BEST MANAGEMENT PRACTICES
OPERATION AND MAINTENANCE PLAN
FOR STORMWATER-MANAGEMENT STRUCTURES
FORT CARSON, COLORADO

Fort Carson Directorate of Public Works
Environmental Division, Stormwater Program

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ACRONYMS AND DEFINITIONS

BMP	Best Management Practice
DPW	Directorate of Public Works
EISA 07	Energy Independence and Security Act of 2007
EPA	Environmental Protection Agency
LID	Low-Impact Development
TDS	Total Dissolved Solids
TSS	Total Suspended Solids

EXECUTIVE SUMMARY

This Operation and Maintenance (O&M) manual provides guidance for the inspection and maintenance of Fort Carson's permanent stormwater best management practices (BMPs). For proper stormwater management, structures used during one storm event must also function properly for the next storm event. Thus, inspection of these structures is important to ensure they are operating correctly and providing the water quality treatment and infiltration capacities for which they were designed.

This stormwater O&M manual was prepared to assist Fort Carson representatives and personnel from the Directorate of Public Works (DPW) to understand and follow the best course of action for maintaining the function of the various stormwater BMP structures. Stormwater BMP structures include collection, conveyance, detention, retention, and treatment structures. They are normally a combination of landscape and constructed components that slow, detain/retain, filter, and/or infiltrate stormwater runoff on-site during and after a storm event.

The inspection forms located in Appendix A provide a plan to ensure the proper operation of stormwater structures associated with the nearby building. Lack of maintenance could lead to local flooding and water damage.

Information is provided for each type of structure to educate the reader about the structure itself, its typical pollutant-removal capabilities, its design, and its operation and maintenance. This information imparts a basic understanding of the device and encourages its use in the most appropriate and effective manner.

1. INTRODUCTION

1.1 Purpose

Stormwater structures are used over the course of multiple storm events and must continually be ready for the next storm event. The hydrology, hydraulics, dam design, or stormwater quantity objectives should be achieved during the design phase, prior to the installation of the structures. From that point forward, the structures should be maintained accordingly until superseded by some other system or requirements.

Inspection of these structures is of the utmost importance to ensure they are functioning correctly to provide the water quality treatment and infiltration capacities for which the structures were designed. To provide this operational level, the BMP operator must adhere to a regularly scheduled inspection and maintenance program.

This Operation and Maintenance (O&M) manual identifies the general maintenance requirements for each type of structure found at Fort Carson and several that may be used in future designs. The guidelines herein address considerations regarding mitigation of impacts for water quality and stormwater volume.

As new BMPs are added to the overall system, this manual should also be updated to reflect these changes and maintenance requirements.

1.2 How to Use This Manual

Maintenance of stormwater controls is crucial to ensuring that the program objectives are met and that each structure continues to function as designed. An O&M plan is one way to ensure that scheduled inspections, maintenance, and practice evaluations take place, thus allowing for continued function of the structures.

For each BMP, a general description is given that details how it works as well as its benefits, disadvantages, and applicability. Pollutant removal is discussed to assist in selecting a particular BMP for target pollutants. General design guidelines are then discussed to highlight the particularly important aspects that should go into the design or redesign of poorly performing BMPs.

Pretreatment of stormwater such as a vegetated filter strip or a pea-gravel diaphragm is strongly recommended where appropriate to increase the performance and lifetime of many types of stormwater-management structures. General guidelines highlight important considerations for the design of new structures or the redesign of old ones to improve their function. The minimum design requirements are discussed for each structure to provide a reference to the minimum conditions needed to successfully operate the structure. It is important to check the local site conditions and soils for each structure and follow the general instructions in this guide before redesigning or installing any stormwater-management structure.

To ensure that stormwater is managed effectively, Fort Carson personnel must understand the general function of stormwater-management structures. These personnel should be assigned the responsibility for each activity to be performed and given a clear timetable showing when each activity must be performed. This plan should be implemented before additional structures are installed to ensure that misunderstandings are avoided and proper maintenance is achieved. Inspection and maintenance of each structure should be tracked by using the checklists contained in Appendix A. A spreadsheet will be maintained that tracks each structure, when it was inspected, if any repairs were required, and when such repairs were completed. The maintenance of these structures is essential for continued, successful operation and performance of each BMP. DPW has the overall task of making sure BMPs are followed so that stormwater-management structures are maintained to a functional level. Personnel must be qualified to properly maintain these stormwater structures. Inadequately trained personnel can cause problems that result in additional maintenance costs.

This manual is organized to cover the three major components of stormwater management: Detention (Section 2), Infiltration (Section 3), and Filtration (Section 4). In these sections, general stormwater-management theories and the goals behind these three major components are discussed along with maintenance requirements.

At the beginning of each section, a table lists the stormwater-management structures that were present at Fort Carson as of June 2013. These structures have been assigned a code that correlates to the sub-watershed in which they are located, a sequential number, and a letter or letters to signify their type. It is important to continually update these tables and the spreadsheet found in Appendix C as new structures and their upkeep are added to the overall stormwater-management system. Appendix A contains a general site map of the cantonment area that illustrates how the area has been broken up into sub-watersheds, and the locations of each of the structures that are addressed in this O&M manual and inspection program. .

1.3 Why Maintain Stormwater Structures?

One of the biggest issues with urbanizing watersheds is the increase in volume, frequency, and magnitude of the runoff as compared to the previously undeveloped area. Stormwater-BMPs slow the rate at which stormwater enters and leaves the system from developed sites. Problems associated with these developed sites include decreased time of concentration; increased rate of stormwater runoff into receiving streams, which creates flooding issues; increased erosion to receiving streams and erosion of the surrounding landscape; from exceeding the capacity of downstream stormwater-conveyance systems. Stormwater-management structures assist in mitigating the increased runoff by utilizing detention/retention, infiltration, and filtration.

Fort Carson's stormwater-management strategy concentrates on stormwater from both the source-area perspective and from the overall watershed approach. Low-impact runoff-control measures are smaller structures that are distributed throughout the source area for the combined source-area treatment. Effective low-impact development (LID) features are typically spread out at multiple locations throughout the watershed to reduce peak flows and provide for water quality treatment prior to the water reaching the channel. It is the Environmental Protection Agency's (EPA's) goal to return watersheds to their natural characteristics in terms of peak runoff; infiltration, water temperature, and groundwater recharge (EISA 07 Section 438). LID features form the key to meeting these requirements. This approach differs from historic systems that conveyed runoff off-site quickly and into the major drainage channel or treating stormwater at a large centralized location downstream. The BMPs discussed in this guide address both LID-type structures and older detention structures to aid in meeting these permits requirements and the goals of Fort Carson. This O&M manual gives insight and presents the rationale behind the LID runoff controls and how they work toward meeting these requirements.

The BMPs in this guide deal with three classes of stormwater-management structures: detention, infiltration, and filtration. The detention structures are typical detention ponds. The infiltration structures include vegetated swales, porous pavement, infiltration basins, and infiltration trenches. The filtration structures consist of bioretention areas, rain gardens, catch-basin inserts, sand filters, and vegetated filter strips. Each structure has a brief description that includes how they work and the applicability, benefits, and disadvantages of that particular BMP. The pollutant-removal capabilities are also discussed to provide assistance in treating common targeted pollutants. Key design considerations are discussed to ensure that the site is appropriate for each particular stormwater structure and to provide for its maximum treatment efficiency. Finally, operation and maintenance considerations are discussed to show what level of effort is required to effectively maintain each type of structure.

2. DETENTION

The purpose of a detention structure is to reduce the peak flow of a storm event by temporarily removing a given volume of water from the overall system. Detention structures are typically located in low-lying areas and are designed to temporarily hold a set amount of water while allowing that water to be slowly released into downstream conveyance systems. It is Fort Carson's preference to minimize the use of detention ponds for source-area treatment. All retention and detention ponds at Fort Carson are required to discharge the stormwater within 72 hours from the time the water was first being retained, as required by Colorado water law. Other design requirements include a maximum design height and an emergency spillway that can safely pass the water from a 100-year storm event.

The map in Appendix A shows the location of detention ponds at Fort Carson. The structures are listed below. Identification numbers begin with the specific sub-watershed, then list the structure's place in the numeric count of BMPs in the sub-watershed, followed by the letter "D".

	Sub watershed	**Identification number**
Dry or Wet Detention Pond	**B-4**	B-4 01 D
	I-2	I-2 04 D, I-2 07 D, I-2 08 D, I-2 09 D, I-2 10 D, I-2 12 D, I-2 13 D, I-2 14 D
	1-3	1-3 02 D
	1-4	I-4 06 D, I-4 07 D
	I-6	I-6 01 D, I-6 02 D, I-6 03 D, I-6 04 D, I-6 06 D, I-6 08 D
	I-8	I-8 01 D
	1-12	1-12 01 D
	R-X	R-X 01 D, R-X 02 D, R-X 03 D
	U-16	U-16 01 D, U-16 02 D, U-16 03 D, U-16 04 D, U-16 05 D
	U-17	U-17 01 D, U-17 02 D, U-17 03 D, U-17 04 D, U-17 05 D, U-17 06 D, U-17 07 D
	U-19	U-19 01 D, U- 19 04 D, U-19 05 D, U-19 06 D, U-19 07 D, U-19 08 D, U-19 09 D, U-19 10 D, U-19 11 D, U-19 12 D, U-19-13 D, U-19 14 D, U-19 15 D, U-19 16 D

	U-20	U-20 02 D, U-20 03 D, U-20 04 D, U-20 05 D, U-20 06 D, U-20 07 D, U-20 09 D, U-20 10 D
	U-X	U-X 01 D

2.1 Dry Detention Pond

Dry detention ponds (also called dry ponds, extended detention basins, detention ponds, and extended detention ponds) are basins constructed by either impoundment in a natural depression or excavation of existing soil. These earthen structures have outlets that have been designed to detain stormwater runoff for minimum and maximum designed time period. Colorado water law prohibits dry detention ponds at Fort Carson from holding water for more than 72 hours. Therefore, unlike wet retention ponds, these structures do not have a permanent pool of water. However, dry detention basins may develop wetland vegetation and sometimes shallow pools in the bottom parts, which can enhance the efficiency of the basins' soluble pollutant removal through biological uptake. Therefore, dry detention ponds are often designed to hold small pools at the inlet and outlet of the basin.

Use of dry detention ponds has previously been one of the most widely used stormwater BMPs. In some instances, such ponds may be the most appropriate best practice. However, if pollutant-removal efficiency is an important consideration, then dry detention ponds may not be the most appropriate choice. Dry detention ponds require a large amount of space. In many instances, smaller-sized structures are more appropriate alternatives.

One common objective of stormwater management is to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Dry detention basins can easily be designed for flood control. This is actually the primary purpose of most detention ponds.

2.1.1 Pollutant Removal

Dry detention basins provide moderate pollutant removal if the design features described in the Design Considerations section are incorporated. Although truly dry basin structures can be effective at removing some pollutants through settling, they are less effective at removing soluble pollutants because of the absence of a permanent pool. Typical removal rates, as reported by Schueler (1997), are as follows:

Total suspended solids:	61%
Total phosphorus:	19%
Total nitrogen:	31%
Nitrate nitrogen:	9%
Metals:	26%–54%

There is considerable variability in the effectiveness of dry detention ponds, and it is believed that properly designing and maintaining ponds may help to improve their performance. The design criteria presented in the next section reflect the best current information and experience to improve the performance of dry ponds.

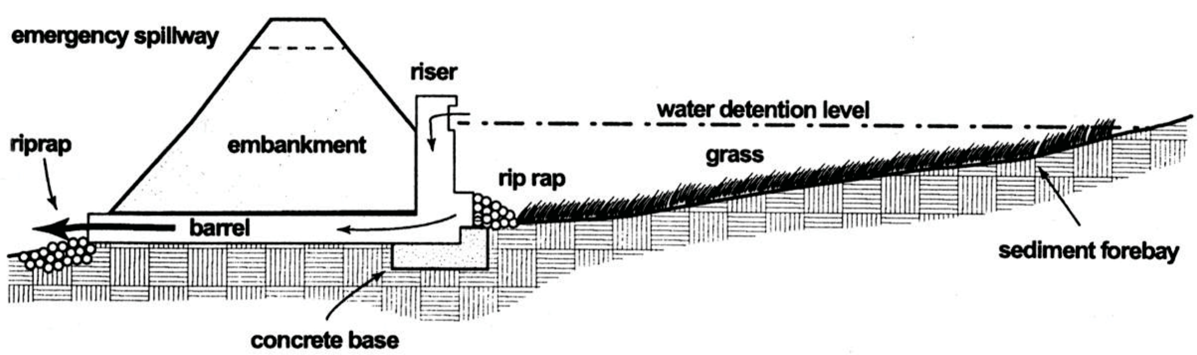
2.1.2 Design Considerations

In general, dry detention ponds should be used on sites with a minimum area of 10 acres. On smaller sites, it can be challenging to provide channel or water quality control because the outlet's orifice diameter needs to control relatively small storms which becomes very small and thus prone to clogging. Low-impact development techniques are recommended for these smaller areas.

Dry detention ponds can be used on sites with slopes as steep as 15%. The local slope needs to be relatively flat, however, to maintain reasonably flat side slopes. There is no minimum slope requirement, but there does need to be sufficient elevation drop from the pond inlet to the pond outlet to ensure that flow can move through the system.

Specific designs may vary considerably, depending on site constraints or preferences of the designer. Some features, however, should be incorporated into most dry detention pond designs. These design features are illustrated in the figure below.

Figure 2-1 Dry Detention Pond



Source: U.S. Environmental Protection Agency (EPA), *National Pollutant Discharge Elimination System (NPDES), Dry Ponds*, May 2006

Regular maintenance is needed to maintain the short-term and long term functions of stormwater detention pond. However, some design features can be incorporated to ease the maintenance burden of each structure. In dry detention ponds, a "micro-pool" at the outlet can prevent re-suspension of sediment and outlet clogging. A good design should include maintenance access to the forebay and micro-pool.

Another design feature that can reduce maintenance needs is a non-clogging outlet. Typical examples include a reverse-slope pipe or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and determines the water elevation of the micro-pool. Because these outlets draw water from below the surface level of the permanent pool, they are less likely to be clogged by floating debris.

Designers should maintain a vegetated buffer around the pond and should select plants within the extended detention zone (i.e., the part of the pond up to the elevation where stormwater is detained) that can withstand both wet and dry periods. The side slopes of dry ponds should be relatively flat to reduce safety risks.

2.1.3 Operation and Maintenance

Clogging from sediment and debris buildup is the primary maintenance concern for dry detention basins. The basin must be checked on a regular interval for sediment and debris. This inspection interval may require adjustment depending on erosional features upstream and/or loading from various debris sources. The basin should also be regularly inspected for signs of erosion, instability, clogging, dead or dying vegetation, illicit materials (e.g., petroleum hydrocarbons), or any type of malfunction. Any damaged structural components such as a primary or emergency spillway should be immediately repaired. See Appendix A for a maintenance check list and tracking forms.

Activity	Schedule
Repair undercut or eroded areas. Mow side slopes. Manage pesticides and nutrients. Remove litter and debris.	Standard maintenance
Note erosion of upstream areas, pond banks, or pond bottom.	Annual inspection

Inspect for damage to the embankment. Monitor for sediment accumulation in the facility and forebay. Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual inspection
Remove sediment from the forebay. Monitor sediment accumulations, and remove sediment when the pond volume has been reduced by 25%. Seed or sod to restore dead or damaged ground cover.	Annual maintenance (as needed)

2.2 Wet Detention Pond

A wet detention pond combines the treatment concepts of the dry detention pond and the wet pond. Wet detention ponds are basins whose outlets have been designed to collect stormwater runoff in a permanent pool of water. Runoff is detained and treated in the permanent pool through settling and pollutant uptake, particularly of nutrients, through biological uptake mechanisms and chemical activity in the pond. A temporary detention volume is provided above this permanent pool where the stormwater is captured and released over a maximum of 72 hours.

2.2.1 Pollutant Removal

Treatment design features help enhance the ability of a detention structure to remove pollutants from stormwater. The purpose of most of these features is to increase the amount of time that stormwater remains in the pond.

Other design features do not increase the volume of a pond, but can increase the amount of time stormwater remains in the pond and eliminate short-circuiting. Ponds should always be designed with a length-to-width ratio of at least 1.5:1. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer route through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat stormwater. Another feature that can improve treatment is to use multiple ponds in series as part of a "treatment train" approach to pollutant removal. This redundant treatment can also help slow the rate of flow through the system. A vegetated buffer with shrubs or trees around the pond area should provide shading and consequent cooling of the pond water to aid cold-water aquatic species.

Research shows that wet ponds are among the most effective structures for removing stormwater pollutants. Typical pollutant-removal rates, as reported for Colorado by Urbonas, are listed in the following table:

Total suspended solids:	78%
Total phosphorous:	49%
Total nitrogen:	–12%
Nitrate nitrogen:	–85%
Metals:	51.57%

2.2.2 Design Considerations

Wet ponds need drainage from a sufficient source area to maintain the permanent pool. In humid regions, this area is typically about 25 acres, but a greater area may be needed in regions with less rainfall. As a BMP, structures that focus on source control, such as bioretention, should be considered for smaller drainage areas.

