Chapter 8 – Water Quality

8.1 Overview

This chapter provides guidance and criteria for selection and design of stormwater best management practices (BMPs) for water quality. These water quality BMPs apply to public and private development and redevelopment projects within the City of Aspen (City). The overall goal of the water quality chapter is protection of receiving waters including the Roaring Fork River, Maroon Creek, Castle Creek and tributaries to these waterways.

8.1.1 Aspen and Roaring Fork River Water Quality

The impacts of Aspen's stormwater on the Roaring Fork River include stream hydrology, stream morphology (physical characteristics), water quality and aquatic ecology. The extent of impact is related to the area's climate, land use in the watershed, and the measures implemented to address the impacts. According to the *State of the Watershed Report* (SoWR) (2008) prepared by the Ruedi Water and Power Authority and the Roaring Fork Conservancy, nearly 20 percent of the riparian habitat and more than 15 percent of instream habitat in the Upper Roaring Fork sub-watershed is classified as "severely degraded." Urban development in Aspen, in addition to other land uses in the watershed, is a contributor to the watershed's effect on the Roaring Fork River.

Potential impacts of Aspen's urban development, without proper mitigation, on the Roaring Fork River include:

Stream Hydrology: Urban development affects the environment through changes in the size and frequency of storm runoff events. For example, in Aspen for an undeveloped site, snowmelt/rainfall events would be expected to generate runoff approximately 30 times during a typical year. For a developed, 100 percent impervious site, approximately 80 snowmelt/rainfall events per year would generate runoff. Development also changes base flows of the stream and stream flow velocities during storms resulting in a decrease in travel time for runoff. Peak flow rates and runoff volume increase as a result of urbanization resulting in more surface runoff and larger loads of some constituents found in stormwater.

Stream Morphology (physical characteristics): When the hydrology of the stream changes, it results in changes to the physical characteristics of the stream. Such changes include streambed erosion and sediment buildup, stream widening, and stream bank erosion. As the stream profile degrades and the stream tries to widen to accommodate higher flows, channel bank erosion increases along with increases in sediment loads. These changes in the stream bed also result in change to the habitat of aquatic life.

Stream Water Quality and Aquatic Ecology: Water quality is impacted through urbanization as a result of erosion during construction, changes in stream morphology, and washing off of accumulated deposits from the urban landscape. For example, runoff from downtown Aspen could include petroleum hydrocarbons from vehicles, vegetation debris from leaf fall, metals and solids from tire wear and streets, fine particulate matter and metals from atmospheric deposition on impervious surfaces and other pollutants. Water quality problems include turbid water, nutrient enrichment, bacterial contamination, and increases in organic matter loads, metals, salts, oil/grease, pesticides and herbicides. In addition, there may be temperature increases and increased trash and debris transported by stormwater runoff to streams and lakes.

Table 8.1 lists the common constituents in stormwater runoff and their impacts.

Table 8.1 Urban Runoff Pollutants

Constituents	Sources	Effects
Sediments—TSS, turbidity, dissolved solids	Construction sites, urban runoff, landfills, atmospheric deposition	Habitat changes, stream turbidity, recreation and aesthetic loss, contaminant transport, bank erosion
Nutrients—nitrate, nitrite, ammonia, organic nitrogen, phosphate, total phosphorus	Lawn runoff, atmospheric deposition, erosion	Algae blooms, ammonia toxicity, nitrate toxicity
Pathogens—total and fecal coliforms, fecal Streptococci viruses, E.coli, Enterococcus	Urban runoff, illicit sanitary connections, domestic/wild animals	Ear/intestinal infections, recreation/aesthetic loss
Organic enrichment—BOD, COD, TOC and DO	Urban runoff	Dissolved oxygen depletion, odors, fish kills
Toxic pollutants—metals, organics	Urban runoff pesticides/herbicides, underground storage tanks, hazardous waste sites/historic mining (Smuggler Mountain Superfund), landfills, illegal disposals, industrial discharges	Toxicity to humans and aquatic life, bioaccumulation in the food chain
Source: United States Environmental Protection Agency (USEPA) Handbook: Urban Runoff Pollution Prevention and Control Planning, 1993 with adaptations for City of Aspen.		

Although the Roaring Fork River, Maroon Creek and Castle Creek are headwaters streams with water quality far better than many streams in the nation, they nonetheless are impacted by Aspen's stormwater runoff. The 2008 State of the Watershed Report identified excessive sedimentation as a primary source of impacts to the Roaring Fork River and data collected by the City of Aspen from 2003 to 2006 show total suspended solids concentrations consistently higher than 130 mg/L and on many occasions (six out of twelve samples) in excess of 1000 mg/L. Primary sources of sediment in runoff include erosion from steep slopes (including Aspen Mountain), sand from winter application, sediment from construction sites, urban runoff from impervious areas where particulates accumulate and natural "background" sources of sediment.

Other water quality parameters cited in the State of the Watershed Report (SoWR) in the vicinity of Aspen include iron, lead, selenium, cadmium, pH, nitrite, total phosphorus and dissolved oxygen. Sources of metals in runoff include vehicular traffic areas including roads and parking areas, atmospheric deposition, and historic mining activities.

In addition to water quality data, the SoWR presented the results of in stream and riparian zone habitat assessments. These types of biological assessments are valuable for evaluating the cumulative, long-term effects of water quality and hydrologic modifications on waterways.

Figure 8.1, from the *SoWR*, illustrates riparian and in-stream habitat assessments for the Roaring Fork River and tributaries. Of particular note for Aspen are the Upper Roaring Fork, Castle Creek and Maroon Creek sub-watersheds. Although fifty percent or more of the areas surveyed near Aspen were ranked “high quality” or only “slightly modified,” the Upper Roaring Fork sub-watershed contained instream and riparian areas characterized as “severely degraded.” Runoff from Aspen contributes increased volumes and peak flows of runoff and additional loads of sediment and other pollutants that contribute to the condition of the river. From **Figure 8.1**, it is apparent that the effects of urbanization and runoff on the Roaring Fork are cumulative, with increased degradation moving downstream.

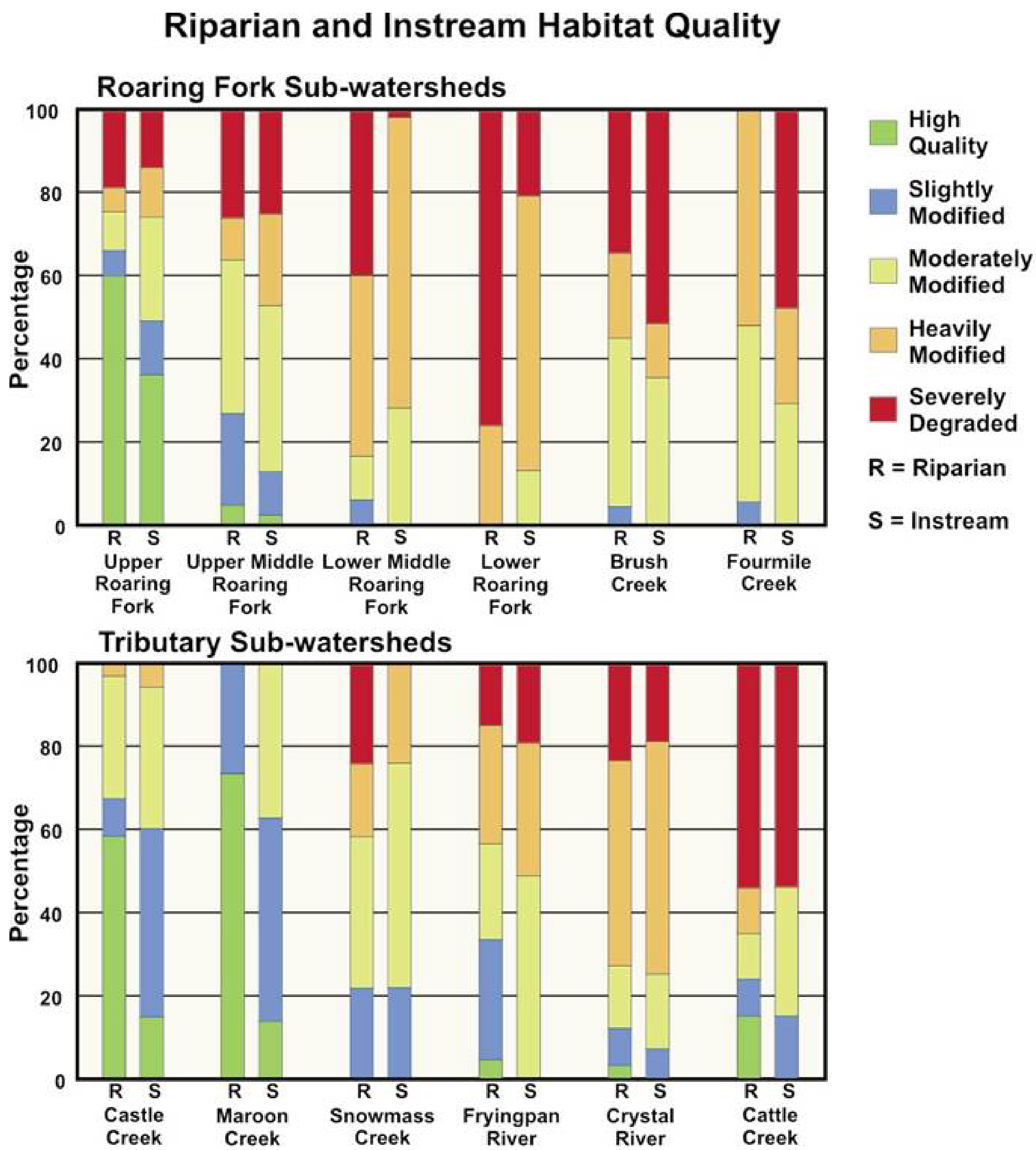


Figure 8.1 Riparian and Instream Habitat Quality for Roaring Fork and Tributary Sub-Watersheds (*State of the Watershed Report* 2008)

8.1.2 Priority Pollutants

There are many potential pollutants that can affect water quality of receiving waters ranging from oxygen depleting organic matter to pathogens to metals. Of special importance is sediment, identified in the Roaring Fork Conservancy report as a primary cause of impairment to the Roaring Fork River in the Aspen area. Sediments discharged to the Roaring Fork River can have many potentially adverse effects including "smothering" of aquatic habitat, increased turbidity/decreased light penetration, increased temperatures, oxygen depletion and impacts to fish. There are many potential sources of sediment in runoff in Aspen, some natural, others anthropogenic. Sources of sediment in Aspen include the following:

- Urban particulates from tire wear, surface wear, decomposing vegetative matter and litter, and dust from atmospheric deposition.
- Erosion from areas that have been disturbed or modified. This includes sediment from Aspen Mountain, construction sites, roadway cuts and forest fire areas.
- Erosion from landscaped areas and lawns.
- Sediment from road sanding.
- Natural sediment eroding from undeveloped watersheds.

Sediment can be removed from runoff by a number of physical processes including gravitational settling, filtration, and straining, among others. Removal of sediment can be a very effective way to address water quality for a range of parameters since many pollutants, including nutrients, pathogens and many metals will adsorb/absorb to sediments under typical environmental conditions. Therefore, by removing sediment, other pollutants attached to the sediments are controlled as well. Removal of sediment is a primary focus of this manual.

There are many types of measurements to characterize sediment, including settleable solids (SS), total suspended solids (TSS), suspended sediment concentration (SSC) and turbidity. Although monitoring of BMPs is not required and numeric limits for sediment in runoff are not specified in Colorado Water Quality Control Commission (CWQCC) regulations, measurement of sediment inflow and outflows from BMPs can be useful for characterizing performance. **To the extent that BMP monitoring for sediment removal is conducted (at Rio Grande Park, for example), measurements using TSS and turbidity are recommended for a high level of comparability with data collected elsewhere.**

8.1.3 Unique Challenges of High Mountain, Cold Weather Resort Environment

There are many challenges related to Aspen's environment that were taken into consideration in developing water quality and BMP design criteria. These include cold climate effects, the steep slope/mountainous setting of Aspen and the fact that Aspen is a world-class resort town with very high land value. **Table 8.2** summarizes many of these challenges.

Table 8.2 Cold Climate and Physiographic Design Challenges in Aspen (adapted from Center for Watershed Protection 1997)

Condition	BMP Design Challenge
Cold Temperatures	• Pipe freezing, in some cases even at locations where there is flowing water that is slowed by a transition such as a bend • Ice-cover on permanent water surfaces • Reduced biological activity • Reduced oxygen levels during ice cover • Reduced settling velocities • Diurnal cycle of melting and freezing in winter and spring • Mid-winter warm ups and runoff
Deep Frost Line	• Frost heaving • Reduced soil infiltration
Short Growing Season	• Short time period to establish vegetation • Different plant species appropriate to cold climates than moderate climates
Significant Snowfall	• High runoff volumes during snowmelt and rain-on-snow • High pollutant loads during spring melt • Sand applied to some roads and walks for improved traction • Snow management may affect BMP storage
Sanding Practices	• Heavy sediment load
Steep Slopes	• Rapid runoff • Potentially high “background” levels of erosion • Potential for mudflows and debris flows • Significant runoff from Aspen Mountain through the City
Resort Setting	• High land value creates space limitations for BMPs • Large portion of development occurs as redevelopment—space constraints and dense development • Need for attractive BMPs • Aspen’s “green” reputation—need to conduct development in an environmentally-sensitive manner and desire to integrate “green” BMPs when feasible

8.1.4 Overall Goals of Criteria

The overall goals of the criteria in the Manual include the following:

1. Provide full water quality treatment for up to the 80^{th} percentile runoff event, corresponding to between a 6-month to 1-year event.

2. For events larger than the 80^{th} percentile event, BMPs designed in accordance with these criteria will provide water quality treatment of the “first flush.”

3. Provide a high level of solids removal for typical suspended sediments found in Aspen urban runoff.

8.1.5 Acknowledgements

Throughout this chapter, information from other criteria manuals, technical papers and other references are cited. There is a considerable body of knowledge related to water quality protection that has been reviewed as a part of creating this chapter. One of the resources most heavily relied upon is the Denver Urban Drainage and Flood Control District *Urban Storm Drainage Criteria Manual Volume 3* (1991992 updated November 2010). The *Urban Storm*

Drainage Criteria Manual is an excellent resource that is routinely updated based on monitoring data, new technologies and methods, and experiences in the metropolitan Denver area. The authors of the Aspen Manual obtained permission from UDFCD to use text from the Urban Storm Drainage Criteria Manual. Entire sections of the UDFCD Manual have been adopted for the Aspen Manual with adjustments for Aspen's environment. If citations were provided every time in the text that information from UDFCD has been inserted, the Aspen Manual would be difficult to read due to the numerous citations; therefore, this acknowledgement is intended to inform users that information from the *Urban Storm Drainage Criteria Manual* is ubiquitous in this document. Users of the Aspen Manual should consult the UDFCD Manual when working on designs to obtain the most up-to-date technical guidance, while still giving due attention to climatic differences that are unique to Aspen.

Special thanks go to Ben Urbonas, P.E. of UDFCD (retired) who was the force behind creation of the original UDFCD Manual and many updates and Ken MacKenzie, P.E. of UDFCD who provided significant input to the UDFCD Manual and is the steward for the UDFCD Manual and updates.

In addition to citations from the *Urban Storm Drainage Criteria Manual*, other sections of this chapter draw on the City and County of Denver *Water Quality Management Plan*, with adaptations for land uses and types of development common to Aspen.

8.2 Water Quality Low Impact Design Requirements

The development of Aspen's stormwater quality management strategy has been based on low impact development design principles (adapted from City and County of Denver Water Quality Management Plan [2004]). In general **a project should attempt to reduce runoff, increase infiltration, and treat the remaining runoff (WQCV). A low impact design process is required and MUST BE DESCRIBED in the Drainage Report for each project that describes how the project accomplished these goals.**

Step 1: Consider stormwater quality needs early in the design process.

Left to the end of site development, stormwater quality facilities will often be "shoe-horned" into the site, resulting in forced, constrained approaches. When included in the initial planning for a project, opportunities to integrate stormwater quality facilities into a site can be fully realized. Stormwater management, water quality and flood control requirements are just as fundamental to good site design as other elements such as building layout, grading, parking, and streets. ***Dealing with stormwater quality after major site plan decisions have been made is too late.***

Step 2: Use the entire site when planning for stormwater quality treatment.

Often, stormwater quality and flood detention are dealt with only at the low corner of the site, and ignored on the remainder of the project. The focus is on draining runoff quickly through inlets and pipes to the stormwater facility. In this "end-of-pipe" approach, all the runoff volume is concentrated at one point and designers often find it difficult to fit the required detention into the space provided. This can lead to drainage plans with expensive, proprietary underground treatment devices, or deep, walled-in basins that detract from a site and are difficult to maintain. Spreading runoff over a larger portion of the site reduces the need for these undesirable alternatives.

Step 3: Avoid unnecessary impervious area.

Impervious area (parking, roofs, drives, etc.) is the most significant factor influencing urban runoff and water quality issues. Many impervious surfaces are necessary as a part of urban and sub-urban development (roofs over buildings, to provide shelter; roads for vehicles, for example). Not all impervious areas in typical developments are necessary, however. For example, in residential areas an extra-wide driveway that is used only infrequently could be considered "unnecessary" impervious area, especially if street parking is available nearby for infrequent additional parking. To reduce the impacts of urban runoff on the environment, each site plan should be carefully evaluated to eliminate unnecessary impervious surfaces. Potential ways to reduce unnecessary impervious surfaces include minimizing parking to the extent practical, narrower roadways and driveways, and the use of permeable pavement systems or green roofs to lower effective imperviousness where a hard but pervious surface is desired.

Step 4: Reduce runoff rates and volumes to more closely match natural conditions.

Before development, for frequent small events most of the rain that falls on the ground soaks into the soil or is captured by vegetation; very little rainfall runs off and flows downstream. However, after development, rain that falls on roofs and pavement mostly runs off (this is a "runoff event"). Whereas one runoff event per year may be typical prior to development, significantly more runoff events per year typically occur after urbanization (Urbonas et al. 1989). Peak flows and volumes of runoff are greater after urbanization than before development.

One of the most effective stormwater quality BMPs—potentially more effective than constructing a detention basin to treat the runoff—is **reducing urban runoff volumes to more closely match natural conditions.** The following techniques can be used to achieve this goal:

<u>Place stormwater in contact with the landscape and soil</u>. Instead of routing storm runoff from impervious areas to inlets to storm sewers to offsite pipes or concrete channels, an approach is recommended that places runoff in contact with landscape areas to slow down the stormwater and promote infiltration. Porous pavement areas also serve to reduce runoff and encourage infiltration. This practice is also known as Minimizing Directly Connected Impervious Area (MDCIA) and can reduce the effective imperviousness of the site. One of the most common and easiest to implement practices for reducing runoff is to direct roof downspouts to pervious areas. Whenever practical this practice should be used as an alternative to connecting roof drains to storm sewers or daylighting them to impervious areas. If there are concerns relative to foundations with directing downspouts to pervious areas, downspout extenders can be used to direct roof runoff to landscaped areas that are further away from the base of the structure. Additionally, lined bioretention/landscaped areas adjacent to structures can receive runoff from downspouts and effectively disconnect the impervious area.

<u>Select treatment areas that promote greater infiltration</u>. Bioretention, sand-filter detention and other infiltration-based BMPs promote greater volume reduction than extended detention basins, since runoff tends to be absorbed into the filter media or infiltrate into underlying soils. As such, they are more efficient for reducing runoff volume and typically can be sized for less overall treatment volume than extended detention facilities.

By employing these techniques, projects can reduce the increase in runoff and related stream degradation and pollutant loading that comes with conventional development. In addition, some of these techniques will reduce the required WQCV and may help to create a more attractive site. **Aspen strongly encourages implementation of these runoff reduction techniques on all new projects to the maximum extent practicable.**

Step 5: Integrate stormwater quality management and flood control.

In cases where an extended detention basin, wetland basin, sand filter basin, or underground treatment system is used to address stormwater quality, these BMPs can be modified to include flood control detention in addition to the WQCV. This will generally increase the overall size of the basin. In these situations, all the runoff from a site, from small and large storms alike, is routed to the combined detention basin. Site BMPs, like bioretention, are intended to promote a stormwater quality function, and are not normally designed to provide flood control detention as well. In these cases, all runoff is directed to the WQCV facility and larger events spill out over the surface or through an inlet and storm sewer to a separate flood control detention basin.

Step 6: Develop stormwater quality facilities that enhance the site, the community, and the environment.

Stormwater quality areas can add interest and diversity to a site. Gardens, plazas, rooftops, and even parking lots can become amenities and provide visual interest while performing stormwater quality functions and reinforcing urban design goals for the neighborhood and community. The integration of BMPs and associated landforms, walls, landscape, and materials can reflect the standards and patterns of a neighborhood and help to create lively, safe, and pedestrian-oriented districts.

The quality and appearance of stormwater quality facilities should reflect the surrounding land use type, the immediate context, and the proximity of the site to important civic spaces. Aesthetics will be a more critical factor in highly visible urban commercial and office areas than at a heavy industrial site. The standard of design and construction should maintain and enhance property values without compromising function. In some cases, this means locating a facility to preserve or enhance natural resources.

Step 7: Use a treatment train approach.

Considerable research has demonstrated that the most effective stormwater management is achieved through a “treatment train” approach with BMPs in series. Different BMPs use different processes to remove pollutants from stormwater. For example, an underground baffle vault might be effective at settling out coarse solids, but for removal of finer solids or other pollutants, a BMP using filtration might be necessary. Similarly, a BMP using filtration may clog quickly and become ineffective if pretreatment to remove coarse sediments is not provided before runoff enters the filter surface.

Step 8: Design sustainable facilities that can be safely maintained.

Stormwater quality facilities must be properly and consistently maintained to function effectively and ensure long-term viability. Regular maintenance is also important for public acceptance of these facilities. Typical maintenance operations to consider in designing facilities include:

- Mowing, trimming, and weed control
- Pruning of shrub and tree limbs
- Trash and debris cleanup, especially at grates and flow control structures
- Sediment removal
- Removal, replacement, and revegetation of porous landscape detention media
- Vacuuming/replacement of porous pavement and porous pavement detention media
- Structural repair

Keeping in mind these and other potential maintenance practices, it is also necessary to fully consider how and with what equipment BMPs will be maintained into the future. Facility design should provide for these operations ensuring adequate access with a minimum of disturbance, disruption, and cost. Removal of trash, debris, and sediment on a regular basis should be considered in the maintenance plan.

Step 9: Design and maintain facilities with public safety in mind.

The highest priority of licensed professional engineers and public officials is to protect public health, safety, and welfare. Stormwater quality facilities must be designed and maintained in a manner that does not pose health or safety hazards to the public. For the purpose of this discussion, public safety issues are largely related to public access. The following should be considered (as examples):

Pond Edges:

- Create safe pond edges with gradually sloping banks.
- Reduce perimeter wall heights as much as practicable.
- Include railings where vertical drops adjoin areas with public access.
- Locate facilities with steep sides away from major pedestrian routes
- Provide an emergency egress route.

Visibility:

- Avoid walled-in or steeply sloped, remote ponds that provide hiding places for illicit activity. Consider the need for site lighting.

8.3 Planning and Implementation Considerations

While much of this Chapter focuses on sizing and design criteria for stormwater BMPs, it is equally important to consider:

- Appropriate selection of BMPs based on project objectives,
- Integration of planned BMPs with other elements of the site plan,
- Effective implementation of BMPs once they are designed,
- Proper installation and construction of BMPs, and
- Maintenance of BMPs over the lifetime of the BMP.

8.3.1 Design Considerations

The following bullets provide an overview of design considerations for addressing stormwater quality and flood control requirements on a site.

- Create attractive facilities that add value to the site. While most designers focus on providing a functional stormwater management system for a site, they should also configure and detail the stormwater system to create an aesthetically pleasing facility. Preserving natural features and areas and effective integration of landscape elements and the stormwater system can enhance a project and the community.

- Develop an initial site design.

  - Identify a rough layout of lots, buildings, streets, parking, and landscape areas with a general idea of proposed site grades.

  - Estimate approximate areas associated with roofs, streets, walks, parking lots, and landscaping or open space.

- Consider the full range of BMP alternatives. The stormwater facilities shown in the Land Use-based BMP Selection Guidance (Section 8.3.2) provide examples of appropriate BMPs for a variety of land uses.

  - Determine which of the land uses in **Table 8.3** most closely match the site.

  - Consider the full range of alternative approaches for addressing drainage and stormwater quality for the site, including techniques to reduce runoff and distribute BMPs throughout the site.

  - Test the influence of several alternatives on the overall character and layout of the site, weigh pros and cons of each, and progress towards an optimum approach.

- Consider long-term or life-cycle costs in the selection of alternative BMPs. These can be assessed by consulting references that discuss life-cycle costs of BMPs (Heaney et al. 2002; Watershed Management Institute 1997; Stormtech et al. 2003; Olson et al. 2009.), or by developing opinions of probable cost for the construction and maintenance of specific BMP alternatives for the site.

- When selecting and designing BMPs that provide for infiltration (i.e., grass buffers and swales, porous pavement detention, porous landscape detention, and sand-filter detention), the designer needs to carefully consider geotechnical and foundation issues and the ability of the property owner to understand and properly maintain these facilities.

- Pursue a functional distribution of landscape areas. Keep detention basins shallow and provide some space for tree and shrub plantings.
  - Initially, provide an area about 10 to 15 percent of the size of the impervious area for stormwater quality treatment. This area may be reduced in later stages of design. For some types of development (i.e. Ultra urban, lot-line-to-lot-line, this may not be feasible.
  - Bioretention (porous landscape detention) areas should be more numerous, and distributed throughout the site. In general, it is prudent to locate porous landscape detention in close proximity to the impervious area being served.
  - For extremely constrained sites, an option may be to locate a BMP in the right-of-way. This option will be considered by the City on a case-by-case basis, and if water quality treatment within the right-of-way is allowed, it must also provide some degree of treatment for adjacent public spaces.

- Consider surface conveyance as an alternative to pipes.
  - Consider how runoff will be conveyed to stormwater quality facilities. Conveying flows on the surface is the best method for getting runoff to porous landscape and porous pavement detention because it allows the facilities to be shallow in depth and provides a defined surface flow route for extra flow unlike a pipe. If flow can be conveyed on the surface in grass swales or in strips of porous pavement, additional stormwater quality benefits will accrue and the required water quality capture volume will be reduced.
  - If runoff must be conveyed under the surface in a pipe, area inlets within a landscaped area are preferred over street or curb inlets, since this gives runoff a chance to sheet flow through vegetation and infiltrate prior to entering the storm sewer. In many locations along streets, area inlets may not be feasible; however, in residential areas where swales of bioretention areas are considered, area inlets may be appropriate.

- Integrate flood control detention. Multiple approaches exist for addressing flood control detention that dove-tail with stormwater quality management.
  - Locate flood control detention in landscape areas and in parking lots.
  - Retaining walls that fully enclose a landscape detention area are unacceptable as they create a deep basin without adequate access.

- Tailor approach to the specific pollutants of concern. The design criteria in this Chapter are geared to sediment removal since this has been identified as a cause of impairment to the Roaring Fork River.

8.3.2 Land Use-based BMP Selection Guidance

Six general land use types have been identified to communicate different conceptual strategies for stormwater quality treatment in Aspen. These general development types are derived from grouping classifications from the City of Aspen Zone District Map into common categories. **Table 8.3** lists the development type categories and corresponding City of Aspen Zoning.

Table 8.3 Land Use Types for Water Quality Planning and Associated City Zoning

Development Type	Zoning Categories
Ultra Urban/Commercial Core including High Density and Multi-family Residential, including Tourist Lodging	CC, R3, AH1-PUD, R/MF, R/MFA
Low to Medium Density Residential	R-6, R-15, R-15A, R-15B, R-30, RR
Commercial, including Ski-Area Base Development	L, CL, C-1, S/C/I, NC, MU, SKI
Institutional/Campus	A, PUB
Streets	T (overlay)
Parks, Natural Areas and Open Space	C, P, OS, WP

The following sections describe typical characteristics for each development type, as well as potential sites for stormwater quality treatment. Design recommendations have been developed for each, covering these four topics:

1. **Runoff Reduction:** Techniques that decrease runoff volume and reduce the Water Quality Capture Volume (WQCV) requiring treatment.

2. **WQCV Treatment:** BMPs that treat the required volume of storm runoff.

3. **Flood Detention:** Methods for attenuating peak runoff from larger storm events on site.

4. **Implementation Details:** Additional details for specific portions of a site.

Sketch diagrams show how some of the design recommendations may be implemented on a representative site, and additional details and photographs further describe treatment options. These guidelines are recommendations only; the designer may choose to mix and match approaches from different development types to best meet the needs of a particular project.

