that collects and slowly conveys runoff. The design of the longitudinal slope and cross-section size forces the flow to be slow and shallow, thereby facilitating sedimentation while limiting erosion.

Green Roof: An engineered vegetated roof that can be used to detain and treat precipitation. Green roofs require an engineered structure that can support soils, vegetation and loads associated with rainfall, snow, people and equipment. Key components include a waterproof membrane, root barrier, drainage layer, soil/growing medium, irrigation system and plants.

Hot Spot: Area where land use or activities have the potential to generate highly contaminated runoff with concentrations of pollutants in excess of those typically found in stormwater.

Household Hazardous Waste: Common everyday products such as paint, paint thinner and pesticides that can be hazardous if not properly disposed.

Illicit Connection: A sanitary plumbing fixture connected to a storm sewer, resulting in illicit discharges to the storm sewer system.

Illicit Discharge: A discharge to a municipal separate storm sewer that is not composed entirely of stormwater and is not authorized by an NPDES permit, with some exceptions (e.g., discharges due to fire-fighting activities).

Impervious Area: A hard surface area (e.g., parking lot or rooftop) that prevents or retards the infiltration of water into the soil, thus causing water to run off the surface in greater quantities and at an increased rate of flow relative to pervious areas.

Infiltration: The percolation of water from the land surface into the ground.

Inlet: An entrance into a ditch, storm sewer, or other waterway.

Integrated Pest Management (IPM): The practice of using biological, chemical, cultural, and physical measures to manage pests while minimizing or eliminating the use of chemical pesticides.

Intensive Green Roof: Landscaped roofs with several feet of soil and a variety of plant types, often including trees.

Level Spreader: An engineered structure designed to convert concentrated runoff to sheet flow and disperse it uniformly across a slope, thereby preventing/minimizing erosion.

Low Impact Development (LID): LID is an overall land planning and engineering design approach to managing stormwater runoff. LID emphasizes conservation and use of on-site natural features to protect water quality. This approach implements engineered small-scale hydrologic controls to mimic the pre-development hydrologic regime of watersheds through infiltrating, filtering, storing, evaporating, and detaining runoff close to its source. The term Green Infrastructure (GI) may also be used, particularly in areas with combined sewer overflow (CSO) issues.

Low Impact Development Practice: Individual practices used as part of overall LID developments or integrated into traditional developments include practices such as bioretention facilities, rain gardens, vegetated rooftops, rain barrels, permeable pavements and other infiltration-oriented practices.

Materials Management Practices: Source control practices at construction sites intended to limit contact of runoff with pollutants such as construction materials and equipment-related fluids. By intentionally controlling and managing areas where chemicals are handled, the likelihood of these materials being transported to waterways is reduced.

Media Filter: A stormwater BMP designed to filter runoff as it passes through media such as sand, compost, sand-peat, perlite-zeolite, or similar materials. (See Sand Filter Extended Detention Basin.)

Micropool: A smaller permanent pool incorporated into the design of larger stormwater ponds to reduce potential of clogging of the outlet and minimize resuspension of sediment.

Minimizing Directly Connected Impervious Areas (MDCIA): A variety of runoff reduction strategies that route runoff from impervious surfaces over pervious areas to decrease runoff velocities and promote infiltration.

Minimum Measures: Stormwater management activities required under Phase II MS4 permits. The six minimum measures include 1) public education and outreach, 2) public participation/involvement, 3) illicit discharge detection and elimination, 4) construction site stormwater runoff control, 5) post-construction stormwater management, and 6) pollution prevention/good housekeeping for municipal operations.

Municipal Separate Storm Sewer System (MS4): A publicly owned conveyance or system of conveyances that discharges to waters of the U.S. and is designed or used for collecting or conveying stormwater, is not a combined sewer, and is not part of a publicly owned treatment works (POTW).

MS4 Permit: A state or federal stormwater discharge permit to regulate discharges from municipal separate storm sewers (MS4s) for compliance with Clean Water Act regulations.

National Pollutant Discharge Elimination System (NPDES): The national program under Section 402 of the Clean Water Act for regulation of discharges of pollutants from point sources to waters of the U.S.