Wet ponds can be used on sites with an upstream slope as steep as 15%. The local slope should be relatively shallow. Although there is no minimum slope requirement, there does need to be sufficient elevation drop from the pond inlet to the pond outlet to ensure that water can flow through the system.

Wet ponds can be used in almost all soils and geology. Unless they receive high levels of pollutants, also called hot-spot runoff, ponds can intersect the groundwater table. However, some research suggests that pollutant removal is reduced when ground water contributes substantially to the pool volume (Schueler, 1997b).

There are some features that should be incorporated into most wet pond designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment incorporates design features that help to settle out coarse sediment particles. By removing these particles from runoff before they reach the large permanent pool, the maintenance burden of the pond is reduced. In ponds, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10% of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge the entire pond.

Treatment design features help enhance the ability of a wet detention pond to remove pollutants. The purpose of most of these features is to increase the amount of time that stormwater remains in the pond. One technique of increasing the pollutant removal by a pond is to increase the volume of the permanent pool. Typically, ponds are sized to be equal to the water quality volume (i.e., the volume of water treated for pollutant removal). Designers may consider using a larger volume to meet specific watershed objectives, such as phosphorous removal in a lake system. Regardless of the pool size, designers need to conduct a water balance analysis to ensure that sufficient inflow is available to maintain the permanent pool.

Other design features do not increase the volume of a wet detention pond, but can increase the amount of time stormwater remains in the pond and eliminate short-circuiting. Ponds should always be designed with a length-to-width ratio of at least 1.5:1. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer route through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat stormwater. Another feature that can improve treatment is to use multiple ponds in series as part of a "treatment train" approach to pollutant removal. This redundant treatment can also help slow the rate of flow through the system. Additionally, a vegetated buffer with shrubs or trees around the pond area should provide shading and consequent cooling of the pond water to aid cold-water aquatic species.

Design features should also incorporated to ease maintenance of both the forebay and the main pool of ponds. Ponds should be designed with maintenance access to the forebay to ease this relatively routine (every 5 to 7 year) maintenance activity. Ponds should generally have a drain to draw down the pond for the more infrequent dredging of the main cell of the pond.

In arid climates, wet ponds are not a feasible option, but they may possibly be used in semiarid climates if the permanent pool is maintained with a supplemental water source or if water presence in the pool is allowed to vary seasonally. This choice needs to be seriously evaluated, however. Saunders and Gilroy (1997) reported that 2.6 acre-feet per year of supplemental water were needed to maintain a permanent pool of only 0.29 acre-feet in Austin, Texas. Hence, wet ponds are normally not ideal in semiarid environments.

Cold climates present many challenges to designers of wet ponds. The spring snowmelt may have a high pollutant load and a large volume to be treated. In addition, cold winters may cause freezing of the permanent pool or freezing at inlets and outlets. Finally, high salt concentrations in runoff resulting from road salting and high sediment loads from road sanding may impair the growth of pond vegetation as well as reduce the storage and treatment capacity of the pond.

Designers should consider planting the pond with salt-tolerant vegetation if the facility receives road runoff.

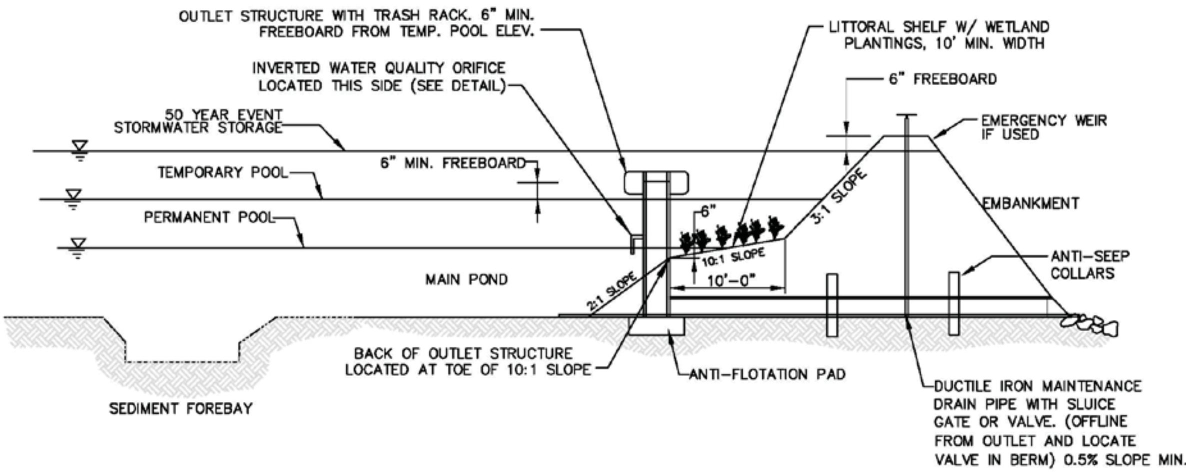
One option to deal with seasonally high pollutant loads and high runoff volumes during spring snowmelt is the use of two water quality outlets, both equipped with gate valves, as proposed by Oberts (1994). In the summer, the lower outlet is closed. During the fall and throughout the winter, the lower outlet is opened to draw down the permanent pool. As the spring snowmelt begins, the lower outlet is closed to provide detention for the melt event. This method can act as a substitute for using a minimum extended detention storage volume. Where wetlands preservation is a downstream objective, seasonal manipulation of pond levels may not be desired. An analysis of the effects on downstream hydrology should be conducted before considering this option. In addition, the manipulation of this system requires some labor and vigilance; a careful maintenance agreement should be confirmed.

Several other modifications may help to improve the performance of ponds in cold climates. To counteract the effects of freezing on inlet and outlet structures, frost-resistant inlet and outlet structures, including weirs and larger-diameter pipes, may be useful. Designing structures online, with a continuous flow of water through the pond, will also help prevent freezing of these structures. Finally, since freezing of the permanent pool can reduce the effectiveness of pond systems, it may be practical to incorporate extended detention into the design to retain a usable treatment area above the permanent pool when it is frozen.

Stormwater should be conveyed to and from all stormwater structures safely and with minimal erosion potential. Outfalls of pond systems should always be stabilized to prevent scour, and an emergency spillway should be provided to safely convey large flood events. To mitigate warming at the outlet channel, provide shade around the channel at the pond outlet.

Landscaping wet ponds can make them an asset to a community and can also enhance their pollutant removal effectiveness. A vegetated buffer should be preserved around the pond to protect the banks from erosion and provide some pollutant removal before runoff enters the pond by overland flow. In addition, ponds should incorporate an aquatic bench (i.e., a shallow shelf with wetland plants) around the edge of the pond. This feature may provide some pollutant uptake, and it also helps to stabilize the soil at the edge of the pond and enhance habitat and aesthetic value.

Figure 2-2 Wet Detention Pond



2.2.3 Operation and Maintenance

Clogging from sediment and debris buildup is the primary maintenance concern for wet detention basins. The basin's pretreatment area must be checked on a regularly for sediment and debris, which must be removed as necessary. The basin should also be inspected for signs of erosion, instability, clogging, dead or dying vegetation, illicit materials (e.g., petroleum hydrocarbons), or any type of malfunction. Any structural components such as an overflow weir should also be inspected regularly to check for signs of instability, erosion, clogging, or failure. See Appendix B for a maintenance check list and tracking forms.

In addition to regular work needed to maintain the function of stormwater pond, some design features can be incorporated to ease the maintenance burden of each practice. Ponds should be designed with a non-clogging outlet such as a reverse-slope pipe or a weir outlet with a trash rack. A reverse-slope pipe draws from below the surface of the permanent pool, extending in a reverse angle up to the riser. This reverse-slope pipe establishes the water elevation of the permanent pool. Because these outlets draw water from below the surface of the permanent pool, they are less likely to be clogged by floating debris. Another general rule is that no orifice should be less than 3 inches in diameter because smaller orifices are more susceptible to clogging.

Activity	Schedule
If wetland components are included, inspect for invasive vegetation.	Annual inspection
Inspect for damage. Note signs of hydrocarbon buildup, and deal with appropriately. Monitor for sediment accumulation in the facility and forebay. Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual inspection
Repair undercut or eroded areas.	As needed maintenance
Clean and remove debris from inlet and outlet structures. Mow side slopes.	As needed maintenance
Manage and harvest wetland plants.	Annual maintenance (if needed)
Remove sediment from the forebay.	5- to 7-year maintenance
Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly or the pond becomes eutrophic.	20- to 50-year maintenance

3. INFILTRATION

Infiltration structures are typically located in low-lying areas and are designed to temporarily hold a set amount of water while allowing that water to soak into the soil column and eventually into the groundwater system. The purpose of infiltration structures is to reduce the peak flow of a storm event while improving water quality as the water moves through the soil. All infiltration areas at Fort Carson must drain within 72 hours from the time the water was first contained, as required by Colorado water law.

Currently, all infiltration features at Fort Carson are considered bioretention. As the features are constructed, they will be added to the map in Appendix A, the table below, and tracked appropriately in Appendix C.

	Sub-watershed	**Identification Number**
Grass-Lined Channel, Trenches, and Swales		

3.1 Infiltration Basin

Infiltration basins are earthen structures that are essentially shallow artificial ponds designed to capture stormwater and allow it to soak through permeable soils into the groundwater over a short period of time (72 hours). Typical components of an infiltration basin include an inlet, sediment forebay, level spreader, principal spillway, back-up underdrain, emergency spillway, and a stilling basin. Infiltration basins have high pollutant-removal efficiency; help recharge groundwater and increase base flow to downstream systems. Infiltration basins do not discharge to a surface water body as they are typically constructed as offline structures. Under most conditions they are designed only to intercept a certain volume of runoff and contain it in overflow structures that operate during flood conditions. Excess volume is generally diverted past the facility to the downstream conveyance system.

Infiltration basins function similarly to dry detention ponds in that they capture and infiltrate a specified quantity of runoff to provide a reduction in peak flows and runoff volume and provide water quality treatment through settling of sediment particles. Infiltration basins contribute to groundwater recharge. These basins do not increase the temperature of the stored water, which is beneficial to cold-water aquatic species. Another positive effect of infiltration basins is an increase in the overall base flow to the stream channels.

Infiltration basins are not appropriate for known stormwater hot spots and highly developed urban areas because of the risk for groundwater contamination from stormwater infiltration. Infiltration structures are typically problematic for highly developed urban areas because they may not have suitable space, infiltration may pose a risk to the structural stability of surrounding infrastructure, and urban soils are typically compacted.

3.1.1 Pollutant Removal

Pollutant-removal rates are assumed to be high for infiltration basins because the structures are located offline and do not discharge into receiving waters. Pollutant removal is achieved through infiltration and settling of suspended sediment and settle-able chemicals. Additional pollutant removal may be achieved with the use of pretreatment.

Very little data are available regarding the pollutant removal associated with infiltration basins. It is generally assumed that they have very high pollutant removal because none of the stormwater entering the infiltration structure remains on the surface. Schueler (1987) estimated pollutant removal for infiltration basins based on data from land disposal of wastewater. Under the assumption that the infiltration basin is sized to treat the runoff from a 1-inch storm, the average pollutant removal is as follows:

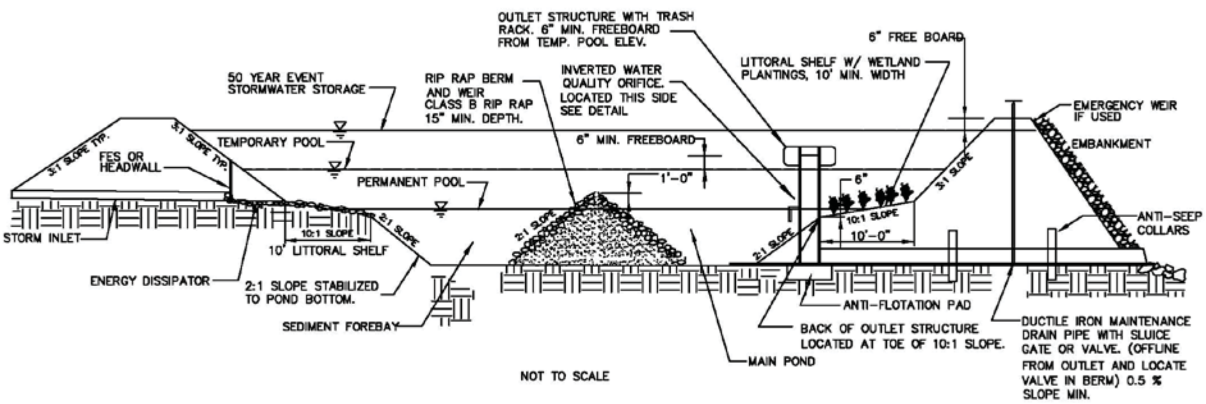
TSS	75%
Phosphorous	60%–70%
Nitrogen	55%–60%
Metals	85%–90%
Bacteria	90%

3.1.2 Design Considerations

The design requirements for BMPs involving infiltration basins must be met to ensure protection of water resources, prevent basin failures, and ensure their proper performance. Vegetated swales, sediment basins, and vegetated filter strips should be used in conjunction with infiltration basins to pre-treat the stormwater so that large particles and debris are removed and do not clog or otherwise damage the infiltration structure.

The site used for the infiltration basin should be as flat as possible to promote infiltration and reduce the chances of failure. It should also be designed in conjunction with knowledge of the actual infiltration rates of the soils to ensure proper function of the basin. Areas with lower infiltration rates should be sized larger to ensure proper treatment of the design storm. Vegetation within and upstream of the basin should be well established, and soils should be stabilized to prevent excessive sediment from entering the basin and increasing the risk of clogging.

Figure 3-1 Infiltration Basin



3.1.3 Operation and Maintenance

Clogging with sediment and debris buildup are the primary maintenance concerns for infiltration basins. These problems are prevented by checking the infiltration basin's pretreatment area at a regular interval for sediment and debris, which must be removed as necessary. An underdrain can also aid in this process. The basin should also be regularly inspected for signs of erosion, instability, clogging, dead or dying vegetation, illicit materials (e.g., petroleum hydrocarbons), or any type of malfunction. Any damaged structural components such as an overflow weir or underdrain should be immediately repaired. See Appendix A for a maintenance check list and tracking forms.

Activity	Schedule
Repair undercut or eroded areas. Mow side slopes. Manage pesticides and nutrients. Remove litter and debris.	Standard maintenance
Inspect for damage to the embankment. Monitor for sediment accumulation in the facility and forebay. Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual inspection
Remove sediment from the forebay. Monitor sediment accumulations, and remove sediment when the pond volume has been reduced by 25%. Seed or sod to restore dead or damaged ground cover.	Annual maintenance (as needed)

3.2 Grassed Swale

In the context of stormwater-management structures that improve water quality, the term “swale” refers to a vegetated, open channel designed specifically to treat and attenuate a specified volume of stormwater runoff. Swales are broad, shallow channels designed to convey and infiltrate stormwater runoff. The swales are vegetated along the bottom and sides of the channel; the vegetation along the sides reaches a height greater than the maximum design stormwater volume. Vegetated swales reduce stormwater volume and peak discharge by promoting infiltration along the swale. Vegetated swales also slow stormwater, which allows it to filter through the vegetation and a subsoil matrix and/or infiltrate into the underlying soils where pollutants can be captured. Variations of the grassed swale include the grass-lined channel. The structural features and methods of treatment differ among specific designs, but all are improvements on the traditional drainage ditch. The designs incorporate a modified geometry and other features so that swales may be used as treatment and conveyance structures.

The advantage to using vegetative swales as stormwater treatments is that they assist in returning the area to the predevelopment hydrology by reducing peak flows, reducing runoff volume, and promoting infiltration. As an added benefit, pollutants are also removed through this process. Dry swales are good choice to use in areas that drain to cold-water fisheries because stormwater is typically held for a minimal time and thus does not have a chance to warm up. Capital costs are typically lower than for traditional drainage systems.

Disadvantages of using vegetated swales exist in certain circumstances. They are ineffective in pollutant removal and flow alterations during large storms and are susceptible to erosion. Vegetative swales are impractical in areas with grades that are too flat or too steep, wet or poorly drained soils, highly erosive soils, or areas where dense vegetation is difficult to sustain. Groundwater contamination is also a concern if the water table is too high. Improperly designed swales may contain standing water that could produce odor, safety, and/or mosquito issues. Swales must be maintained to be effective, and the maintenance schedule is typically more intensive than for traditional drainage systems.

Vegetated swales are best suited to receive discharge from areas resulting in low flows. These could include certain residential, industrial, and commercial areas with medium to low density. Highly developed urban areas or other areas with impervious soils or surfaces are not ideal for vegetated swales, owing to their potential to produce high flows and the lack of space for the swale itself. Stormwater hot spots, which have a greater likelihood to contribute pollutants to stormwater, are not suited to be treated by a vegetative swale.

3.2.1 Pollutant Removal

The effectiveness of grass swales for pollution removal depends on the type of swale used, the effectiveness of the design, the settling capacity of the swale, its maintenance, along with other factors. Factors believed to increase performance include the use of rock check dams, gentler longitudinal slopes, permeable soils, dense vegetation cover, increased runoff contact time, and smaller storm events. Factors believed to decrease performance include steeper longitudinal slopes, compacted soils, frozen ground, short vegetation height, short runoff contact time, large storm events, and high runoff velocity and peak flows.

It should be noted that some studies indicate that vegetated swales increase the presence of bacteria in surface waters. The cause of this is unknown; however, possible explanations involve bacteria thriving in conditions created by the swales or faults in studies for not accounting for local inputs of bacteria, e.g., wildlife or walked dogs (EPA (Grassed Swale) 2006).