Table 8.4 summarizes general characteristics of development types, while **Table 8.5** provides an overview of potentially applicable BMPs based on development type. It should be noted in **Table 8.5** that there are often several different types of BMPs that may be considered for a specific type of development. Multiple types of BMPs may be desirable within a development—the developer and designer should carefully consider various combinations of BMPs to develop an optimal treatment strategy for a specific site. For most sites, it will be necessary to go beyond selecting a single BMP for stormwater quality treatment. This approach is mandatory where elevated sediment loads in stormwater runoff are anticipated. In such a case, pretreatment must be provided to remove coarse sediments. This will allow the next BMP downstream in the “treatment train” to function more effectively by reducing potential for clogging and reducing the required maintenance frequency.

In terms of BMP scale, there are several distinctions relevant to the Aspen area:

- On-site BMPs are BMPs that are constructed to serve a single development (and potentially some small adjacent areas). On-site BMPs typically provide treatment for an area that is on the order of 1 acre-or less. They are typically constructed as the development is built and they are generally privately owned and maintained.

- Sub-regional BMPs typically treat runoff from a neighborhood or small watershed area (multiple properties), typically ranging from more than 1 acre to approximately 130 acres. There is often an economy of scale for sub-regional facilities because the footprint required to provide an overall storage volume is generally less if a single facility is used as opposed to multiple smaller facilities with multiple embankments and appurtenances. An example of a sub-regional facility could be an extended dry detention pond in a neighborhood park that treats runoff from adjacent residences and businesses. For contribution areas larger than 5 acres (typical of a sub-regional BMP) commonly used BMPs include extended dry detention basins and constructed wetland basins, which would typically be publicly owned and/or maintained.

- Regional BMPs are large-scale BMPs that treat runoff from areas typically greater than 130 acres. In the Aspen area, examples of regional BMPs include the Jennie Adair Stormwater Wetlands and the Rio Grande Park sediment vault. Regional BMPs offer an economy of scale in terms of size requirements and costs; however, since the capital costs for a regional facility are typically large, funding of facilities to keep pace with development can be difficult. When on-site and sub-regional facilities are not feasible; however, regional; facilities may be necessary. Major advantages of regional facilities are that they are typically publicly owned and maintained and can provide multiple benefits, especially when integrated into a park.

For effective stormwater management in Aspen, a combination of on-site, sub-regional and regional facilities will be implemented.

Table 8.4 Land Use Type Characteristics

Development Type	Percentage Landscaping (Typ.)	Percentage of Surface Parking/Paving (Typ.)	Percentage Building Footprint	Parking Type	Examples
Ultra Urban/ Commercial Core including High Density and Multi-family Residential, including Tourist Lodging	0-5%	0-5%	90-100%	Structure	Downtown Aspen
Commercial and Industrial, including Ski-Area Base Development	0-5%	0-5%	90-100%	Structure	
Streets	0-5%	95-100%	N/A	Structure / Surface	Mill Street
Institutional/Campus	15-30%	10-25%	45-75%	Structure / Surface	Aspen Valley Hospital
Low to Medium Density Residential	40-70%	5-20%	10-45%	Structure/ Surface	
Parks, Natural Areas and Open Space	80-95%	5-15%	0-10%	Surface	Rio Grande Park

Table 8.5 Development Types and Applicable BMPs

Development Type/BMPs	Runoff Reduction/Conveyance BMPs							Storage Volume BMPs							Sub-Surface BMPs	
	MDCIA	Vegetated Swales	Grass Buffers	Pervious Pavement	Constructed Wetland Channel	Tree Canopy Credit	Green Roof	Grass Swale Sed.	Bioretention	Pervious Pavement Detention	Extended Detention Basin (EDB)	Sand Filter EDB	Constructed Wetlands Basin	Modular Suspended Pavement System	Sed./ Filtration Vaults	Dry Wells
Ultra Urban/ Commercial Core	●	⊘	⊘	● ✖Sand	⊘	●	●	⊘	● ✖Sand	⊘ ✖Sand	⊘	⊘ ✖Sand	⊘	●	●	○ ✖Sand
High Density and Multi-family Residential, including Tourist Lodging	●	⊘	⊘	● ✖Sand	⊘	●	●	⊘	● ✖Sand	● ✖Sand	⊘	⊘ ✖Sand	⊘	●	●	○ ✖Sand
Low to Medium Density Residential	●	●	●	● ✖Sand	○	●	●	●	● ✖Sand	● ✖Sand	●	● ✖Sand	○	●	⊘	○ ✖Sand
Commercial and Industrial including Ski-Area Base Development	●	⊘	○	● ✖Sand	⊘	●	●	⊘	● ✖Sand	● ✖Sand	●	● ✖Sand	⊘	●	●	○ ✖Sand
Institutional/Campus	●	●	●	● ✖Sand	○	●	●	●	● ✖Sand	● ✖Sand	●	● ✖Sand	●	●	⊘	⊘ ✖Sand
Streets	●	○	○	○ ✖Sand	⊘	○	⊘	○	○ ✖Sand	⊘ ✖Sand	⊘	● ✖Sand	⊘	●	●	○ ✖Sand
Parks, Natural Areas and Open Space	●	●	●	● ✖Sand	●	●	○	●	● ✖Sand	● ✖Sand	●	○ ✖Sand	●	⊘	⊘	⊘ ✖Sand
On-Site (OS), Sub-Regional (SR), or Regional (R)	**OS**	**OS**	**OS**	**OS**	**SR, R**	**OS**	**OS**	**OS**	**OS**	**OS**	**SR, R**	**OS, SR**	**SR, R**	**OS**	**OS**	**OS**

● = Highly Applicable

○ = Somewhat Applicable

⊘ = Not Recommended

✖Sand = Not for Use in Sanded Areas—some of these BMPs may be applicable if adequate pretreatment is provided

Ultra Urban

Characteristics: Ultra Urban sites are characterized by structured or underground parking, high to mid-rise buildings, and little to no landscape area at grade—most landscape areas are in the Right-Of-Way or over structure. Ultra Urban sites are primarily located in the Downtown Commercial Core where buildings occupy up to 100% of the property. Ultra Urban sites also include High Density Residential, Multi-family Residential, and Tourist Lodging that are characterized by 0-10% open space as paving or landscape area.

Potential Stormwater Quality Treatment Sites: Area for treatment is limited to roofs, plazas, and courtyards. Treatment generally occurs over or adjacent to buildings in contained systems or planters that drain to the storm sewer. Underground treatments vaults (some with pumped outfalls) are used in some situations where land values are extremely high and space is a premium. In these cases, a very high level of maintenance is required.

Design Recommendations:

1. Runoff Reduction

- Minimize directly connect impervious area by directing roof downspouts to landscaped areas, planter boxes or small “pocket” bioretention areas (i.e. landscaped area on patio with underdrain).
- Develop pervious pavement in plazas, courtyards, sidewalks, and parking areas where sanding is not used.

2. WQCV Treatment

- Drain roofs to bioretention in planters adjacent to buildings.
- Drain roofs to pervious pavement detention or bioretention in plazas and courtyards. Aggregate layer beneath pervious pavement or structural soils in bioretention areas may have significant storage.
- Below ground sediment or filtration vaults should be considered only as a last resort if surface solutions are unworkable and/or do not provide adequate WQCV. For extremely constrained sites, an option may be to locate a BMP in the right-of-way. This option will be considered by the City on a case-by-case basis, and if water quality treatment within the right-of-way is allowed, it must also provide some degree of treatment for adjacent public spaces.

3. Flood Detention

- Direct roof runoff to bioretention. Convey flows in excess of WQCV to below-grade vaults or directly to storm sewers in areas where sub-regional detention is provided.

4. Implementation Details

- Planting. Provide additional support for plants in urban settings where they are subject to the additional stresses of heat (summer), stacked snow (winter and spring) and restricted growing area.
- Roofs. Route roof runoff through the building or through external downspouts to vegetated areas.
- Sediment removal. Provide for the removal of debris, trash, and sediment loads that come from roof runoff, construction, sidewalks, outdoor sitting areas, plazas, parking areas, driveways, private roads, and street maintenance. For BMPs relying on infiltration for pollutant removal, pretreatment for sediment removal is absolutely necessary and

some practices, such as pervious pavement, may not be used in areas where sand is applied.

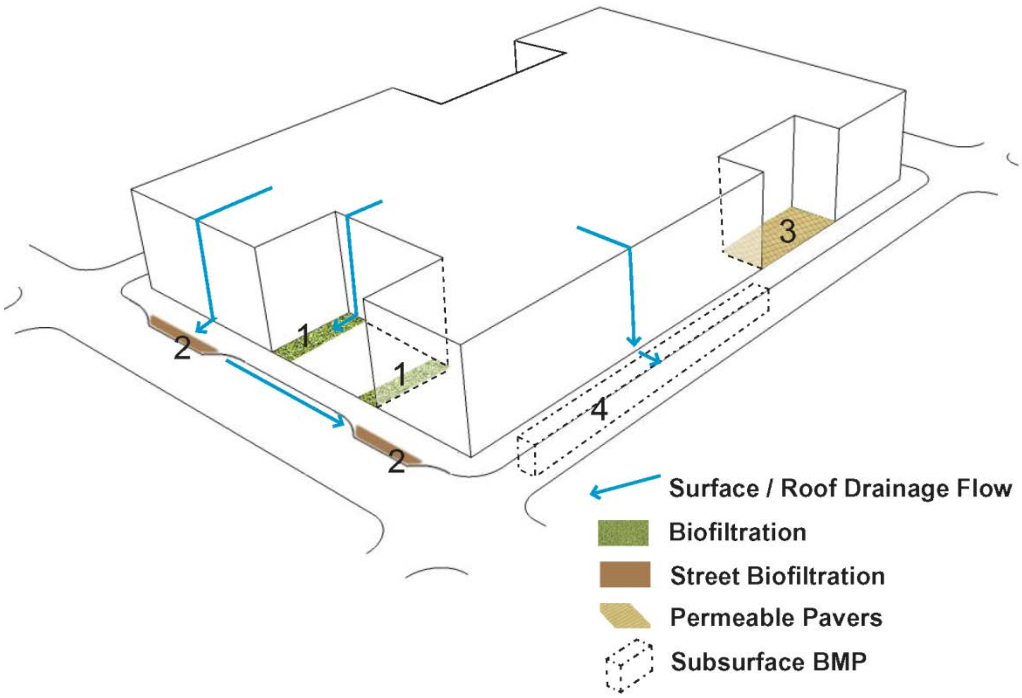


Figure 8.2 Ultra Urban Development Sketch

Key

1 Roof Drainage can be directed to Biofiltration planters adjacent to the building and interior courtyards. This formal urban detailing can create an attractive landscape edge.

2 Roof Drainage and site drainage directed to Biofiltration planters in street bulb outs and along sidewalks. These can be attractive planting areas also utilized for street traffic calming and planting of urban street trees.

3 Permeable Pavers can be utilized for outdoor plazas, patios, and parking spaces (if applicable)

4 Sub-surface BMPs provide stormwater runoff treatment and flood storage and should be considered where site availability for other BMP's are constrained.

Commercial Including Ski-Area Base Development

Characteristics: This type of development is predominantly impervious with little room for landscaped areas. Sites include commercial retailers, industrial facilities, grocery stores, gas stations and ski area base development. Impervious surfaces include parking, roofs, walks, and pedestrian plazas/courtyards account for up to 90 percent of the site.

Potential Stormwater Quality Treatment Sites: Treatment occurs in islands and/or perimeters of sites. Corner-of-the-site treatment options may include limited use of retaining walls that minimize the basin's footprint, but still provide for maintenance access.

Design Recommendations:

1. Runoff Reduction

- Drain roofs to grass buffers at parking islands, medians, and buffers.
- Sheet-drain parking to grass buffers and grass swales.
- Develop pervious pavement in low-traffic areas. Pervious pavement should not be used in areas where sand is applied.
- Where structures do not create an edge at or near the property lines, develop continuous grass buffers.

2. WQCV Treatment

- Drain runoff to bioretention at parking islands, medians, and buffers.
- Develop pervious pavement detention (storage in aggregate pore spaces) in areas with minimal traffic such as outer areas of parking and emergency access drives.
- Develop detention basin BMPs including extended detention and constructed wetlands. These BMPs are typically applicable only for contributing drainage areas of 5 acres or more. For smaller sites (1 to 5 acres), consider sand filter basins.
- Incorporate covering of storage area where materials such as restaurant waste, fertilizers, etc. could potentially be exposed to stormwater.
- Dry wells may not be used in areas where sand is applied or where there is potential for industrial contaminants such as oil and grease to be transported in runoff.

3. Flood Detention

- Provide flood detention within parking areas or underground using pore spaces in aggregate underlying pervious pavement. When extended detention or constructed wetlands are used for water quality treatment, consider expanding the facility to provide flood control benefits as well.

4. Implementation Details

- Parking. Break up extensive parking areas with pervious pavement detention or bioretention.
- Planting. Where the site is contiguous with open space buffers, develop plantings that create a smooth transition between these spaces.
- Stormwater Distribution. Sheet-drain large areas of paving to landscape, or spread flows with slotted curbs or level spreaders.

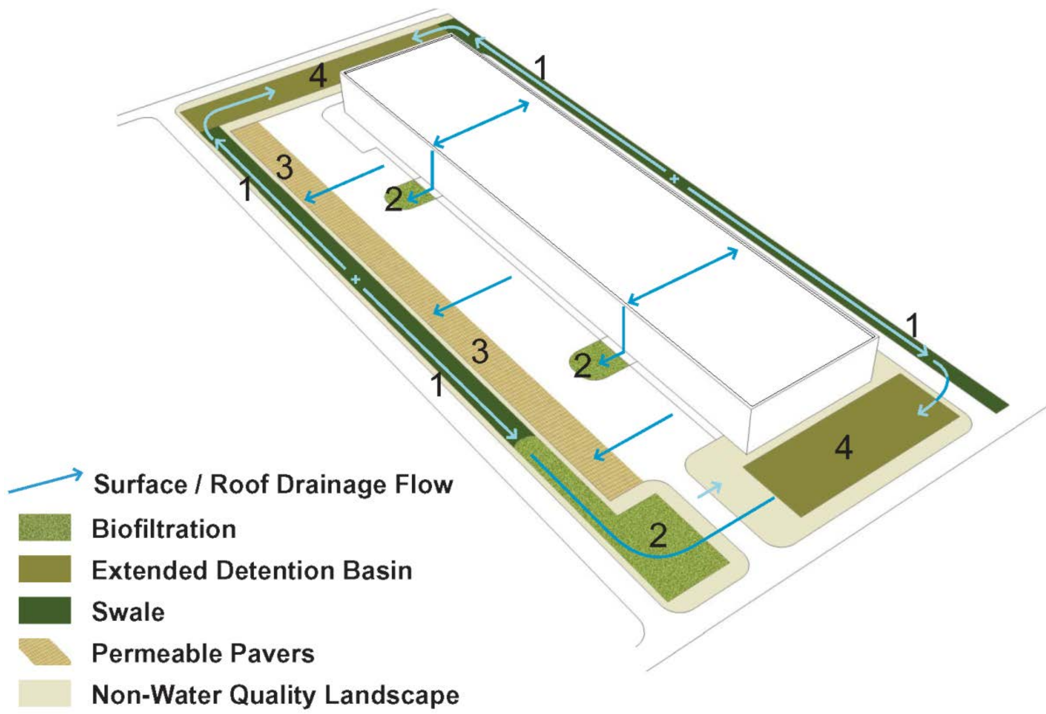


Figure 8.3 Commercial Development Sketch

KEY

1 Grass swales receive roof runoff from downspouts and direct it towards the detention basin at the back of the site. Site runoff is directed to grass swales, reducing runoff and removing large sediment.

2 Biofiltration planters receive and treat runoff from portions of the roof in the front and back of the building. These can be attractive planting areas and/or flower gardens

3 Permeable Pavers at driveways and parking stalls allows stormwater to infiltrate, reducing runoff volumes for the site

4 A linear detention basin at the back and sides of the site treats the WQCV and detains flood water. Sub-surface BMPs may be more applicable where space on site is limited

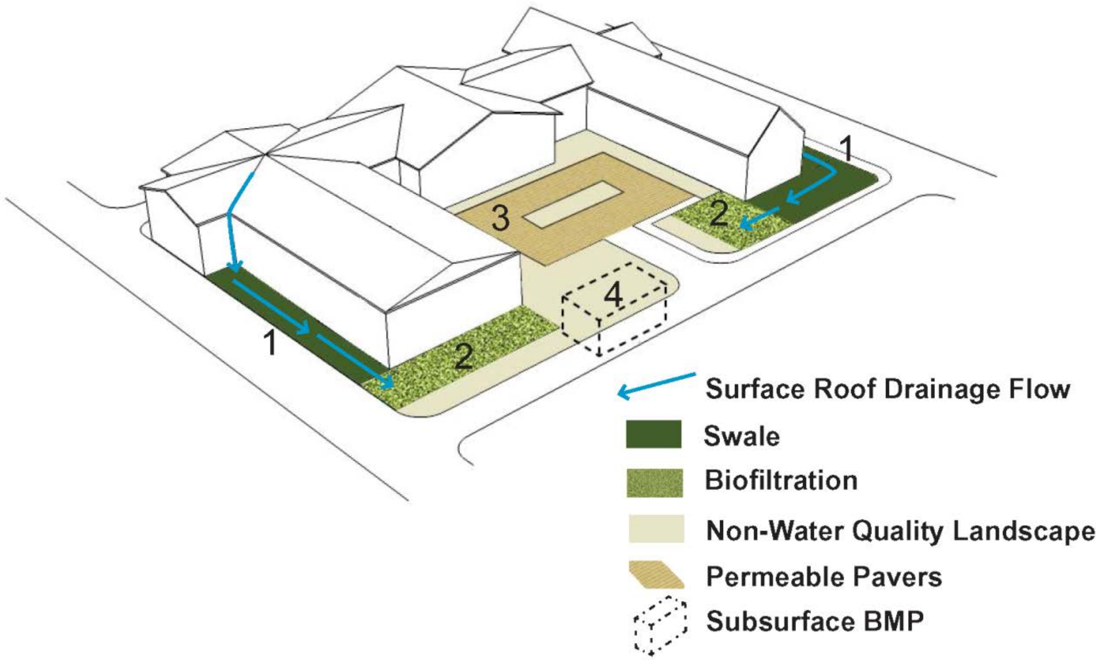


Figure 8.4 Ski Area Development Sketch

KEY

1 Grass swales receive roof runoff from downspouts and direct runoff towards the biofiltration planters or other BMPs.

2 Biofiltration planters receive and treat stormwater runoff. These can be attractive planting areas and/or flower gardens. These areas can also provide snow storage on site during winter months.

3 Permeable Pavers at driveways and drop offs allows stormwater runoff to infiltrate, reducing overall runoff volumes for the site

4 Sub-surface BMPs provide stormwater runoff treatment and flood storage and should be considered where site availability for other BMPs are constrained.

Streets

Characteristics: Streets in Aspen have the potential to contribute a large sediment load in the winter and spring, especially those that are sanded. Streets that run south to north in Aspen are generally steeply sloped while west to east streets are considerably milder. Streets in highly urbanized areas typically have curb and gutter and are served by a storm sewer system. In lower-density residential areas, many streets drain to roadside swales rather than inlets and storm sewers. BMP's located within streets and rights-of-way provide opportunities to greatly minimize sediment transport to the Roaring Fork River.

Potential Stormwater Quality Treatment Sites: Since streets are essential for traffic movement, it is generally not advisable to have frequent accumulation of runoff in streets (they may serve a conveyance purpose in large flood events, but for typical storms, they must remain passable). Therefore, the primary water quality treatment options for streets must fit in the adjacent right-of-way. Treatment options range from bioretention areas in medians and shoulders, to grassed swales and buffers to underground sedimentation vaults. In addition, in areas where right-of-way does not provide adequate space for stormwater treatment, "end-of-pipe" sub-regional or regional facilities may be an alternative for treatment.

Design Recommendations:

1. Runoff Reduction

- When feasible drain runoff from streets to vegetated areas including bioretention, swales and buffers. For many of these types of BMPs, which rely on infiltration to be effective, some degree of pretreatment for sediment removal is necessary.
- Consider pervious pavement for low traffic areas and on street parking. This practice can only be used in areas that are not sanded. Sanding of pervious pavement areas will result in plugging and failure of the BMP.

2. WQCV Treatment

- Drain streets to bioretention areas, medians, and buffers. Bioretention areas can be designed in areas with storm sewers so that the initial portion of runoff flows into the bioretention area while larger events bypass the surface treatment and enter the storm sewer via an inlet
- Consider pervious pavement detention (storage in aggregate pore spaces) in areas where pervious pavement is used.
- For areas with inlets and storm sewers consider on-line underground sedimentation vaults. Maintenance access for vaults is essential for allowing this type of system to function properly.
- Consider sub-regional or regional treatment when space constraints are severe.

3. Flood Detention

- Streets may be used for conveyance during large flood events in accordance with the streets and inlets section of the manual. Flood storage is not a compatible function for most of the BMPs that are applicable to streets. Sub-regional or regional detention may be the most appropriate method for addressing increases in peak flows caused by street imperviousness.

4. Implementation Details

- Sediment removal. Provide for periodic removal of sediment that accumulates in bioretention areas, swales or underground vaults. For BMPs relying on infiltration for pollutant removal, pretreatment for sediment removal is absolutely necessary and some practices, such as pervious pavement, may not be used in areas where sand is applied.

Figure 8.5 Typical Residential Street Biofiltration Planter
Slotted curbs allow stormwater runoff into biofiltration planters.

Figures 8.6 and 8.7 Typical Urban Street Biofiltration Planters
Curb cuts, and chases, with metal grated covers, convey stormwater runoff from the curb to biofiltration planters located along streets.

Figure 8.8 Typical Residential Street Permeable Pavers
Permeable pavers can be used for on-street parking lanes. They should only be used in areas that are not sanded during winter. Sanding of pervious pavement areas will result in plugging and failure of the BMP.

Institutional/Campus

Characteristics: An institutional/campus site consists of multiple buildings with a related purpose or function, organized around pedestrian-oriented spaces. Emphasis on automobile circulation and parking can vary considerably. The percentage of building footprint is nearly 50%-75% while nearly 15-30% of the site(s) are available for landscaping.

Potential Stormwater Quality Treatment Sites: Runoff reduction techniques, infiltration techniques, and WQCV detention options can be integrated into the landscape to create site amenities where space permits. Strategies shown in the High Density and Multi-family Residential Development Type Guidelines are also appropriate for confined spaces on campuses, including treatment in plazas, islands and buffers at surface parking, and roofs.

Design Recommendations:

1. Runoff Reduction

- Drain roofs, walks, drives and surface parking to grass buffers and grass swales throughout the landscape. Locate grass swales along paths and drives. Develop pervious pavement in areas with low traffic such as outer areas of parking and emergency access drives.
- Consider bioretention areas on buildings and parking structures in planter boxes with underdrains.

2. WQCV Treatment

- Drain surface parking to bioretention parking islands, medians, and buffers. (See BMP Fact Sheet)
- Develop pervious pavement detention (storage in aggregate pore spaces) in pedestrian areas or areas with minimal traffic such as outer areas of parking and emergency access drives.
- Develop detention basin BMPs including extended detention and constructed wetlands. These BMPs are typically applicable only for contributing drainage areas of 5 acres or more. For smaller sites (1 to 5 acres), consider sand filter basins.

3. Flood Detention

- Provide flood detention within parking areas or underground using pore spaces in aggregate underlying pervious pavement. When extended detention or constructed wetlands are used for water quality treatment, consider expanded facility to provide flood control benefits as well.

4. Implementation Details

- Roofs. Include treatment and runoff reduction on campus roofs (i.e. bioretention with underdrains) where density and land values make them viable.
- Parking. Design large parking areas with pervious pavement and bioretention in islands or medians where adjacent land cannot be employed for treatment.
- Planting. Consider foot traffic patterns when locating and selecting plantings for runoff reduction and WQCV treatment areas.
- Sediment removal. Provide for periodic removal of sediment that accumulates in detention basins. Include a concrete forebay or rock bench to provide equipment access. For BMPs relying on infiltration for pollutant removal, pretreatment for sediment removal is absolutely necessary and some practices, such as pervious pavement, may not be used in areas where sand is applied.

- Stormwater Distribution. Include slots or interruptions in curbs that control traffic in parking areas to disperse runoff as it flows to adjacent grass swales and buffers.

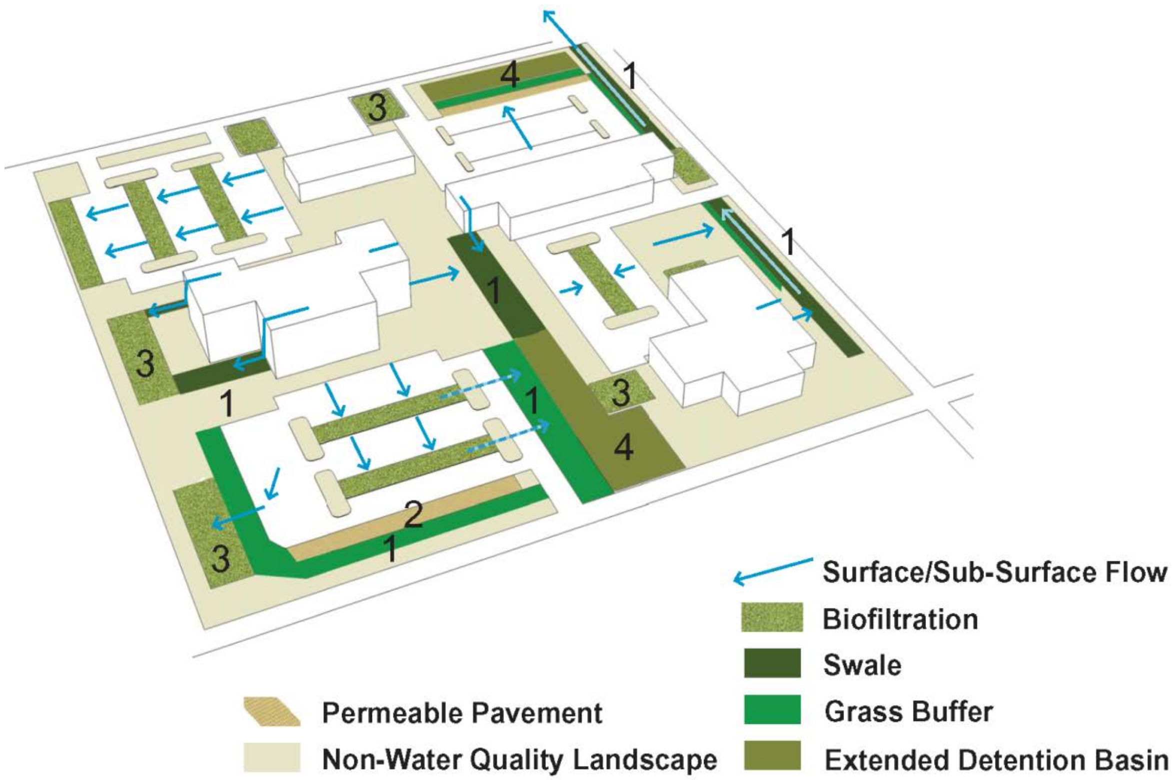


Figure 8.9 Campus and Institutional Development Sketch

KEY

1 Grass buffers and swales receive runoff from parking and paving throughout campus, and direct it to larger BMPs and detention facilities.

2 Permeable Pavers in surface parking lots treats runoff and reduces overall runoff volumes for the site

3 Biofiltration planters can be campus amenities while serving to treat stormwater runoff. These can be attractive planting areas and/or flower gardens

4 Extended detention basins can be located at the back or edges of site, and utilized to treat stormwater quality and provide flood control at the “regional” level for the campus.

Low to Medium Density Residential

Characteristics: Low to Medium Density development types refer to those areas normally zoned for low and medium density Residential uses. These areas are characterized by residential dwellings lined along City streets, and typically include open areas in the front and back of each structure. Paved surfaces are usually limited to driveways, parking courts, and patios. Low and Medium Density residential uses typically have a low percentage of the site as building footprint (10% to 45%)

Potential Stormwater Quality Treatment Sites: The focus in this development type is on reducing runoff from homes. Yards and gardens surrounding each structure or group of structures receive runoff from roofs as well as paved walks and drives.

Design Recommendations:

1. Runoff Reduction

- Drain roofs to grass buffers and grass swales in gardens and yards.
- Drain driveways, walks and patios to adjacent grass buffers either directly or through slot drains or pervious pavement. Provide sufficient slope and/or a ledge between the pavement and the landscape to accommodate future thatch buildup on lawns.
- Construct driveways and parking aprons using pervious pavement. Do not use excessively wide driveways that add unnecessary impervious area.
- Public Space: In appropriate neighborhoods with less-urbanized character, develop roadside grass swales with or without curbs. Allow swales to drain frequently to open space areas or storm sewers to maintain shallow swales.

2. WQCV Treatment

- In lawns or open space, develop bioretention to treat runoff from adjacent areas.
- In parks, greenways, or open space within residential areas, develop sub-regional detention basin BMPs, including extended detention, sand filter basins and constructed wetlands to serve larger tributary areas.

3. Flood Detention

- Locate residences at an elevation to accommodate the 100-year storm event within the adjacent roadway.
- Combine flood control and water quality functions in multi-use sub-regional facilities.