Non-Point Source (NPS) Pollution: Pollution that occurs when rainwater, snowmelt, or irrigation transports pollutants from diffuse sources across land surfaces into waterbodies. Nonpoint source pollution is contrasted with point source pollution in that it is not discharged from single discharge points such as storm sewers and wastewater treatment plants.

Non-Structural BMPs: Stormwater BMPs that focus on management of pollutants at their source by minimizing exposure to runoff, rather than treating runoff in constructed facilities. Non-structural BMPs are referred to as source controls in this manual.

NPDES: National Pollutant Discharge Elimination System, as described above.

Peak Runoff Rate: The highest actual or predicted flow rate (typically measured in cubic feet per second) for runoff from a site for a specific event.

Permeability: The ability of a material to allow the passage of a liquid, such as water through rocks or soil. Permeable materials, such as gravel and sand, allow water to move quickly through them, whereas impermeable material, such as clay, does not allow water to flow freely.

Permeable Pavement Systems (PPS): A general term to describe pavements designed to allow infiltration of water from the paved surface into subsurface layers. Depending on the design, permeable pavements can be used to promote volume reduction, provide treatment and slow release of the WQCV, and/or reduce effective imperviousness. Permeable pavement systems include permeable interlocking concrete pavement, concrete grid, pervious concrete, reinforced grass, and porous gravel.

Point Source Pollution: Pollutants from a single, identifiable source such as a factory, refinery, or place of business. In the context of TMDLs, point sources typically include NPDES-permitted sanitary wastewater treatment facilities, municipal separate storm sewer systems (MS4s), and confined animal feeding operations (CAFOs).

Pollutant (as defined by CDPS Regulation 6.3.0 [51]): Dredged spoil, dirt, slurry, solid waste, incinerator residue, sewage, sewage sludge, garbage, trash, chemical waste, biological nutrient, biological material, radioactive material, heat, wrecked or discarded equipment, rock, sand, or any industrial, municipal or agriculture waste.

Pollutant Load: The mass of pollutants carried in runoff, calculated based on flow volume multiplied by pollutant concentration. Pollutant loading has units of mass and is calculated over specific timescales such as day, month or year.

Porous Landscape Detention (PLD): Also known as a rain garden or bioretention facility, this stormwater quality BMP consists of a low lying vegetated area underlain by a permeable media with an underdrain. A shallow surcharge zone exists above the porous landscape detention for temporary storage of the WQCV.

Rain Garden: See definitions of Bioretention and Porous Landscape Detention (PLD).

Receiving Pervious Area (RPA): The pervious portion of a site that receives runoff from an upgradient impervious area prior to draining to the storm sewer system. RPA is a key component of the conceptual model used in the volume reduction calculations in Chapter 3 of this manual.

Redevelopment: Improvements to an existing developed area, typically involving removal of existing structures and construction of new buildings and associated infrastructure. Depending on the scale of the redevelopment activity, post-development stormwater permit requirements may be triggered.

Retention Pond: A BMP consisting of a permanent pool of water designed to treat runoff by detaining water long enough for settling, filtering, and biological uptake. Also known as wet ponds, these ponds may also be designed to have an aesthetic and/or recreational value. These BMPs have a permanent pool of water that is replaced with stormwater, in part or in total, during storm runoff events. In addition, a temporary extended detention volume is provided above this permanent pool to capture storm runoff and enhance sedimentation. Retention ponds require a perennial supply of water to maintain the pool and are typically used on larger sites.

Retrofit: The creation or modification of a stormwater management practice, usually in a developed area, that improves or combines treatment with existing stormwater infrastructure.

Revised Universal Soil Loss Equation (RUSLE): An erosion prediction method originally developed for agricultural land use that can also be used for estimating erosion potential on construction sites and adjusting BMPs to reduce the estimated erosion. Factors included in this equation include rainfall-runoff erosivity, soil erodibility, slope length and steepness, surface cover management, and erosion control practice implementation.

Runoff: Water from rain, melted snow, or irrigation that flows over the land surface.