Few studies are available regarding the effectiveness of grassed channels. The data suggest relatively high removal rates for some pollutants, negative removals for some bacteria, and fair performance for phosphorous. One study of available performance data (Schueler, 1997) estimates the pollutant-removal rates for grassed channels as follows:

Total suspended solids:	81%
Total phosphorous:	29%
Nitrate nitrogen:	38%
Metals:	14%–55%
Bacteria:	–50%

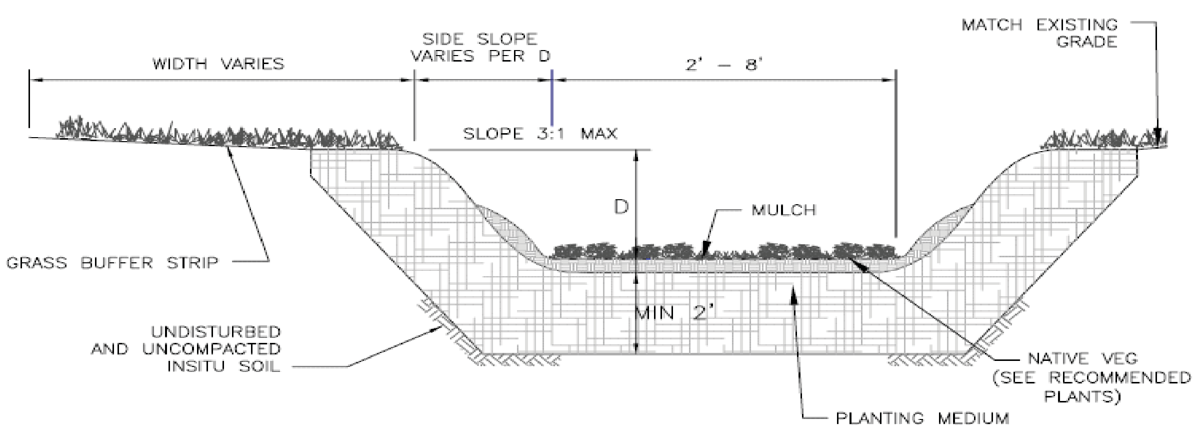
3.2.2 Design Considerations

Essential design components for the effective operation of a vegetated swale include the vegetation types, swale and vegetation dimensions, underlying soils, and contributing area characteristics. A fine, close-growing, water- and drought-resistant grass is recommended. The surface area of the vegetation should be maximized to contact and treat the runoff. Site-specific characteristics should be considered when choosing the vegetation.

Optional features of grassed swales are check dams, sediment forebays, or protective side materials. Check dams should be considered when the channel slope is greater than 2%. Check dams are beneficial because they promote infiltration, increase storage, and reduce velocity. When utilized, they should be installed every 50 feet of swale or when the top elevation of the down-gradient check dam reaches the bottom elevation of the next upstream check dam location forming a stair step.

Sediment forebays and check dams act as stormwater pretreatment within the swale and may aid in reducing sediment loads. Protective side materials, such as a gravel strip, can protect the swale from erosion resulting from sheet flow entering from the sides.

Figure 3-2 Grassed Swale



3.2.3 Operation and Maintenance

Maintenance of a swale should focus on sustaining a healthy, densely vegetated cover. The work required includes a mowing or trimming routine that ensures the vegetation is not allowed to grow unrestrained but also is not cut shorter than the design flow depth. Invasive species should be addressed, preferably without the use of pesticides or herbicides as their over-application can become a source of pollutants. Bare areas should be repaired and reseeded as required. Watering should be considered during times of drought to maintain healthy cover. Trash, woody debris, and sediment should be cleared out. Cleared materials, clippings, and any other residue should be properly disposed of at appropriate structures.

Inspection should be conducted to determine the stability of the vegetation and any other structures that may be present as part of the swale (e.g., forebay, check dams, overflow weirs, under drains). Erosion, scouring, or any other damage should be noted and corrected. Trees, beaver dams, rodent holes, or any other obstruction that may cause instability in the structures should also be corrected.

Activity	Schedule
Inspect grass on bordering slopes for erosion and formation of rills or gullies and correct. Remove trash and debris accumulated in the inflow forebay. Inspect and correct erosion problems in the sand or soil bed of dry swales. Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established. Replant wetland species (for wet swale) if not sufficiently established.	Annual inspection
Rototill or cultivate the surface of the sand or soil bed of dry swales if the stormwater does not draw down within 48 hours. Remove sediment buildup within the bottom of the swale once it has accumulated to 25% of the original design volume.	As needed
Mow grass to maintain a height of 3–4 inches.	As needed (seasonally)

3.3 Infiltration Trench

The infiltration trench is a trench that is backfilled with rock and coarse, granular material. It has no outlet and receives stormwater runoff for temporary storage and infiltration. The infiltration trench can only capture a small amount of runoff; therefore, such trenches are most effective and have a longer life cycle when some form of stormwater pretreatment is included in their design. The infiltration trench stores runoff in the void spaces between the stones and allows the runoff to filter through the bottom into the soil matrix. The trench is designed to capture only a set quantity of runoff, and an overflow structure is typically included in the design to bypass excess flows.

Infiltration trenches function similarly to infiltration basins and dry detention ponds in that they temporarily capture a specified quantity of runoff (thereby reducing peak flows and runoff volume) and provide water quality treatment through settling of sediment particles and settle-able chemicals. The rock and coarse granular material provide additional filtering of pollutants. The settling velocity of sediment and settle-able chemicals is increased by a value equal to the infiltration rate in the trench (influencing the removal of smaller, clay-sized particles). Infiltration basins contribute to groundwater recharge. The fact that they do not increase the stored water's temperature is beneficial to cold-water aquatic species. An infiltration trench is typically designed as an underground structure and as such does not impact much of the site area.

Certain areas are not appropriate for infiltration trenches. They are not appropriate treatments for stormwater hot spots due to the potential for groundwater contamination. Highly developed urban areas may not be appropriate for an infiltration trench as soils may be too compacted for appropriate treatment or infiltration may pose a risk to damaging infrastructure. Steep slopes and fill sites are also not appropriate settings for infiltration trenches.

Like most infiltration structures, trenches are most effective with proper maintenance and may become ineffective and costly if not maintained. Historically, infiltration trenches have not performed well due to a lack of maintenance. Studies from Maryland showed that, of approximately 50 infiltration trenches, less than one-third were functional after 5 years (EPA (Infiltration Basins) 2006).

3.3.1 Pollutant Removal

Pollutant-removal rates are assumed to be high for infiltration trenches because the structures are located offline and do not discharge into receiving waters. Pollutant removal is achieved through infiltration and settling of suspended sediment and settle-able chemicals as well as filtration of water through the rock and coarse granular materials. Additional pollutant removal may be achieved with the use of pretreatment.

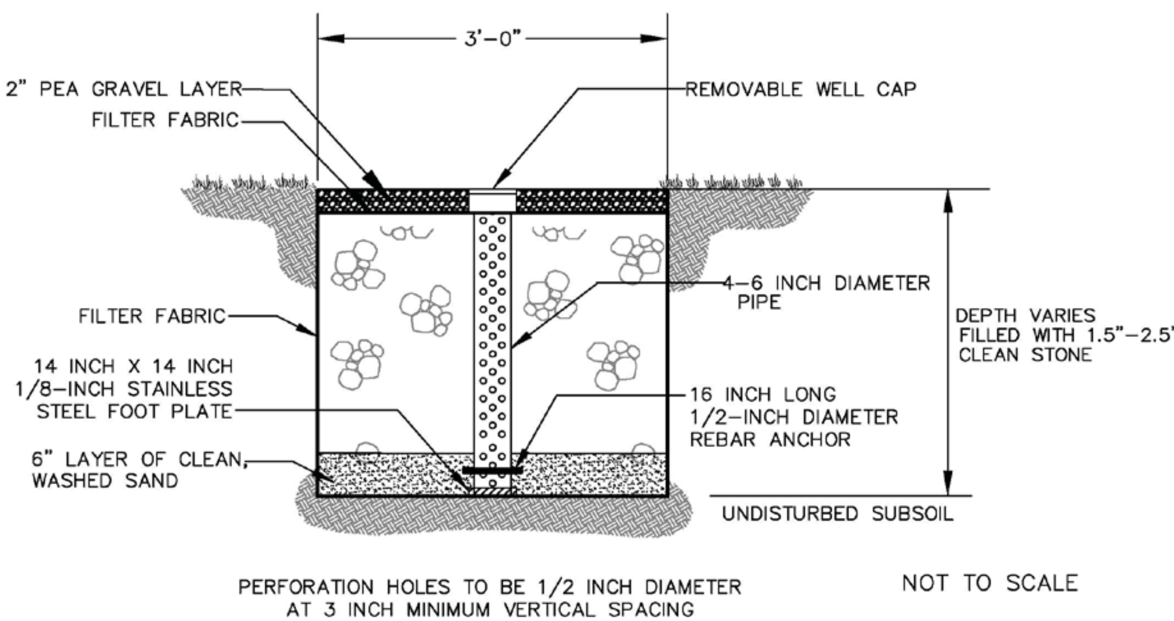
3.3.2 Design Considerations

Design requirements for an infiltration trench must be met to ensure protection of water resources, prevent failure of the structure, and ensure proper performance. Pretreatment in the form of vegetated swales and vegetated filter strips should be used in conjunction with an infiltration trench. These ensure that large particles and debris are removed from stormwater and do not clog or otherwise damage the infiltration trench.

Infiltration trenches should also be designed in conjunction with knowledge of the actual infiltration rates of the soils to ensure proper function of the basin. Infiltration trenches installed in areas with lower infiltration rates should be larger in size to ensure proper treatment of water from the design storm. Vegetation within and upstream of the basin should be well established, where soils should be stabilized in order to prevent excessive amounts of sediment from entering the basin and increasing the risk of clogging. Long-term maintenance practices should be considered in the design to allow for access and should consider an underdrain to remove clogged particles.

Variations of the trench could include dry wells, pits designed to control small volumes of runoff (e.g., from a rooftop), or enhanced systems with elaborate treatments designed for specific pollutants of concern (e.g., oil or sediment). The design requirements for an infiltration trench are summarized in Figure 3-3.

Figure 3-3 Infiltration Trench



3.3.3 Operation and Maintenance

Features need to be incorporated into the design, to ensure that the maintenance burden of an infiltration trench is reduced. These features can make regular maintenance activities easier or reduce the need to perform maintenance. As with all stormwater-management structures, infiltration trenches should have an access path for maintenance activities. An observation well (i.e., a perforated PVC pipe that leads to the bottom of the trench) can enable inspectors to monitor the drawdown rate. Where possible, a trench should have a means to be drained if it becomes clogged, such as an underdrain. An underdrain is a perforated pipe system in a gravel bed, installed on the bottom of filtering structures to collect and remove filtered runoff. An underdrain pipe with a shutoff valve can be used in an infiltration system to act as an overflow in case of clogging.

There is no landscaping on the infiltration trench structure itself, but it is important to ensure that the upland drainage is properly stabilized with thick vegetation to form a filter strip. In arid regions, infiltration trenches are often highly recommended as part of best management practices because of the need to recharge the ground water. One concern in these regions is the potential for infiltration trenches to clog because of relatively high sediment concentrations in these environments. Stormwater pretreatment should be heavily emphasized in dryer climates.

In cold climates, the volume may need to be increased in order to treat snowmelt. In addition, if the infiltration trench is used to treat roadside runoff, it may be desirable to divert flow around the trench in the winter to prevent infiltration of chlorides from road salting. Finally, a minimum setback from roads is needed to ensure that the trench does not cause frost heaving.

Although infiltration trenches can be a useful stormwater-management structure, they have several limitations. Although they do not detract visually from a site, infiltration trenches also provide no visual enhancements. Their application is limited owing to concerns over ground-water contamination and other soils requirements. Finally, maintenance can be burdensome, and infiltration trenches have a relatively high rate of failure.

In addition to incorporating features into the design to minimize maintenance, some regular maintenance and inspection of these BMPs are needed. The following table outlines some of these best practices:

Activity	Schedule
Check observation wells following 3 days of dry weather. Failure to percolate within this time period indicates clogging. Inspect pretreatment devices and diversion structures for sediment buildup and structural damage.	Annual inspection
Remove sediment and oil or grease from pretreatment devices and overflow structures.	Standard maintenance
If bypass capability is available, it may be possible to regain the infiltration rate in the short term by using measures such as providing an extended dry period.	5-year maintenance
Total rehabilitation of the trench should be conducted to maintain storage capacity within 2/3 of the design treatment volume and 72-hour infiltration rate limit. Trench walls should be excavated to expose clean soil.	Upon failure

Infiltration trenches have historically had a high rate of failure compared to other stormwater-management practices. One study conducted in Prince George's County, Maryland (Galli, 1992), revealed that less than half of the infiltration trenches investigated (of about 50) were still functioning properly and less than one-third still functioned properly after 5 years. Many of these trenches, however, did not incorporate advanced pretreatment. By carefully selecting the location and improving the design features of infiltration practices, their performance should improve.

3.4 Porous Pavement and Interlocking Blocks

Porous pavement (PP) is a permeable surface that replaces traditional pavement, asphalt, or concrete that allows stormwater runoff to infiltrate through the otherwise impervious surface. This system provides storage and water quality treatment.

Various types of porous surfaces include porous asphalt; pervious concrete; traditional concrete with porous joints or gaps, called permeable interlocking concrete pavers; and reinforced turf. On the surface, porous asphalt and pervious concrete paving materials appear nearly indistinguishable from nonporous materials. However, unlike traditional pavement, PP contains little or no fine materials. Instead, it contains voids that allow for infiltration. Porous asphalt consists of an open-graded coarse aggregate bonded together by asphalt cement with sufficient interconnected voids to make it highly permeable to water. Pervious concrete typically consists of specially formulated mixtures of Portland cement, uniform open-graded coarse aggregate, and water. Pervious concrete has enough void space to allow rapid percolation of liquids through the pavement.

Porous pavements are appropriate to replace typical pervious surfaces such as residential or light commercial parking lots and roads having low to medium volume and speed. They are not suited for stormwater hot spots, including industrial parking structures or high-volume or high-speed roads. Permeable surfaces can be a stand-alone treatment or can be installed in sections to treat adjacent impervious areas to minimize cost. They can also be installed in coordination with inlets to other stormwater-management structures (e.g., bioretention areas) to accommodate overflows.

The advantage of using PP surfaces over traditional surfaces is the reduction of the volume, rate, and pollutants of stormwater runoff. Thus, PP surfaces aid in replicating predevelopment hydrology. There is also some indication that the use of porous concrete or interlocking concrete pavement surfaces may lower ambient air temperatures, benefiting air quality, and reduce the need for nighttime lighting because of their lighter color (EPA (Porous Asphalt) 2006). Though costs may be higher, they may be offset by the reduced cost and land use required for traditional collection, conveyance, and detention infrastructure.

Permeable interlocking concrete pavement (PICP) consists of manufactured concrete units that reduce stormwater runoff volume, rate, and pollutants. The impervious units are designed with small openings between permeable joints. The openings typically comprise 5% to 15% of the paver surface area and are filled with highly permeable, small-sized aggregates. The joints allow stormwater to enter a crushed stone aggregate bedding layer and base that together support the pavers while providing storage and runoff treatment. PICPs are highly attractive, durable, easily repaired, require low maintenance, and can withstand heavy vehicle loads.

Disadvantages to PP surfaces are the potential costs of the materials, installation, and maintenance. Steps must be taken to prevent sediment-filled run-off from entering the porous surface. These surfaces can also be susceptible to freeze-thaw weathering and damage if not properly maintained, which can decrease their functionality and life. Individuals who have a disability may have difficulty traveling over porous pavements depending on their type and quality of installation; however, most such surfaces are compliant with the Americans with Disabilities Act (EPA (Porous Asphalt) 2006).

The map in Appendix A shows the location of porous pavers at Fort Carson. The structures are listed below. Identification numbers begin with the specific sub-watershed, then list the structure's place in the numeric count of BMPs in the sub-watershed, followed by the letters "PP".

Porous Pavement	Sub-watershed	Identification Number
	1-2	1-2 11 PP
	1-4	1-4 04 PP
	U-19	U-19 03 PP

3.4.1 Pollutant Removal

The effectiveness of PP surfaces for removing pollutants has been debated. Observations from the mid-Atlantic region found that PP surfaces yielded poor removal of pollutants, which was attributed to lack of proper installation and maintenance. Results from the southeast have shown more successful results (Field et al., 2006).

In theory, pollutants are removed when the surface of the pavement slows runoff and allows for infiltration. This process reduces sediment as well as any pollutants (e.g., nutrients, metals) that are present in the runoff. The effectiveness of PP surfaces can also be increased depending on the type of sub grade soil used.

Van Seters (TRCA 2007) compared pollutants in soils under and next to six PP sites 3- to 16-years old in Ontario. There were no increases in oils (PAHs), iron, lead, zinc, copper, or iron in soils under the PPs compared to soils adjacent to them. Chlorides were increased under the PP sites, which would be expected under all permeable pavements subject to snow and deicers.