4. Implementation Details

- Roofs. Drain roofs to adjacent landscape to reduce runoff. Avoid storing water on foundation soils at the building perimeter.
- Planting. Design gardens and planting beds to accommodate and thrive on runoff from roofs and paving.
- Stormwater Distribution. Direct runoff to roadside swales with curb-less streets.

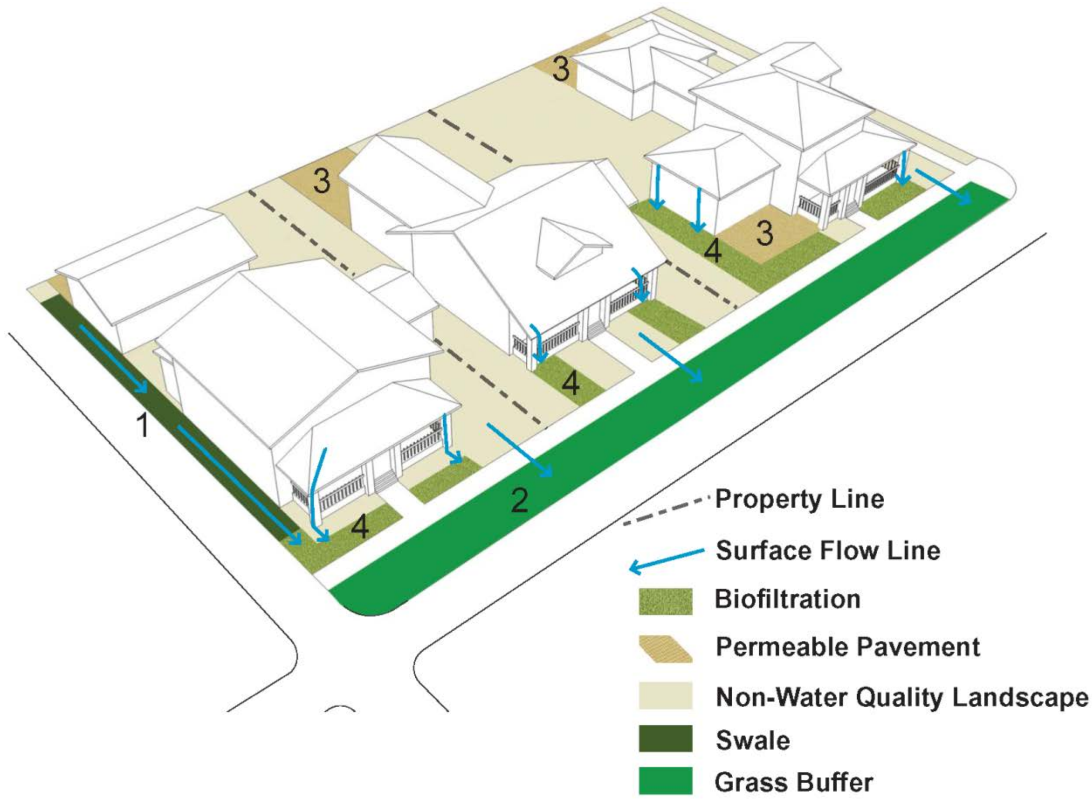


Figure 8.10 Medium/ Low-Density Residential Development Sketch

Key

1 Roof drains and runoff can be directed to shallow swales that convey stormwater to Biofiltration Areas

2 Positive drainage from the sidewalk to the street allows the tree lawn to act as a grass buffer and reduce runoff.

3 Porous pavement at driveways and patios allows runoff to infiltrate.

4 Roof drains and site runoff can be directed to Biofiltration areas. These can be attractive planting areas and/or flower gardens

Parks, Natural Areas and Open Space

Characteristics: Due to the minimal amount of impervious area in parks, supplemental efforts to reduce runoff are not typically required. In fact, Aspen Parks may efficiently serve to treat runoff from surrounding areas if approved by the Parks Department; however, this practice must preserve the quality of park features and programmed uses. The Jennie Adair Stormwater Wetlands facility is a good example of compatibility between parks and water quality treatment.

Potential Stormwater Quality Treatment Sites: The green areas in park spaces create a tremendous opportunity for reducing and treating runoff at a sub-regional or regional level. Stormwater quality facilities are best included in parks larger than an acre, where they do not take up more than a third of the total park area, and can be combined with other park uses. Treatment facilities may be in conflict with active recreation areas like sports fields.

Criteria for the Use of Parks as Stormwater Treatment Sites: Consider the following in determining a park's feasibility as a stormwater treatment site:

- Compatibility with design, historic designation or other protective constraints including wildlife habitat and protection.
- Compatibility with recreational uses. The level of organized and informal activity in a park must be considered.
- Technical constraints and opportunities including soil characteristics, turf management, or terrain.
- Potential for new natural areas and wildlife corridors.
- Size and configuration of the park.
- Facility safety.
- Aesthetics of facility and park.
- Maintenance and operations, funding resources, successful techniques for dealing with silt, debris, etc.
- The configuration and easements for underground utilities and their impact on the existing park land.

Design Recommendations:

1. Runoff Reduction

- Sheet-drain parking and paving to grass buffers and grass swales.
- Drain roofs to grass buffers, grass swales, and pervious pavement.
- Develop multi-purpose trails, maintenance routes, and parking areas to minimize directly connected impervious areas. Avoid concentrating runoff from roadways and parking lots by allowing runoff from those areas to sheet drain over landscape areas.
- Use pervious pavement to the maximum extent practicable for parking areas, patios, trails, etc.

2. WQCV Treatment

- Treat runoff from parking lots and roadways using bioretention and pervious pavement detention where practicable.
- Develop regional stormwater quality treatment in detention basin BMPs, including extended detention basins and wetlands. Construct all facilities as site amenities, with the ability to support diverse ecology, and the ability to be drawn down for clean out and maintenance. Incorporate public education and participation for these sub-regional and regional facilities.
- Do not combine WQCV facilities with active recreation.

- Implement source control BMPs. It is important to properly apply pesticides, herbicides, fertilizers and other chemicals. Use integrated pest management (IPM).

3. Flood Detention

- Consider constructing berms around existing ponds, lakes, and extended detention facilities to increase water storage capacities within the park.

4. Implementation Details

- Parking. Direct runoff from parking to adjacent landscape areas.
- Planting. Parks present a tremendous opportunity to include diverse plantings in larger treatment areas in natural areas and open space.

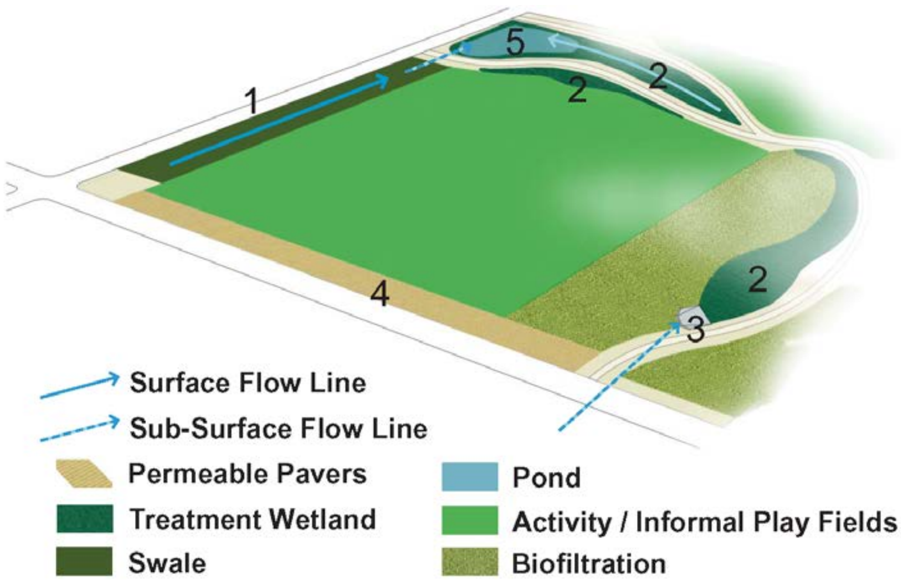


Figure 8.11 Park Development Sketch

KEY

1 Swales and buffers convey stormwater runoff from the fields, and streets (if applicable) before channeling to wetlands or ponds where stormwater can be treated and stored

2 Storm sewers can be daylighted in the park and channeled through treatment wetlands.

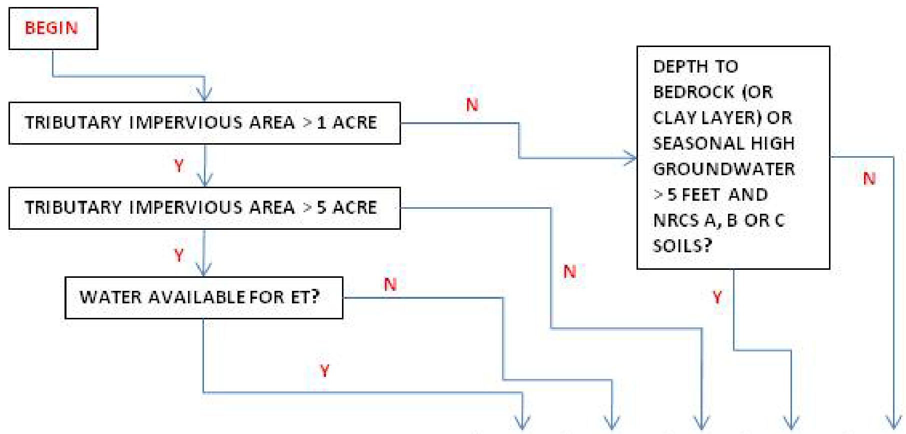
3 A forebay at the end of pipe will provide settlement of large particles. This will reduce the frequency of maintenance, and help manage an attractive wetland planting.

4 Permeable pavers may be used along street edges, or parking stalls to reduce overall stormwater runoff volumes

5 A wet pond can help manage “regional” flood volumes, while being an attractive amenity for the park as long as these do not significantly impact the integrity of the park’s design and functions.

8.3.3 BMP Selection Decision Tree

In addition to land use and development type, other factors are important for selecting the appropriate BMP for a site. These factors include soil type and permeability, size of tributary area, depth to groundwater and bedrock, pretreatment provided, and others. **Figure 8.12** provides a decision tree that can be used to determine appropriate BMPs for a site in conjunction with the development type guidance from **Section 8.3.2**.



MDCIA				□	□
Grassed Swale				□	□
Grassed Buffer	□	□	□	□	□
PPS with Infiltration to Sub-grade				◈	
PPS with Underdrain					◈
Constructed Wetlands Channel	□	□	□	□	□
Street BMPs/Sediment Traps				□	□
Bioretention				◈	
Bioretention with Underdrains					◈
Extended Detention Basins	○	○			
Sand Filter Extended Detention Basin	◈	◈	◈	◈	◈
Constructed Wetland Basin	○				
Subsurface Proprietary BMPs				○	○*
Subsurface Sedimentation Vault				○	○*
Subsurface Sand Filter				○	○*
Dry Well				○	

Notes:

□	Provides modest to moderate runoff reduction and pollutant removal
◈	Provides runoff reduction and WQCV
○	Provides WQCV
PPS	Pervious Pavement System
MDCIA	Minimize Directly Connected Impervious Area
*	Special Design Conditions Necessary to Anchor Against Groundwater

Figure 8.12 BMP Decision Tree

8.4 Design Event and Water Quality Capture Volume (WQCV) Requirements

The design event for Water Quality Capture Volume (WQCV) is the 80th percentile runoff event which corresponds to roughly a 6-month to 1-year storm event. The design brim-full emptying time for the WQCV shall be a minimum of 12 hours. Eighty percent of all runoff events, on a volumetric basis, are expected to be less than or equal to this design event and will be fully treated by BMPs that provide the WQCV. Based on calculations for fine sand-sized particles (60 microns) using settling velocities modified for low temperatures, a drain time of 12 hours for the WQCV should provide a very high level of removal (greater than 90%) for this size of particles (USEPA 1986). While extended drain times (longer than 12-hours) may provide a higher level of removal, they are not practical in Aspen due to the freezing conditions that frequently occur over night during the winter and spring.

Figure 8.13 shows the relationship between impervious area and the WQCV to be used for sizing the WQCV. The following guidelines apply for using **Figure 8.13**:

- The imperviousness used on the x-axis in **Figure 8.13** is the imperviousness of the area tributary to a stormwater BMP. This imperviousness is determined from a site plan by determining the preliminary location of a BMP and then delineating the area that will contribute runoff to the BMP. Impervious areas within the tributary area (watershed) including roofs, walks, drives, roads, etc. can be identified and added to determine the total impervious area within the tributary area. The total imperviousness, as a percent is calculated as: Impervious Area in Tributary Watershed/ Total Area in Tributary Watershed x 100. If a BMP is sized to provide only on-site water quality treatment, the WQCV may be calculated based on only on-site impervious area; however, the BMP must be sized to pass off-site flows from impervious and pervious areas without causing downstream problems. It is preferable to size a BMP for all tributary impervious area (on-site and off-site) as this will provide the greatest water quality benefit for the community.

- For sites that employ runoff reduction measures such as swales, buffers, trees and other BMPs that minimize directly connected impervious area or the effect of the impervious area, the total imperviousness should be adjusted to effective imperviousness before using **Figure 8.13** to determine the WQCV. Adjustment procedures for converting total imperviousness to effective imperviousness are described in **Section 8.4.1**.

- The WQCV in **Figure 8.13** has units of watershed-inches. To determine a volume in ft^3, the following conversion applies:

$$Volume\ (ft^3) = \ WQCV\ in\ Watershed\ inches\ x\ \frac{1ft}{12\ in} x\ Area\ (sf)$$

For a site that is 100 percent impervious the WQCV corresponds to 0.26 watershed-inches (i.e. the storage volume required for a BMP is equivalent to 0.26 inches of runoff distributed over the area tributary to the BMP). 0.26 watershed inches is equivalent to approximately 950 ft^3/acre.

An example of how to determine the WQCV is provided in **Section 8.4.2**.

Figure 8.13 Aspen Water Quality Capture Volume

8.4.1 Calculating Effective Imperviousness Based on Disconnected Impervious Area or Tree Canopy Credit

The WQCV is a function of the imperviousness of the area tributary to the BMP. When certain low impact development (LID) and runoff reduction techniques are used such as grass swales, grass buffers, downspouts directed to pervious areas, etc., the **effective** imperviousness of a watershed may be lower than the **total** imperviousness. Two levels of MDCIA are defined for the purposes of this Chapter:

- **Level 1.** The goal of Level 1 is to direct the flow of runoff from impervious surfaces over grass-covered areas or pervious pavement, and to provide sufficient travel time to maximize the removal of suspended solids before the runoff leaves the site, enters a curb and gutter, or enters another stormwater collection system. Thus, at Level 1, *all* impervious surfaces are made to drain over grass buffer strips (criteria in **Section 8.5.1.3**) before reaching a stormwater conveyance system.

- **Level 2.** As an adjunct to Level 1, this level replaces solid street curb and gutter systems with no curb or slotted curbing and low-velocity grass-lined swales and pervious street shoulders. Conveyance systems and storm sewer inlets will still be needed to collect runoff at downstream intersections and crossings where stormwater flow rates exceed the capacity of the swales. Small culverts will be needed at street crossings and at individual driveways until inlets are provided to convey the flow to a storm sewer.

Figure 8.14 illustrates adjustments to effective imperviousness based on Level 1 and 2 MDCIA. **Section 8.4.2** provides an example of how to use **Figure 8.14** to determine effective imperviousness.

Another way to reduce the effective imperviousness of a tributary area is through a tree canopy credit. Trees are a valuable natural resource and can considerably reduce stormwater runoff through interception, transpiration, and infiltration.

The following method can be used to receive credit for the tree canopy in a tributary area.

Step 1: Identify the proposed impervious areas within the property lines and the existing tree canopy within the property lines. Tree canopies must be divided into deciduous and coniferous. Only existing, pre-project trees can be counted. The minimum canopy for consideration is 10 ft and the trunk of the trees counted must be within 50 ft of the impervious areas on a site. Show this step in aerial photo or landscaping plan for review.

Step 2: Calculate the coniferous tree canopy area and multiply by 0.30. Calculate the deciduous tree canopy area and multiply by 0.15. Sum these two totals.

Step 3: Subtract the sum in Step 2 from the impervious area.

Step 4: Divide the new reduced impervious area by the total tributary area and multiply by 100 to get effective imperviousness. Use Figure 8.14 to calculate WQCV for the tributary area/sub-basin in design.

If canopy in consideration is required to be removed by the City Forester, then that canopy credit will not be lost.

Section 8.4.2 provides an example of how to use tree canopies to reduce the effective imperviousness for a site.

8.4.2 WQCV and Effective Imperviousness Example

Problem: Determine the WQCV and effective imperviousness for a 6,000 sf lot with an imperviousness of 70% draining to a BMP. Assume Level 1 MDCIA (impervious areas disconnected to drain to pervious areas.

Solution: First apply **Figure 8.14** to determine effective imperviousness for Level 1 MDCIA and a total imperviousness of 70 percent. As shown in **Figure 8.15**, below, the effective imperviousness is approximately 68 percent.

Next, apply an effective imperviousness of 68 percent to **Figure 8.13** to determine the WQCV in watershed inches. As shown in **Figure 8.16**, the WQCV is approximately 0.135 watershed inches.

Finally, calculate the WQCV in cubic feet:

$$WQCV = 0.135\, watershed\ inches\ x\ \frac{1ft}{12\ in} x\ 6000\ ft^2 = 67.5\ ft^3$$

Problem: Determine the effective imperviousness and WQCV for a 7,000 sf lot with 3000 sf of impervious area. On the eastern portion of the property is a deciduous tree canopy of 600 sf and a coniferous canopy of 250 sf. On the western portion of the property is a deciduous canopy of 400 sf and a coniferous canopy of 500 sq ft.

Solution: First determine effective impervious area for the property.

Eff Imp Area = 3000 – (500+250)0.3 – (600+400)0.15 = 3000 – 225 – 150 = 2625 sf

Imperviousness = (2625 / 7000) 100 = 37.5% WQCV = 0.075 watershed-inches

Finally, calculate the WQCV in cubic feet:

$$WQCV = 0.063\, watershed\ inches\ x\ \frac{1ft}{12\ in} x\ 7000\ ft^2 = 43.75\ ft^3$$

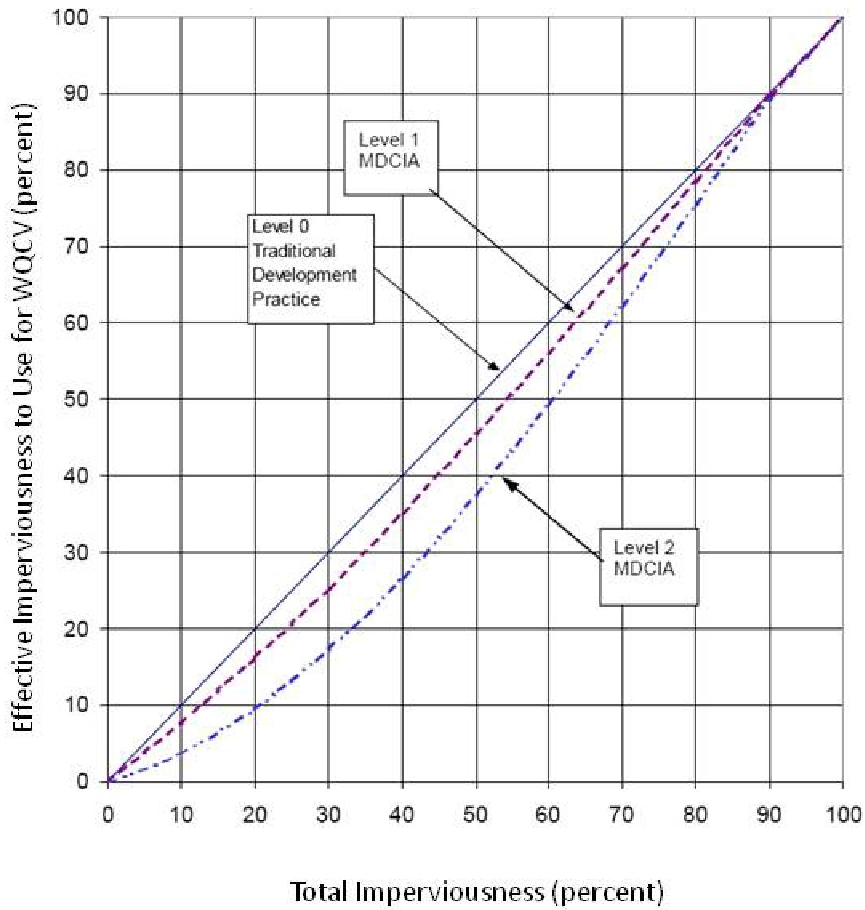


Figure 8.14 Imperviousness Adjustments for Level 1 and 2 MDCIA (UDFCD 1999)

When MDCIA and other LID practices are used, the WQCV should be calculated based on effective impervious area rather than total impervious area. Along with MDCIA, the use of pervious pavement systems (PPS) has the potential to reduce effective imperviousness. Specific guidance for adjustments to imperviousness for PPS is provided in **Section 8.5 Structural BMPs**.

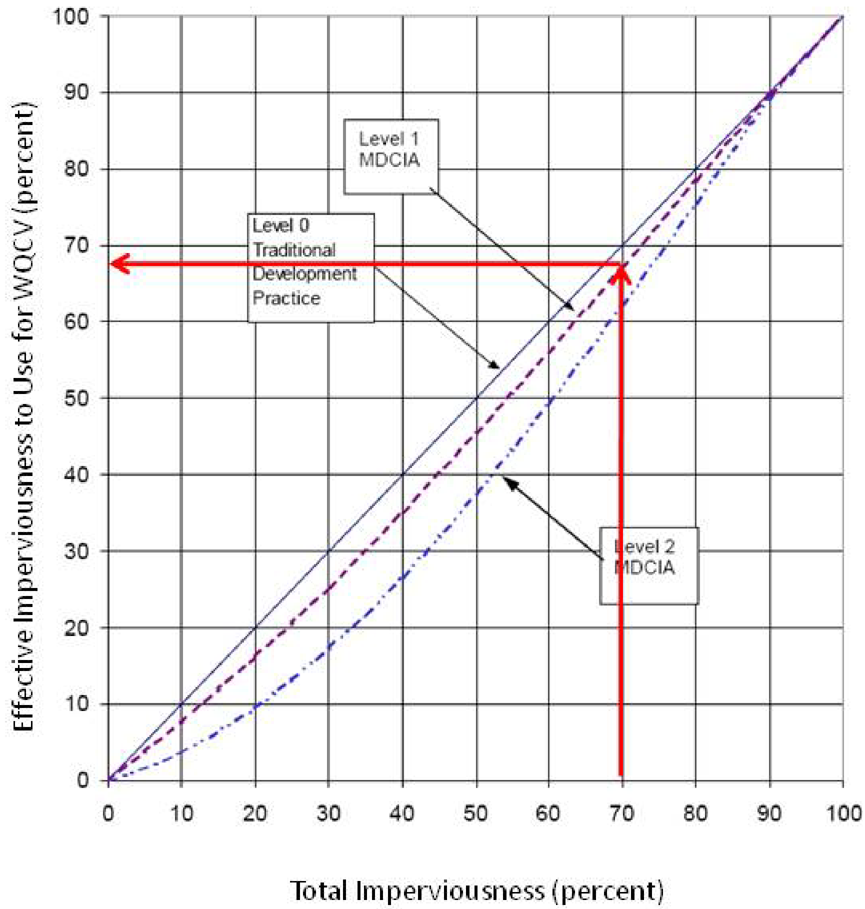


Figure 8.15 Imperviousness Adjustments Example (Total Imperviousness = 70 percent, Level 1 MDCIA)

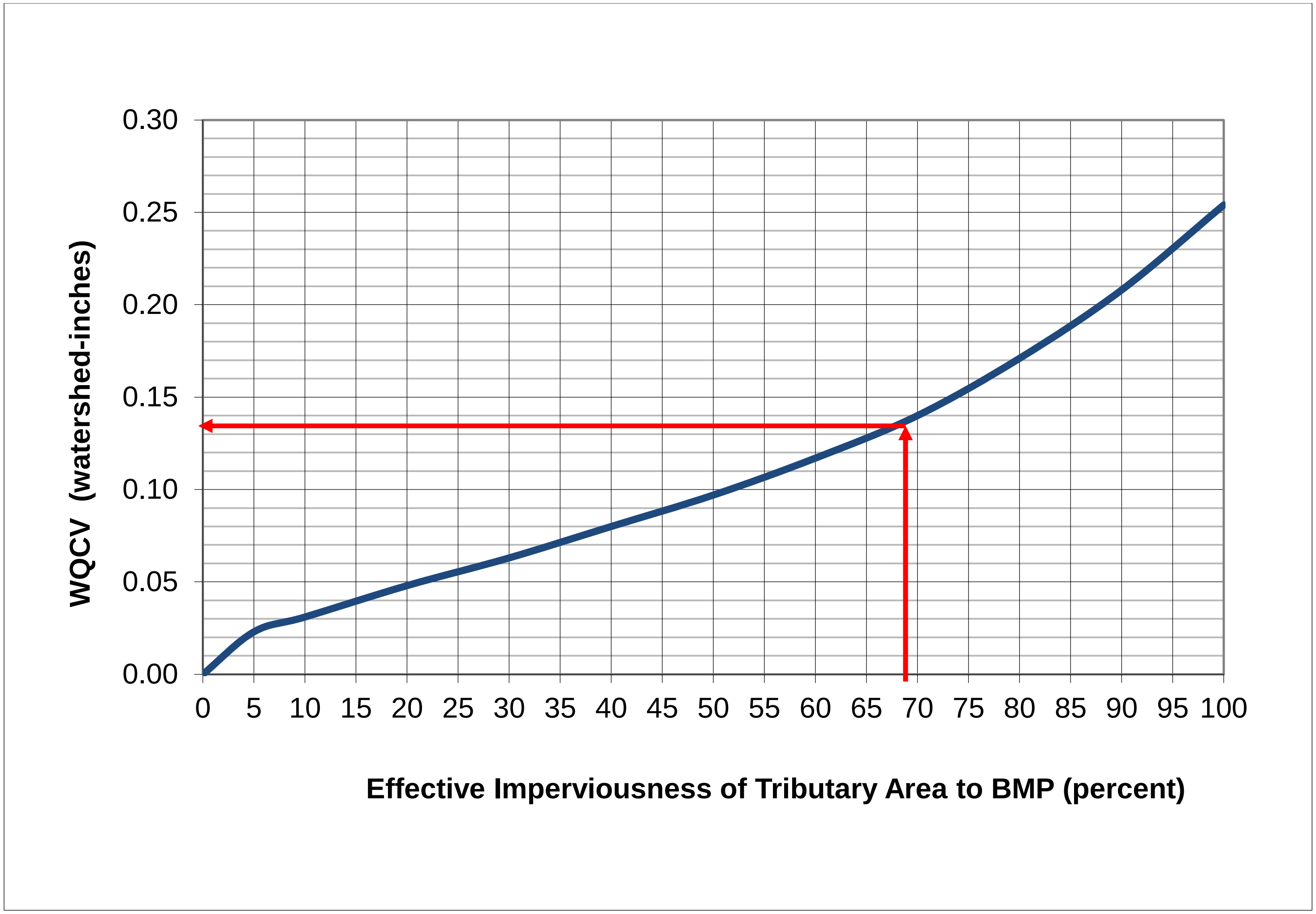


Figure 8.16 Aspen Water Quality Capture Volume Example (Total Imperviousness = 70 percent, Level 1 MDCIA, Effective Imperviousness = 68 percent)

8.5 Structural BMPs

This section provides design criteria for structural BMPs that are applicable for water quality treatment in Aspen. This is not an exhaustive list of structural BMPs nor are the BMP criteria set in stone. Stormwater quality treatment is a constantly evolving subject and alternate BMPs or modifications to stated criteria may be permitted at the discretion of the City Engineering Department.

8.5.1 Runoff Reduction/Conveyance BMPs

Runoff reduction measures such as MDCIA and pervious pavements reduce the amount of surface runoff requiring treatment by storage-based BMPs and reduce the "flashy" nature of urban hydrographs. Conveyance based BMPs such as grassed swales and buffers slow down runoff (lengthening the time of concentration), promote infiltration during conveyance and provide filtration of runoff as it passes through vegetation. When used in conjunction with a storage-based BMP, runoff reduction and conveyance BMPs provide the first step in a "treatment train."

8.5.1.1 Minimizing Directly Connected Impervious Area (MDCIA)

Minimizing directly connected impervious area (MDCIA) requires a basic change in land development design philosophy. This change seeks to reduce paved areas, use porous pavement and direct stormwater runoff to landscaped areas, grass buffer strips, and grass-lined swales to slow down the rate of runoff, reduce runoff volumes, attenuate peak flows, and encourage filtering and infiltration of stormwater. The fundamental method for MDCIA is to first eliminate unnecessary impervious area or seek to replace impervious pavement areas with pervious pavements and then to strive to direct runoff from impervious areas to pervious areas such as buffers and swales before discharging to the collection system/storm sewer.