Sand Filter Extended Detention Basin: A stormwater quality BMP consisting of a sand bed and underdrain system. Above the vegetated sand bed is an extended detention basin sized to capture the WQCV. A sand filter extended detention basin provides pollutant removal through settling and filtering and is generally suited to off-line, on-site configurations where there is no base flow and the sediment load is relatively low.

Sediment Control Measures: Practices that reduce transport of sediment off-site to downstream properties and receiving waters. Sediment controls generally either provide filtration through a permeable media or slow or detain runoff to allow settling of suspended particles.

Separate Pervious Area (SPA): The pervious portion of a site that drains to the storm sewer system, but does not receive runoff from upgradient impervious areas. SPA is a key component of the conceptual model used in the volume reduction calculations in Chapter 3 of this manual.

Sheet Flow: The portion of precipitation that flows overland in very shallow depths before eventually reaching a stream channel or other conveyance.

Site Management Practices: A combination of construction site management practices that help reduce pollutants leaving a construction site. These include practices such as construction sequencing and scheduling, vehicle tracking controls and street sweeping, and good management of practices associated with site construction such as stream crossing, temporary batch plants, dewatering operations and other measures.

Slotted Curbs: Curbs with slots or cut-out areas that allow stormwater to flow away from the curbed pavement into an adjacent landscape or turf area, as opposed to transporting runoff directly to a storm sewer system.

Source Controls: A variety of practices implemented to minimize pollutant transport in runoff by controlling pollutants where they originate and/or accumulate. Representative source controls include good housekeeping measures, landscape management practices, pet waste controls, public education regarding household hazardous waste, covering outdoor storage areas, etc.

Spill Prevention Control and Countermeasure (SPCC) Plan: A written plan prepared for an industrial, commercial or construction operation identifying measure to minimize the likelihood of a spill and to expedite control and cleanup activities should a spill occur. SPCC plans are legally required for certain types of operations.

Stormwater Management Plan (SWMP): A written plan required under state and federal stormwater discharge permits identifying measures that will be implemented to minimize the discharge of pollutants in stormwater. Requirements for SWMPs are legally specified in state and federal discharge permits. Requirements vary depending on whether the discharge permit is associated with municipal, industrial, or construction activities.

Structural BMPs: Engineered structures constructed to provide temporary storage and treatment of stormwater runoff.

Surface Water: Water that remains on the surface of the ground, including rivers, lakes, reservoirs, streams, wetlands, impoundments, seas, estuaries, etc.

Total Maximum Daily Load (TMDL): The maximum allowable loading of a pollutant that a designated waterbody can assimilate and still meet numeric and narrative water quality standards. Section 303(d) of the federal Clean Water Act requires states to identify waterbodies that do not meet federal water quality standards and establish TMDLs that result in attainment of stream standards.

Trash Rack: Grill, grate or other device installed at the intake of a channel, pipe, drain, or spillway for the purpose of preventing oversized debris from entering the structure. Trash racks may also serve a safety function.

Treatment Train: BMPs that work together in series to provide stormwater quality treatment.

Unconnected Impervious Area (UIA): The impervious portion of a site that drains over a receiving pervious area before discharging to the storm sewer system. UIA is a key component of the conceptual model used in the volume reduction calculations in Chapter 3 of this manual.

Underdrain: A perforated pipe, typically 4- to 6-inches in diameter, placed longitudinally at the invert of a stormwater facility for the purposes of achieving a desired discharge rate and controlling nuisance ponding.

Water Quality Capture Volume (WQCV): The quantity of stormwater runoff that must be treated in stormwater quality BMPs in Denver. This volume is equivalent to the runoff from an 80^{th} percentile storm, meaning that 80 percent of the most frequently occurring storms are fully captured and treated and larger events are partially treated.

Waters of the United States: All waters that are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters subject to the ebb and flow of the tide. Waters of the U.S. include all interstate waters and intrastate lakes, rivers, streams (including intermittent streams), mudflats, sand flats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds. [See 40 CFR 122.2 for the complete definition.]

Watershed: A geographical area that drains to a specified point on a water course, usually a confluence of streams or rivers (also known as drainage area, catchment, or river basin).

Wet Pond: See definition of Retention Pond.

Wet Weather Flows: Water entering storm sewer systems as a result of precipitation events.

Wetlands: Areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

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