Monitored Pollutant Removals of Permeable Pavement

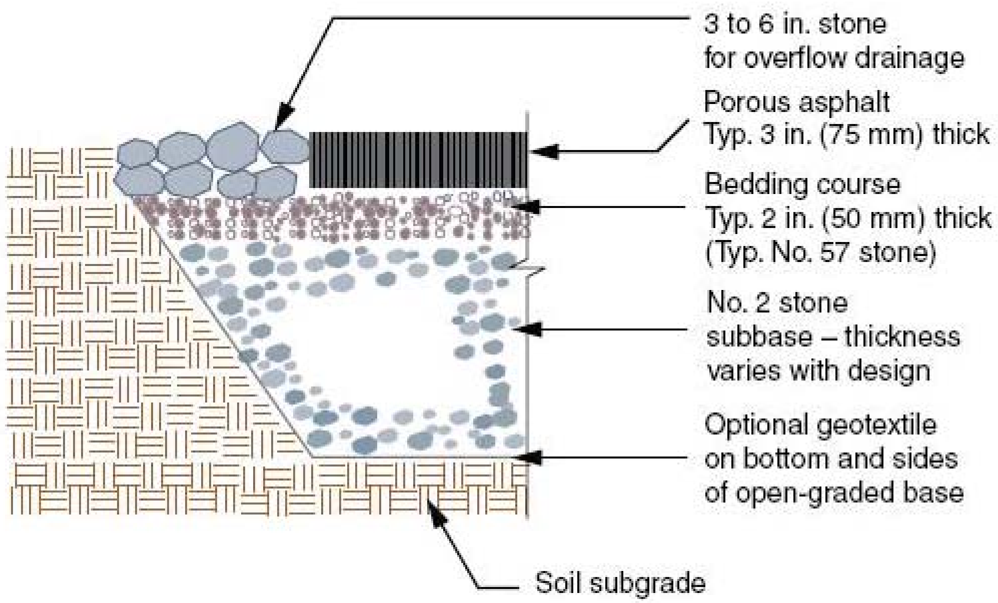
Application	Location	TSS	Metals	Nutrients
Porous Asphalt				
Highway (friction course only)	Austin, TX	94%	76%–93%	43%
Parking lot	Durham, NH	99%	Zn: 97%	TP: 42%
Permeable Interlocking Concrete Pavers				
Driveways	Jordan Cove, CT	67%	Cu: 67% Pb: 67% Zn: 71%	TP: 34% NO_3-N: 67% NH_3-N: 72%
Parking lot	Goldsboro, NC	71%	Zn: 88%	TP: 65% TN: 35%

Parking lot	Renton, WA	--	Cu: 79% Zn: 83%	--
Parking lot	King College, ON	81%	Cu: 13% Zn: 72%	TP: 53% TKN: 53%

3.4.2 Design Considerations

PP surfaces should be designed to intercept, contain, filter, and infiltrate stormwater on site. Several design possibilities can achieve these design aspects. For example, PPs can be installed across an entire street width or an entire parking area. The pavement can also be installed in combination with impermeable pavements to infiltrate runoff and initiate a treatment train. Several applications use PPs in parking lot lanes or parking stalls to treat runoff from adjacent impermeable pavements and roofs. This design economizes PP installation costs while providing sufficient treatment area for the runoff generated from impervious surfaces.

Figure 3-4 Porous Pavement



Source: Smart Planet, *EPA testing 'porous pavement' to filter pollutants in stormwater*, Nov 2009

In preparing to install PP surfaces, several base layers are required. The following is a list from the top down of the typical layers. Coarse open-graded bedding is typically 50 mm (2 in.) thick and provides a level bed for the pavers. It consists of small-sized, open-graded aggregate.

The open-graded base reservoir layer lies immediately beneath the bedding layer. The base is typically 75 to 100 mm (3 to 4 in.) thick and consists of crushed stones typically 20 mm down to 5 mm (¾ in. to $^{3}/_{16}$ in.). Besides storing water, this high-infiltration-rate layer provides a transition between the bedding and sub base layers.

The open-graded sub base reservoir is generally constructed with stone sizes larger than those of the base, typically 65 mm down to 20 mm (2½ in. to ¾ in.) stone. Like the base layer, water is stored in the spaces among the stones. The sub base layer thickness depends on water storage requirements and traffic loads. A sub base layer may not be required in pedestrian or residential driveway applications. In such instances, the base layer is increased to provide water storage and support.

The optional underdrain is installed over soils characterized by low infiltration rates. An underdrain facilitates water removal from the base and sub base. The underdrain is perforated pipe that ties into an outlet structure. Supplemental storage can be achieved by using a system of pipes in the aggregate layers. The pipes are typically perforated and provide some additional storage volume beyond the stone base.

An optional geotextile fabric can be used to separate the sub base from the sub grade and prevent the migration of soil into the aggregate sub base or base. The sub grade is a layer of soil immediately beneath the aggregate base or sub base. The infiltration capacity of the sub grade determines how much water can infiltrate from the aggregate into the surrounding soils. The sub grade soil is generally not compacted.

Measures should be taken to protect PPs from high sediment loads, particularly fine sediment. Appropriate pretreatment structures for stormwater that will infiltrate pavers include filter strips and swales. Preventing sediment from entering the base or permeable pavement is critical for long-term efficiencies. Runoff from disturbed areas should be diverted away from the PPs until the soils are stabilized.

A PP surface is not appropriate for stormwater hot spots where hazardous materials are loaded, unloaded, or stored or where there is a potential for spills and fuel leakage. For slopes greater than 2%, terracing of the soil sub grade base may likely be needed to slow runoff from flowing across the pavement structure rather than infiltrating it.

There are many PP paver designs on the market. Although most pavers are ADA compliant, units with large openings filled with aggregate may not be appropriate for some paths or parking areas used by persons who have disabilities, bicyclists, pedestrians with high-heels, and the elderly (SPU, 2009). Such areas can be paved with solid interlocking concrete pavements.

PP water quantity and pollutant-reduction characteristics such as 80% TSS reductions can qualify a PP surface to earn credits under green or sustainable building evaluation systems such as Leadership in Energy and Environmental Design (LEED®) and Green Globes. Credits also can be earned for water conservation, urban heat island reduction, and conservation of materials by utilizing some recycled materials and regional manufacturing and resource use.

3.4.3 Operation and Maintenance

The most prevalent maintenance concern is the potential clogging of the openings and joints between the pavers. Fine particles that can clog the openings are deposited on the surface from vehicles, the atmosphere, and runoff from adjacent land surfaces. Clogging will increase with age and use; however, even as more particles become entrained in the pavement surface, it does not become impermeable. Studies of the long-term surface permeability of PPs and other permeable pavements have found high infiltration rates initially, followed by a decrease, and then a leveling off with time. With initial infiltration rates of hundreds of inches per hour, the long-term infiltration capacity remains high even with clogging. When substantially clogged, surface infiltration rates usually well exceed 1 inch per hour, sufficient in most circumstances to effectively manage stormwater. If clogging results in standing water, freeze and thaw cracking of the materials may be a possibility if rapid changes in temperature occur. Clogging could also result in damage to adjacent infrastructure if stormwater is unable to infiltrate and runs off onto unprepared areas.

To prevent clogging, a vacuuming or sweeping routine should be scheduled at a minimum of twice per year. Local conditions (e.g., sanded roads after a snow storm) may require a more intense vacuuming schedule. Under drains as well as any other supporting infrastructure should be monitored routinely for problems. Specific items to be monitored for should include trash and debris accumulation, standing water, structural integrity, and the quality of the vegetation in the contributing areas (from EPA (Porous Asphalt), 2006; EPA (Porous Concrete), 2006; and EPA (Permeable Interlocking Concrete Pavers), 2006). Precautions should be made to ensure that maintenance crews do not pile plowed snow on top of pervious pavement systems as this could be a significant source of sediment.

3.5 Soil Amendments

Soil amendments are used to reduce soil compaction and improve the function of disturbed and low-organic soils by breaking up the soil and mixing in other matrix to aid in restoring soil porosity and adding a soil amendment, such as low bulk-density materials, including compost, fly ash, or peat. Soil amendments, which include both soil conditioners and fertilizers, make the soil more suitable for the growth of plants and increase water retention capabilities. These measures change the physical, chemical, and biological characteristics of the soil, allowing it to reduce runoff volume and filter pollutants more effectively. Soil amendments are valuable in areas with poor soils because they can add plant nutrients, sustain vegetative cover, reduce long-term erosion, and help reduce runoff peak volumes and discharges by absorption of rainfall and runoff. Soil amendments can also be used to improve the performance of grassed swales, bioretention basins, and vegetated filter strips.

4. FILTRATION

Filtration structures are typically located along the flow path of stormwater and close to the source en route to some form of drainage way. As the water passes through them, they are designed to capture contaminants by filtering the water. Depending on the size of the filtration structure, peak flows may or may not be attenuated. It is Fort Carson's preference to utilize filtration both as a primary BMP and as a method to reduce contaminant loads before they reach other BMPs.

4.1 Bioretention

The map in Appendix A shows the locations of biorention stormwater-management structures that were in place as of June 2013. The structures are listed below. Identification numbers begin with the specific sub-watershed, then list the structure's place in the numeric count of BMPs in the sub-watershed, followed by the letter "BR".

	Sub watershed	Identification Number
Bioretention	**B-3**	B-3 01 BR
	B-4	B-4 02 BR
	B-7	B-7 01 BR
	I-2	I-2 01 BR, I-2 02 BR, 1-2 03 BR, I-2 05 BR, I-2 06 BR, I-2 15 BR
	I-3	I-3 01 BR, I-3 03 BR
	I-4	I-4 01 BR, I-4 02 BR, I-4 03 BR, I-4 05 BR, I-4 08 BR, I-4 09 BR
	I-6	I-6 05 BR, I-6 07 BR
	I-8	I-8 02 BR, I-8 03 BR
	U-16	U-16 06 BR, U-16 07 BR
	U-20	U-20 08 BR

Bioretention areas are landscaped features in shallow basins designed to treat stormwater runoff close to the source. Bioretention areas temporarily hold stormwater and improve its quality through the actions of natural chemical, biological, and physical properties of plants, microbes, and soils. Stormwater runoff is treated by rapid filtering through bioretention soil media, by biological and biochemical reactions within the soil matrix and around the root zones of the plants that allow uptake of stormwater components, and by infiltration into the underlying soil. Bioretention areas are commonly located in parking lot islands or within small pockets of residential land uses. Surface runoff is directed into shallow, landscaped depressions that are designed to incorporate natural pollutant-removal mechanisms. During storm events, runoff pools above the mulch and is allowed to infiltrate into the soil. Excess runoff is generally diverted past the facility to the downstream conveyance system. The filtered runoff is allowed to infiltrate into the surrounding soil naturally or is collected by a perforated underdrain system that discharges to the storm sewer system or directly to receiving waters. Bioretention basins may be designed as online or offline systems. Online systems typically provide treatment within the flow path and must be able to convey large flow volumes. In contrast, offline systems provide treatment away from the flow path of the runoff and are typically designed to receive only a limited, specified discharge rate or volume.

Bioretention areas are applicable for most settings as they filter runoff through an engineered soil matrix and can be designed to return runoff to the stormwater system. They should be located in an open space that is approximately 5% to 10% of the contributing area. The subsurface must be free of underground utilities, and overhead the area must be free of wires that may interfere with future tree growth. Bioretention areas are appropriate for highly developed urban environments. Although urban settings may lack open space, bioretention can be integrated to parking islands or landscaping features that may already exist or be planned. Bioretention can treat stormwater hot spots if they are designed with an impermeable liner and underdrain system.

Because bioretention areas improve water quality and reduce runoff volume, they help achieve the goal of returning the site runoff to the predevelopment conditions. They are also beneficial for areas designated as a cold-water resource as they do not increase the temperature of the stormwater. Disadvantages to bioretention areas are the initial cost and their maintenance requirements.

4.1.1 Pollutant Removal

The pollutant-removal efficiency of bioretention areas is increased when pretreatment is included in the facility. The use of vegetated filter strips or a level spreader to help remove coarse sediment and to prevent clogging of the bioretention area will improve performance. Pollutant removal is typically improved when bioretention is used for smaller contributing areas. Larger areas tend to clog bioretention structures and provide challenges conveying runoff into the structures. Wet- and dry-tolerant plants are required to be installed in bioretention areas to ensure plant health throughout the growing season. Plant health will increase the effectiveness of pollutant removal. Estimated pollutant-removal rates for two bioretention areas in Maryland are shown in the following table:

Pollutant	Pollutant Removal
Copper	43%–97%
Lead	70%–95%
Zinc	64%–95%
Phosphorus	65%–87%
Total Kjeldahl nitrogen (TKN)	52%–67%
Ammonium (NH_4^+)	92%
Nitrate (NO_3^-)	15%–16%
Total nitrogen (TN)	49%
Calcium	27%

4.1.2 Design Considerations

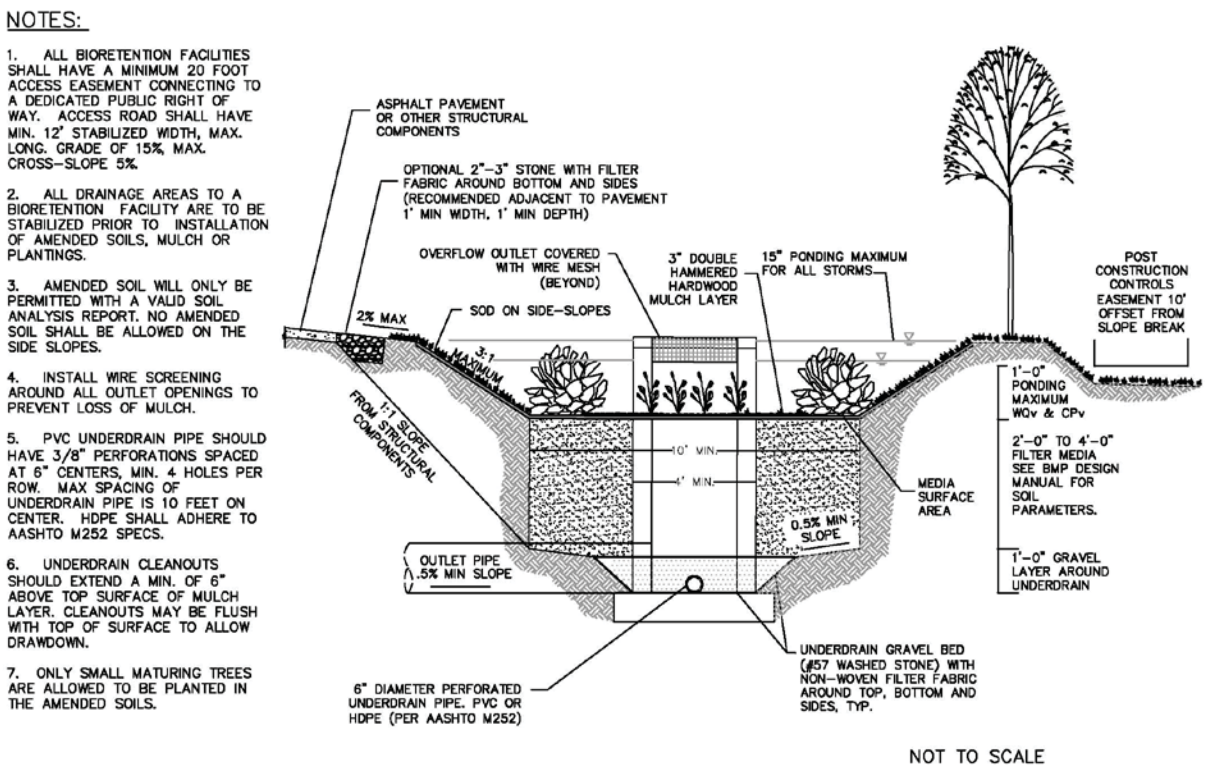
Bioretention areas are composed of a top layer of compost or mulch, underlain by an engineered soil mixture typically consisting of a mixture of sand and organic topsoil. An optional sand layer below the soil mixture can provide additional filtration. If a sand layer is used, a geosynthetic filter fabric should be installed below the sand layer. A coarse gravel layer is the lowest layer of the bioretention area. An underdrain can be placed within this gravel layer if the underlying natural soils are not adequate or appropriate to allow infiltration of the treated water. The underdrain is typically connected to the nearest storm sewer connection; therefore, the functionality and feasibility of bioretention areas are limited by the elevation of this connecting storm sewer line. There must be approximately 4 to 5 feet of head from the bottom invert of the storm sewer line for water to effectively drain through the system.

Pretreatment can aid in the function of the bioretention area and can minimize future maintenance burdens. Examples of effective pretreatment include vegetated or grass-lined channels, filter strips, or a pea-gravel diaphragm (level spreader). These pretreatments tend to remove coarser sediment. Larger bioretention areas may benefit from a sediment forebay (a small depression or trench at the head of the bioretention structure) to remove coarse sediment.

The bioretention area should be sized to be approximately 5%–10% of the contributing area. The design should allow for approximately 6 to 12 inches of ponded water atop the filter bed. An emergency spillway should be incorporated into the design to ensure that larger storms are safely passed through the system into an adequate conveyance device. The invert of the emergency spillway should be set at the top of the storage area for the 6 to 12 inches of ponded water.