8.5.1.2 Grassed Swales

Figure 8.18 Native grass species can be utilized in swales when the longitudinal slope of a swale is flat-- less than 0.5 percent

Figure 8.17 A shallow grass swale collects runoff from roof downspouts and adjacent pavement. The flush curb allows sheet flows into the swale.

Description

A grassed swale (GS) is an integral part of the MDCIA development concept. They are densely vegetated drainageways with low-pitched side slopes that collect and slowly convey runoff. Design of their longitudinal slope and cross-section size forces the flow to be slow and shallow, thereby facilitating sedimentation while limiting erosion. Berms or check dams should be installed perpendicular to the flow as needed to slow it down and to encourage settling and infiltration.

General Application

A grassed swale can provide a reduction in the effective imperviousness for a site but does not hold volume and therefore cannot be used as a water quality treatment facility. A GS can be located to collect overland flows from areas such as parking lots, buildings, residential yards, roadways and grass buffer strips (GBs). They can be used instead of a curb-and-gutter system to disconnect impervious area. A GS is set below adjacent ground level, and runoff enters the swales over grassy banks or rundowns. The potential exists for wetland vegetation to become established if the swale experiences standing water or if there is a base flow. If that condition is possible, consider the use of underdrains. A site with a base flow should be managed as either a swale with an unlined trickle channel, or as a wetland bottom channel, the latter providing an additional BMP for stormwater runoff treatment.

Advantages/Disadvantages

A GS, which can be more aesthetically pleasing than concrete or rock-lined drainage systems, is generally less expensive to construct. This BMP generally provides some reduction in runoff volumes from small storms. Dense grasses can reduce flow velocities and protect against erosion during larger storm events. Swales in residential and commercial settings can also be used to limit the extent of directly connected impervious areas.

The disadvantages of using GSs without underdrains include the possibility of soggy and wet areas in front yards and the potential need for more right-of-way than is needed for a storm sewer.

Physical Site Suitability

A GS is practical only at sites with general ground slopes of less than 4 to 5 percent and is not practical for sites steeper than 6 percent. The longitudinal slopes of a GS should be kept to less than 1.0 percent, which often necessitates the use of grade control checks or drop structures.

When soils with high permeability (for example, Class A or B) are available, the swale will infiltrate a portion of the runoff into the ground; however, such soils are not required for effective application of this BMP. When Class C and D soils are present, the use of a sand/gravel underdrain is recommended.

Pollutant Removal

Removal rates reported in literature vary and fall into the low to medium range. Under good soil conditions and low flow velocities, moderate removal of suspended solids and associated other constituents can be expected. If soil conditions permit, infiltration can remove low to moderate loads of some of the soluble pollutants when flow velocities are very low. As a result, small frequently occurring storms can benefit the most.

Cold Weather Considerations

Since GSs function primarily based on filtration by vegetation and infiltration, they are most effective in the summer months when vegetation is healthy and the ground is not frozen. During melting periods, grass swales can be effective at slowly infiltrating snow accumulated in swales, which may be used as snow storage areas in the winter. If there are significant sediment loads to the swales, from sand removed from streets and stacked in swales or from other sources, excessive sediment may accumulate in the swale, choking out vegetation. Periodic maintenance may be required to remove excess accumulated sediment and to reestablish vegetation.

Design Considerations

Figure 8.19 shows trapezoidal and triangular swale configurations. A GS is sized to maintain a low velocity during small storms and to collect and convey larger runoff events, all for the projected fully developed land use conditions. If the design flows are not based on fully developed land conditions, the swales will be undersized and will not provide the intended pollutant removal, flow attenuation, or flow conveyance capacity.

A healthy turf grass cover must be developed to foster dense vegetation. Permanent irrigation in some cases may be necessary. Judicious use of GSs can replace both the curb-and-gutter systems and greatly reduce the storm sewer systems in the upper portions of each watershed when designed to convey the "initial storm" (for example, a 2- or a 5-year storm) at slow velocities.

Design Procedure and Criteria

The following steps outline the GS design procedure and criteria.

1. Design Discharge—Determine the 2-year flow rate to be conveyed in the GS. Use the hydrologic procedures described in Runoff Chapter of the Manual. If the swale is used for minor event conveyance purposes as well as for water quality, the overall capacity may be greater than the 2-year event. Swale geometry at the 2-year flow rate should follow the guidance in this section.
2. Swale Geometry—Select geometry for the GS. The cross section should be either trapezoidal or triangular with side slopes flatter than 4:1 (Horizontal/ Vertical). Even flatter side slopes will provide greater infiltration benefits. The wider the wetted area of the swale, the slower the flow and the more effective it is in removing pollutants.
3. Longitudinal Slope—Maintain a longitudinal slope of the GS between 0.2 and 1.0 percent. If the longitudinal slope requirements cannot be satisfied with available terrain, grade-control checks or small drop structures must be incorporated to maintain the required longitudinal slope. If the slope of the swale exceeds 0.5 percent in semi-arid areas of Colorado, the swale must be vegetated with irrigated turf grass. Milder slopes will provide greater water quality benefits.
4. Flow Velocity and Depth—Calculate the velocity and depth of flow through the swale. Using the Manning's equation and a Manning's roughness coefficient of n=0.06, find the channel velocity and depth using the peak 2-year flow rate determined in Step 1. Maximum flow velocity in the swale shall not exceed 1-foot per second and the maximum flow depth shall not exceed 1-foot at the 2-year peak flow rate. If these conditions are exceeded, repeat steps 2 through 4 each time altering the depth and bottom width or longitudinal slopes until these criteria are satisfied.
5. Vegetation—Vegetate the GS with dense turf grass to promote sedimentation, filtration, and nutrient uptake, and to limit erosion through maintenance of low flow velocities.
6. Drainage and Flood Control—Check the water surface during larger storms including the minor and major events to ensure that drainage from these larger events is being handled without flooding critical areas or residential, commercial, and industrial structures.

Maintenance

Table 8.6 outlines maintenance recommendations for GSs.

Table 8.6 Maintenance Recommendations for Grassed Swales (UDFCD 1999)

Required Action	Maintenance Objective	Frequency of Action
Inspections	Check the grass for uniformity of cover, sediment accumulation in the swale, and near culverts.	Routine – Annual inspection is suggested.
Lawn mowing and Lawn care	Maintain irrigated grass at 2 to 4 inches tall and non-irrigated native grass at 6 to 8 inches tall. Collect cuttings and dispose of them offsite or use a mulching mower.	Routine – As needed.
Debris and Litter removal	Keep the area clean for aesthetic reasons, which also reduces floatables being flushed downstream.	Routine – As needed by inspection, but no less than two times per year. Check each spring after snowmelt.
Sediment removal	Remove accumulated sediment near culverts and in channels to maintain flow capacity. Replace the grass areas damaged in the process.	Routine – As needed by inspection. Check each spring after snowmelt.
Grass reseeding and mulching	Maintain a healthy dense grass in channel and side slope.	Non-routine – As needed by annual inspection.

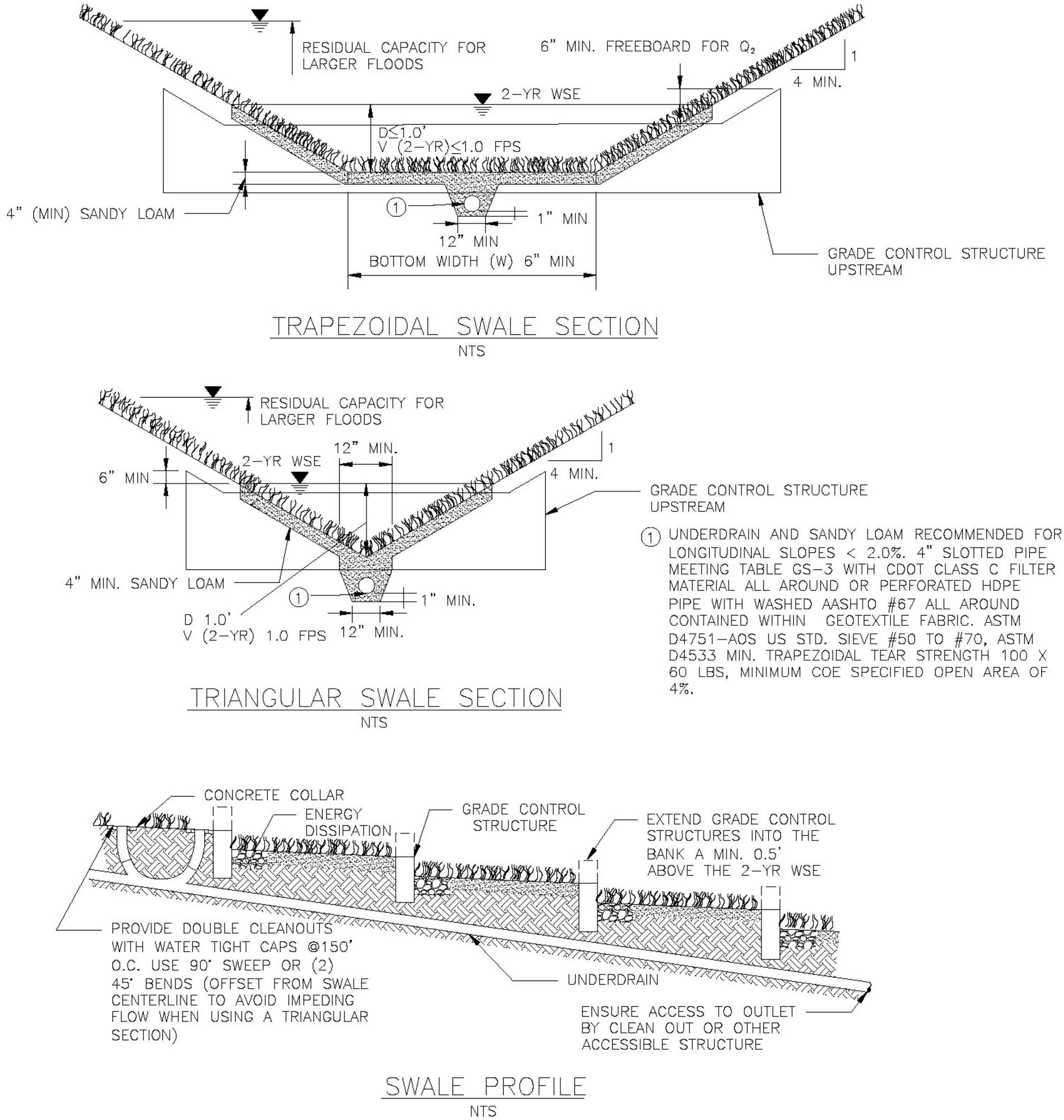


Figure 8.19 Grassed Swale Typical Sections and Profile (UDFCD 1999)

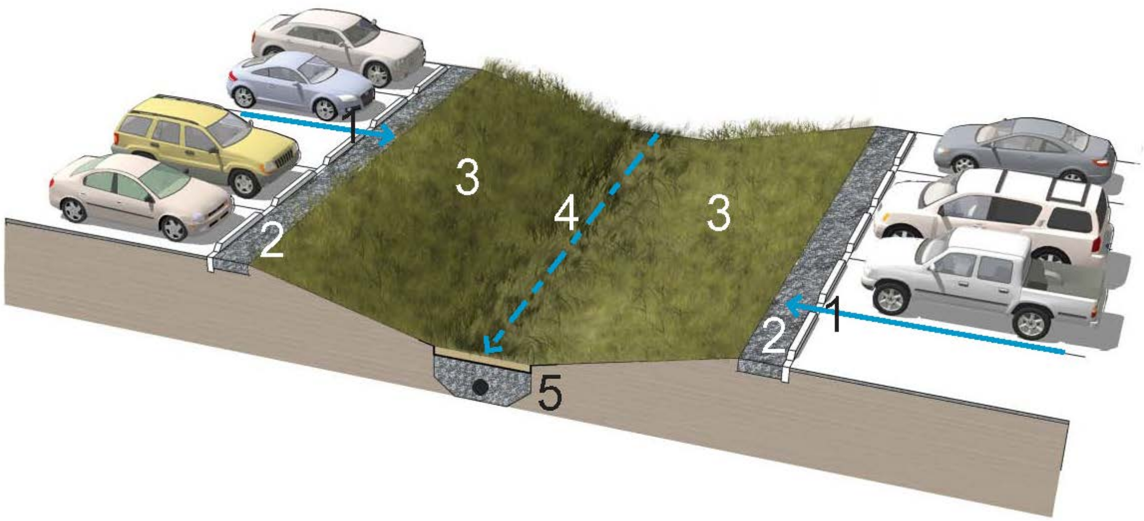


Figure 8.20 Typical Grass Swale Design Sketch

1: Inlet: Slotted curbs or curbless streets/ paved areas allow for sheet flows into the swale, side slopes serve as grass buffers. Control for sediment and erosion at inlets and wherever flows are concentrated.

2: Sediment Trap: A sloped edge, three inches below the pavement surface. Sediment trap can be landscaped or non-vegetated. Provide a non-vegetated trap, such as a gravel filter, if large volumes of sediment are anticipated. Provide sediment traps at pipe outfalls to dissipate energy and allow easier sediment removal. Locate sediment traps above the low flow conveyance of the swale to minimize re-mobilization of sediments.

3: Slopes: Longitudinal slopes should be shallow (less that 0.2-1.0) Provide check structures where longitudinal slopes exceed 1% or as needed along the length of the swale. Side slopes shall be 4:1 max., flatter preferred.

4: Vegetation: Dense turf grass is most commonly used. Plantings vary depending on context. Select appropriate plant materials for appropriate wet and dry cycles, and that can withstand storm flow velocities. Native grasses can be used where longitudinal slopes are less than 0.5%.

5: Underdrain/Liner: Underdrains are not required for Type A and Type B soils per UDFCD 2010; however, in some instances they may be considered for these soils types if there is concern with future reduced infiltration capacity due to sediment accumulation. Underdrains are required for Type C and Type D soils, or when swales are in close proximity to buildings, structures, or where geotechnical requirements dictate. Refer to Typical Sections and Profile **Figure 8.19**.

6: Soils: Consisting of native soils and/or soils as needed for specified plant types (not shown in graphic). Refer to Typical Sections and Profile **Figure 8.19.**

8.5.1.3 Grass Buffers (GB)

Description

Grass buffer (GB) strips are an integral part of the MDCIA land development concept and in the City of Aspen they are also considered a stormwater BMP that when appropriately designed can provide for the removal of sediment and provide the WQCV. They are densely vegetated areas of turf grass that require sheet flow to promote filtration, infiltration and settling to reduce runoff pollutants. GBs differ from grass swales as they are uniformly graded and designed to accommodate overland sheet flow rather than concentrated or channelized flow. They can be used to remove larger sediment from runoff from impervious areas.

Whenever concentrated runoff occurs, it should be evenly distributed across the width of the buffer via a flow spreader. GBs can also be combined with riparian zones in treating sheet flows and in stabilizing channel banks adjacent to major drainageways and receiving waters. GBs can be interspersed with shrubs and trees to improve their aesthetics and to provide shading. Irrigation in the semi-arid climate of Colorado may be required to maintain a healthy and dense grass on the GB to withstand the erosive forces of runoff from impervious areas.

General Application

A GB is located adjacent to impervious areas and can be used in residential and commercial areas and along streets and roads. Because their effectiveness depends on having an evenly distributed sheet flow over their surface, the size of the contributing area, and the associated volume of runoff have to be limited. Flow can be directly accepted from a parking lot, roadway or building roof, provided the flow is distributed uniformly over the strip. Grass buffers can be used for treatment of the water quality capture volume.

Figure 8.21 A gravel mulch band next to the traps sediment before it enters the grass buffer.

Figure 8.22 A curbless street allows parking lot stormwater to flow evenly from the road through a grass buffer.

Advantages/Disadvantages

The grass and other vegetation can provide aesthetically pleasing green space. In addition, their use adds little cost to a development that has to provide open space, and their maintenance should be no different than routine maintenance of the site's landscaping. Eventually, the grass strip next to the spreader or the pavement will have accumulated sufficient sediment to block runoff. At that time, a portion of the GB strip will need to be removed and replaced. Grass and trees within these buffer strips can provide wildlife habitat. Because infiltration occurs and water quality capture volume can be treated within the buffer, the size of downstream drainage facilities can often be reduced. Gravel underdrains can be used where soils are not suited for infiltration.

Physical Site Suitability

The site, after final grading, should have a uniform slope and be capable of maintaining an even sheet flow throughout without concentrating runoff into shallow swales or rivulets. The allowable tributary area depends on the width, length, and the soils that lay under the GB. Hydrologic Soil Groups A and B provide the best infiltration capacity, while Soil Groups C and D provide best site stability. The swelling potential of underlying soils should also be taken into account when used adjacent to structures and pavement. Irrigation may be required for some types of vegetation.

Pollutant Removal

Pollutant removal depends on many factors such as soil permeability, site slope, the flow path length along the buffer, the characteristics of drainage area, runoff volumes and velocities, and the type of vegetation. The general pollutant removal of both particulate and soluble pollutants is projected to be low to moderate. GBs rely primarily upon the straining through grass and settling of solids, and to only a minor degree, on biological uptake and runoff infiltration.

Cold Weather Considerations

Cold weather considerations for GBs are similar to those of GSs. Performance can be expected to be best in summer months when vegetation is healthy and the ground is not frozen. Some infiltration may occur at the bottom of a ripe snowpack; however, it is likely the soils will be saturated, reducing the infiltration rate. Snow may be stored in GBs during winter months. If snow is stored in these areas, excessive sediment may accumulate in the GBs and impact vegetation. Periodic removal of excess sediment and replacement of vegetation should be anticipated.

Design Considerations

Design of GBs is based primarily on maintaining sheet-flow conditions across a uniformly graded, irrigated, dense grass cover strip. When a GB is used over unstable slopes, soils, or vegetation, the formation of rills and gullies that disrupt sheet flow will occur. The resultant short-circuiting will invalidate the intended water quality benefits and will render the GB no functional. GBs should be protected during construction (cannot be compacted) and from excessive pedestrian or vehicular traffic that can damage the grass cover and affect even sheet-flow distribution post-construction. A mixture of grass and trees may offer benefits for slope stability and improved aesthetics. If used adjacent to pavement, there should be a 1 – 2 inch drop into the buffer area.

Design Procedure and Criteria

The following steps outline the GB design procedure and criteria. **Figure 8.23** depicts a typical GB with key design criteria.

1. Minimum Length (L_G)—Calculate the minimum length (normal to flow) of the GB*.* The upstream flow needs to be uniformly distributed over this length, either by design water to sheet flow from the tributary area or through the use of a level spreader.

   $$L_G \geq 0.7L_T$$

2. Minimum Width - The minimum width (W_G) (the distance along the sheet flow direction) of the GB is five (5) feet.

3. Minimum Area – To meet WQCV requirements for an impervious area the minimum grass buffer area (A_G) shall be greater than or equal to the tributary area (A_T). There shall be a 1:1 ratio of impervious area to grass buffer area.

4. Geometry - A rectangular strip is the preferred shape for the GB and should be free of gullies or rills that concentrate the flow over it.

5. Maximum Slope—Design slope of a GB in the primary direction of flow should not exceed 4 percent.

6. Flow Distribution—Incorporate a device on the upstream end of the buffer to evenly distribute flows along the design length. Slotted curbing, modular block porous pavement (MBP), or other spreader devices can be used to apply flows. Concentrated flow supplied to the GB must use a level spreader (or a similar device) to evenly distribute flow onto the buffer.

7. Soils and Vegetation — GB are not permitted on compacted soils and evidence of infiltration ability might be required. Additionally, if GB are constructed as part of new construction, 6" of topsoil is recommended. It is recommended to vegetate the GB with irrigated dense turf in semi-arid areas of Colorado to promote sedimentation and entrapment and to protect against erosion. However, plantings can/should vary depending on context. Select appropriate plant materials for appropriate wet and dry cycles, and that can withstand storm flow velocities. Native grasses can be used where longitudinal slopes are less than 0.5%, but bunch grasses are not acceptable.

8. Outflow Collection – Provide a means for outflow collection. Much of the runoff during significant events will not be infiltrated and will require a collection and conveyance system. A grass swale (GS) can be used for this purpose and can provide another MDCIA type of a BMP. The buffer can also drain to a storm sewer or to a street gutter. In some cases the use of underdrains can maintain better infiltration rates as the soils saturate and help dry out the buffer after storms or irrigation periods.

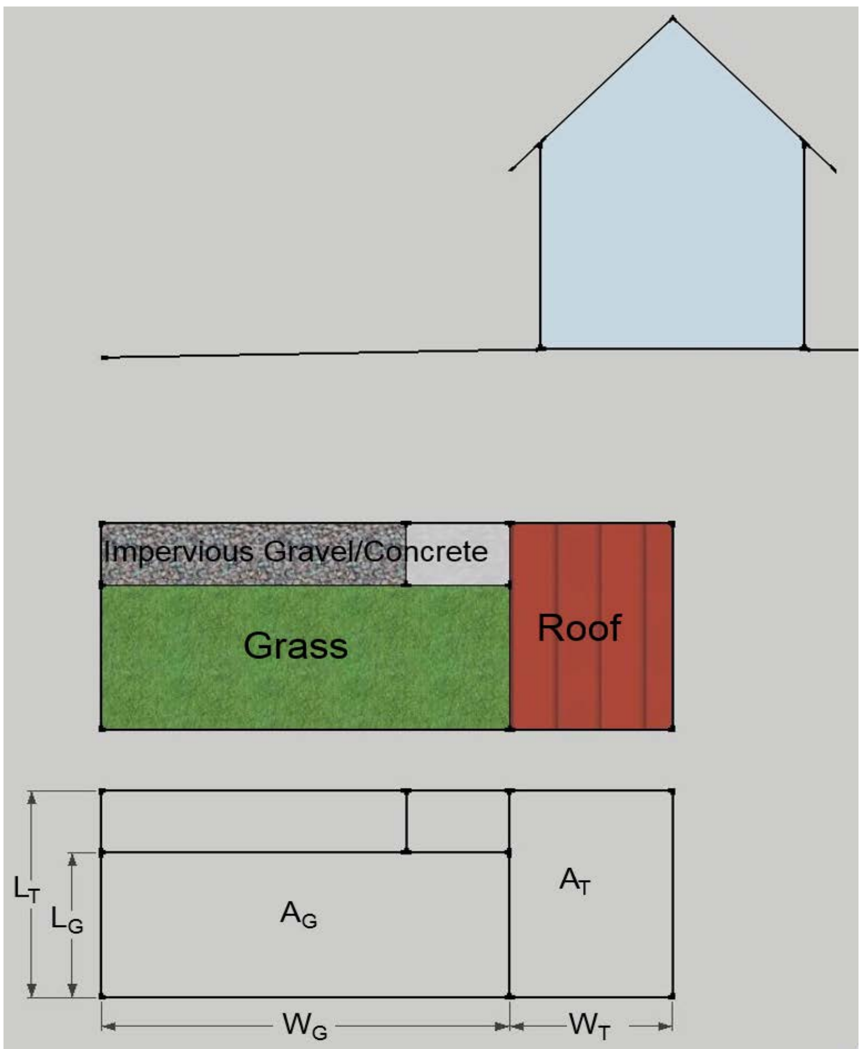
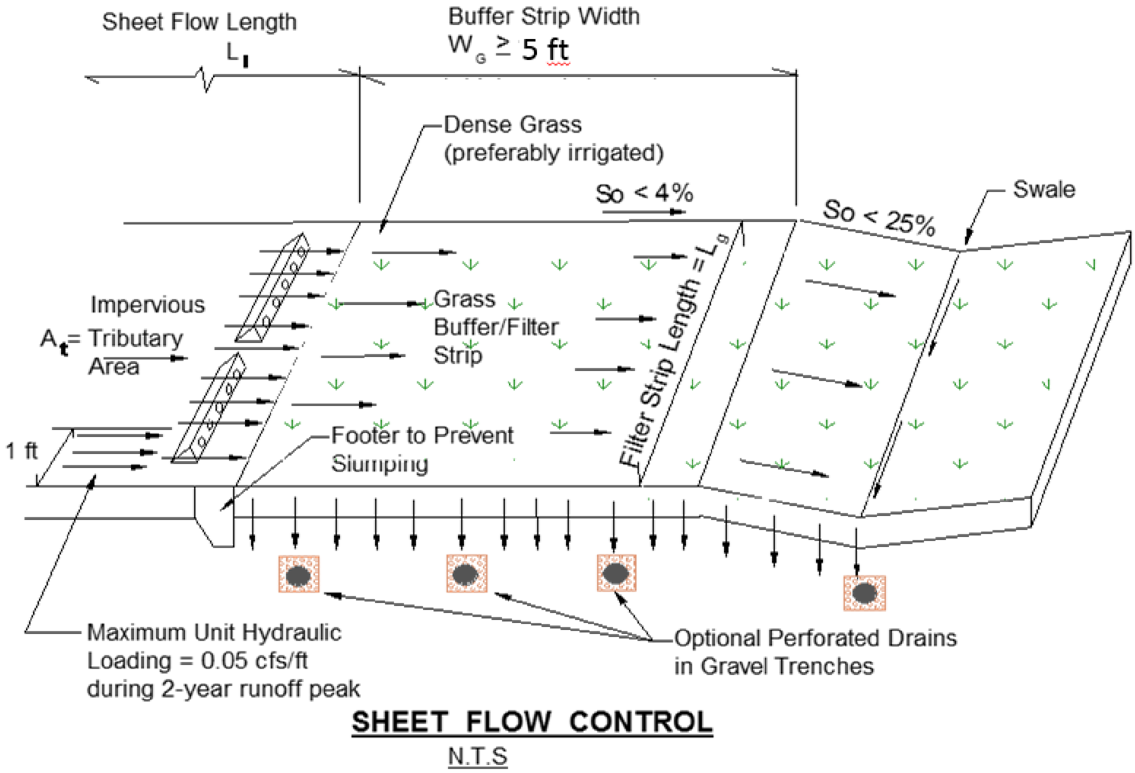


Figure 8-23. Example Grass Buffer Lawn



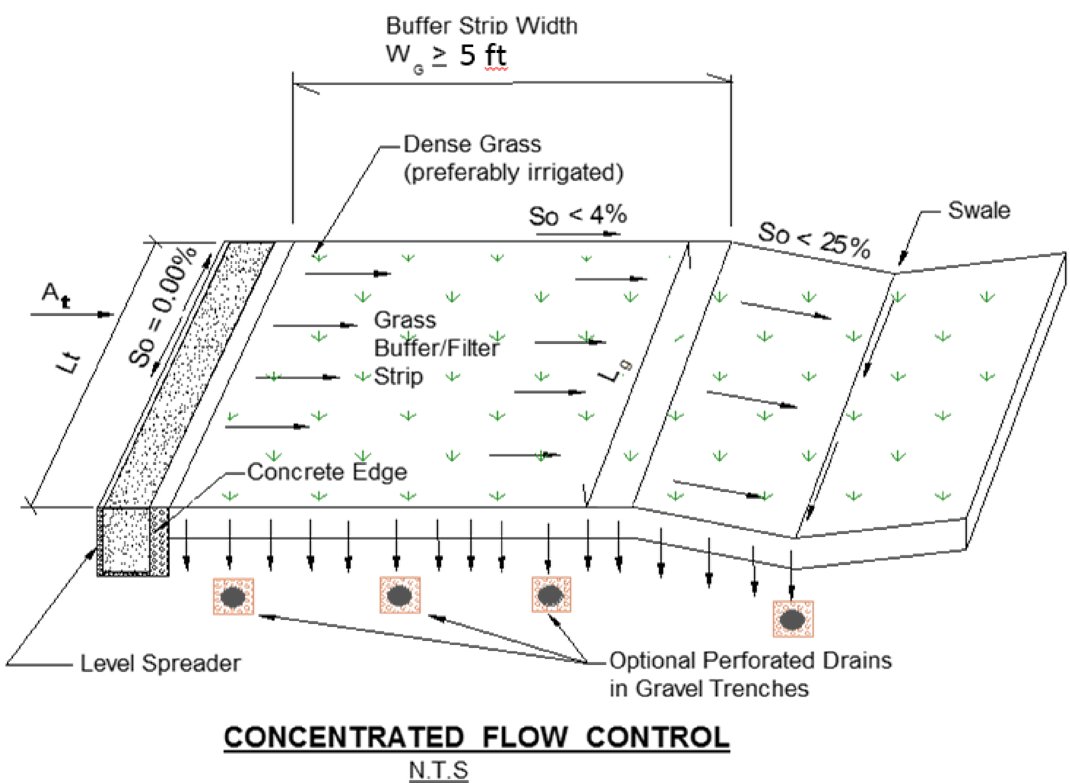


Figure 8.24 Typical Grass Buffer (GB)

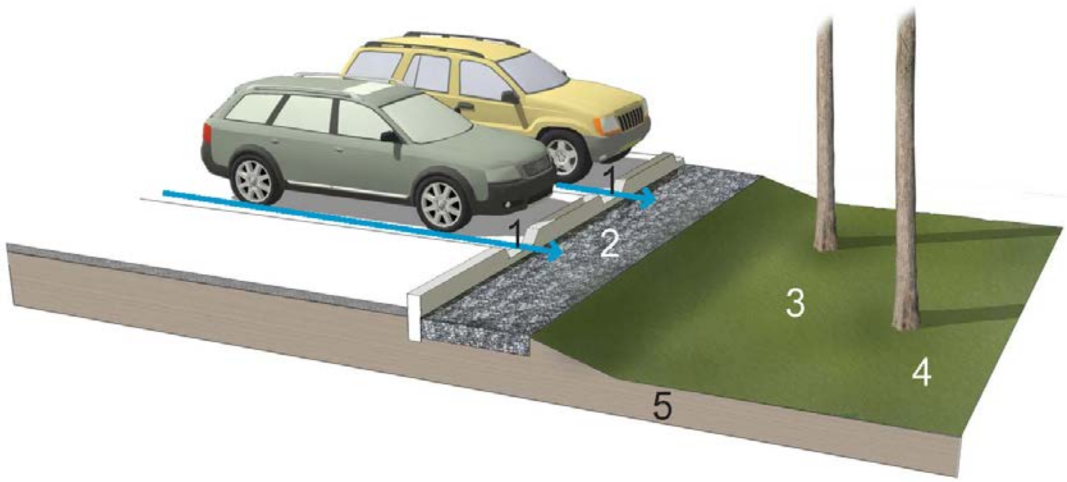


Figure 8.25 Grass Buffer Design Sketch

1: Inlet: Having no curbs or slotted curbs promotes uniform storm flows. Depress the grade three inches below pavement to provide positive drainage even with moderate sediment accumulation.