It should be noted that the costs for bioretention structures are variable and depend on several factors such as the specific type and quantity of materials used, the presence or absence of an underdrain, and the design and construction of the individual facility. Some costs may be offset by a size reduction of other associated stormwater-management structures or by reducing the watering requirements for the area if it were operated using typical landscaping. Maintenance costs should also be considered in the overall cost of the bioretention structure.

Figure 4-1 Bioretention Basin



4.1.3 Operation and Maintenance

Bioretention requires landscaping maintenance, including measures to ensure that the area is functioning properly. In many cases, bioretention areas initially require intense maintenance, but less maintenance is needed over time. Maintenance tasks can commonly be completed by a landscaping contractor, who may already be hired at the site. Landscaping maintenance for bioretention structures can be less resource intensive than traditional landscaping maintenance such as that required for elevated landscaped islands in parking areas.

Items to be inspected should include signs of clogging such as ponded water after a small storm or excessive sediment and debris buildup. If clogging is a repeated problem, it may be necessary to aerate or till the surface layer. The surface layer may need to be replaced every 2 to 3 years to ensure proper function and pollutant-removal capabilities. The facility should be inspected for signs of any illicit discharging (e.g., sheens on ponded water). Any associated pretreatment or underdrain structures should be inspected for signs of clogging, sediment buildup, erosion, or other signs of failure (EPA (Bioretention) 2006).

Typical maintenance activities for bioretention areas

Activity	Schedule
Remulch void areas. Treat diseased trees and shrubs. Mow turf areas.	As needed
Water plants daily for 2 weeks.	At project completion
Inspect soil and repair eroded areas. Remove litter and debris.	Annual inspection
Remove and replace dead and diseased vegetation.	As needed
Add mulch. Replace tree stakes and wires.	As needed

4.2 Rain Garden

A rain garden manages and treats small volumes of stormwater runoff by using a conditioned planting soil bed and planting materials to filter and treat runoff stored within a shallow depression. A rain garden consists of a small excavated area covered with a mulch layer and planted with different types of native woody and herbaceous vegetation. The treatment method is a variation of the bioretention area and combines physical filtering and adsorption with biochemical processes to remove pollutants. Rain gardens are typically smaller than bioretention areas and are generally designed as a more passive filter system without an underdrain connected to the storm drain system; although a gravel filter bed is recommended. Stormwater is directed to the device, temporarily ponds in the rain garden, and then percolates through the mulch and into the native soil where it is treated by a variety of physical, chemical, and biological processes. Runoff can be from sheet flow or from direct discharge from rain spouts or swales or drainage from impervious areas.

Benefits of rain gardens include groundwater recharge, decreased stormwater runoff volume, and pollutant removal. Aside from the hydrologic benefits, rain gardens increase and promote personal involvement in watershed awareness and add an aesthetic benefit from the garden itself and the created bird habitat.

4.2.1 Pollutant Removal

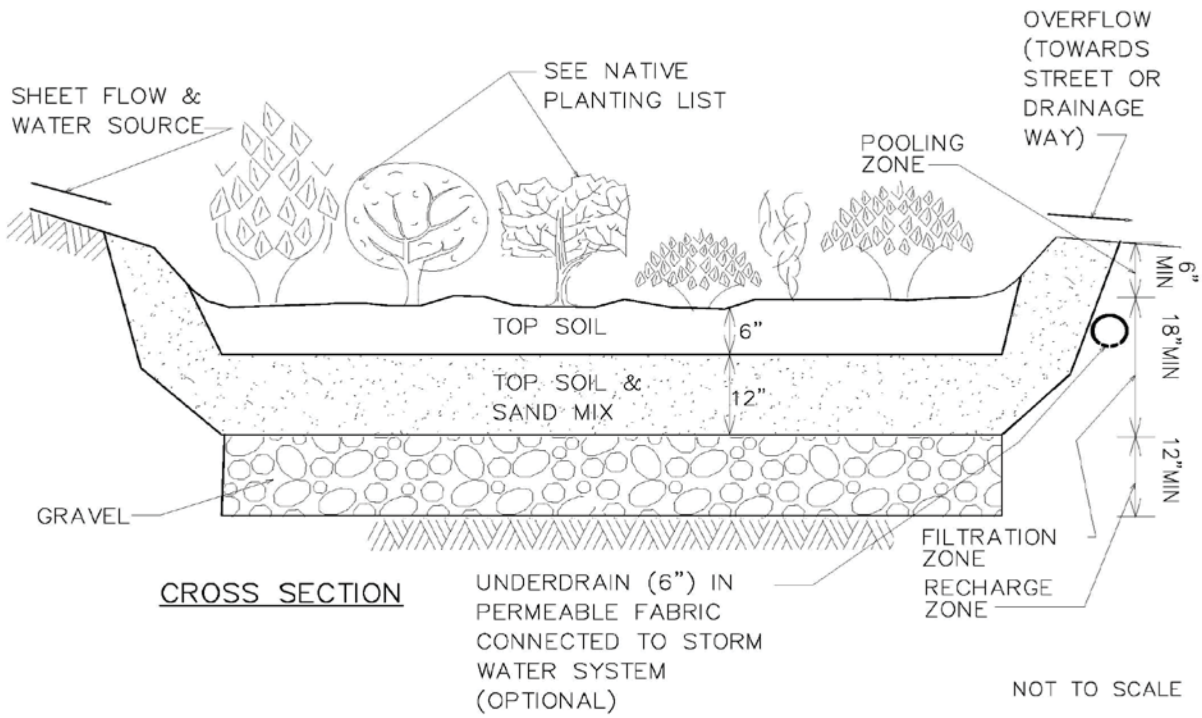
Pollutant-removal information for rain gardens is limited; however, the effectiveness of rain gardens is expected to be similar to, but slightly less than, that of bioretention areas (see Section 4.1.1). The pollutant-removal efficiency of rain gardens can be increased when pretreatment is included in the facility. The use of vegetated filter strips can help remove coarse sediment (and any attached pollutants) and prevent clogging of the rain garden, which will also improve its performance. Pollutant removal is typically improved when smaller contributing areas are treated. Wet- and dry-tolerant plants should be installed in rain gardens to ensure plant health under typical conditions. Plant health will increase the effectiveness of pollutant removal.

4.2.2 Design Considerations

If rain gardens are not properly maintained, they may pose a risk for basement flooding or ponding water. To influence the hydrology (i.e., water quality improvements, volume reductions, etc.) of an entire sub watershed, many rain gardens must be used. The entire housing community must be involved in kind of this task (Center for Watershed Protection, 2007).

Rain gardens should be located at least 10 feet away from buildings to minimize seepage or flooding into basements. When used to treat rooftop runoff and if sizing for a 1-inch storm, the rain garden should be 20% to 30% of the rooftop area. Native soils with poor infiltration may require the addition of soil amendments or under drains (Center for Watershed Protection, 2007).

Figure 4-2 Rain Garden



4.2.3 Operation and Maintenance

Rain gardens should be properly maintained to ensure proper function and to gain community acceptance. The vegetation should be monitored and periodically watered, mowed, and trimmed as necessary to ensure healthy growth. The rain garden should be inspected for signs of erosion or bare soils, sediment, and debris. Particular attention should be paid to areas adjacent to buildings or homes to ensure resources are protected. Accompanying infrastructure such as a downspout connection, pretreatment buffer strip, or overflow structures should be inspected regularly for structural integrity and proper function (Center for Watershed Protection, 2007).

4.3 Catch-Basin Insert

A catch-basin insert is a device that attaches to a storm drain inlet and filters stormwater before it enters the storm sewer system. Inserts are available for most types and sizes of inlets and are manufactured by several different vendors. The specific type, function, and cost vary depending on the specific brand. Inserts can be made of fiberglass, fiber cloth, plastic, or metal basket and can include a cloth filter to aid in the absorption of hydrocarbons.

Catch-basin inserts function by catching and filtering suspended pollutants before they enter the storm sewer system. The inserts are typically designed to do so without obstructing flows or causing head losses. They may be beneficial in highly developed urban areas where space is not available for other, land-intensive stormwater-management structures. Less-traveled roads with easy access are beneficial for future maintenance considerations. Inserts are also appropriate for situations where gross solids such as trash and large sediment are a concern.

Catch-basin inserts typically have a small storage capacity and accordingly must be cleaned often to maintain performance. Depending on the location (e.g., busy street), maintenance access may be difficult and may present safety concerns.

Catch-basin inserts are desirable because keeping pollutants out of the storm sewer system is typically less expensive than removing them by hand along the stream channel. The initial cost for the purchase and installation of these devices is low. The inserts are placed within storm sewer inlets, so they can be installed in many different existing locations and do not require additional land as other stormwater-management structures would.

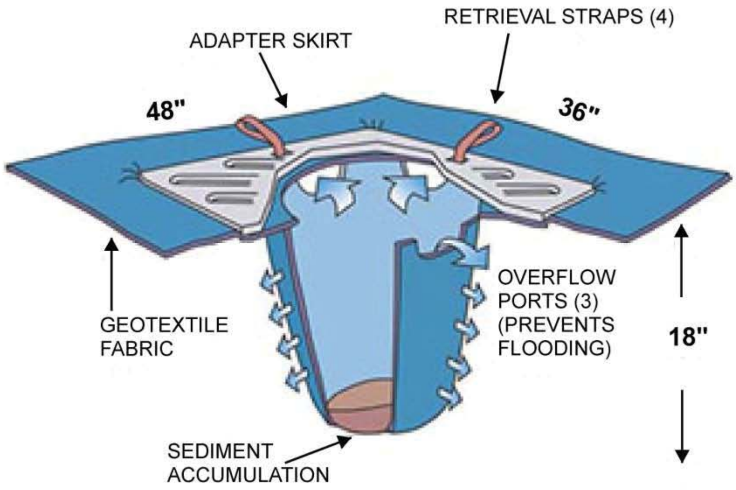
4.3.1 Pollutant Removal

Catch-basin inserts filter suspended particles and debris but do not treat dissolved components. Typically, they are able to remove particles greater than 0.04 inch in diameter, though specific performance will depend on the particular brand used. Some catch basins are able to treat hydrocarbons with the use of specially designed cloth materials. The performance of catch-basin inserts has yielded mixed results.

4.3.2 Design Considerations

The design of catch-basin inserts will vary depending on the particular brand used. Key components of the design that should be considered before choosing a brand include the ability to trap particles and debris without obstructing flows, adequate bypass capacity for large storm events, and ease of maintenance. The general minimum design requirements are provided; however, brand-specific instructions should be considered before a catch-basin insert is used.

Figure 4-3 Catch-Basin Insert



The performance of catch basins is related to the volume in the sump (i.e., the storage in the catch basin below the outlet). Catch basins can be sized to accommodate the volume of sediment that enters the system. Pitt et al. (1997) proposed a sizing criterion based on the concentration of sediment in stormwater runoff. The catch basin is sized, with a factor of safety, to accommodate the annual sediment load in the catch-basin sump. This method is preferable where high sediment loads are anticipated.

The basic design should also incorporate a hooded outlet to prevent floatable materials and trash from entering the storm drain system. Adding a screen to the top of the catch basin would not likely improve the performance of catch basins for pollutant removal, but it would help prevent trash from entering the catch basin (Pitt et al., 1997).

Several basic varieties of catch-basin inserts exist for filtering runoff. One insert option consists of a series of trays, with the top tray serving as an initial sediment trap and the underlying trays composed of media filters. Another option uses filter fabric to remove pollutants from stormwater runoff. Yet another option is a plastic box that fits directly into the catch basin; the box construction is the filtering medium. Hydrocarbons are removed as the stormwater passes through the box while trash, rubbish, and sediment remain in the box itself as stormwater exits. These devices have a very small volume, compared to the volume of the catch-basin sump, and would typically require very frequent sediment removal. Bench test studies found that a variety of options showed little removal of total suspended solids, partially due to scouring from relatively small (6-month) storm events (ICBIC, 1995).

One design adaptation of the standard catch basin is to incorporate infiltration through the catch-basin bottom. Two challenges are associated with this design: potential ground water impacts and potential clogging that would prevent infiltration. Infiltrating catch basins should not be used in commercial or industrial areas, because of possible ground-water contamination. Although it is difficult to prevent clogging at the bottom of a catch basin, it might be possible to incorporate some pretreatment into the design.

4.3.3 Operation and Maintenance

Typical maintenance of catch basins includes trash removal, if a screen or other debris-capturing device is used, and removal of sediment with a vacuum truck. Operators need to be properly trained in catch-basin maintenance, which should include keeping a log of the amount of sediment collected and the date of removal. Some cities have used GIS systems to track sediment collection and to optimize future catch-basin cleaning efforts.

One study (Pitt, 1985) concluded that catch basins can capture sediments up to approximately 60% of the sump volume. When sediment fills greater than 60% of that volume, catch basins reach steady state. Storm flows will bypass treatment and can even re-suspend sediments trapped in the catch basin. Frequent clean-out can retain the volume in the catch-basin sump available for treatment of stormwater flows.

At a minimum, catch basins should be cleaned once or twice per year. Two studies suggest that increasing the frequency of maintenance can improve the performance of catch basins, particularly in industrial or commercial areas. One study of 60 catch basins in Alameda County, California, found that increasing the maintenance frequency from once per year to twice per year could increase the annual total of sediment removed by catch basins (Mineart and Singh, 1994). Annual sediment removed per inlet was 54 pounds for annual cleaning, 70 pounds for semiannual and quarterly cleaning, and 160 pounds for monthly cleaning. For catch basins draining industrial uses, monthly cleaning increased total annual sediment collected to six times the amount collected by annual cleaning (180 pounds versus 30 pounds). These results suggest that, at least for industrial uses, more frequent cleaning of catch basins may improve efficiency. However, the increased operation and maintenance costs need to be weighed against the improved pollutant removal.

In some regions, it may be difficult to find environmentally acceptable disposal methods for collected sediments. The sediments may not always be land-filled, land-applied, or introduced into the sanitary sewer system because of hazardous waste, pretreatment, or ground-water regulations, particularly when catch basins drain runoff from hot-spot areas.

4.4 Sand and Organic Filters

Sand filters for stormwater utilize a flow-through water quality treatment system in which runoff is diverted to a self-contained bed of sand and discharged into a stream, channel, or storm sewer system. The water quality treatment is achieved when the stormwater is filtered through the sand. However, the volume is not reduced under typical designs. Sand filters are usually designed as a two-chambered structure: the first is a settling chamber, and the second is a filter bed filled with sand or other filtering medium. As stormwater flows into the first chamber, large particles settle out; finer particles and other pollutants are then removed as the stormwater flows through the filtering medium.

Some other designs for sand filters are the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and multi-chamber treatment train. All of these filtering practices operate on the basic principle described above. Modifications to the traditional surface sand filter are made primarily to fit sand filters into more challenging design sites (e.g., underground and perimeter filters).

Sand filters are self-contained structures that do not rely on native soils; thus they are applicable at sites where other stormwater-management structures may not be appropriate. They also are appropriate where groundwater contamination may be a concern. The relatively small size of these units and the potential to be located underground makes them advantageous for application in urban settings where open space for other stormwater-management structures may not be available. They also are advantageous for cold receiving waters as they typically do not raise water temperatures.

4.4.1 Pollutant Removal

Pollutants are removed by the filtration of the stormwater through the sand medium. Sand filters have shown success in removing some pollutants. Studies have shown that owing to the decay of organic matter trapped in the filter medium, nitrate rates may increase in water treated by sand filters (England and Stein, 2007).

Typical percent removal rates or ranges are as follows:

TSS	65%–90%
TP	40%–85%
TN	44%–47%
Metals	25%–90%
Bacteria	55%

4.4.2 Design Considerations

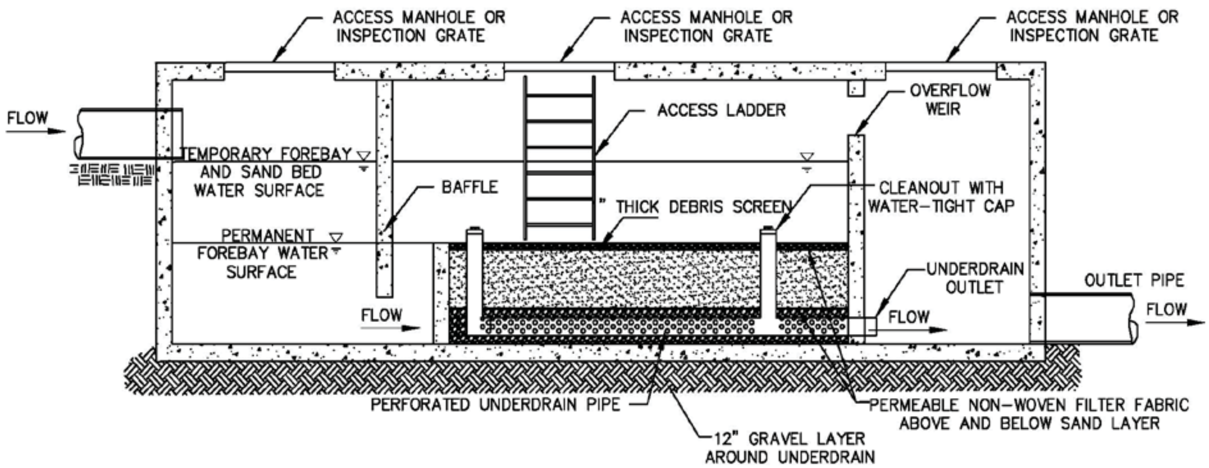
Pretreatment is a critical component of any stormwater management structure. In sand filters, pretreatment is achieved in the sedimentation chamber that precedes the filter bed. In this chamber, the coarsest particles settle out and thus do not reach the filter bed. Pretreatment reduces the maintenance burden of sand filters by reducing the potential of these sediments to clog the filter. Designers should provide a dry or wet sedimentation chamber having at least 25% of the water quality volume as pretreatment to the filter system. The water quality volume is the amount of runoff that will be treated for pollutant removal in the filter system. Typical water quality volumes are the runoff to the sand filter from a 1-inch storm or ½ inch of runoff over the entire drainage area.

Sand filters are intended to be offline structures and as such are typically designed to treat the first flush of stormwater runoff and bypass any excess. Excess runoff should be safely routed past the sand filter. A fairly large hydraulic head (5 to 8 feet) is required to drive runoff through the filter media, so the topography of the site should be considered before installing such a device. Vegetated filter strips or sediment forebays should be considered for pretreatment to improve performance.

Sand filters are best applied on relatively small sites up to 10 acres for surface sand filters and closer to 2 acres for perimeter or underground filters. Sand filters have been used on drainage areas of up to 100 acres, but such structures can clog unless adequate measures are provided to prevent clogging, such as a larger sedimentation chamber or more intensive regular maintenance. It is challenging to use most sand filters in very flat terrain because they require a significant amount of elevation drop, or head, to allow flow through the system. One exception is the perimeter sand filter, which can be applied with as little as 2 feet of head.

Designers should provide at least 2 feet of separation between the bottom of the filter and the seasonally high ground-water table. This design feature prevents both structural damage to the filter and possibly, though unlikely, ground-water contamination.

Figure 4-4 Sand Filter



4.4.3 Operation and Maintenance

Inspections should be conducted to ensure that sediment, debris, and/or trash is not clogging the device. Inlet grates and concrete structures associated with the device should be inspected for cracks or other deterioration. Inlets and outlets, including emergency outlets or bypasses, should be inspected for signs of erosion or other deterioration. The sand-filter material should be inspected to ensure the designed infiltration rate is achieved and the sand is free of debris. Sand may need to be replaced yearly to avoid bacteria formation, and the associated unsightly odor and appearance. Sand should be analyzed to determine if any potentially hazardous wastes are present, and what the appropriate disposal procedures should be. In some instances (e.g., underground or perimeter filters), maintenance may require safety precautions for confined-space entry.

Typical maintenance requirements and their frequency are as follows:

Activity	Schedule
Check to see that the filter bed is clean of sediments and the sediment chamber is no more than one-half full of sediment. Remove sediment if necessary.	Once per year
Make sure that there is no evidence of deterioration, spalling, or cracking of concrete.	Once per year
Inspect inlets, outlets, and overflow spillway to ensure good condition and no evidence of erosion.	Once per year
Ensure that flow is not bypassing the facility.	Once per year
Ensure that contributing area, filtering practice, inlets, and outlets are clear of debris.	Once per year
Check to ensure that the filter surface is not clogging (also after moderate and major storms).	Once per year
Ensure that no noticeable odors are detected outside the facility.	Once per year

4.5 Vegetated Filter Strip

Vegetated filter strips (also called grassed filter strips, filter strips, grassed filters, and buffer strips) are vegetated surfaces that treat overland flow (versus vegetated swales or channels, which treat concentrated channelized flows). Stormwater runoff travels over the filter strip and is treated through biological and chemical processes to filter and infiltrate stormwater. The remaining stormwater travels to a downstream conveyance or another stormwater-management structure to receive further treatment.

Vegetated filter strips are commonly used as a pretreatment for other, more complex and more effective stormwater-management structures. They can be utilized in many places; however, their appropriateness is limited by open space availability and the design requirements for length and gradient. Use of vegetated filter strips in highly developed, urban environments may not be ideal because of the lack of open space. Roads and highways, on the other hand, typically provide adequate length and small drainage areas, which are ideal for these BMPs. When used in a highway or road application, they also provide space for vehicle pull offs and aesthetic benefits. Other places they may be utilized include the tops and toes of slopes and at the inlets of other stormwater-management structures.

Vegetated filter strips are designed to improve water quality, specifically by capturing total suspended solids. They are fairly inexpensive to install and maintain, especially in comparison to other stormwater-management structures. They can also aid in stream-bank restoration when used in conjunction with a riparian buffer system.

Vegetated filter strips do not reduce runoff rates as peak flows are not lowered and the predevelopment hydrology is not mimicked. The strips are only effective in treating overland flow and can erode and become a source of sediment if flows are allowed to channelize. The size of the contributing area for these structures must be small, and so there are circumstances where the physical location may restrict their implementation. Groundwater contamination is a concern for stormwater hot spots within the contributing area and in areas with a seasonal high ground-water table.

4.5.1 Pollutant Removal

Vegetated filter strips are best suited to treat total suspended solids. Their effectiveness for treatment of other pollutants is variable. Factors that can improve pollutant removal by vegetated filter strips include a longer flow length, a lower gradient, and healthy, full vegetative cover. Vegetated filter strips may experience a seasonal decrease in pollutant-removal efficiencies during the winter owing to the decrease in vegetation. Frozen soils may decrease the strips' ability to infiltrate stormwater as well.

Filter strips can provide a small amount of ground-water recharge as runoff flows over the vegetated surface and ponds at the toe of the slope. In addition, it is believed that filter strips can provide modest pollutant removal. Studies from agricultural settings suggest that a 15-foot-wide grass buffer can achieve a 50% removal rate of nitrogen, phosphorus, and sediment and that a 100-foot buffer can reach closer to 70% removal of these constituents (Desbonette et al., 1994). It is unclear how these results can be translated to the urban environment, however. The characteristics of the incoming flows are radically different both in terms of pollutant concentration and the peak flows associated with similar storm events. To date, only one study (Yu et al., 1992) has investigated the effectiveness of a grassed filter strip to treat runoff from a large parking lot. The study found that the pollutant removal varied depending on the length of flow across the filter strip. The narrower (75-foot) filter strip had moderate removal for some pollutants and actually appeared to export lead, phosphorus, and nutrients.

Pollutant removal of an urban vegetated filter strip (Source: Yu et al., 1993):

	Pollutant Removal (%)	
	75-Ft Filter Strip	150-Ft Filter Strip
Total suspended solids	54%	84%
Nitrate + nitrite	–27%	20%
Total phosphorus	–25%	40%
Extractable lead	–16%	50%
Extractable zinc	47%	55%

4.5.2 Design Considerations

Vegetative filter strips are fairly simple stormwater-management structures. The most important components of the design are the flow length, longitudinal slope, and the vegetative cover itself. Filter strips perform best with longer lengths, gentler slopes, and denser, uniform vegetative cover. Pretreatment for the filter strip itself is generally not necessary, but a level spreader can help ensure even distribution of flows across the filter strip and can improve performance. A bypass should be designed to safely convey flows from rainfall greater than the 2-year event. If groundwater contamination is a concern, a liner should be considered.

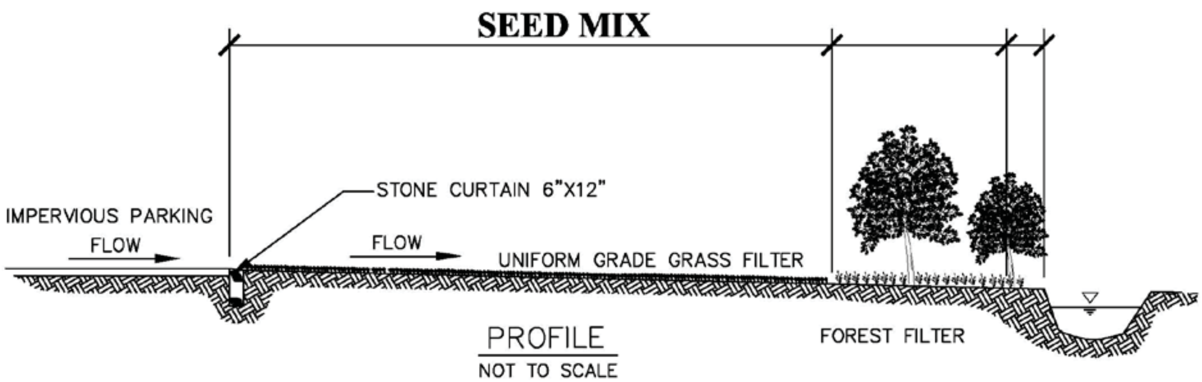
A pea-gravel diaphragm should be used at the top of the slope. The pea-gravel diaphragm (a small trench running along the top of the filter strip) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the filter strip. Second, it acts as a level spreader, maintaining sheet flow as runoff crosses the filter strip if the down-gradient side of the trench is level and does not focus the flow paths.

The filter strip should be at least 25 feet long; 150 feet is optimal for providing water quality treatment. Designers should choose a grass that can withstand relatively high velocity flows and both wet and dry periods. Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.

In cold climates, filter strips provide a convenient area for snow storage and treatment. If used for this purpose, vegetation in the filter strip should be salt-tolerant, (e.g., creeping bentgrass), and a maintenance schedule should include the removal of sand built up at the bottom of the slope. In arid or semiarid climates, designers should specify drought-tolerant grasses (e.g., buffalo grass) to minimize irrigation requirements.

Filter strips have several limitations related to their performance and space consumption. This kind of stormwater-management structure has not been shown to achieve high pollutant removal. Filter strips require a large amount of space, typically equal to the impervious area they treat, making them often infeasible in urban environments where land prices are high. If improperly designed, filter strips can hold water and allow mosquitoes to breed.

Figure 4-5 Vegetated Filter Strip



4.5.3 Operation and Maintenance

Routine maintenance should be completed to keep the vegetation in good condition and collect any accumulated trash or sediment. Mowing perpendicular to the flow path can help to avoid rill formation. Inspection should accompany maintenance to identify and repair bare spots of vegetation and any rills that may have formed. Bare spots will decrease the efficiency of the vegetated filter strip, whereas rill formation can cause flows to bypass the treatment completely. Any associated structures such as a level spreader, outlet, or bypass should also be inspected regularly to check for signs of erosion or malfunction.

Maintenance of filter strips is similar to that required for other vegetative practices (see Grassed Swales Section 3.2.3).

Typical maintenance activities for vegetated filter strips

Activity	Schedule
Inspect pea-gravel diaphragm for clogging and remove built-up sediment. Inspect vegetation for rills and gullies and correct. Seed or sod bare areas. Inspect to ensure that grass has established. If not, replace with an alternative species.	Annual inspection
Remove sediment buildup from the bottom when it has accumulated to 25% of the original capacity.	As needed

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APPENDIX A

MAP OF BMPS

APPENDIX B

INSPECTION FORMS

Retention/Detention Checklist Dry/Wet Detention Pond

Item to be Inspected/	Frequency	Conditions to Check For	Action
Trash and Debris	Annually	Any trash and debris which exceeds 5 cubic feet per 1000 square feet. There should be no visual evidence of dumping.	Trash and debris removed from site.
Poisonous Vegetation	Annually	Any poisonous or nuisance vegetation which may constitute as a hazard to maintenance personnel or the public. Any evidence of noxious weeds as defined by State or local regulations (Apply requirements of adopted IPM policies for the use of herbicides).	Remove poisonous vegetation where maintenance personnel or the public might normally be. (Coordinate with local weed board) Complete eradication of noxious weeds may not be possible. Compliance with State or local eradication policies required.
Pollution and Contaminants	Annually	Any evidence of oil, gasoline, contaminants or other pollutants. (Coordinate removal/cleanup with local water quality response agency).	Contaminants or pollutants removed.
Rodent Holes	Annually	Any evidence of rodent holes, facility is acting as dam or berm. Evidence of water piping through dam or berm via rodent holes.	Pest control measures shall be taken and dam or berm repaired.
Beaver Dams	Annually	Beaver dams that result in a change or function of facility.	Facility is returned to design function.
Tree Growth	Annually	Tree growth that does not allow for maintenance access or maintenance activities.	Remove necessary tress so they do not hinder maintenance activities. If trees are not interfering with maintenance access do not remove. Harvested trees should be recycled into mulch or other beneficial uses.
Hazardous Trees	Annually	Dead, diseased, or dying trees are present (use a certified arborist to identify hazardous trees).	Remove hazardous trees.
Erosion	Annually	Erosion that is over 2 inches deep, where the cause of damage is still present or where there is potential for continued erosion.	Slopes should be stabilized using erosion control measures; e.g. rock reinforcement, grass planting, or compaction.
Erosion	Annually	Erosion on the compact berm embankment.	Licensed civil engineer should be consulted to resolve source of erosion.
Sediment	Annually	Accumulated sediment that exceeds 10% of the designed pond depth or affects inletting or outlet condition of pond.	Clean sediment out to designed pond shape and depth; reseed if necessary to control erosion.

Retention/Detention Checklist Dry/Wet Detention Pond

Item to be Inspected/	Frequency	Conditions to Check For	Action
Liner	Annually	If liner is visible and has more than three 1/4 inch holes in it.	Liner repaired or replaced.
Settlement	Annually	Any part of the berm which has settled 4 inches lower than the designed elevation. If settlement is apparent, measure berm to determine amount of settlement. Settling can be an indication of more severe problems with the berm or outlet works.	Licensed civil engineer should be consulted to determine source of settlement. Build pond berm back to design elevation.
Piping	Annually	Any apparent water flow through pond berm. Ongoing erosion with potential for continual erosion.	Recommend a geotechnical engineer be called to inspect and evaluate condition and recommend repair. Eliminate piping. Resolve erosion potential.
Tree Growth	Annually	Tree growth on emergency spillways that creates blockage problems and which can cause failure of the berm due to uncontrolled overtopping.	Trees should be removed. If root system is small, roots may remain in place. Otherwise the roots should be removed and berm restored. Licensed civil engineer should be consulted for proper berm/spillway restoration.
Emergency Overflow /Spillway	Annually	Only one layer of rock exists above native soil in area of 5 square feet or larger, or any exposure of native soil at the top of the flow path of spillway.	Rocks and pad depth to be restored to design standards

Operation and Maintenance Inspection Form
Wet / Dry Pond

Inspector Name: ____________________ **Feature ID# :** ____________________

Inspection Date: ____________________ **Community:** ____________________

Type of BMP: ____________________ **Address:** ____________________

Watershed: ____________________

Overall Condition of Facility (Check One): Acceptable ☐ Unacceptable ☐ Maintenance Priority 1 2 3 4 5

Item Inspected	Checked			Maintenance		Observations and Notes:
	Y	N	N/A	Y	N	
Pond Dam Embankments and Emergency Spillway						
1. Vegetation and ground cover adequate						
2. Surface erosion						
3. Animal burrows						
4. Cracking, bulging, or sliding of dam						
a. Upstream face						
b. Downstream face						
c. Emergency spillway						
5. Pond, toe and chimney drains clear and function						
6. Seeps/leaks on downstream face						
7. Slope protection or rip rap failures						
8. Vertical and horizontal alignment of top of dam as per "As-Built" plans						
9. Emergency spillway clear of obstructions and debris						
10. Other (specify)						
Riser and principal spillway						
Type (check one)						
Reinforced Concrete:						
Corrugated Pipe:						
Masonry:						
1. Low flow orifice obstructed- Dry Pond						
2. Low flow trash rack-Dry Pond						
a. Debris removal necessary						
b. Corrosion control						
3. Weir trash rack maintenance						
a. Debris removal necessary						
b. Corrosion control						
4. Excessive sediment accumulation inside riser						
5. Concrete/Masonry condition riser and barrels						
a. Cracks or displacement						
b. Minor spalling (<1")						

Operation and Maintenance Inspection Form
Wet / Dry Pond

c. Major spalling (rebar exposed)						
d. Joint failures						
e. Water tightness						
6. Metal pipe condition						
7. Control valve						
a. Operational/exercised						
b. Chained and locked						
8. Pond drain valve						
a. Operational/exercised						
b. Chained and locked						
9. Outfall channels functioning						
10. Other (specify)						
Permanent Pool- Wet Ponds						
1. Undesirable vegetative growth						
2. Floating or floatable debris accumulation						
3. Visible pollution						
4. Low flow channels clear of obstruction						
5. Standing water or wet spots						
6. Sediment and/or trash accumulation						
7. Other (Specify)						
Condition of Outfalls into Pond Area						
1. Rip rap failures						
2. Storm drain pipes						
3. End walls/headwalls						
4. Other (Specify)						
Miscellaneous						
1. Encroachments on pond or easement area						
2. Complaints from local residents						
3. Aesthetics						
a. Grass mowing required						
b. Graffiti removal required						
c. Other						
4. Public hazards						
5. Maintenance access						

Summary

Inspector's Remarks: ____________________

Infiltration Checklist Grassed-Lined Channel, Grass Swale, Infiltration Basin, & Infiltration Trench

Item to be Inspected/ Problem	Frequency	Conditions to Check For	Action
Trash and Debris	Annually	Any trash and debris which exceeds 5 cubic feet per 1000 square feet. There should be no visual evidence of dumping.	Trash and debris removed from basin.
Pollution and Contaminants	Annually	Any evidence of oil, gasoline, contaminants or other pollutants. (Coordinate removal/cleanup with local water quality response agency).	Contaminants or pollutants removed.
Rodent Holes	Annually	Any evidence of rodent holes, facility is acting as dam or berm. Evidence of water piping through dam or berm via rodent holes.	Pest control measures shall be taken and dam or berm repaired.
Beaver Dams	Annually	Beaver dams that result in a change or function of facility.	Facility is returned to design function.
Sediment	Annually	Accumulated sediment that exceeds 10% of the designed pond depth or affects inletting or outlet condition of pond.	Clean sediment out to designed pond shape and depth; reseed if necessary to control erosion.
Sediment and Debris	Annually	Little or no water is flowing through filter during rain storms.	Gravel in rock filter should be replaced.
Erosion	Annually	Erosion that is over 2 inches deep, where the cause of damage is still present or where there is potential for continued erosion.	Slopes should be stabilized using erosion control measures; e.g. rock reinforcement, grass planting, or compaction.
Settlement	Annually	Any part of the berm which has settled 4 inches lower than the designed elevation. If settlement is apparent, measure berm to determine amount of settlement. Settling can be an indication of more severe problems with the berm or outlet works.	Licensed civil engineer should be consulted to determine source of settlement. Build pond berm back to design elevation.
Piping	Annually	Any apparent water flow through pond berm. Ongoing erosion with potential for continual erosion.	Recommend a geotechnical engineer be called to inspect and evaluate condition and recommend repair. Eliminate piping. Resolve erosion potential.
Tree Growth	Annually	Tree growth on emergency spillways that creates blockage problems and which can cause failure of the berm due to uncontrolled overtopping.	Trees should be removed. If root system is small, roots may remain in place. Otherwise the roots should be removed and berm restored. Licensed civil engineer should be consulted for proper berm/spillway restoration.
Standing Water	Annually	Standing water in swale between storms. Water that is not draining freely.	Remove sediment or trash, improve grade of swale, remove clogged check dams, or add under drains.