2: Sediment Trap: In areas with high sediment loads, include a rock mulch strip contained by a landscape edger.

3: Vegetation: Irrigated dense turf or native grasses—may include other dense groundcovers. Provide a gradual positive slope to allow gradual deposition of sediment while maintaining positive drainage

4: Outlet/Overflow: Grass buffers should drain to a grass swale, storage BMP, or depression with inlet and storm sewer.

5: Infiltration Matrix: Native soils.

Maintenance

Table 8.7 outlines maintenance recommendations for GBs.

Table 8.7 Maintenance Recommendations for Grass Buffers (UDFCD 1999)

Required Action	Maintenance Objective	Frequency of Action
Lawn mowing	Maintain a dense grass cover at a recommended length of 2 to 4 inches. Collect and dispose of cuttings offsite or use a mulching mower.	Routine – As needed or recommended by inspection.
Lawn care	Use the minimum amount of biodegradable, nontoxic fertilizers and herbicides needed to maintain dense grass cover, free of weeds. Reseed and patch damaged areas.	Routine – As needed.
Irrigation	Adjust the timing sequence and water cover to maintain the required minimum soil moisture for dense grass growth. Do not overwater.	As needed.

Required Action	Maintenance Objective	Frequency of Action
Litter removal	Remove litter and debris to prevent gully development, enhance aesthetics, and prevent floatables from being washed offsite.	Routine – As needed by inspection.
Inspections	Inspect irrigation, turf grass density, flow distribution, gully development, and traces of pedestrian or vehicular traffic and request repairs as needed.	Annually after spring runoff and after each major storm (that is, larger than 1.0 inches in precipitation).
Turf replacement	To lower the turf below the surface of the adjacent pavement, use a level flow spreader, so that sheet flow is not blocked and will not cause water to back up onto the upstream pavement.	As needed when water padding becomes too high or too frequent a problem. The need for turf replacement will be higher if the pavement is sanded in winter to improve tire traction on ice. Otherwise, expect replacement once every 5 to 15 years.
Rock Mulch Strip	Remove litter and debris from rock mulch strip.	As needed. Expect to replace rock mulch once every 5 to 15 years depending on size and concentration of runoff area.

8.5.1.4 Pervious Pavement (PP)

Figure 8.26 Modular block permeable pavement in this small parking lot allows runoff from roof downspout, promoting infiltration and reducing the overall storage volumes for the site.

Figure 8.27 Modular block permeable pavement is used for an on-street parking lane on this residential street.

Description

Pervious Pavement (PP) covers a variety of stabilized surfaces that can be used for the movement and parking of vehicles (automobiles, trucks, construction equipment, etc.) and storage of materials and equipment. Pervious pavement differs from conventional pavement. It is designed to infiltrate stormwater runoff instead of shedding it off the ***surface***. PP offers the advantage of decreasing the effective imperviousness of an urbanizing or redevelopment site, thereby reducing runoff and pollutant loads leaving the site.

Pervious pavement can be designed with and without underdrains. Whenever underdrains are used, infiltrated water will behave similarly to interflow and will surface at much reduced rates over extended periods of time. All types of pervious pavement help to return stormwater runoff hydrology to more closely resemble pre-developed conditions. However, the actual consumptive use of water falling onto the ground is considerably less than under pre-developed conditions and for grass lawns in urban areas. The designer needs to consult with a geotechnical engineer as to the suitability of each type of pervious pavement for the loads and traffic it will support and carry, and the geologic conditions the pavement will rest upon.

For modular block pavement and reinforced grass pavement, the WQCV can be provided by providing adequate aggregate depth to provide the storage required for the WQCV in the pore volume beneath the pavement. Because of the very limited net open area of a cobblestone block pavement, it is generally not feasible to attain enough infiltration to provide WQCV storage beneath the pavement. All of the types of pervious pavement discussed reduce effective imperviousness.

The following sections describe three types of pervious pavement that may be used in Aspen. Porous concrete and asphalt are not allowed in Aspen, largely because of experience with failures of these types of pervious pavements in other parts of Colorado.

Modular Block Pavement (MBP)

This pavement consists of concrete block units with open surface voids laid on a gravel sub-grade with open surface voids. These voids occupy at least 20% of the total surface area that are filled with sand (ASTM C-33 sand fine concrete aggregate or mortar sand) or sandy loam turf that has at least 50% sand by weight in its volume. However, unless the pavement will be watered regularly (i.e., using a sprinkler system) to keep the vegetation viable, concrete sand infill is the recommended material.

Modular block pavement may be sloped or flat. Modular block pavement has been in use in United States since the mid-1970s. Although field data that quantify their long-term performance are somewhat limited, the data collected locally, and at other part of United States, and the episodic reports from Canada, Australia, Asia, and Europe, indicate that properly installed modular block pavements are reliable and have experienced few problems under a wide range of climates.

Cobblestone Block Pavement (CBP)

This pavement consists of concrete block units replicating the appearance of cobblestone that create open voids by beveling the corners of each block and/or wider spacing between the blocks. One of the commercial “cobblestone” products that meets this description is Eco-stone™ made by Pavestone Co®. These “cobblestones” are laid on a gravel sub-grade. The surface area has voids that occupy at least 8% of the total surface area and are filled with sand or stone per the manufacturer recommendation and compliance with PICP standards.

Cobblestone block pavement may also be laid on a sloped or on a flat grade. This type of pavement has been in use since the 1980s. Field data that quantify the long-term performance of cobblestone block pavement are limited; however, the data and the episodic reports from other parts of the United States, Canada, Australia, Asia and Europe indicate that when properly installed, Cobblestone block pavement is reliable and has experienced few problems under a wide range of climates.

Reinforced Grass Pavement (RGP)

This is a stabilized grass surface intended for use in parking lots that experience intermittent use. Past experience has shown that RGP may not be suitable for heavy vehicles, especially those associated with critical services such as fire trucks. It has been shown to function well under wet-weather conditions and, when properly designed and installed, it will infiltrate rainwater at rates that equal or exceed the infiltration rates of NRCS Hydrologic Soil Group Type B soils. The grasses need to be mowed on a cycle that depends on the grass types and whether or not irrigation is used. Use of irrigated grasses should be considered for more actively-used parking lots.

Another type of reinforced grass pavement design is based on the Federal Aviation Administration’s (FAA) recommendations for *Aggregate Turf* originally developed for use with light aircraft that do not exceed a gross load of 12,500 pounds. This design offers a very stable surface and has a relatively simple cross-section. When it is installed using good site preparation, compaction and the specified gravel-topsoil mix, it has functioned well on small general aviation airports for many years.

General Application

Modular Block and Cobblestone Block Pavement

Modular block pavements and cobblestone block pavements are best suited for use in low vehicle movement zones, such as roadway shoulders, driveways, parking strips and parking lots. Vehicle movement (i.e., not parking) lanes that lead up to one of these types of porous pavement parking pads may be better served, but not always, by solid asphalt or concrete pavement. The following are potential applications for these two types of porous pavement:

- Low vehicle movement zones
- Crossover/emergency stopping/parking lanes
- Residential street parking lanes
- Private and public building driveways
- Maintenance roads and trails
- Roadway shoulders and parking lanes
- Emergency vehicle and fire access lanes
- Low vehicle movement commercial and industrial parking lots, including driveways
- Commercial/retail parking lots
- Equipment storage areas

Reinforced Grass Pavement

Reinforced grass pavement is best used in overflow parking zones or in parking lots that experience occasional uses (e.g., once-a-week-used portions of church and football stadium parking lots), roadway shoulders, residential street parking lanes, and emergency vehicle access lanes. Vehicle movement lanes (i.e., not parking pads themselves) that lead up to one of these reinforced grass pavement surfaces need to be served by solid asphalt or concrete pavement. The following are potential applications for this type of porous pavement:

- Crossover/emergency stopping/parking lanes
- Roadway shoulders and parking lanes
- Maintenance roads and trails
- Commercial/retail parking lot overflow areas
- Church parking areas more remote from buildings
- Residential parking areas with light use.

Advantages/Disadvantages

Aside from the potential for high particulate pollutant removal and the removal of other constituents similar to what a sand filter would provide, pervious pavements can dramatically reduce the surface runoff from most rainstorms and snowmelt events and virtually eliminate surface runoff from smaller storms. These reductions in runoff volumes translate directly to proportional reductions in pollutant loads leaving the site. Its use can result in stormwater surface runoff conditions that approximate the predevelopment site conditions, something that can be used in selecting surface retention and infiltration parameters that are close to pre-developed conditions when using stormwater runoff hydrologic models. Even when underdrains are used, the response time of runoff is significantly delayed and approaches the characteristics of what hydrologists call *interflow* (flow that enters the subsurface via infiltration and then reemerges to the surface with a time delay). As a result, drainage and downstream flooding problems can be significantly reduced. These can translate in savings since the downstream facilities needed to address site runoff, such as *WQCV*, detention volumes and conveyance facilities can be smaller. For modular block and reinforced grass pavements, the WQCV can actually be provided in the aggregate pore space beneath the pavement surface. If aggregate is deep enough, flood control benefits (i.e. minor storm) may also be achieved.

Another advantage that the use of pervious pavement offers is that creative selection by land planners and landscape architects of pervious pavement materials, patterns and colors can also provide aesthetic enhancements to what often are very mundane surfaces. Some types of pervious pavements may be snowmelted.

The primary disadvantage of pervious pavements is that they cost more to install and maintain than conventional concrete or asphalt pavement. These added costs can be somewhat offset by the cost savings in the downsizing of on-site and downstream drainage systems and facilities such as detention basins, numbers of inlets, storm sewers and channels. Other disadvantages of pervious pavements can include uneven driving surfaces and potential inconvenience of walking on these types of surfaces in high heel shoes. Pervious pavements are not compatible with sanding activities. Snow plowing has the potential to damage many types of pervious pavements, and special plowing techniques may be necessary.

Physical Site Suitability

Pervious pavements can be installed even when free draining sub-soils are not present at the site by providing them with underdrains. An underdrain insures that the gravel sub-grade is drained when the sub-soils or site conditions do not allow infiltration.

Not all types of pervious pavements may be suitable for heavy equipment/fire lane access. Applications of pervious pavements that are anticipated to experience heavy loads should be evaluated to assure that the pervious pavement is compatible with the intended use.

In the case where the installation is located on top of expansive soils, the installation of an impermeable liner along with underdrains is strongly recommended. The liner is needed to prevent wetting the underlying expansive clays. In addition, pervious pavements installed over expansive soils should not be located adjacent to structure foundations in order to reduce the potential for damages to structures.

An impermeable liner with underdrains shall be utilized anywhere pavers are installed immediately adjacent to a structure. The impermeable liner shall be installed along the foundation of the structure and extend a minimum of 10' away from the structure walls. Liners and underdrains shall direct runoff away from the building foundation.

A continuous impermeable liner with underdrains shall also be used whenever commercial or industrial sites may have activities, or processes, that could result in the storage and/or handling of toxic or caustic chemicals, fertilizers, petroleum products, fats, or greases. An impermeable liner has to be designed to prevent groundwater and soil contamination should such products or materials come into contact with stormwater and could infiltrate into the ground. If the site is expected to have contaminants mentioned above, the underdrains shall be directed or connected to runoff capture and treatment facilities.

Construction Considerations

The construction phase and staging is critical to producing PPS that are structurally sound and have good rates of stormwater infiltration into surface of the pavement and into the underlying sub-grade or underdrains. It is important to understand that permeable pavement systems are examples of high performance infrastructure that have two functions: a structural pavement and a stormwater management BMP. It is not sufficient to use the same construction practices for PPS as for conventional, non-porous pavement. Issues of concern that can affect the eventual performance of the PPS include but are not limited to the following:

- Excessive compaction of the sub-grade and heavy equipment traffic over these surfaces.
- Sediment loading from adjacent construction areas. Pervious pavements should be constructed as late in the phasing of a project as feasible, and if there are adjacent disturbed areas redundant erosion and sediment control measures should be provided (i.e. silt fence and wattles).
- Proper gradation and installation of the fracture-faced aggregate and sand materials at

various levels of the PPS cross section.

- Proper use and installation of geotextiles and geogrids.
- Impermeable geomembrane (liner) installation, seaming and liner penetrations.
- Underdrain installation, including providing adequate slope and avoiding damage to the underdrain pipe.
- Edge restraints for permeable interlocking concrete pavers and concrete grid pavement.
- Achieving uniform gradation of aggregate and soils for reinforced turf type of pavements.

Pollutant Removal and Effective Imperviousness

Specific field data on the reductions of pollutant concentrations by various pervious pavements are very limited as of 2009. However, reductions in the concentrations of total suspended solids and associated constituents, such as metals, oils and greases appear to be relatively high. At the same time, the fact that all pervious pavements significantly reduce the average annual runoff volume makes them very effective in reducing pollutant loads reaching the receiving waters. Filtration of stormwater runoff through the sand and gravel of the modular block voids and entrapment in the gravel media are the primary removal mechanisms of pollutants. Adsorption and ion exchange that occur as stormwater travels through the underlying soils before the stormwater reaches groundwater are secondary removal mechanisms.

When using pervious pavements, the site designer can take advantage of the fact that it reduces the effective surface runoff rates and volumes. Based on field testing and observations of modular block pavement by the Denver Urban Drainage and Flood Control District at a test site in Lakewood and other information gleaned from literature, interim recommendations for reducing *total site imperviousness* to *effective imperviousness* were developed. Because this represents the best currently available data, these guidelines have been adopted by Aspen. The use of these interim guidelines is recommended when planning stormwater quality and drainage facilities for new land development and redevelopment sites. These guidelines are summarized in **Figure 8.28** and are called “interim” because they are based, in part, on limited amounts of short-term data and best professional judgment that considered the type of pavement, its long term maintenance needs, its sealing potential and its loss of void space volume over time.

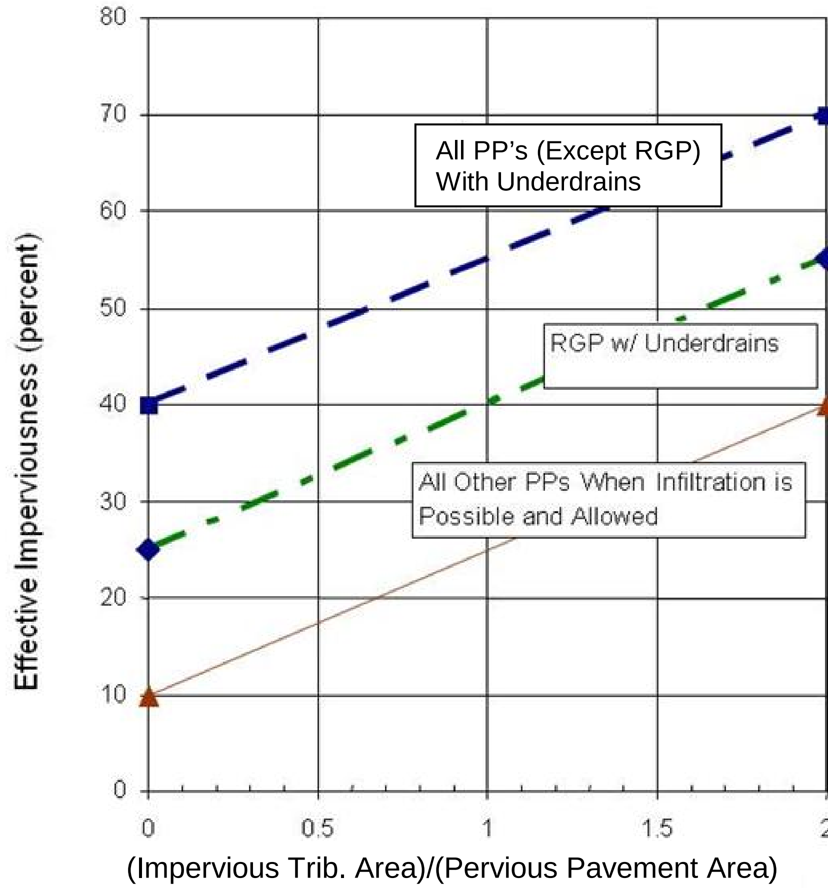


Figure 8.28 Recommended Effective Percent Imperviousness for PPS (Based on the Ratio of the Impervious Area Tributary to Porous Pavement)

The following notes apply to using **Figure 8.28**:

1. It is recommended that impervious areas be made to drain to pervious pavements where possible. **Figure 8.28** shows the effective imperviousness values used for all paved area (impervious and pervious) in situations where impervious areas drain to pervious pavements. To calculate the ratio shown on the x-axis, divide the impervious area that drains to pervious pavement by the area that is pervious. For example if 500 ft^2 of impervious area flows uniformly over 500 ft^2 of pervious pavement the ratio in **Figure 8.28** is 1.0. If modular block pavement is used without underdrains, the effective imperviousness for a ratio of impervious area to pervious pavement area of 1.0 would be approximately 25 percent according to **Figure 8.28**. The effective imperviousness, 25%, would apply to the entire 1000 ft^2.

2. Use no more than two units of impervious area for each unit of PP. All impervious areas exceeding this ratio shall be treated as 100% impervious in hydrologic calculations, including runoff volumes. For example, the maximum amount of impervious area that could drain to a 500 ft^2 pervious pavement area would be 1000 ft^2. Any imperviousness beyond that should not be directed to the pervious pavement area or, if it must be directed to the pervious pavement area, it should be treated as 100

percent impervious area in all calculations.

3. Whenever impervious areas cannot be made to run onto the pervious areas in a uniform sheet-flow fashion, identify individual areas and what ratios apply to each and then composite them treating each as a separate area.

Cold Weather Considerations

PPS have been applied in cold weather climates including the northeast, northern states in the Mid-West and even Canada. In cold climates PPS have an advantage of quicker melting of accumulated snow due to circulation of air beneath the surface. Potential challenges in cold climates include plugging from accumulated sediment (sanding) and freeze-thaw deterioration. These disadvantages can be minimized in the following ways:

- PPS may not be used in areas that are sanded or in locations where adjacent tributary drainage areas are sanded.
- Signage should be used for PPS to caution against sanding.
- Achieving a well-drained sub-base is critical to avoid problems with freezing. Studies in the northeast have shown that PPS with at least 12 inches of sub-base material are more resistant to freeze-thaw damage. It may be feasible to install a snowmelt system beneath the surface of cobblestone block or modular block pavements; however, care should be taken to assure that the snowmelt tubing does not interfere with infiltration.

Design Considerations

Design criteria for pervious pavements vary depending on the wearing course. Volume 3 of the UDFCD Urban Storm Drainage Criteria Manual provides extensive guidance for all of the types of pervious pavements in this Manual. Because of the length of the UDFCD guidance (more than 80 pages) and the desire to keep the Aspen Manual streamlined, the following is provided as general guidance and criteria for pervious pavements. The designer should refer to the Denver Urban Storm Drainage Criteria Manual for detailed guidance, figures, etc. All pervious pavement designs in the City of Aspen should be checked against the most current version of Volume 3 of the UDFCD guidance since pervious pavement criteria are currently evolving.

Modular Block and Cobblestone Block Pavements

Figure 8.29 below shows one type of locally available modular block pervious pavement. There are other block patterns that may be used, provided they have at least 20 percent (≥ 40% preferred) of their surface area as open annular spaces. This is the minimum open surface area to be considered as modular block pavement.

Figure 8.29 Modular Block Pavement

Figure 8.30 is of a typical cobble block pervious pavement available locally. It has to have at least eight percent (8%) of its surface area as open annular spaces to qualify as cobblestone block pervious pavement.

Figure 8.30 Cobblestone Block Pavement

Figure 8.31 below shows typical cross-sections for modular block and cobblestone block pervious pavements.

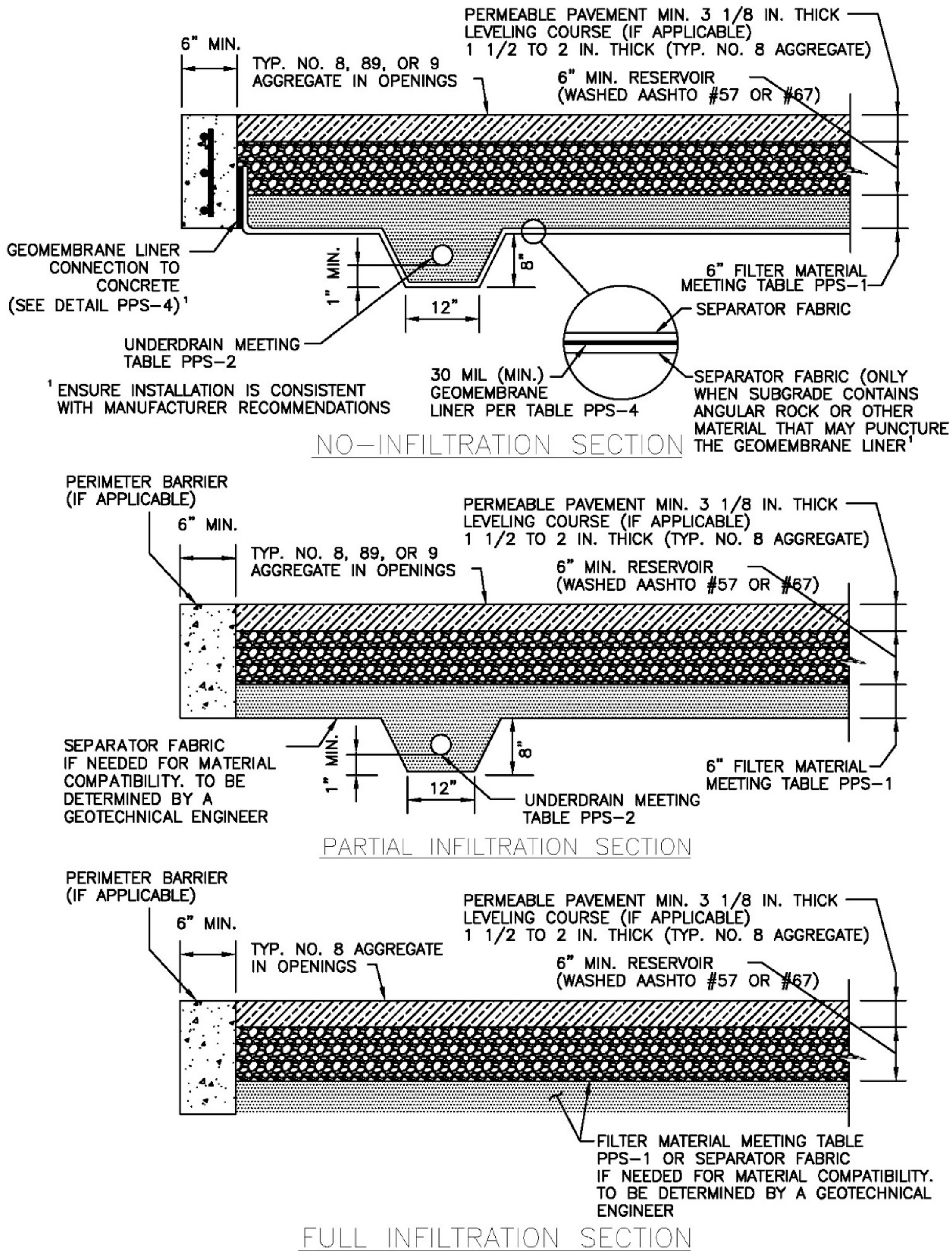
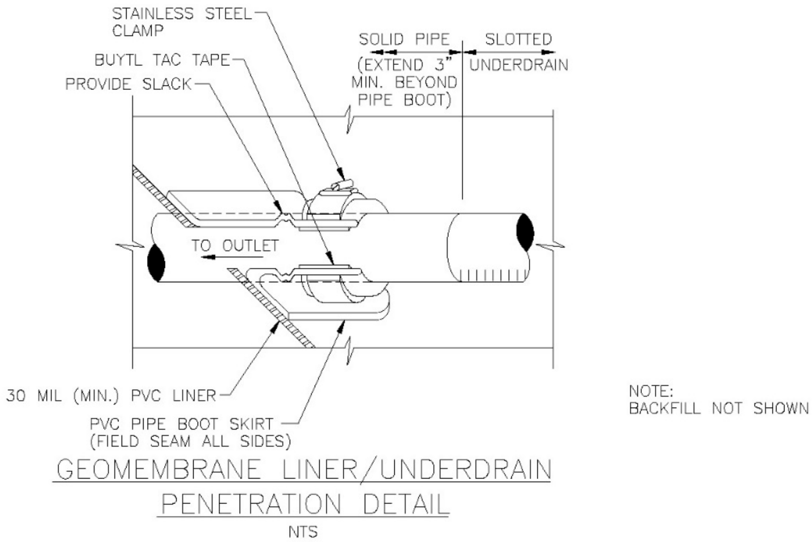


Figure 8.31 Typical Pervious Pavement Cross Section



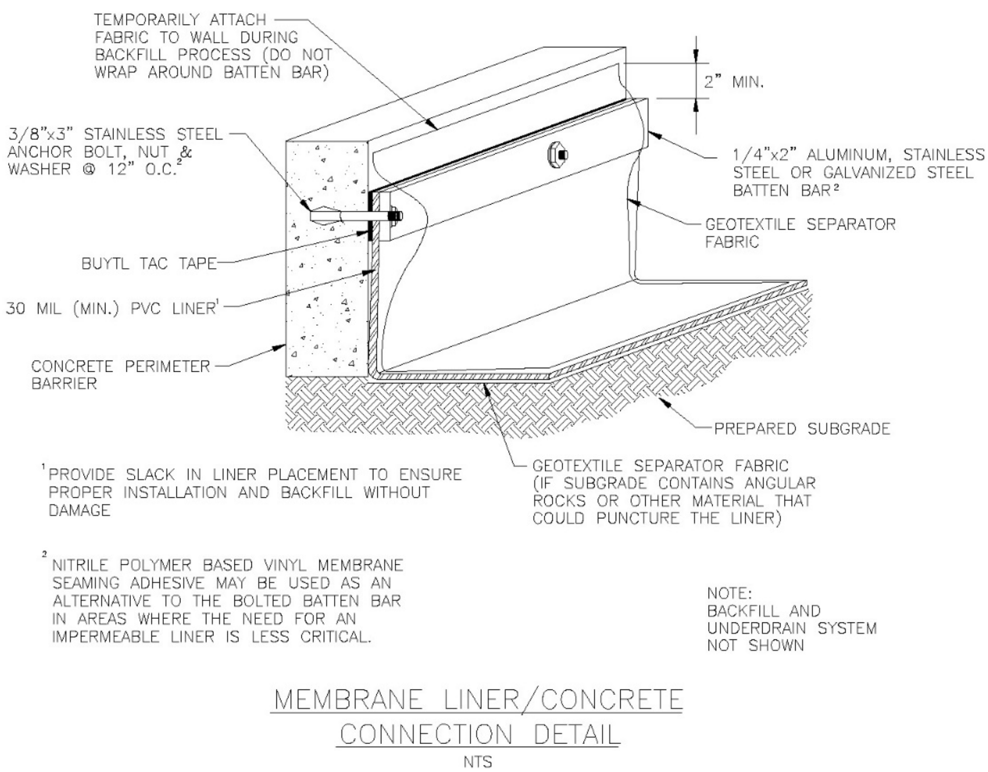


Figure 8.32 Membrane Liner/Concrete Connection Detail

Table PPS-1. Gradation Specifications for Class C Filter Material (Source: CDOT Table 703-7)

Sieve Size	**Mass Percent Passing** Square Mesh Sieves
19.0 mm (3/4")	100
4.75 mm (No. 4)	60-100
300 µm (No. 50)	10-30
150 µm (No. 100)	0-10
75 µm (No. 200)	0-3

Table PPS-2. Dimensions for Slotted Pipe

Pipe Diameter	Slot Length[1]	Maximum Slot Width	Slot Centers[1]	Open Area[1] (per foot)
4"	1-1/16"	0.032"	0.413"	1.90 in^2
6"	1-3/8"	0.032"	0.516"	1.98 in^2

[1] Some variation in these values is acceptable and is expected from various pipe manufacturers. Be aware that both increased slot length and decreased slot centers will be beneficial to hydraulics but detrimental to the structure of the pipe.