Infiltration Checklist Grassed-Lined Channel, Grass Swale, Infiltration Basin, & Infiltration Trench

Item to be Inspected/ Problem	Frequency	Conditions to Check For	Action
Flow Spreader (if applicable)	Annually	Flow spreader is clogged or uneven resulting in flow that is not uniformly distributed through entire swale width.	Level and clean the spreader so flows are evenly spread over swale.
Constant Base flow	Annually	Small quantities of water that continually flow through swale and an eroded, muddy channel bottom has formed, even when it has been dray for weeks.	Add pea gravel, drain the length of swale or bypass the base flow around the swale.
Vegetation	Annually	Grass is sparse or bare or eroded patches occur in more than 10% of swale bottom.	Determine the cause of poor grass growth and correct the condition. Replant plugs of grass from upper slope. Or reseed into loosened, fertile soil.
Vegetation	Annually	Grass that is excessively tall. Weeds and other vegetation starting to take over.	Mow vegetation or remove vegetation so that flow is not impeded.
Inlet/Outlet	Annually	Inlets or outlets clogged with debris or sediment.	Remove material so that there is no clogging or blockage at the inlet or outlet areas.
Erosion/Scouring	Annually	Eroded or scoured swale bottom.	For ruts or bare areas less than 12 inches wide, repair area by filling with gravel. Grass will creep in over the rock in time. If bare area is greater than 12 inches wide, channel should be re-graded and reseeded. Over-seed when small bare spots are seen.

Operation and Maintenance Inspection Form
Grass-Lined Channel, Grass Swale, Infiltration Basin, Infiltration Trench

Inspector Name: ______________________ **Community:** ______________________

Inspection Date: ______________________ **Address:** ______________________

Type of BMP: ______________________ ______________________

Watershed: ______________________ ______________________

Item Inspected	Checked			Maintenance		Observations and Notes:
	Y	N	N/A	Y	N	
Debris Cleanout						
1. Basin and contributing areas clean of debris						
2. No dumping of wastes into basin						
3. Litter (branches, trash, etc) has been removed						
4. Build up of sediment within the basin						
5. Other (specify)						
Vegetation						
1. No evidence of erosion						
2. Grass height not greater than 10"						
3. Evidence of noxious weed growth						
4. Other (specify)						
Dam Banks						
1. Cracking, bulging, or sloughing of dam						
a. Upstream face						
b. Downstream face						
2. Erosion and/or loss of dam material						
3. Animal burrows						
4. Soft spots or boggy areas						
5. Woody growth or unauthorized plantings on dam						
6. Vertical and horizontal alignment of dam as per "As-built" plans						
7. Other (specify)						
Emergency Spillway						
1. Vegetation and ground cover adequate						
2. Woody growth or unauthorized plantings						
3. Surface Erosion						
4. Back cutting						
5. Soft or boggy areas						
6. Obstruction/debris						
7. Seeps/leaks on downstream face						

Operation and Maintenance Inspection Form
Grass-Lined Channel, Grass Swale, Infiltration Basin, Infiltration Trench

8. Slope protection or rip rap failures						
9. Other (specify)						
Principal Spillway						
Reinforced Concrete:						
Corrugated Pipe:						
Masonry:						
1. Weir trash rack maintenance						
a. Debris removal necessary						
b. Corrosion control						
2. Excessive sediment accumulation inside riser						
3. Concrete/masonry condition riser and barrels						
a. Cracks or displacement						
b. Minor spalling (<1")						
c. Major spalling (rebar exposed)						
d. Joint failures						
e. Water tightness						
f. Corrosion						
g. Protective material deficient						
h. Misalignment or split seams/joints						
4. Metal Pipe Condition						
a. Corrosion						
b. Protective material deficient						
c. Misalignment or split seams/joints						
d. Joint Failures						
e. Loss of joint material						
f. Water tightness						
g. Cracks or displacement						
5. Other (specify)						
Riser						
Reinforced Concrete:						
Corrugated Pipe:						
Masonry:						
1. Minor spalling or parging (<1")						
2. Major spalling (exposed rebar)						
3. Joint failure						
4. Loss of joint material						
5. Water tightness						
6. Corrosion						

Operation and Maintenance Inspection Form
Grass-Lined Channel, Grass Swale, Infiltration Basin, Infiltration Trench

7. Protective material deficient						
8. Misalignment or split seams/joints						
9. Manhole access and steps acceptable						
10. Sediment within riser						
11. Wood or vegetative growth						
12. Safety rebar/pipes in place						
13. Safety rebar/pipes corroded						
14. Other (specify)						
Dewatering						
1. Basin dewatering between storms						
2. No evidence of standing water						
3. Evidence of soggy basin bottom for extended periods						
4. Other (specify)						
Soil/Filter Material						
1. Depth and material layers						
2. Accumulation of oil/chemicals						
3. Filter fabric						
4. Sediment accumulation						
5. Other (specify)						
Inflow Pipes						
Number of pipes						
Size (s)						
1. End walls, headwalls, end sections						
2. Outfall pipes						
3. Discharge undercutting outlet or displacing rip rap						
4. Discharge water causing outfall erosion						
5. Sediment accumulation						
6. Other (specify)						
Under drains						
1. Broken						
2. Day lighted						
3. Clogged						
4. Other (specify)						
Check Dams						
1. Clear of debris and trash						
2. Sediment build up > 25% of original water quality volume						
3. Undermined/eroded						
4. Wood condition						

Operation and Maintenance Inspection Form
Grass-Lined Channel, Grass Swale, Infiltration Basin, Infiltration Trench

5. Pea gravel at correct level						
6. Other (specify)						
Miscellaneous						
1. Encroachments on basin or easement area						
2. Complaints from local residents						
3. Aesthetics						
a. Grass mowing required						
b. Graffiti removal required						
c. Other						
4. Public hazards						
5. Maintenance access						
6. Mosquitoes						
7. Unauthorized modifications						
8. Significant engineering/design flaws						
9. Other (specify)						

Summary

Inspector's Remarks: ____________________

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Overall Condition of Facility (Check One): Acceptable ☐ Unacceptable ☐

Infiltration Checklist Porous Pavement

Item to be Inspected/ Problem	Frequency	Conditions to Check For	Action
Trash and debris Accumulation	Annually	Trash and debris accumulated on contributing drainage areas and porous pavement surface.	Clear contributing area and porous pavement surface of trash and debris.
Vegetation in Contributing Areas	Annually	Grass that is excessively tall, weeds or other vegetation that starts to take over, decreasing the flow onto the pavement.	Mow grass, control nuisance vegetation to ensure flow is not impeded. Grass should be mowed to a height between 3 and 4 inches.
Sediment	Annually	Accumulation of sediment on the porous pavement surface.	Vacuum sweep porous pavement surface to keep free of sediment.
Efficient Dewatering	Annually	Ponding of water on surface for longer than 24 hours.	Clear pavement of clogging, vacuum sweep porous pavement if needed.
Structural Integrity	Annually	Evidence of deterioration or spalling.	Replace or repair the porous pavement, including the top and base course to design specifications.

Operation and Maintenance Inspection Form Porous Pavement

Inspector Name: ______________________ **Feature ID # :** ______________________

Inspection Date: ______________________ **Community:** ______________________

Type of BMP: ______________________ **Address:** ______________________

Watershed: ______________________

Overall Condition of Facility (Check One): Acceptable ☐ Unacceptable ☐ Maintenance Priorty 1 2 3 4 5

Item Inspected	Checked			Maintenance		Observations and Notes:
	Y	N	N/A	Y	N	
General						
1. Signs of clogging (e.g. standing water)						
2. Debris (mulch, trash) accumulation						
3. Evidence of sediment accumulation						
4. Standing water						
5. Erosion from underdrain (if applicable)						
6. Exposed soil in areas discharging or adjacent to porous pavement areas						
7. Other (specify)						
Dewatering						
1. Standing during or between storms						
2. Evidence of soggy trench bottom for extended periods						
3. Other (specify)						
Under drains						
1. Broken						
2. Clogged						
3. Other (specify)						
Miscellaneous						
1. Encroachments on porous pavement or easement area						
2. Complaints from local residents						
3. Public hazards						
4. Maintenance access						
5. Unauthorized modifications						
6. Significant engineering/design flaws						
7. Other (specify)						

Summary

Inspector's Remarks: ______________________

Filtration Checklist - Bioretention Basin, Rain Garden, & Vegetated Filter Strip

Item to be Inspected/	Frequency	Conditions to Check For	Action
Trash and Debris Accumulation	Annually	Trash and debris accumulated on basin surface.	Clear bioretention basin of trash and debris.
Ponding	Annually	Ponding of water on surface for longer than 72 hours.	Subsurface soils may be inefficient, remove soil surface and replace with sand. Underdrain may be clogged, clear underdrain of debris.
Pollution and Contaminants	Annually	Any evidence of oil, gasoline, contaminants or other pollutants. (Coordinate removal/cleanup with local water quality response agency).	Contaminants or pollutants removed.
Sediment	Annually	Accumulated sediment that exceeds 10% of the designed pond depth or affects inlet or outlet condition of pond.	Clean sediment out to designed pond shape and depth; reseed if necessary to control erosion.
Erosion	Annually	Erosion that is over 2 inches deep, where the cause of damage is still present or where there is potential for continued erosion.	Slopes should be stabilized using erosion control measures; e.g. rock reinforcement, grass planting, or compaction.
Settlement	Annually	Any part of the berm which has settled 4 inches lower than the designed elevation. If settlement is apparent, measure berm to determine amount of settlement. Settling can be an indication of more severe problems with the berm or outlet works.	Licensed civil engineer should be consulted to determine source of settlement. Build pond berm back to design elevation.
Piping	Annually	Any apparent water flow through pond berm. Ongoing erosion with potential for continual erosion.	Recommend a geotechnical engineer be called to inspect and evaluate condition and recommend repair. Eliminate piping. Resolve erosion potential.
Tree Growth	Annually	Tree growth on emergency spillways that creates blockage problems and which can cause failure of the berm due to uncontrolled overtopping.	Trees should be removed. If root system is small, roots may remain in place. Otherwise the roots should be removed and berm restored. Licensed civil engineer should be consulted for proper berm/spillway restoration.
Flow Spreader (if applicable)	Annually	Uneven or clogged flow spreader so that flows are not uniformly distributed through entire filter width.	Clean and level the spreader so that flows are spread evenly over entire filter width.
Vegetation	Annually	Grass that is excessively tall, weeds or other vegetation that starts taking over.	Mow grass, control nuisance vegetation to ensure flow is not impeded. Grass should be mowed to a height between 3 and 4 inches.
Erosion and Scouring	Annually	Eroded or scoured areas due to flow channelization or higher flows.	For ruts or bare areas less than 12 inches wide, repair area by filling with gravel. Grass will creep in over the rock in time. If bare area is greater than 12 inches wide, channel should be re-graded and reseeded. Over-seed when small bare spots are seen.

Operation and Maintenance Inspection Form Bioretention Basin, Rain Garden, Vegetated Filter Strip

Inspector Name: ____________________ **Feature ID #:** ____________________

Inspection Date: ____________________ **Community:** ____________________

Type of BMP: ____________________ **Address:** ____________________

Watershed: ____________________

Overall Condition of Facility (Check One): Acceptable Unacceptable ☐ Maintenance Priority 1 2 3 4 5

Item Inspected	Checked			Maintenance		Observations and Notes:
	Yes	No	N/A	Yes	No	
Inlet/Outlet						
1. Structural integrity of inlet/outlet						
2. End walls, headwalls, end sections						
3. Inlet/outlet clear of debris						
4. Overflow spillway or catch basin clear of debris						
5. Erosion control at inlet in place (e.g. rock, mat)						
6. Erosion control at outlet in place/ evidence of erosion						
7. Discharge undercutting outlet or displacing rip rap						
8. Discharge water causing outfall erosion						
9. Woody growth within 5' of outfall						
10. Outfall channel functioning						
11. Excessive sediment deposits						
12. Soft or boggy areas						
13. Other (specify)						
Debris Cleanout						
1. Swale and contributing areas clean of debris						
2. No dumping of wastes into swale						
3. Litter (branches, trash, etc) has been removed						
4. Other (specify)						
Vegetation						
1. No evidence of erosion						
2. Grass height not greater than 10"						
3. Evidence of noxious weed growth						
4. Other (specify)						
Dewatering						
1. Swale dewatering between storms						
2. Evidence of soggy swale bottom for extended periods						
3. Other (specify)						
Check Dams						
1. Clear of debris and trash						

Operation and Maintenance Inspection Form Bioretention Basin, Rain Garden, Vegetated Filter Strip

2. Sediment build up > 25% of original water quality volume						
3. Undermined/eroded						
4. Other (specify)						
Filter						
1. Sediment accumulation (>1")						
2. Ponding more than 72 hours after storm						
3. Oil/ chemical accumulation on soil bed						
4. Filter fabric						
5. Other (specify)						
Inflow Pipes						
1. End walls, headwalls, end sections						
2. Outfall pipes						
3. Discharge undercutting outlet or displacing rip rap						
4. Discharge water causing outfall erosion						
5. Sediment accumulation						
6. Other (specify)						
Under drains						
1. Broken						
2. Day lighted						
3. Clogged						
4. Other (specify)						
Culverts						
Reinforced Concrete:						
Corrugated Pipe:						
Masonry:						
1. Debris						
2. Metal corrosion						
3. Metal misalignment or split seams/joints						
4. Leaks						
5. Concrete/masonry major spalling (exposed rebar)						
6. Concrete/masonry minor spalling or parging (< 1")						
7. Concrete/masonry joint failure						
8. Other (specify)						
Pretreatment (if applicable)						
1. Maintenance access						
2. Stone diaphragm level						
3. Stone diaphragm clogged with sediment/debris						
4. Grass filter strip erosion						
5. Evidence of short circuiting, rails/ gullies in filter strip						

Operation and Maintenance Inspection Form Bioretention Basin, Rain Garden, Vegetated Filter Strip

6. Level spreader						
7. Other (specify)						
Miscellaneous						
1. Encroachments on basin or easement area						
2. Complaints from local residents						
3. Aesthetics						
a. Grass mowing required						
b. Graffiti removal required						
c. Other						
4. Public hazards						
5. Maintenance access						
6. Mosquitoes						
7. Unauthorized modifications						
8. Significant engineering/design flaws						
9. Other (specify)						

Summary

Inspector's Remarks: ____________________

Filtration Checklist - Catch Basin Insert

Item to be Inspected/	Frequency	Conditions to Check For	Action
Media Insert	Annually	Media insert not removing oil. Water from the media insert has a visible sheen.	Ensure that effluent from media insert is free of oil and has no visible sheen.
Media Insert	Annually	Media Insert not removing water. Catch basin inset is saturated with water and cannot absorb further.	Remove and replace media insert.
Media Insert	Annually	Media oil saturated due to petroleum spill that drains into catch basin.	Remove and replace media insert.
Media Insert	Annually	Media has been used beyond the typical average life of media insert product.	Remove and replace media at regular intervals.
Sedimentation	Annually	Sediment forms a cap over the insert media of the insert and/or unit.	Sediment is removed. No sediment cap on the insert media and its unit.
Trash and Debris Accumulation	Annually	Trash and debris accumulated on insert unit creating a blockage or restriction.	Remove trash and debris from insert unit.

Operation and Maintenance Inspection Form Catch Basin Insert

Inspector Name:	______________	**Community:**	______________
Inspection Date:	______________	**Address:**	______________
Type of BMP:	______________		______________
Watershed:	______________		______________

Item Inspected	**Checked**			**Maintenance**		**Observations and Notes:**
	Yes	**No**	**N/A**	**Yes**	**No**	
Accessibility						
1. Vehicular access from public right-of-way						
2. Ingress/egress to structure						
3. Manholes, frames and covers						
4. Vents (if applicable)						
5. Ladders secure						
6. Top slab, cracks or spalling						
7. Parging						
8. Erosion around structure						
9. Structure obstructed by objects						
10. Throat trash rack opening > 4" (debris)						
11. Other (specify)						
Trash/Debris/ Sediment						
1. Trash or debris blocks more than 10% of inlet						
2. Trash or debris exceeds 60% of sump depth						
3. Trash or debris blocks 1/3 of inlet or outlet pipe						
4. Sediment to 60% or more of sump depth						
5. Other (specify)						
Structure						
1. Top slab has holes or cracks that may let material enter						
2. Frame not securely attached to top slab						
3. Fractures or cracks in basin walls or bottom						
4. Basin misaligned, creating safety or function problem						
5. Catch basin cover missing or out of place						
6. Cover cannot be removed						
7. Ladder rungs unsafe, missing, corroded, or not secure						
8. Metal grate opening broken, unsafe or blocked with debris						
9. Other (specify)						
Vegetation						
1. Vegetation grows and blocks 10% or more of opening						

Operation and Maintenance Inspection Form Catch Basin Insert

2. Vegetation grows in pipe joints > 6" tall or < 6" apart							
3. Other (specify)							
Miscellaneous							
1. Encroachments on basin or easement area							
2. Complaints from local residents							
3. Aesthetics							
a. Trash removal required							
b. Graffiti removal required							
c. Other							
4. Public hazards							
5. Maintenance access							
6. Unauthorized modifications							
7. Significant engineering/design flaws							
8. Other (specify)							

Summary

Inspector's Remarks: ______________________________

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Overall Condition of Facility (Check One): Acceptable ☐ Unacceptable ☐

Filtration Checklist - Sand Filter

Item to be Inspected/ Problem	Frequency	Conditions to Check For	Action
Sedimentation on Sand Media Section	Annually	Sediment depth exceeds a half inch.	Remove sediment on sand filter section increasing the permeability of the filter section.
Sedimentation in Pre-Settling Portion of Vault	Annually	Sediment accumulation in vault bottom exceeds depth of sediment zone plus 6 inches.	Remove sediment in first chamber or vault.
Trash and Debris Accumulation	Annually	Trash and debris accumulated in vault or pipe inlet/outlet.	Trash and debris removed from vault and inlet/outlet piping.
Sediment in Drain, Pipes/Cleanouts	Annually	Drain pipes, cleanouts full with debris and/or sediment.	Remove sediment and debris.
Short Circuiting	Annually	Seepage/flow occurs along the vault walls and corners. Sand eroding inflow area.	Re-lay sand filter media section and compact along vault perimeter to form a semi-seal. Add erosion protection to dissipate force of incoming flow and curtail erosion.
Pipes	Annually	Damaged or broken inlet/ outlet piping in need of repair.	Pipe either repaired or replaced.
Access Cover	Annually	Cover cannot be opened, corrosion/deformation of cover.	Cover repaired to proper working specifications or replaced.
Ventilation	Annually	Ventilation area blocked or plugged.	Remove blockage or clear ventilation area. A specified percent of the vault surface area must provide ventilation to the vault interior according to design specifications.
Vault Structure	Annually	Cracks wider than a half inch or evidence of soil particles entering structure through the cracks or maintenance/ inspection personnel determine that the vault is not structurally sound.	Replace vault or make necessary repairs to meet design specifications.
Vault Structure	Annually	Cracks wider than a half inch at the joint of any inlet/outlet pipe or evidence of soil particles entering through cracks.	Repair vault so no cracks exist wider than a quarter inch at the joint of an inlet/outlet pipe.
Baffles/ Internal Walls	Annually	Baffles or walls corroding, cracking, warping and/or showing signs of failure as determined by maintenance /inspection person.	Baffles repaired or replaced to specifications.
Access Ladder	Annually	Ladder is damaged by corrosion or deterioration, not functioning correctly, not securely attached to wall, cracks, misaligned, and missing rungs.	Replace or repair ladder to specifications.

Operation and Maintenance Inspection Form Sand Filter

Inspector Name: ______________________	**Community:** ______________________
Inspection Date: ______________________	**Address:** ______________________
Type of BMP: ______________________	______________________
Watershed: ______________________	______________________

Item Inspected	Checked			Maintenance		Observations and Notes:
	Yes	No	N/A	Yes	No	
Accessibility						
1. Adequate maintenance access						
2. Vehicular access from public right-of-way						
3. Ingress/egress to structure						
4. Manholes, frames and covers						
5. Vents (if applicable)						
6. Ladders secure						
7. Top slab, cracks or spalling						
8. Parging						
9. Erosion around structure						
10. Structure obstructed by objects						
11. Throat trash rack opening > 4" (debris)						
12. Other (specify)						
Sedimentation Chamber						
1. Throat opening support block less than 6"						
2. Trash, debris, or sediment blocks more than 10% of chamber						
3. Cracks or displacements						
4. Minor spalling or parging (<1")						
5. Major spalling (exposed rebar)						
6. Joint failure						
7. Loss of joint material						
8. Water tightness						
9. Gutter pan spalling						
10. Scour present						
11. Other (specify)						
Pretreatment (if applicable)						
1. Maintenance access						
2. Less than 18" of sediment						
3. Debris/ trash accumulated on orifice or standpipe						
4. Standpipe condition						
5. Dewater time less than 36 hours						

Operation and Maintenance Inspection Form Sand Filter

6. Other (specify)						
Trash Rack						
1. Present						
2. Obstructed						
3. Corrosion						
4. Other (specify)						
Filter Chamber						
1. Scour present						
2. Cracks or displacements						
3. Minor spalling or parging (<1")						
4. Major spalling (exposed rebar)						
5. Joint failure						
6. Loss of joint material						
7. Water tightness						
8. Trash, debris, or sediment blocks more than 10% of chamber						
9. Gutter pan spalling						
10. Other (specify)						
Sand Filter						
1. Filter existing as designed						
2. Sediment accumulation (<1")						
3. Dewater time less than 48 hours						
4. Vegetation						
5. Sediment/ trash/ debris accumulation in gravel/sand						
6. Oil/ chemical accumulation on gravel/sand						
7. Filter fabric condition						
8. Clogging visible						
9. Other (Specify)						
Outfall Chamber						
1. Scour present						
2. Cracks or displacements						
3. Minor spalling or parging (<1")						
4. Major spalling (exposed rebar)						
5. Joint failure						
6. Loss of joint material						
7. Water tightness						
8. Trash, debris, or sediment blocks more than 10% of chamber						
9. Exit pipes adequately parged						
10. Other (specify)						
Outfall from Sediment Chamber						
1. Excessive sediment/trash/debris deposits						

Operation and Maintenance Inspection Form Sand Filter

2. End walls, headwalls, and end sections condition						
3. Outfall pipes						
4. Displaced rip-rap						
5. Undercut outlet						
6. Erosion at outfall						
7. Other (specify)						
Flow Splitter Chamber						
1. Excessive sediment/trash/debris deposits						
2. Cracks or displacements						
3. Minor spalling or parging (<1")						
4. Major spalling (exposed rebar)						
5. Joint failure						
6. Loss of joint material						
7. Water tightness						
8. Gutter pan spalling						
9. Scour present						
10. Corrosion						
11. Metal grate						
12. Condition of inflow/outflow pipes						
13. Other (specify)						
Miscellaneous						
1. Encroachments on basin or easement area						
2. Complaints from local residents						
3. Aesthetics						
a. Trash removal required						
b. Graffiti removal required						
c. Other						
4. Public hazards						
5. Maintenance access						
6. Unauthorized modifications						
7. Significant engineering/design flaws						
8. Other (specify)						

Summary

Inspector's Remarks: ______________________________

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Overall Condition of Facility (Check One): Acceptable ☐ Unacceptable ☐

APPENDIX C

MAINTENANCE/INSPECTION SPREADSHEET

Maintenance NEEDS for Post Construction Stormwater BMPs (Annual Inspection) 2013						
Building #	Identification #	BMP	Manual Reference	Notes	Priority (U= Unnacceptable) (A=Acceptable) (1 = worst) (5 = best)	Status
510	B-3 01 BR	Bio-Retention	Section 4.1.3	Project is under design for construction of a new structure by DPW Engineering (Gate 3 Shopette)	U1	?
2330	I-6 05 BR	Bio-Retention	Section 4.1.3	Lots of trash and weeds, no structural problems. Was recently mowed.	U1	Signage is incorrect, says I-6 05 D. SO# 579931 turned in by Joe Hurst 6/3/14 with Bldg # 2336 listed. Completion in 30 days.
2010	I-4 08 BR	Bio-Retention	Section 4.1.3		U2	SO# 579933 Turned in by Joe Hurst on 6/3/14 Completion in 30 days
2010	I-4 09 BR	Bio-Retention	Section 4.1.3		U2	
4356	B-4 02 BR	Bio-Retention	Section 4.1.3	Trash removal needed, rip rap needs to be raised at inlet	U3	
7418	U-20 08 BR	Bio-Retention	Section 4.1.3	Dead tree, inlet gets clogged with debris during storms	U3	
2764	I-8 03 BR	Bio-Retention	Section 4.1.3	Some structural problems, rip rap should be repositioned so it functions a bit better	A2	
1840	I-4 01 BR	Bio-Retention	Section 4.1.3	Pipes clogged with sediment and debris	A3	
1840	I-4 02 BR	Bio-Retention	Section 4.1.3		A3	
1925	I-4 05 BR	Bio-Retention	Section 4.1.3	Needs additional construction, plants need to be replanted, there is also ponding water, which needs to be remedied	A3	
4355	B-7 01 BR	Bio-Retention	Section 4.1.3		A4	
9416	I-2 03 BR	Bio-Retention	Section 4.1.3	Structural problems, riprap needs to be readjusted	A4	
6110	U-16 07 BR	Bio-Retention	Section 4.1.3		A4	
4790	I-2 02 BR	Bio-Retention	Section 4.1.3	Ok	A4	
4790	I-2 01 BR	Bio-Retention	Section 4.1.3		A5	
840	I-2 05 BR	Bio-Retention	Section 4.1.3	New	A5	
840	I-2 06 BR	Bio-Retention	Section 4.1.3	New	A5	
1430	I-2 15 BR	Bio-Retention	Section 4.1.3	Good shape, Birches are getting too big	A5	
9062	I-3 01 BR	Bio-Retention	Section 4.1.3	Some trash	A5	
1840	I-4 03 BR	Bio-Retention	Section 4.1.3	Good shape	A5	
2260	I-6 07 BR	Bio-Retention	Section 4.1.3	Beaver slides too high, runoff does not effectively reach the structure.	A5	
6070	U-16 06 BR	Bio-Retention	Section 4.1.3	Good shape	A5	
9079	I-3 03 BR	Bio-Retention	Section 4.1.3	Ok	A5	
1005	I-2 08 D	Detention	Section 2.1.3		U1	

2346	I-6 06 D	Detention	Section 2.1.3	Stagnant and very stinky water, high amounts of trash, concern for wildlife	U1	SO# 579932 Turned in by Joe Hurst 6/3/14 Completion in 30 days
6070	U-16 02 D	Detention	Section 2.1.3	Gate Broken, safety concern	U1	Balfour Beatty
6433	U-19 05 D	Detention	Section 2.1.3	Large amounts of trash at the outfall. Standing water, vegetation overgrowth. Pipe may be clogged	U1	Balfour Beatty
6509	U-19 06 D	Detention	Section 2.1.3		U1	Balfour Beatty
6573	U-19 07 D	Detention	Section 2.1.3	Lots of trash and vegtetation overgrowth	U1	Balfour Beatty
6974	U-19 14 D	Detention	Section 2.1.3	Standing water near housing complex	U1	Balfour Beatty
70	U-19 16 D	Detention	Section 2.1.3	Numerous problems here, culvert buried, safety and environmental hazard write next to housing complex	U1	Balfour Beatty
1449	I-2 13 D	Detention	Section 2.1.3	Structural problems	U2	
1829	I-4 06 D	Detention	Section 2.1.3	Erosion and rocks need to be repositioned	U2	
2132	I-6 02 D	Detention	Section 2.1.3	Water seep coming from out the side of the hill, where is this coming from?	U2	SO# 579928 Turned in by Joe Hurst 6/3/14 Completion in 30 days
6502	U-19 08 D	Detention	Section 2.1.3	Trash in several places, concerns with structural integrity, water is seeping out the side.	U2	Balfour Beatty
7240	U-19 09 D	Detention	Section 2.1.3	Trash in may places	U2	Balfour Beatty
6256	U-19 13 D	Detention	Section 2.1.3	Under construction / maintenance by Balfour Beatty	U2	Balfour Beatty
7508	U-20 03 D	Detention	Section 2.1.3	Trash and standing water	U2	
2144	I-6 01 D	Detention	Section 2.1.3	Trash removal, standing water	U3	SO# 579927 Turned in by Joe Hurst 6/3/14 with Bldg # 2146 listed. Completion in 30 days
6012	U-16 01 D	Detention	Section 2.1.3	Weeds	U3	
6362	U-19 04 D	Detention	Section 2.1.3	Drain clogged	U3	Balfour Beatty
7492	U-20 09 D	Detention	Section 2.1.3	Some sediment in pipe	U3	
4343	B-4 01 D	Detention	Section 2.1.3	Pooling below spillway in weir, lots of trash, bottom of pond wet	U4	
2146	I-6 03 D	Detention	Section 2.1.3	Trash, overgrown cattails	U4	SO# 579927 Turned in by Joe Hurst 6/3/14 Completion in 30 days
7999	U-17 02 D	Detention	Section 2.1.3	Outlets are missing trash racks and are a safety hazard. Some are also cracking	U4	?? Balfour Beatty
7924	U-17 03 D	Detention	Section 2.1.3	Outlets safety hazard; SPILLWAY RISER NEEDS MAINTENANCE; INFLOW CULVERT AND RIP RAP NEEDS TO BE CLEANED	A4	
7922	U-17 04 D	Detention	Section 2.1.3		U4	
7916	U-17 05 D	Detention	Section 2.1.3		U4	
7914	U-17 06 D	Detention	Section 2.1.3		U4	
7790	U-17 07 D	Detention	Section 2.1.3		U4	
7490	U-20 02 D	Detention	Section 2.1.3	Erosion	U4	
7492	U-20 10 D	Detention	Section 2.1.3	Irrigation needs to be checked	U4	

7222	U-19 10 D	Detention	Section 2.1.3		A1	
6203	U-16 04 D	Detention	Section 2.1.3	Steel Plate on outlet is blocking flows, it is propped open with a wooden stake.	A2	
6204	U-16 05 D	Detention	Section 2.1.3	Steel Plate on outlet is blocking flows, it is propped open with a wooden stake.	A2	
1800	I-4 07 D	Detention	Section 2.1.3	Trash and sediment accumulating	A3	
6425	U-19 02 D	Detention	Section 2.1.3	Broken pipes, please refer to the photos	A3	
9439	R-X 01 D	Detention	Section 2.1.3	Erosion and water in forebay along with trash	A3	
9655	R-X 03 D	Detention	Section 2.1.3	Large amounts of trash and other debris, will eventually clog the outlet	A3	
80	U-19 15 D	Detention	Section 2.1.3	Erosion and seed has not established	A3	
9416	I-2 04 D	Detention	Section 2.1.3	pipes filled with sediment, rip rap needs to be repositioned, vegetation overgrown	A4	
1000	I-2 07 D	Detention	Section 2.1.3	Sediment and trash	A4	
1210	I-2 10 D	Detention	Section 2.1.3	Good shape	A4	
9062	I-3 02 D	Detention	Section 2.1.3	Erosion problems in a few spots and sediment and trash	A4	
2146	I-6 04 D	Detention	Section 2.1.3	Trash, overgrown vegetation	A4	
2650	I-8 01 D	Detention	Section 2.1.3	Ponding	A4	
6070	U-16 03 D	Detention	Section 2.1.3		A4	
7862	U-17 01 D	Detention	Section 2.1.3		A4	
6200	U-19 01 D	Detention	Section 2.1.3		A4	
7500	U-19 11 D	Detention	Section 2.1.3		A4	
3705	I-12 01 D	Detention	Section 2.1.3		A5	
1210	I-2 09 D	Detention	Section 2.1.3	Good shape	A5	
1355	I-2 12 D	Detention	Section 2.1.3	Few Clogged pipes	A5	
1533	I-2 14 D	Detention	Section 2.1.3	A little trash and sediment	A5	
2496	I-6 08 D	Detention	Section 2.1.3		A5	
7500	U-19 12 D	Detention	Section 2.1.3	Good shape	A5	
9487	R-X 02 D	Detention	Section 2.1.3		A5	
7412	U-20 04 D	Detention	Section 2.1.3	Ok	A5	
7465	U-20 05 D	Detention	Section 2.1.3	Ok	A5	
9095	U-20 06 D	Detention	Section 2.1.3		A5	
9096	U-20 07 D	Detention	Section 2.1.3		A5	
9420	U-X 01 D	Detention	Section 2.1.3		A5	
1227	I-2 11 PP	Permable Pavers	Section 3.4.3	Good shape	A5	
6237	U-19 03 PP	Permeable pavers	Section 3.4.3		A4	
1843	I-4 04 PP	Permeable pavers	Section 4.1.3		A5	