Table PPS-3. Physical Requirements for Separator Fabric[1]

Property	Class B		Test Method
	Elongation <50%[2]	Elongation >50%[2]	
Grab Strength, N (lbs)	800 (180)	510 (115)	ASTM D 4632
Puncture Resistance, N (lbs)	310 (70)	180 (40)	ASTM D 4833
Trapezoidal Tear Strength, N (lbs)	310 (70)	180 (40)	ASTM D 4533
Apparent Opening Size, mm (US Sieve Size)	AOS < 33 mm (US Sieve Size No. 50)		ASTM D 4751
Permittivity, sec^{-1}	0.02 default value, Must also be greater than that of soil		ASTM D 4491
Permeability, cm/sec	K fabric > k soil for all classes		ASTM D 4491
Ultraviolet Degradation at 500 hours	50% strength retained for all classes		ASTM D 4355

Table PPS-4. Physical Requirements for Geomembrane

Property	Thickness 0.76 mm (30 mil)	Test Method
Thickness, % Tolerance	±5	ASTM D 1593
Tensile Strength, kN/m (lbs/in) width	12.25 (70)	ASTM D 882, Method B
Modulus at 100% Elongation, kN/m (lbs/in)	5.25 (30)	ASTM D 882, Method B
Ultimate Elongation, %	350	ASTM D 882, Method A

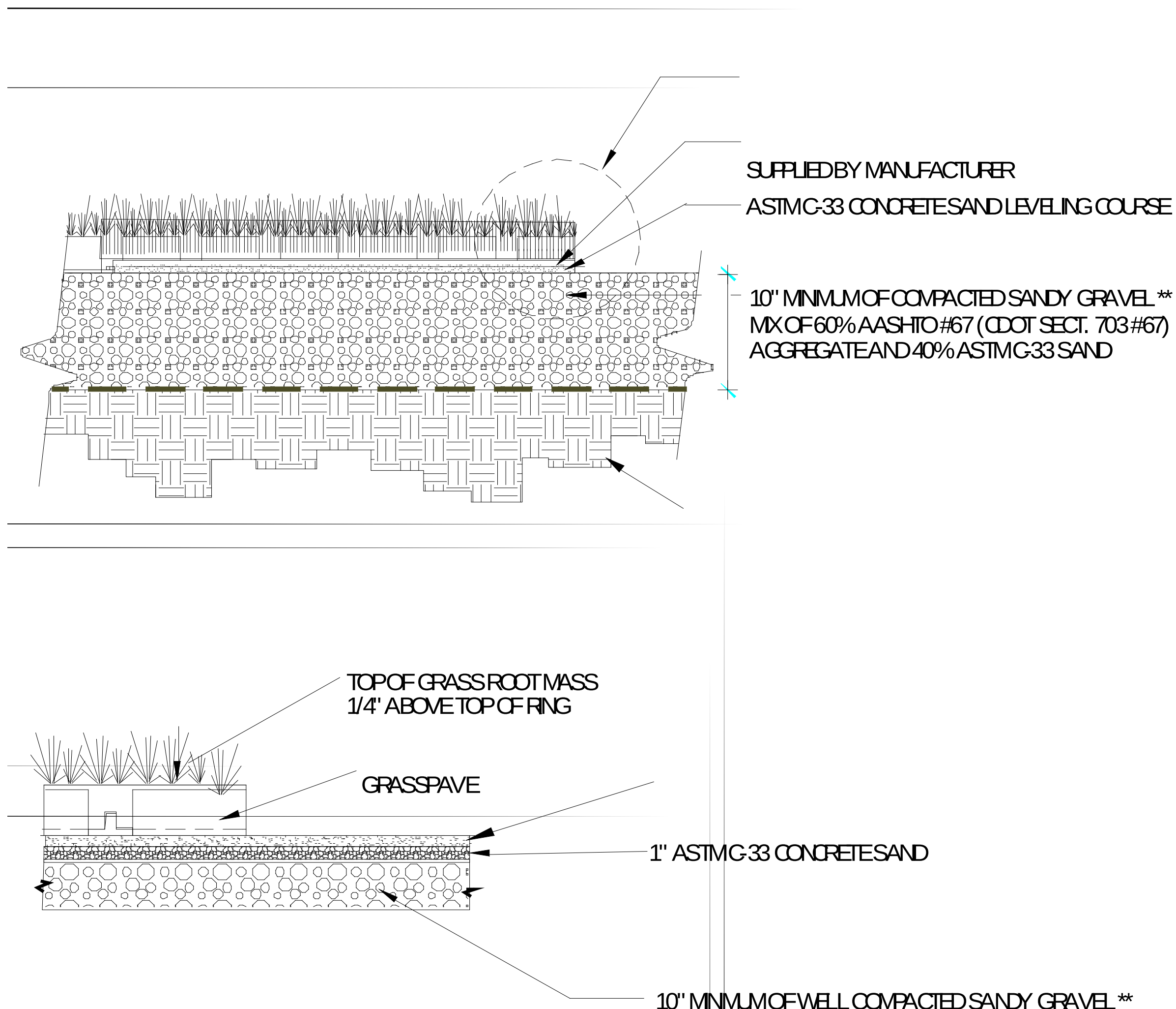
Tear Resistance, N (lbs)	38 (8.5)	ASTM D 1004
Low Temperature Impact, °C (°F)	-29 (-20)	ASTM D 1790
Volatile loss, % max.	0.7	ASTM D 1203, Method A
Pinholes, No. Per 8 m2 (No. per 10 sq. yds.) max.	1	N/A
Bonded Seam Strength, % of tensile strength	80	N/A

Reinforced Grass Pavement

Figure 8.33 shows typical cross-sections and details for one type of reinforced grass pavement based on a product called Grasspave2™ by Invisible Structures, Inc. Other products that achieve the same end goal and structural stability are also available. Regardless of which brand of product is used, the manufacturer's instructions should **be closely followed except as called for differently in this Chapter.**

The typical section of an RGP design based on the Federal Aviation Administration's (FAA) recommendations for *Aggregate Turf* is illustrated in **Figure 8.34**. The thickness is designed same as for asphalt pavement; however the design includes extra base course thickness for compensate in the carrying capacity of asphalt pavement sections.

When designing and installing *Aggregate Turf*, it is critical that the sub-grade be adequately compacted, especially when the gravel and pavement is being placed on fill. Additional guidance is provided in Volume 3 of the Denver UDFCD Urban Storm Drainage Criteria Manual



NOTES:

1. INSTALL GRASS TURF REINFORCING LAYER PER MANUFACTURER'S RECOMMENDATIONS INCLUDE MODIFICATIONS SHOWN ON THIS DRAWING.

2. DETAIL BASED ON INVISIBLE STRUCTURES, INC., ET AL DETAILS, BUT MODIFIED TO SUIT USDCM REQUIREMENTS.

**** GREATER DEPTH OF PAVEMENT MAY BE REQUIRED BY PAVEMENT DESIGNER**

Figure 8.33 Typical Reinforced Grass Pervious Pavement Cross Section

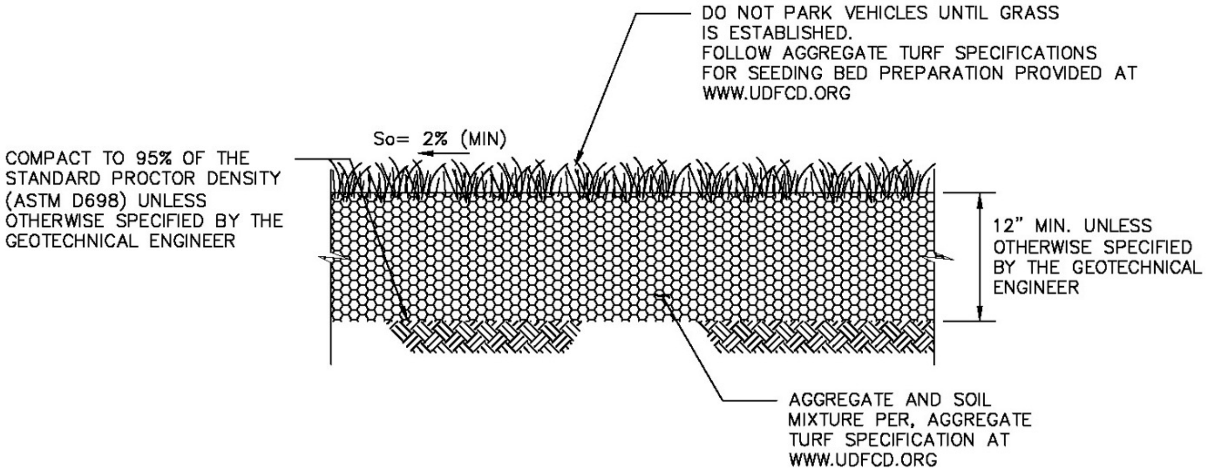


Figure 8.34 Typical Aggregate Turf Reinforced Grass Pervious Pavement Cross Section

Design Procedure and Criteria

Modular Block Pervious Pavement

1. Select Blocks — Select MBP that have 20% or more (40% preferred) of the surface area open. Follow Manufacturer's installation instructions, except that *Porous Pavement Infill* and *Base Course* materials and dimensions specified in this section shall be strictly adhered to.

2. Infill materials and Leveling Course — The MBP openings shall be filled with ASTM C-33 graded sand or very sandy loam and shall be placed on a one-inch thick leveling course of C-33 sand.

3. *Base Course* — The *Base Course* shall be AASHTO No. 3 coarse aggregate; all fractured surfaces. For volume calculations assume 30 percent of total volume to be open pore space. Unless an underdrain is provided, at least 6-inches of the sub-grade underlying the *Base Course* shall be sandy and gravely material with no more than 10% clay fraction.

4. Impermeable Liner Under the *Base Course* — When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 30 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement.

5.	Membrane Installation	Place by rolling membrane parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets. Bring up impermeable membrane to the top of perimeter walls. Attach membrane to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.
6.	Perimeter Wall	Recommend that a concrete perimeter wall be installed to confine the edges of the MBP block areas.
7.	Contained Cells – Lateral Flow Barriers	Install lateral-flow cut-off barriers using 30 mil, or thicker, PE or PVC membrane liner or concrete walls installed parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the PP installation. Distance (L_{MAX}) between these cut-off barriers shall not exceed: $L_{MAX} = \frac{D}{1.5 \bullet S_O}$ in which, L_{MAX} = Maximum distance between cut off membrane normal to the flow (ft.), S_O = Slope of the base course (ft/ft), D = Depth of gravel *Base Course* (ft).
8.	Sub-drain System	When the MBP is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, or when an impermeable membrane liner is needed, install a sub-drain system using Schedule 40 HDPE pipe. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 20-foot spacing. Use a control orifice sized to drain the pore volume to empty each cell in 6-12 hours.
9.	Design Area Ratio and Effective Imperviousness	The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divided by porous pavement area). In certain cases where the land use of the contributing drainage basin is known to carry low sediment levels, a slightly higher design area ratio may be permitted. The interim recommendations for the "Effective Imperviousness" are given in **Figure 8.28** and may be used when sizing detention basins, *WQCV* and stormwater conveyance systems.

Cobblestone Block Pervious Pavement

1.	Select Blocks	Select CBP blocks that have 8% or more of the surface area open. Follow Manufacturer's installation instructions, except that *Porous Pavement Infill* and *Base Course* materials and dimensions specified in this section shall be strictly adhered to.
2.	Infill materials and Leveling Course	The CBP openings shall be filled with AASHTO No. 8 fractured aggregate and shall be placed on a one-inch thick leveling course of same No. 8 aggregate.
3.	*Base Course*	The *Base Course* shall be AASHTO No. 67 coarse aggregate; all fractured surfaces. For volume calculations assume 30 percent of total volume to be open pore space.

4.	Impermeable Liner Under *Bottom Sand Layer*	When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 30 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement.
5.	Membrane Installation	Place by rolling membrane parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets. Bring up impermeable membrane to the top of perimeter walls. Attach membrane and fabric to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.
6.	Perimeter Wall	Recommend that a concrete perimeter wall be installed to confine the edges of the MBP or CBP block areas.
7.	Contained Cells – Lateral Flow Barriers	Install lateral-flow cut-off barriers using 30 mil, or thicker, PE or PVC membrane liner or concrete walls installed parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the PP installation. Distance (L_{MAX}) between these cut-off barriers shall not exceed: $$L_{MAX} = \frac{D}{1.5 \bullet S_O}$$ in which, L_{MAX} = Maximum distance between cut off membrane normal to the flow (ft.), S_O = Slope of the base course (ft/ft), D = Depth of gravel *Base Course* (ft).
8.	Sub-drain System	When the CBP is located on NRCS Type D soils, when the Type B or C soil sub-base is to be compacted for structural reasons, or when an impermeable membrane liner is needed, install a sub-drain system using Schedule 40 HDPE pipe. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 20-foot spacing. Use a control orifice sized to drain the pore volume of empty each cell in 6-12 hours
9.	Design Area Ratio and Effective Imperviousness	The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divide by porous pavement area). In certain cases where the land use of the contributing drainage basin is known to carry low sediment levels, a slightly higher design area ratio may be permitted. The interim recommendations for the "Effective Imperviousness" are given in **Figure 8.28** and may be used when sizing detention basins, *WQCV* and stormwater conveyance systems.

Reinforced Grass Pavement

1.	Select Type of RGP to be Used	Select which type of RGP will be used. The two types that are described in this *Manual* are *Reinforced Grass*, as illustrated in **Figure 8.33** and *Aggregate Turf*, as illustrated in **Figure 8.34**.
2.	*Base Course* for	Provide the required *Base Course* of AASHTO No. 67 (CDOT Section 703) coarse aggregate for the *Reinforced Grass* type of RGP as called for in **Figure**

	Reinforced Grass	**8.33**. The aggregate shall have all fractured surfaces. No Base Course is required for *Aggregate Turf.*
3.	Impermeable Membrane Under the *Base Course*	For *Reinforced Grass* type of RGP, and when expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 30 mil thick, or heavier, liner on the bottom and sides of the basin under the pavement.
4.	Membrane Installation	Place by rolling impermeable membrane parallel to the contours starting at the most downstream part of the pavement. Provide a minimum of 18-inches of overlap between adjacent sheets. Bring up impermeable membrane to the top of perimeter walls. Attach membrane to perimeter walls with roofing tar or other adhesive or concrete anchors. Provide sufficient slack in the membranes to prevent stretching them when sand and/or rock is placed. Seal all joints of impermeable membrane to be totally leak free.
5.	Design Area Ratio and Effective Imperviousness	The design area ratio shall not exceed 2.0 (ratio = contributing impervious area divide by porous pavement area). In certain cases where the land use of the contributing drainage basin is known to carry low sediment levels, a slightly higher design area ratio may be permitted. The interim recommendations for the "Effective Imperviousness" are given in **Figure 8.28** and may be used when sizing detention basins, *WQCV* and stormwater conveyance systems.

Construction/Installation

The construction phase is very critical in having a successful pervious pavement installation. Successful PP installations are structurally sound and have good rates of stormwater infiltration into surface of the pavement and into the underlying sub-base or underdrains. It is not sufficient to use the same construction practices for pervious pavement as for conventional, non-porous pavement. Issues of concern are excessive compaction of the sub-grade and heavy equipment traffic over these surfaces, proper gradation and installation of the gravel and sand materials at various levels of the pervious pavement section, proper use and installation of geotextile and impermeable liner membranes, edge restraints for modular block types of pervious pavements, achieving uniform gradation of gravels and soils for reinforced turf type of pavements and other issues that can affect the eventual performance of the pervious pavement.

Sub-grade

When the native soils in the sub-grade are suitable for infiltration (i.e., NRCS Hydrologic Group A, B and C), it is important maintain their infiltration capacities as much as possible. When the sub-base is deliberately compacted to provide greater pavement stability or is inadvertently compacted by construction equipment traffic over them, infiltration capacity will be significantly reduced. To prevent the latter, it is crucial that heavy construction equipment, especially rubber-tired machinery, be kept off the sub-grade. This will require the use of light track equipment, delivery of gravels via conveyors, delivery of concrete via extended chutes (not conveyors) or lift pour buckets, and stopping all work when the sub-grade is wet or thawing.

When compaction of the sub-grade is needed for structural support of the pavement that will carry or park vehicular traffic, an underdrain system may be needed to compensate for the loss of infiltration capacity. This will be the case if the sub-grade soils have significant fractions of silt or clay and are not granular in nature (e.g., not Type A or B).

Compaction of the sub-grade is recommended for sites where the pavement will be placed on top of fill. Unless the fill is composed of predominantly granular materials, the engineer needs to plan for underdrains for all PP types except *Aggregate Turf*, which essentially duplicates natural grass surfaces.

Preventing Clogging from Excess Sediment

It is common to install pavement before all site work such as landscaping and finishing of buildings is completed. As a result, sediment loads from construction and landscaping activities after the pervious pavement is installed can be very high. It crucial to protect all surfaces of the pervious pavement from runoff and sediment deposits until all construction activities are completed and the areas tributary to the pervious pavement are fully stabilized.

Regardless of the type of pervious pavement being used, the highest priority during construction has to be to prevent sediment from entering the *base course* and the surface of pervious pavement. The following practices will help to keep the pervious pavement form being clogged during these construction periods:

- Keep muddy equipment and materials away from the pervious pavement area
- Install silt fences and temporary swales to divert water away from the pervious pavement area
- Cover the surfaces with heavy flexible impermeable membrane whenever construction activities threaten to deposit sediment onto the pervious pavement area

Base Course Each lift shall not exceed 6-inches and shall be compacted by using a 10-ton, or heavier, vibrating steel drum roller. Make at least four passes with the roller, with the initial passes made while vibrating the roller and the final one to two passes without vibration.

If the design calls for an upper layer of the *Base Course*, install it using the same layer thicknesses and compaction requirements described above. Follow-up the installation of the uppermost layer of the *Base Course* by installing the specified geotextile fabric on top of it. The leveling course or porous pavement, as required by the plans, is then applied over the uppermost geotextile fabric.

When a sand leveling course is called for in the plans, compact it using the drum roller before laying the paver units on top of it. If the top of the *Base Course*, sand filter layer or the leveling course layers are disturbed and not uniform, they shall be re-leveled and re-compacted. The top of each layer below the leveling course shall uniform and will not deviate more than $\pm$1/2-inch when a 10 foot straight edge is laid on its surface. The top of the leveling course shall not deviate more than $\pm$3/8-inch in 10 feet.

Modular Block and Cobblestone Block Installation

Place the paver blocks tightly against each other on top of the compacted sand leveling course. Before compacting the pavers into place, cut and place paver units to tightly fill spaces between adjacent pavers and the restraining wall at the edges.

Compact the installed paver blocks initially using a plate compactor that exerts a minimum of 5,000 lbs/ft^2 when using 4-inch thick pavers and a minimum of 6,800 lbs/ft^2 when using pavers thicker than 4-inches. After initial compaction, fill the paver openings and joints to the top with ASTM C-33 sand and compact again. If the sand or gravel infill drops more than 1/8 inch below the top of the paver block, add more sand and re-compact. Remove excess sand or gravel by broom sweeping the surfaces. Paver installation can be done by hand or using mechanical equipment specially designed for this type of work. If the latter is used, follow the requirements and procedures provided in the ICPT (1998) *Technical Specification 11 – Mechanized Installation of Interlocking Concrete Pavements*.

Reinforced Grass Pavement Installation

For the *Reinforced Grass* type of installations adhere strictly to the recommendations of the manufacturer for the installation of this pavement.

Maintenance

Tables 8.8 through 8.10 outline maintenance recommendations for pervious pavements.

Table 8.8 Maintenance Recommendations for Modular Block Pervious Pavement

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Sod maintenance	If sandy loam turf is used, provide lawn care, irrigation system, and inlay depth maintenance as needed.	Routine – As dictated by inspection.
Inspection	Inspect representative areas of surface filter sand or sandy loam turf for accumulation of sediment or poor infiltration.	Routine and during a storm event to ensure that water is not bypassing these surfaces on frequent basis by not infiltrating into the pavement.
Rehabilitating sand infill surface	To remove fine sediment from the top of the sand and restore its infiltrating capacity.	Routine – Sweep the surface annually and, if need be, replace lost sand infill to bring its surface to be ¼ below the adjacent blocks.
Replacement of Surface Filter Layer	Remove, dispose, and replace surface filter media by pulling out turf plugs or vacuuming out sand media from the blocks. Replace with fresh ASTM C-33 sand or sandy loam turf plugs, as appropriate.	Non-routine – When it becomes evident that runoff does not rapidly infiltrate into the surface. May be as often as every two year or as little as every 5 to 10 years.
Replace modular block pavement	Restore the pavement surface. Remove and replace the modular pavement blocks, the sand leveling course under the blocks and the infill media when the pavement Surface shows significant deterioration.	Non-routine – When it becomes evident that the modular blocks have deteriorated significantly. Expect replacement every 10 to 15 years dependent on use and traffic.

Table 8.9 Maintenance Recommendations for Cobblestone Block Pervious Pavement

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Inspection	Inspect representative areas of surface filter fine gravel infill for accumulation of sediment and poor infiltration.	Routine and during a storm events to ensure that stormwater is infiltrating and not bypassing the pavement surface on frequent basis.
Rehabilitating fine grave infill surface	To remove fine sediment and trash accumulations from the top of the gravel and restore its infiltrating capacity.	Routine – Vacuum sweep the as indicated by inspection and if need be replace lost or clogged gravel infill to bring its surface to be ¼ below the adjacent blocks.
Replace cobble block pavement	Restore the pavement surface. Remove and replace the cobble pavement blocks, the leveling course under the blocks, the infill media, gravel base and geotextile materials when the pavement surface shows	Non-routine – When it becomes evident that the modular blocks have deteriorated significantly and the underlying gravels have accumulated much sediment and/or when the geotextile fabrics underneath it are clogged. Expect replacement every 10

	significant deterioration or when the pavement no longer infiltrates stormwater at rates that are acceptable.	to 25 years dependent on use and traffic.

Table 8.10 Maintenance Recommendations for Reinforced Grass Pervious Pavement

Required Action	Maintenance Objective and Action	Frequency of Action
Debris and litter removal	Accumulated material should be removed as a source control measure.	Routine – As needed.
Inspection	Inspect all surface areas for healthy grass growth, areas of dead grass, tire rutting, surface erosion, accumulation of sediment and slow infiltration.	Routine and during a storm events to ensure that water is infiltrating and not bypassing the pavement's surface on frequent basis.
Repair sod surface	To repair worn out or damaged sod with sod grown in very sandy loam type soils.	Routine – As needed. Repairs may be needed as often as every year.
Repair and replacement of sod	Major repair of damaged and aged sod. Remove and replace, as needed the sod layer to maintain a healthy vegetative cover or when sod layer builds up significant amount of silt (i.e., >1.5 inches) above the originally installed surface layer.	Non-routine – When it becomes evident that many parts of the sod has deteriorated or when runoff does not rapidly infiltrate into the surface. Major replacement of sod may be as little as every 10 to 25 years.

8.5.1.5 Green Roofs (GR)

Figures 8.35 and 8.36 Two local examples of green roofs are pictured above. These roofs have a significant impact on stormwater runoff and are aesthetically pleasing while providing extra insulation for homes. A wide variety of plants can be used on green roofs. These plants help reduce the impervious area of roofs to nearly zero in some cases.

Description

Green Roofs incorporate several different layers of materials at varying depths depending on the design. These layers include a waterproof layer to protect the roof, a drainage layer, a root barrier, and a soil substrate which can range from lightweight with little organic material, to standard topsoil. There are two basic types of green roofs, intensive and extensive, both of which are defined by the depth of the soil placed on them. Intensive roofs have 6 inches or more of soil and are typically designed for the use of shrubs, large gardens, or small trees. This type of roof is recommended if access to the green roof is desired. Extensive green roofs have anywhere between 1.5 to 6 inches of soil. They require little to no maintenance and don't have to be regularly accessed. Typically in the design of extensive green roofs smaller drought resistant plants are utilized which lowers maintenance requirements.

General Application

There is a wide range of areas where green roofs are utilized. Extensive green roofs (soil depth 1.5 to 6 inches) are ideal for retrofits and new designs. They can be placed across an entire roof, or above areas that typically see significant amounts of sunlight. For example roofs above porches, garages, sheds, and sunrooms are all candidates for a retrofit or design. Due to the large soil loads of intensive roofs an intensive green roof typically should be designed before initial construction and be designed with sufficient reinforcement to avoid damage to the roof. Impermeable liners installed on green roofs shall be carefully applied so as not to damage the roof.

Advantages/Disadvantages

Green roofs have several advantages. The first is that they negate the need for WQCV on an area that would, on a typical roof, be impervious area. According to several different studies, stormwater events of one inch of rainfall in one hour typically produced no runoff. Green roofs can be used in areas where other BMPs would be impractical due of the cost of the land. Green roofs help to improve urban air quality and are an excellent insulator. They reduce heating and cooling costs as well as energy use. Green roofs have the ability to extend the life of a roof by reducing thermal stresses and ultraviolet rays. Finally, green roofs reduce urban "heat island" effects and can lower the temperature on building roofs by up to 40 to 50 degrees.

A disadvantage of a green roof is they cost more than traditional roofs for materials, installation, and maintenance. Also, if not installed or maintained properly leaks in the roof could occur which could lead to damages and failure if left untreated for an extended time period. Another disadvantage of green roofs is if a storm is large enough to generate a runoff event, green roofed buildings typically produce a larger TSS and chemically changed water than asphalt roofs.

Physical Site Suitability

Typically a flat or mostly flat roof is better suited for both intensive and extensive rain gardens. However, if a roof is sloped, designers should not be deterred. A green roof can be designed on a sloped roof with additional reinforcement to support the weight. This BMP is recommended for areas where space is limited and the installation of other BMP's are infeasible.

Pollutant Removal

Green roofs are capable of retaining the full rainfall depth of smaller storms. Due to this retention component, when compared to traditional roofs, green roofs reduce stormwater runoff and thus reduce pollutant loads which are typically carried by runoff. In larger storm events where runoff is generated from a green roof there is potential for the green roof to add solids and chemicals to the stormwater. Runoff generated from a green roof typically contains a higher pH (more basic water), higher concentrations of phosphorous, potassium, and produced harder water (i.e. more calcium and magnesium). These higher values closely resemble that of other landscaped areas. Pollutants that flow into a green roof are removed through evaporation, infiltration and plant uptake, in much the same way as a rain garden or bioretention area.

It has also been shown that in more urban areas when compared to traditional roofs, green roofs reduce the amount of cadmium, copper and lead in runoff by over 95 percent and zinc by 16 percent.

Cold Weather Considerations

Green roofs will be most effective between late spring and early fall months when the ground is not frozen and vegetation is healthy. The weight of snow in addition to the weight of soil must be taken into account when designing a green roof so that the structure does not fail under the combined load. The extra stress of freeze thaw should be taken into account when designing root and waterproof barriers as there is potential for damage throughout the freeze thaw cycle. Also due to the natural insulation of the roof snow may melt at a slower rate than on a typical roof. This could lead to potentially larger drifts of snow and larger runoff events in the spring.

Design Considerations

Green roofs can be installed during initial construction or placed on buildings as part of a retrofit. The amount of stormwater that a green roof mitigates is directly proportional to the area it covers, the depth and type of the growing medium, slope, and the type of plants selected. The larger the green roof area, the more stormwater mitigated. Pictured below is a typical cross section of a green roof.

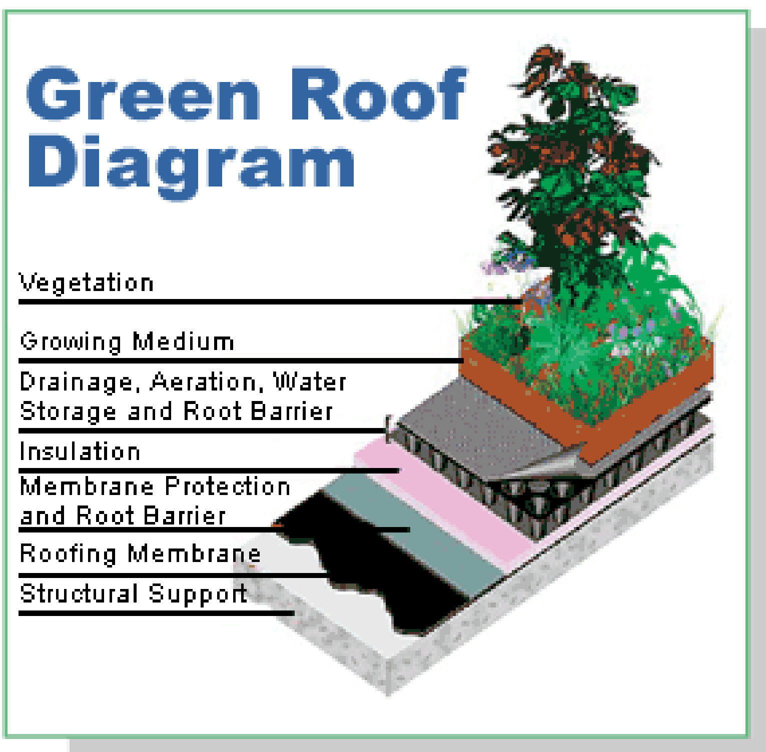


Figure 8.37 Green Roof Layers

Note the different layers all must be present in the final design, although insulation may be put inside of the roof. These layers are all essential to the functionality of the green roof and should all be designed for using these guidelines: ASTM international standards E2396-05 through E2399-05 and ASTM international standard E2400-06. Following these guidelines will help insure that the green roof is designed correctly and limit the potential for unforeseen circumstances and damages.

Design Procedure and Criteria

1. The types of soil used in a green roof vary depending on whether the roof is going to be extensive or intensive. For an extensive roofs at least 2 inches of a lightweight growth substrate consisting of sand and 10% organic material. For intensive roofs a soil depth of greater than 6 inches is required. Due to the high structural demand required by an intensive garden and hugely varying depths of soil a case by case approach will be used for intensive roofs.
2. Green roof areas can act as a WQCV for impervious areas which cover other sections of the roof.
    a. The storage capacity of a green roof can be determined using the following equation:

$$Volume = \frac{Depth\ of\ Material * (\%\ sand) * (0.3)}{0.255}$$

Where:

- $Depth\ of\ Material$ is the depth of the soil medium in the green roof.
- $\%\ sand$ is the percentage of sand used in your soil medium
- 0.3 is the porosity of sand
- 0.255 is the maximum WQCV for impervious areas

3. Typically the plants that are used in an extensive green roof are *Sedum Spurium and Sedum Album*—otherwise known as succulents. These plants are particularly hardy and will survive with the least amount of effort. Ornamental grasses can also be used on an extensive roof but a larger amount of soil should be used. In an intensive roof, a much wider range of plants can be used. This can be determined on case by case bases depending on the design.
4. A level spreader system is required if impervious areas are draining onto a green roof area. Examples of this include perforated piping, gravel pour out, and filter fabrics.

8.5.1.6 Constructed Wetlands Channels (CWC)

Description

Constructed wetland-bottomed channels takes advantage of dense natural vegetation (rushes, willows, cattails, and reeds) to slow down runoff and allow time for settling out sediment and biological uptake. It is another form of a sedimentation facility and a treatment plant.

Figure 8.38 Man-made Constructed Wetland Channels can enhance the ecological value of open spaces while treating and managing urban runoff.

Constructed wetlands differ from "natural" wetlands as they are artificial and are built to enhance stormwater quality. Sometimes small wetlands that exist along ephemeral drainageways on Colorado's high plains may be enlarged and incorporated into the constructed wetland system. Such action, however, requires the approval of federal and state regulators.

Regulations intended to protect natural wetlands recognize a separate classification of wetlands constructed for a water quality treatment. Such wetlands generally are not allowed to be used to mitigate the loss of natural wetlands but are allowed to be disturbed by maintenance activities. Therefore, the legal and regulatory status of maintaining a wetland constructed for the primary purpose of water quality enhancement is separate from the disturbance of a natural wetland. Nevertheless, any activity that disturbs a constructed wetland should be first cleared through the U.S. Army Corps of Engineers to ensure it is covered by some form of an individual, general, or nationwide 404 permit.

General Application

Wetland bottom channels can be used in the following two ways:

- A wetland can be established in a totally man-made channel and can act as a conveyance system and water quality enhancement facility. This design can be used along wide and gently sloping channels.

- A wetland bottom channel can be located downstream of a stormwater detention facility (water quality and/or flood control) where a large portion of the sediment load can be removed. The wetland channel then receives stormwater and base flows as they drain from the detention facility, provides water quality enhancement, and at the same time conveys it downstream. This application of a wetland channel is recommended upstream of receiving waters and within lesser (i.e., ephemeral) receiving waters, thereby delivering better quality water to the more significant receiving water system.

A CWC requires a net influx of water to maintain their vegetation and microorganisms. A complete water budget analysis is necessary to ensure the adequacy of the base flow.

Advantages/Disadvantages

Constructed wetlands offer several potential advantages, such as natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal. Constructed wetlands provide an effective follow-up treatment to onsite and source control BMPs that rely upon settling of larger sediment particles. In other words, they offer yet another effective BMP for larger tributary basins.

The primary drawback to wetlands is the need for a continuous base flow to ensure their presence. In addition, salts and scum can accumulate and unless properly designed and built, can be flushed out during larger storms.

Other disadvantages include the need for regular maintenance to provide nutrient removal. Regular harvesting and removal of aquatic plants, cattails, and willows is required if the removal of nutrients in significant amounts has to be assured. Even with that, recent data puts into question the net effectiveness of wetlands in removing nitrogen compounds and some form of phosphates. Periodic sediment removal is also necessary to maintain the proper distribution of growth zones and of water movement within the wetland.

Physical Site Suitability

A perennial base flow is needed to sustain a wetland, and should be determined using a water budget analysis. Loamy soils are needed in wetland bottom to permit plants to take root. Infiltration through a wetland bottom cannot be relied upon because the bottom is either covered by soils of low permeability or because the groundwater is higher than the wetland's bottom. Wetland bottom channels also require a near zero longitudinal slope; drop structures are used to create and maintain a flat grade.

Pollutant Removal

Removal efficiencies of constructed wetlands vary significantly. Primary variables influencing removal efficiencies include design, influent concentrations, hydrology, soils, climate, and maintenance. With periodic sediment removal and plant harvesting, expected removal efficiencies for sediments, organic matter, and metals can be moderate to high; for phosphorous, low to moderate; and for nitrogen, zero to low. Pollutants are removed primarily through sedimentation and entrapment, with some of the removal occurring through biological uptake by vegetation and microorganisms. Without a continuous dry-weather base flow, salts and algae can concentrate in the water column and can be released into the receiving water in higher levels at the beginning of a storm event as they are washed out.

Harvesting aquatic plants and periodic removal of sediment also removes nutrients and pollutants associated with the sediment. Researchers still do not agree that routine aquatic plant harvesting affects pollutant removals. Until research documents these effects, periodic harvesting for the general upkeep of wetland, and not routine harvesting of aquatic plants, is recommended.

Cold Weather Considerations

Constructed wetland channels may be used in cold climate; however, the functions of the wetland vegetation for aesthetics and pollutant removal can be limited by the shortened growing season. Snow accumulation during winter months may reduce available channel conveyance capacity in early spring.

Design Considerations

Wetlands can be set into a drainageway to form a wetland bottom channel as shown in **Figure 8.39**. An analysis of the water budget is needed so that the inflow of water throughout the year is sufficient to meet all the projected losses (such as evaporation, evapotranspiration, and seepage). An insufficient base flow could cause the wetland bottom channel to dry out and die.

Design Procedure and Criteria

The following steps outline the Constructed Wetlands Channel design procedure. Refer to **Figure 8.35** for design components.

1. Design Discharge — Determine the 2-year peak flow rate in the wetland channel *without* reducing it for any upstream ponding or flood routing effects.

2. Channel Geometry — Define the newly-built channel's geometry to pass the design 2-year flow rate at 2.0 feet per second with a channel depth between 2.0 to 4.0 feet. The channel cross-section should be trapezoidal with side slopes of 4:1 (Horizontal/Vertical) or flatter. Bottom width shall be no less than 8.0 feet.

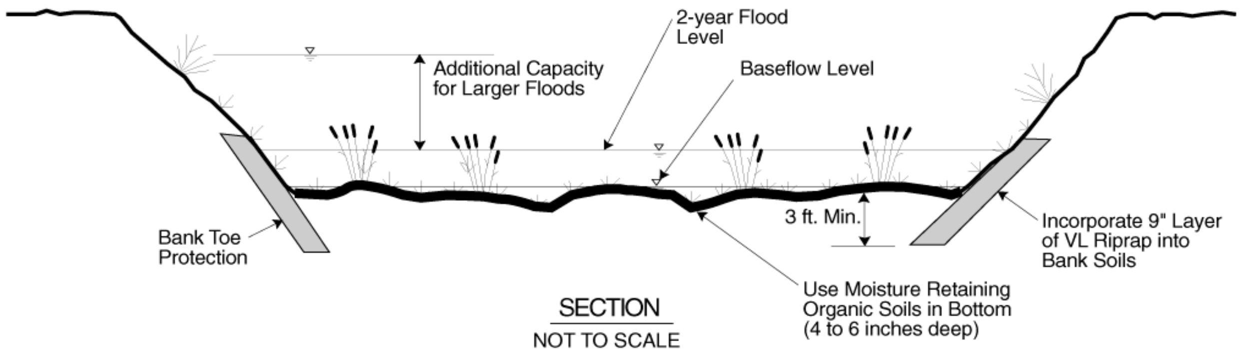
3. Longitudinal Slope — Set the longitudinal slope using Manning's equation and a Manning's roughness coefficient of n=0.03, for the 2-year flow rate. If the desired longitudinal slope cannot be satisfied with existing terrain, grade control checks or small drop structures must be incorporated to provide desired slope.

4. Final Channel Capacity — Calculate the final (or mature) channel capacity during a 2-year flood using a Manning's roughness coefficient of n=0.08 and the same geometry and slope used when initially designing the channel with n=0.03. The channel shall also provide enough capacity to contain the flow during a 100-year flood while maintaining one foot of free-board. Adjustment of the channel capacity may be done by increasing the bottom width of the channel. Minimum bottom width shall be 8 feet.

5. Drop Structures — Drop structures should be designed to satisfy the drop structure criteria of the *Major Drainage* chapter in Volume 1 of the *USDCM.*

6. Vegetation — Vegetate the channel bottom and side slopes to provide solid entrapment and biological nutrient uptake. Cover the channel bottom with loamy soils upon which cattails, sedges, and reeds should be established. Side slopes should be planted with native or irrigated turf grasses.

7. Maintenance Access — Provide access for maintenance along the channel length. Maximum grades for maintenance vehicles should be 10 percent and provide a solid driving surface.



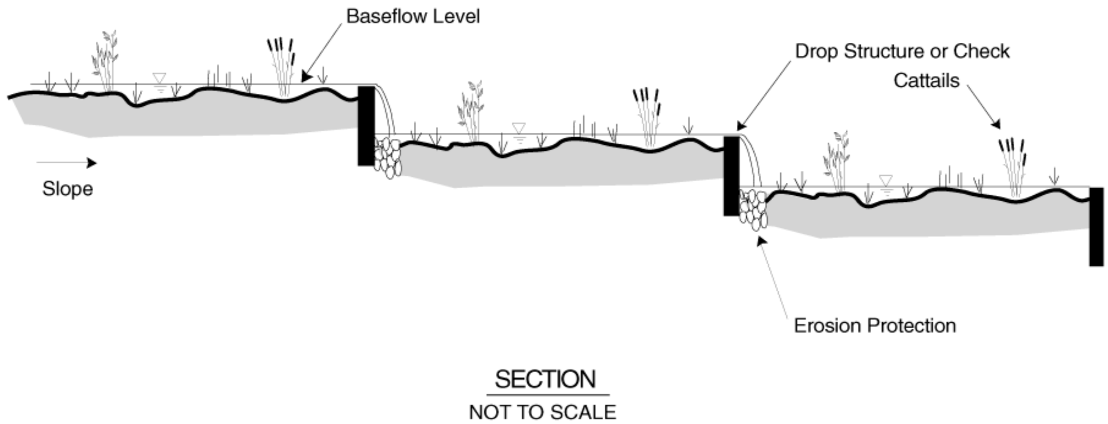


Figure 8.39 Constructed Wetland Channel Typical Plan and Profile

Maintenance

Table 8.11 provides maintenance recommendations for constructed wetland channels.

Table 8.11 Maintenance Recommendations for Constructed Wetland Channels

Required Action	Maintenance Objective	Frequency of Action
Lawn mowing and lawn care	Mow occasionally to limit unwanted vegetation. Maintain irrigated turf grass at 2 to 4 inches tall and non-irrigated native turf grasses at 4 to 6 inches.	Routine – Depending on aesthetic requirements.
Debris and litter removal	Remove debris and litter from the channel.	Routine – Including just before annual summer storm seasons (that is following snowmelt), following significant rainfall events, and in fall prior to snow cover.

Required Action	Maintenance Objective	Frequency of Action
Sediment removal	Remove accumulated sediment and muck along with wetland vegetation growing on top of it. Re-establish growth zone depths and revegetate with original wetland species.	Non-routine – Every 10 to 20 years as needed by inspection if no construction activities take place in the tributary watershed. More often if they do.
Aquatic plant harvesting	Cut and remove plants growing in wetland (such as cattails and reeds) to remove nutrients permanently with manual work or specialized machinery.	Non-routine until further evidence indicates such action would provide significant nutrient removal. In the meantime, perform this task once every 5 years or less frequently as needed to clean the wetland zone out.
Inspections	Observe inlet and outlet works for operability. Verify the structural integrity of all structural elements, slopes, and embankments.	Routine – At least once a year, preferably once during one rainfall event resulting in runoff.

8.5.2 Street BMPs/Sediment Traps

Figure 8.40 Bioretention planters within the street rights-of-way to help treat and store stormwater runoff, as well as provide traffic calming. *The City of Portland, Department of Environmental Services*

Description

Street BMPs and sediment traps refer to BMPs described in this manual that are designed and constructed within the street Right-of-Way. The in-street treatment options range from bioretention areas or planters, grassed swales, grass buffers, underground sedimentation vaults, and permeable pavers (not to be used where streets are sanded),

Street BMPs and sediment traps will provide important pretreatment of urban runoff, and are designed primarily for sediment/sand removal. In-street sediment traps can be utilized in the City of Aspen to greatly reduce the sediment transport to the Roaring Fork River, especially where streets are sanded in the winter.

Street BMPs may not satisfy WQCV requirements. WQCV BMPs are recommended areas, in a regional or sub-regional facility for removal of other pollutants and fine sediment.

General Application

Street BMPs and sediment traps are appropriate for streets in new developments, or retro-fitted within existing street rights-of-way in residential areas and commercial areas of Aspen, where street widths tend to be wider. In-street BMPs can also be used along busy streets as a “traffic calming” strategy. In-street sediment traps and BMPs should be constructed along existing flow lines (curb and gutter), and upstream of existing inlets in order to maximize the benefits of sediment removal. Geotechnical issues should be carefully considered prior to locating in-street BMPs. Additionally, street BMP’s should not negatively impact vehicular traffic lanes, bicycles and pedestrian sidewalks within the City, and therefore should be carefully planned with appropriate City agencies.

Advantages/Disadvantages

The City of Aspen’s high land values and current zoning regulations encourage full coverage development-- lot line to lot line. This equates to nearly 90%-100% imperviousness of sites within ultra-urban areas, resulting in very little available land for stormwater treatment and storage. The primary advantage of in-street BMPs and sediment traps are that they utilize City rights-of-way and can be combined with other City initiatives such as street beautification through tree and groundcover plantings, as well as traffic calming through the use of planted medians and “bulb outs”.

The primary disadvantages of in-street BMP’s and sediment traps are that they are highly visible and will require careful design as well as frequent maintenance to uphold their water quality function and aesthetic appearance. Additionally, street BMPs may serve multiple owners because they are located outside of property lines, within City rights-of-way or private access easements, which may be an advantage. However, a special district may need to be established in order to fund and maintain the BMPs.

Design Considerations, Procedure and Criteria

Refer to appropriate Runoff Reduction BMP’s and Structural BMP figures, procedures and criteria located throughout the manual for the design and development of in-street BMP’s. The basins of In-street sediment traps should be constructed with a permeable hard surface so that sediments can be easily removed with small equipment, or a shovel, without doing permanent damage to the BMP.

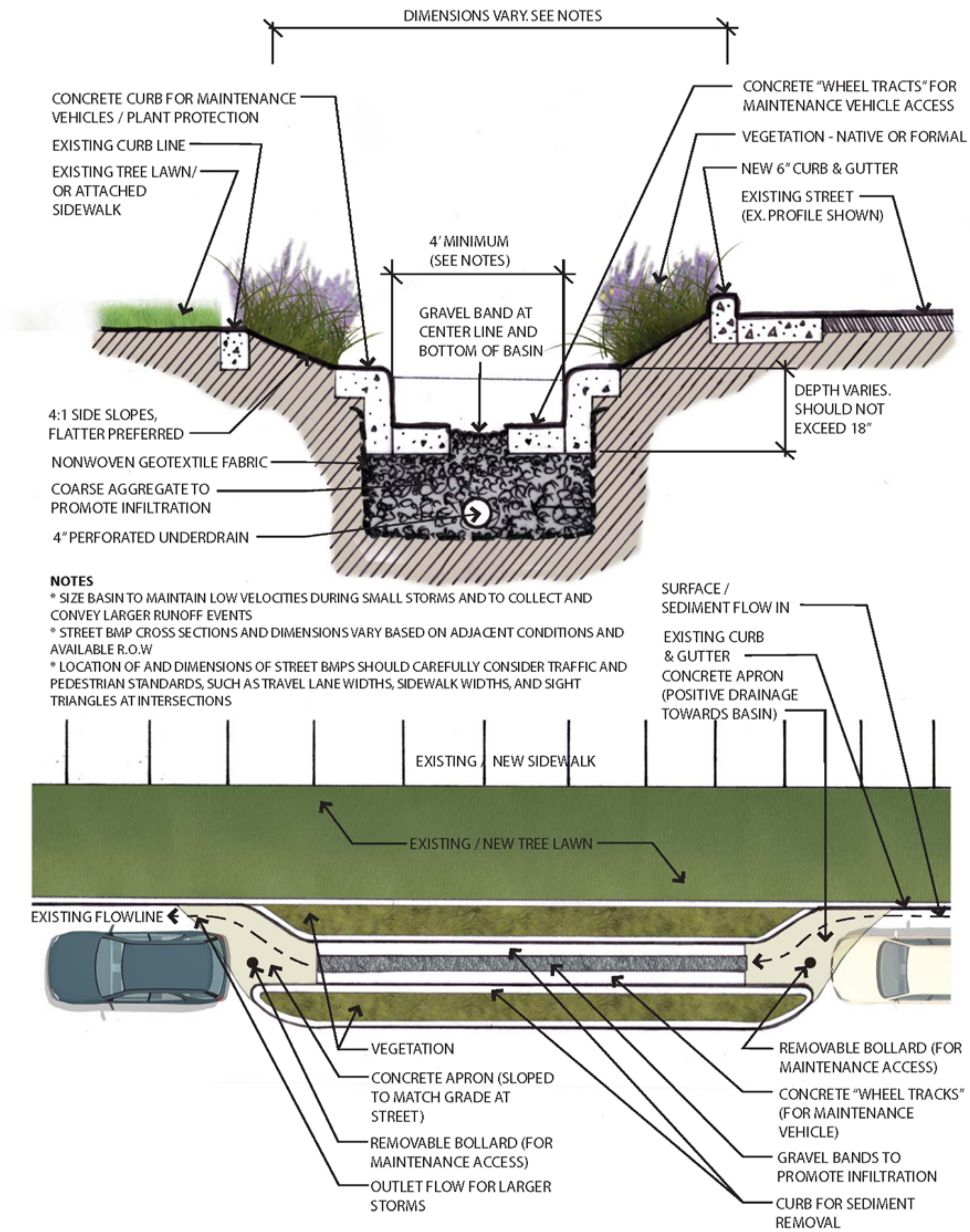
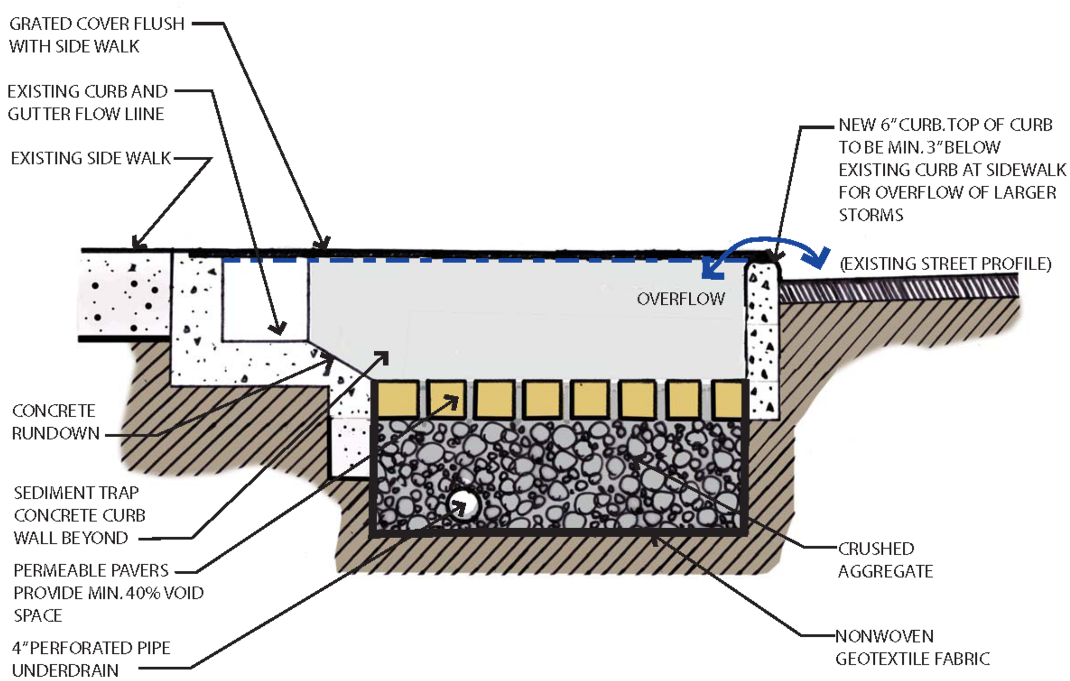


Figure 8.41 In-street Sediment Trap Conceptual Design Sketch - Plan and Section-Residential Street Application



NOTES

* SIZE BASIN TO MAINTAIN LOW VELOCITIES DURING SMALL STORMS AND TO COLLECT AND CONVEY LARGER RUNOFF EVENTS
* STREET BMP CROSS SECTIONS AND DIMENSIONS VARY BASED ON ADJACENT CONDITIONS AND AVAILABLE R.O.W
* LOCATION OF AND DIMENSIONS OF STREET BMPS SHOULD CAREFULLY CONSIDER TRAFFIC AND PEDESTRIAN STANDARDS, SUCH AS TRAVEL LANE WIDTHS, SIDEWALK WIDTHS, AND SIGHT TRIANGLES AT INTERSECTIONS

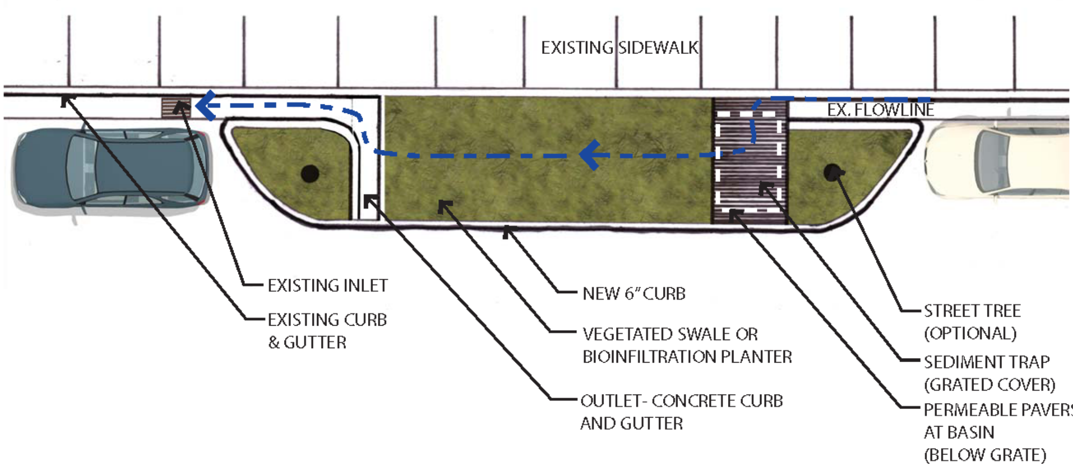


Figure 8.42 In-street Sediment Trap Conceptual Design Sketch- Plan and Section- Urban/ Commercial Street Application

Figures 8.43 and 8.44 Parking Examples

Some parking stalls in Aspen's commercial core could be replaced with in-street BMP planters and sediment traps in order to manage sediment transport, provide water quality treatment, and add attractive plantings and street trees in the Downtown.

8.5.3 Storage Volume BMPs

Storage volume BMPs are designed to provide the WQCV determined using the methods described in **Section 8.4**. These BMPs include bioretention (BR) (also known as porous landscape detention [PLD]), extended detention basins (EBDs), and constructed wetland basins (CWBs). These BMPs function by capturing runoff and releasing it over an extended period of time (typically 12 hours for Aspen). This allows time for sedimentation, and in the case of BR and CWBs, contact time with vegetation for biological treatment.

8.5.3.1 Bioretention and Rain Gardens

Figure 8.45 Bioretention planters can be used to treat stormwater runoff from the building site and roof, as well as being attractive planting areas or flower gardens

Figure 8.46 This larger Bioretention area manages stormwater runoff for a medium density residential neighborhood. The forebay sediment trap (in the foreground) is located at the outlet of the storm sewer to trap settlement larger

Figure 8.47 Rain gardens are used to collect and filter stormwater runoff. As seen in the examples above they can be planted in a variety of areas with a wide variety of plant life from flowers and grasses to trees.

Description

Bioretention is a depressed landscape area with soils, typically Hydrologic Soil Group (HSG) A or B (sand to loam) that promotes filtration and infiltration of runoff. Bioretention areas (without underdrains) can significantly reduce runoff volume through infiltration, reducing flooding and erosion in downstream receiving waters.

General Application

Typical areas for implementation of bioretention include parking islands, medians, landscape buffers, courtyards, and planters. Geotechnical and foundation issues must be carefully considered when locating bioretention facilities and designing underdrains and linings.

Advantages/Disadvantages

A primary advantage of bioretention is making it possible to provide *WQCV* on a site while reducing the impact on developable land. It works well with irrigated bluegrass, whereas experience has shown that conditions in the bottom of extended detention basins (EDBs) become too wet for bluegrass. Bioretention provides a natural moisture source for vegetation, enabling “green areas” to exist with reduced irrigation.

The primary disadvantage of bioretention is a potential for clogging if a moderate to high level of silts and clays is allowed to flow into the facility. Also, this BMP should not be placed close to building foundations or other areas when expansive soils are present, although an underdrain and impermeable liner can ameliorate some of this concern.

Physical Site Suitability

If an underdrain system is incorporated into this BMP, bioretention is suited for about any site regardless of in-situ soil type. If sandy soils are present, the facility can be installed without an underdrain (infiltration option); granular sub-soils are not a requirement. This BMP has a flat surface area, and may be more difficult to incorporate it into steeply sloping terrain.

Pollutant Removal

Although not tested to date in the Denver area, the amount of pollutant removed by this BMP should be significant and should equal or exceed the removal rates provided by sand filters, extended detention basins, or wetland basins. In addition to settling, bioretention provides for filtering, adsorption, and biological uptake of constituents in stormwater. In addition, because it provides for some infiltration and evaporation, volume of runoff is also reduced, which translates into a reduced pollutant load leaving the site.

Cold Weather Considerations

Bioretention areas will perform most effectively in late-spring and summer months when the ground is not frozen and vegetation is healthy. Bioretention areas should not be installed in areas that are sanded or that receive runoff from adjacent sanded areas unless pretreatment for sediment removal is provided. Even if pretreatment is provided, heavy sediment loads may result in sediment accumulation in bioretention areas, reducing infiltration capacity and potentially impacting vegetation. Designers should consider operation of bioretention facilities in late-winter, early-spring melting conditions when infiltration capacity may be limited by frozen ground. Under these circumstances, the designer should provide a path for runoff to flow out of the bioretention area and into the drainage system without causing flooding. Bioretention areas may be used for snow storage; however, spring maintenance should be expected given sediment loads in stockpiled snow.

Design Considerations

Figure 8.43 shows a typical cross-section for a bioretention area. When implemented using multiple small installations on a site, it is increasingly important to accurately account for each upstream drainage area tributary to each bioretention site to make sure that each facility is properly sized, individual bioretention sites intercept runoff from their respective tributary areas, and that all portions of the development site are directed to a bioretention area.

The designer needs to decide early on if infiltration is possible or allowed at the bioretention site as that will affect the design cross-section and whether underdrains will be needed. Considerable savings can be achieved if the site is suitable for infiltration, sites that typically have NRCS Soil Types A, B or C. The best way to determine if the site is suitable for bioretention without underdrains is to perform a standard individual percolation tests or infiltration tests <u>at a depth equal to the bottom of the bioretention area</u>. The test shall be performed or supervised by a licensed professional engineer. If the engineer certifies that the site has a percolation rate of less than 60 minutes per inch, underdrains and the supporting gravel and geotextile fabric layers may be eliminated.

A wide variety of plant types are possible, ranging from native grasses, groundcovers, flowers, and shrubs. Turf grass is discouraged because of the difficulty of maintenance. Trees should not be included in porous landscape detention areas (roots decrease storage volume and make maintenance difficult). Dense shrub plantings may become difficult to maintain, and should be limited to edges not prone to sediment build-up. Rock mulches (especially in high sediment areas) are discouraged because they limit the available pervious surface and are difficult to remove sediment from. The use of long fiber shredded wood mulch is encouraged because of a higher level of perviousness. It is important to account for each upstream drainage area in order to ensure that bioretention is properly sized and stormwater is directed to it.

Design Procedure and Criteria

1. Basin Storage Volume — Determine WQCV for the bioretention area using the procedure described in Section 8.4. The WQCV should be calculated for the area tributary to the bioretention area.

2. Surface Area and Maximum WQCV Depth — Calculate the minimum required **<u>flat</u>** surface area of the bioretention area as follows:

$$Flat\ Surface\ Area = \frac{Design\ Volume\ in\ ft^3}{d}$$

in which,

d = *WQCV* depth (12-inch maximum) of the bioretention basin, ft.

3. Sand/Topsoil/Organic Media — Provide, as a minimum, an 18-inch layer of well mixed sand and soil (70% sand and 30% combination of topsoil and large organic matter by volume as shown in **Figure 8.43**. Less than 5% of the media can pass the 200 sieve and the media must infiltrate at least 2 inches/hour. Maintain top surface flat. If sideslopes need to be steeper than 3:1 use vertical walls. Media shall be delivered fully mixed in a drum mixer. On-site mixing of piles shall not be allowed.

4. Granular Sub-base and Underdrains — Granular material shall have all fractured faces and meet the technical requirements of AASHTO #3 or #4 aggregate (CDOT 703, #3 or #4).

   For NRCS Type D soils, or when standard percolation tests show percolation drawdown rates exceeding 60 minutes per inch, or when potential for groundwater contamination exist, install an 8-inch layer of granular base with underdrains and an impermeable liner under it. For

Type C soils, retain the underdrain system and utilize an impermeable liner if percolation rates prove it necessary. When underdrains are not needed, the 8-inch layer of gravel may be eliminated. Use a control orifice sized to drain the pore volume to empty each cell in approximately 12-hours.

5. Impermeable Membrane — When expansive or NRCS Type D soils are present, or potential for groundwater contamination exists, install an impermeable 30 mil, or heavier, liner on the bottom and sides of the basin. If vertical walls are permeable or of stacked blocks, extend the impermeable liner behind the walls.

Wrap all liners to top of the bioretention basin and attach firmly with staples to the soil vertical wall using staples or concrete anchors. Provide sufficient slack so that the liners are not stretched when rock and sand are placed. If tears are seen or discovered, repair them as recommended by manufacturer with no less than 18 inches of overlap on all sides of the tear.

See **Appendix E** for general criteria regarding planting and selected plant species applicable for BMPs.

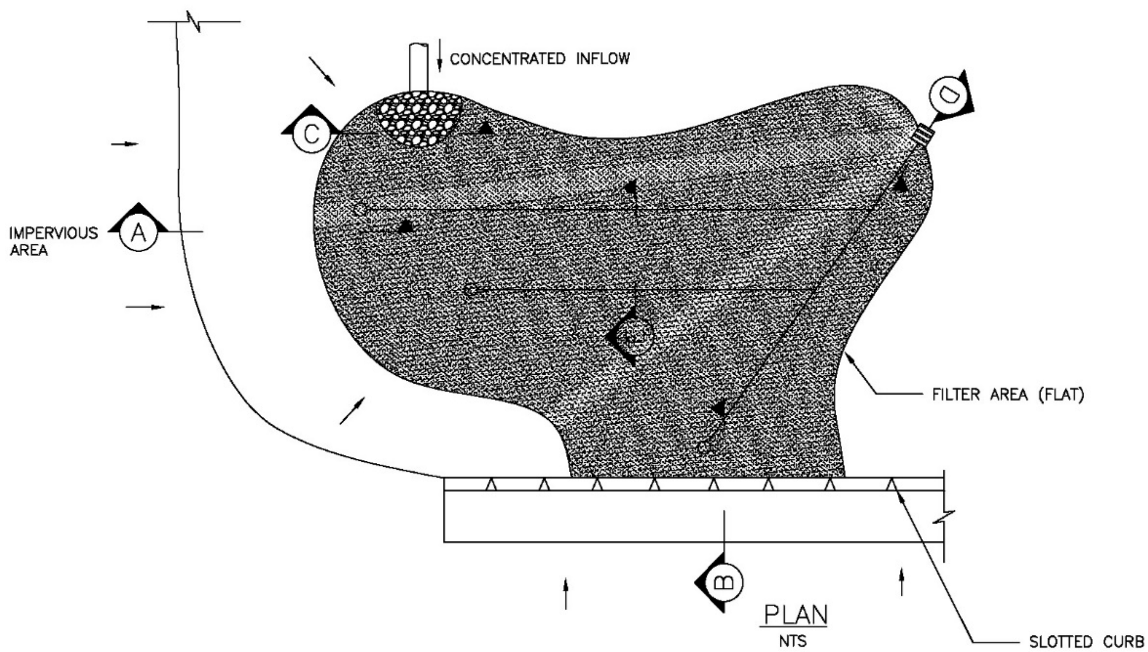


Figure 8.48 Typical Bioretention Section

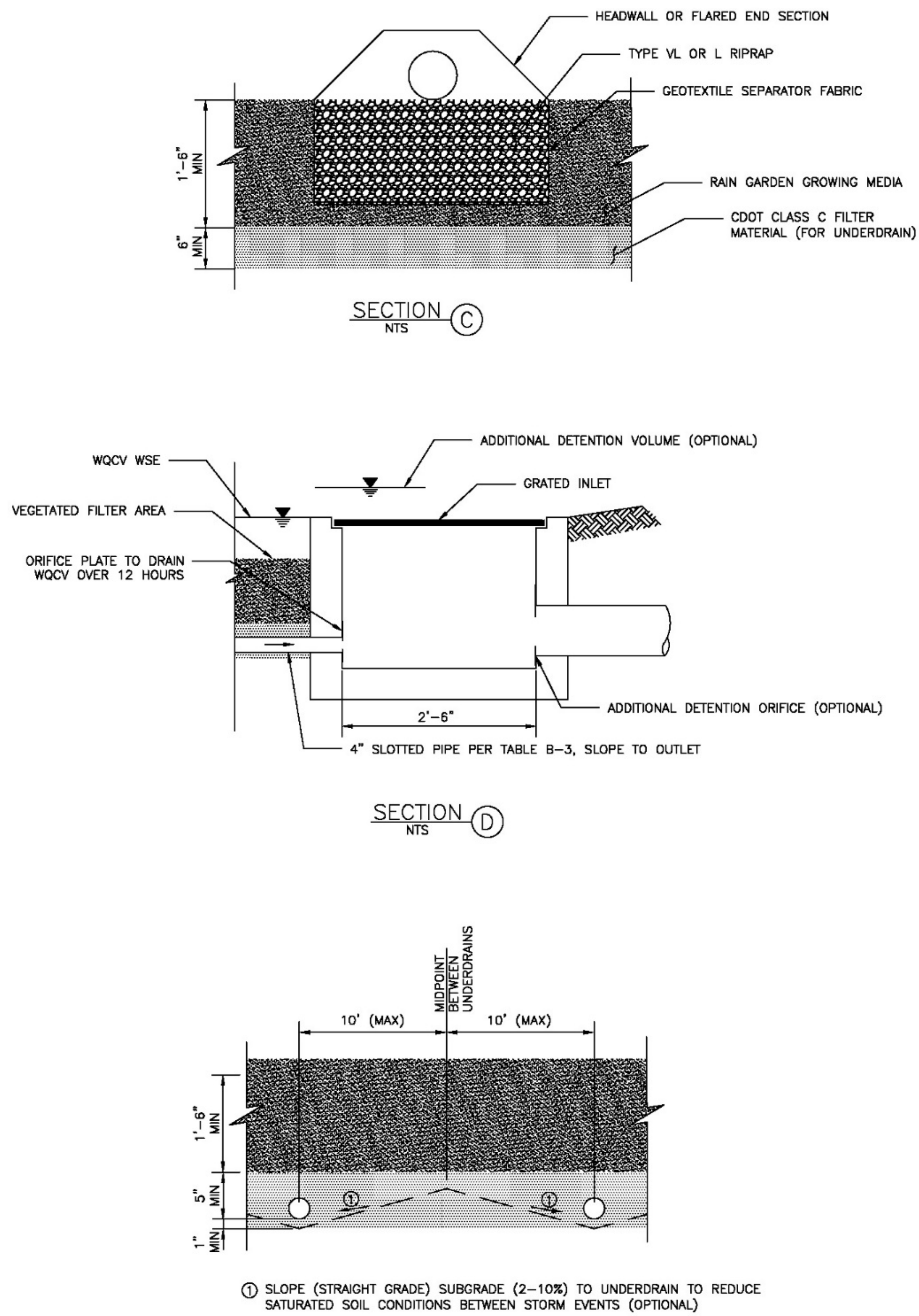


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Figure 8.49 Bioretention Cross Sections

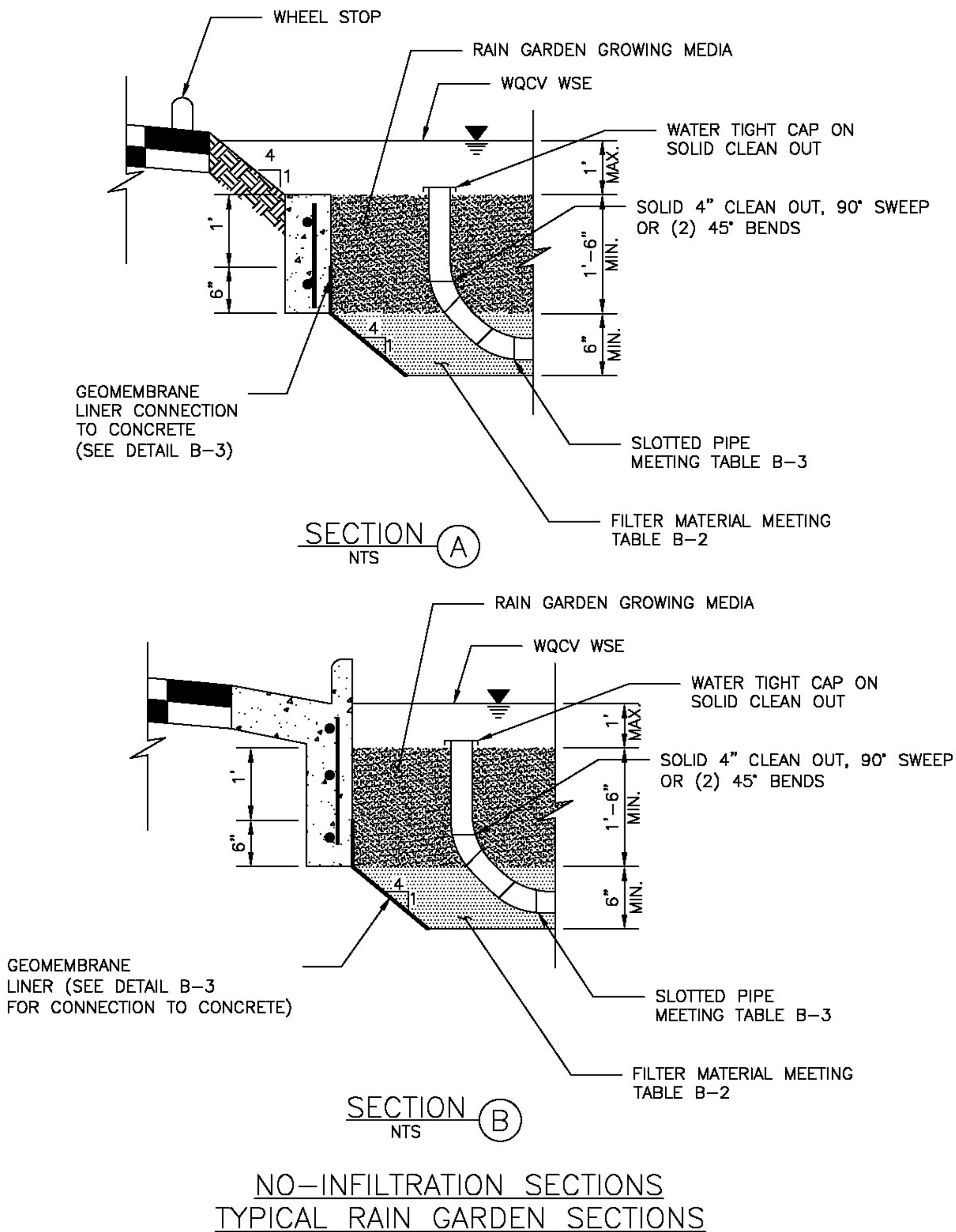
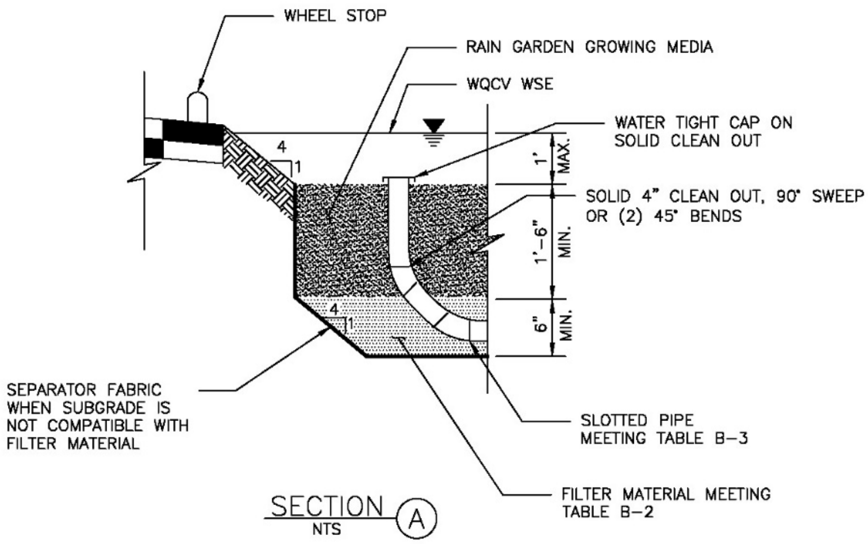
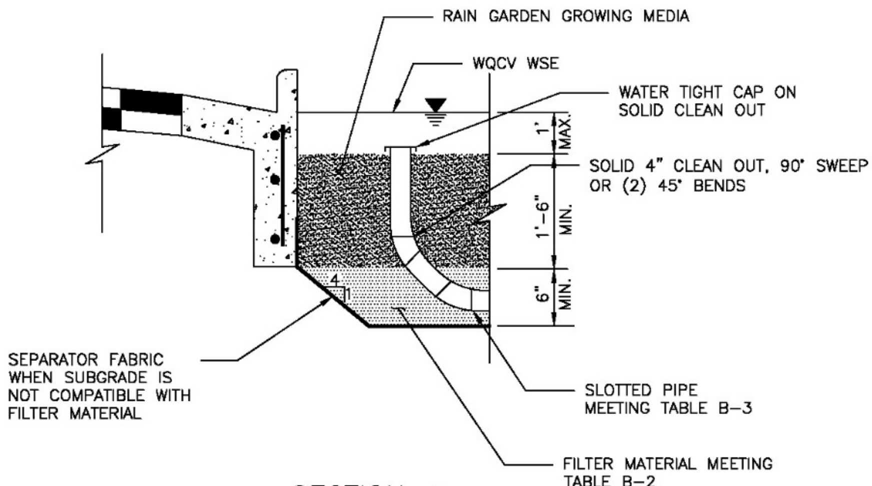


Figure 8.50 No Infiltration Sections



SECTION (A)
NTS



SECTION (B)
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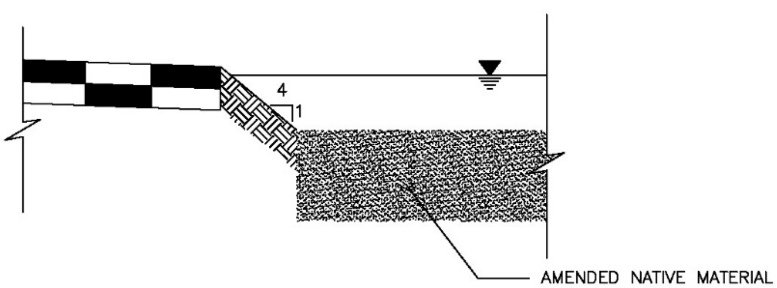
PARTIAL INFILTRATION SECTIONS



SECTION (A)
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FULL INFILTRATION SECTION

Figure 8.51 Full Infiltration Sections

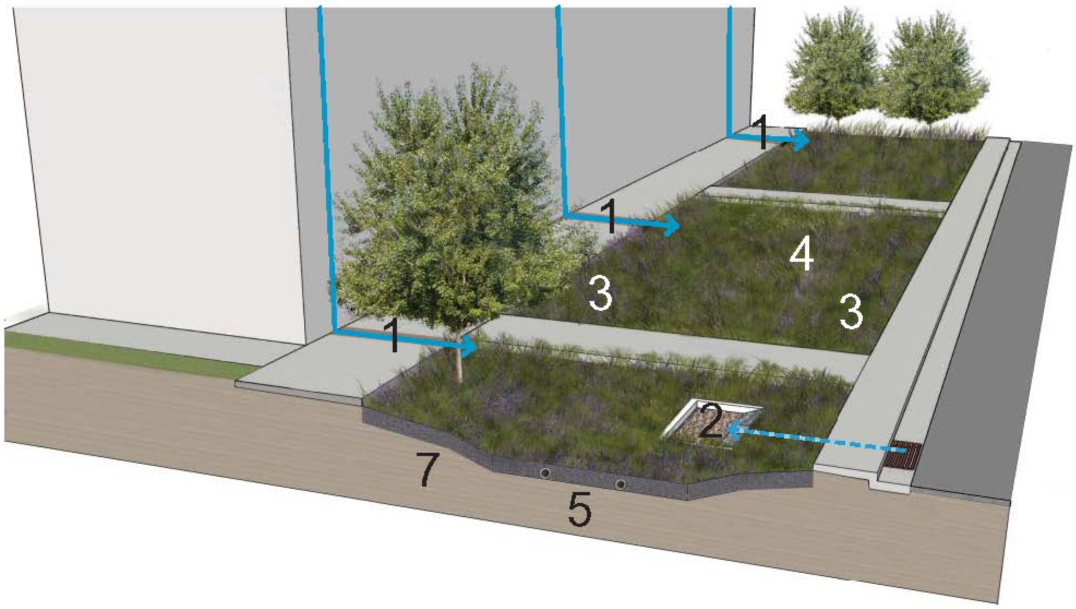


Figure 8.52 Typical Bioretention Design Sketch

1: Inlet: Roof downspouts are directed towards Bioretention Planter. Provide chases (with grated covers) in highly used pedestrian areas or where stormwater runoff crosses sidewalks.

2: Erosion Protection: Include a forebay or rock rundown, where storm sewers daylight into Bioretention areas, to reduce the likelihood of erosion and trap larger sediments.

3: Slopes: Relatively flat bottom with a 6-12 inch deep WQCV zone. Sides may include up to a 4:1 slope, flatter preferred.

4: Vegetation: Varies depending on site context. See **Appendix E** for vegetation types applicable to Aspen.

5: Underdrain/Liner: Underdrain is required when underlying soils have insufficient infiltration capacity. Underdrain and liner are recommended where geotechnical concerns exist. Refer to **Figure 8.43** for Bioretention Typical Section

6: Outlet/Overflow: Provide overflow above WQCV for larger storm events. (Not shown in sketch)

7: Infiltration Matrix: Provide infiltration media in accordance with design requirements shown in UDFCD Volume 3.

Figures 8.53 and 8.54 Planters, such as these shown in Downtown Aspen, could be utilized as biofiltration planters to treat and manage stormwater quality in dense urban environments where space for stormwater management is limited.

Maintenance

Sediment build-up may require periodic removal of sediments and plants when clogging reduces infiltration capacity to unacceptable levels. Access to facility must be provided to enable maintenance operations. Plant materials in areas prone to sediment build-up should be limited to grasses and groundcovers tolerant of periodic wet-dry cycles.

Table 8.12 Maintenance Recommendations for Bioretention

Required Action	Maintenance Objectives	Frequency
Inspections	Inspect detention area to determine if the sandy growth media is allowing acceptable infiltration.	Routine – Annual inspection of hydraulic performance.
Lawn mowing and vegetative care	Occasional mowing of grasses and weed removal to limit unwanted vegetation. Maintain irrigated turf grass as 2 to 4 inches tall and non-irrigated native turf grasses at 4 to 6 inches.	Routine – Depending on aesthetic requirements.
Debris and litter removal	Remove debris and litter from detention area to minimize clogging of the sand media.	Routine – Depending on aesthetic requirements.
Landscaping removal and replacement	The sandy loam turf and landscaping layer will clog with time as materials accumulate on it. This layer will need to be removed and replaced to rehabilitate infiltration rates, along with all turf and other vegetation growing on the surface.	Every 5 to 15 years, depending on infiltration rates needed to drain the WQCV in 12-hours or less. May need to do it more frequently if exfiltration rates are too low to achieve this goal.

8.5.3.2 Pervious Pavement Detention

Description

Pervious pavement detention (PPD) takes advantage of the storage available in the sub-base layer of the pervious pavement to provide WQCV and potentially detention volume. Pervious pavement criteria in **Section 8.5.1.4** should be followed for PPD, in addition to the following:

1. The maximum sub-base porosity for determination of storage volume is 30 percent. The storage volume can be calculated by multiplying the depth of the sub-base by 0.30.

2. For WQCV applications, the captured runoff should be designed to infiltrate into the underlying soils or, if an underdrain is used, to be released over a period of 12 hours. This can be accomplished by restricting the underdrain with an orifice to provide the controlled release.

3. For detention applications, the captured runoff should be designed to infiltrate into the underlying soils or, if an underdrain is used, to be released at rates in accordance with the allowable release rates in the Detention Chapter of this Manual.

8.5.3.3 Extended Detention Basin

Figure 8.55 Typical Extended Detention Basins are normally designed at the outlet of storm sewers—"end of pipe". EDB's can manage large volumes of stormwater runoff utilizing a single BMP facility. This EDB has steep side slopes and a deep ponding depth and therefore limits the range plant species that can survive in this environment.

Figure 8.56 This Extended Detention Basin is spread out over the length of the parking lot, has minimal side slopes, and a shallow ponding depth. This design criteria allows this basin to utilize a greater plant species diversity than that of **Figure 8.55**

Description

An extended detention basin (EDB) is a sedimentation basin designed to totally drain dry sometime after stormwater runoff ends. It is an adaptation of a detention basin used for flood control. The primary difference is in the outlet design. The EDB uses a much smaller outlet that extends the emptying time of the more frequently occurring runoff events to facilitate pollutant removal. The EDB's drain time for the brim-full water quality capture volume (i.e., time to fully evacuate the design capture volume) of 12 hours is recommended to remove a significant portion of fine particulate pollutants found in urban stormwater runoff while taking into consideration freeze-thaw cycles common in Aspen. Soluble pollutant removal can be somewhat enhanced by providing a small wetland marsh or ponding area in the basin's bottom to promote biological uptake. The basins are considered to be "dry" because they are designed not to have a significant permanent pool of water remaining between storm runoff events. However, EDB may develop wetland vegetation and sometimes shallow pools in the bottom portions of the facilities.

General Application

An EDB can be used to enhance stormwater runoff quality and reduce peak stormwater runoff rates. If these basins are constructed early in the development cycle, they can also be used to trap sediment from construction activities within the tributary drainage area. The accumulated sediment, however, will need to be removed after upstream land disturbances cease and before the basin is placed into final long-term use. Also, an EDB can sometimes be retrofitted into existing flood control detention basins.

EDBs can be used to improve the quality of urban runoff from roads, parking lots, residential neighborhoods, commercial areas, and industrial sites and are generally used for regional or follow-up treatment. They can also be used as an onsite BMP and work well in conjunction with other BMPs, such as upstream onsite source controls and downstream infiltration/filtration basins or wetland channels. If desired, a flood routing detention volume can be provided above the WQCV of the basin.

Advantages/Disadvantages

An EDB can be designed to provide other benefits such as recreation and open space opportunities in addition to reducing peak runoff rates and improving water quality. They are effective in removing particulate matter and the associate heavy metals and other pollutants. As with other BMPs, safety issues need to be addressed through proper design.

Physical Site Suitability

Normally, the land required for an EDB is approximately 0.5 to 2.0 percent of the total tributary development area. In high groundwater areas depth to seasonally high groundwater with 2-3 feet of pond bottom, consider the use of retention ponds (RP) instead in order to avoid many of the problems that can occur when the EDB’s bottom is located below the seasonal high water table. Soil maps should be consulted, and soil borings may be needed to establish design geotechnical parameters.

Pollutant Removal

Removal of suspended solids and metals can be moderate to high, and removal of nutrients is low to moderate. The removal of nutrients can be improved when a small shallow pool or wetland is included as part of the basin's bottom or the basin is followed by BMPs more efficient at removing soluble pollutants, such as a filtration system, constructed wetlands or wetland channels.

The major factor controlling the degree of pollutant removal is the emptying time provided by the outlet. The rate and degree of removal will also depend on influent particle sizes. Metals, oil and grease, and some nutrients have a close affinity for suspended sediment and will be removed partially through sedimentation.

Cold Weather Considerations

Since the EDB does not have a large permanent pool, freezing concerns are less pronounced than with some types of BMPs. Nonetheless, freezing of the outlet is a possibility during extended duration events such as spring runoff or mid-winter melts when nighttime temperatures drop below freezing. The outlet should be designed so that it can be accessed and ice cleaned off if necessary. Siting the pond so that the outlet has favorable solar exposure, when feasible, may also help. Snow accumulation in the pond bottom over the course of the winter may reduce available storage volume in the spring.

Design Considerations

Whenever desirable and feasible, incorporate the EDB within a larger flood control basin. Also, whenever possible try to provide within the basin for other urban uses such as passive recreation, and wildlife habitat. If multiple uses are being contemplated, consider the multiple-stage detention basin to limit inundation of passive recreational areas to one or two occurrences a year. Generally, the area within the WQCV is not well suited for active recreation facilities such as ballparks, playing fields, and picnic areas. These are best located above the WQCV pool level.

Figure 8.49 shows a representative layout of an EDB. Although flood control storage can be accomplished by providing a storage volume above the water quality storage, how best to accomplish this is not included in this discussion. Whether or not flood storage is provided, all embankments should be protected from catastrophic failure when runoff exceeds the design event. The State Engineer's regulatory requirements for larger dam embankments and storage volumes must be followed whenever regulatory height and/or volume thresholds are exceeded. Below those thresholds, the engineer should design the embankment-spillway-outlet system so that catastrophic failure will not occur.

Perforated outlet and trash rack configurations from Volume 3 of the UDFCD Urban Storm Drainage Criteria Manual should be followed.

Although the soil types beneath the pond seldom prevent the use of this BMP, they should be considered during design. Any potential exfiltration capacity should be considered a short-term characteristic and ignored in the design of the WQCV because exfiltration will decrease over time as the soils clog with fine sediment and as the groundwater beneath the basin develops a mound that surfaces into the basin.

High groundwater should not preclude the use of an EDB. Groundwater, however, should be considered during design and construction, and the outlet design must account for any upstream base flows that enter the basin or that may result from groundwater surfacing within the basin itself.

Stable, all weather access to critical elements of the pond, such as the inlet, outlet, spillway, and sediment collection areas must be provided for maintenance purposes.

Design Procedure and Criteria

The following steps outline the design procedure and criteria for an EDB to detain and treat the WQCV. Refer to Chapter 5 to determine proper sizing for both WQCV and detention volume.

1. Basin Storage Volume — Provide a storage volume equal to 130 percent of the WQCV calculated according to the procedures in **Section 8.4**. The additional 30 percent of storage volume provides for sediment accumulation and the resultant loss in storage volume.

2. Outlet Works — The Outlet Works are to be designed to release the WQCV (i.e., not the “Design Volume”) over a 12-hour period. Use the fewest number of perforation columns possible to maximize the perforation hole diameter. This helps to reduce clogging problems.

3. Trash Rack — Provide a trash rack of sufficient size to prevent clogging of the primary water quality outlet. Size the rack so as not to interfere with the hydraulic capacity of the outlet.

4. Basin Shape — Shape the pond whenever possible with a gradual expansion from the inlet and a gradual contraction toward the outlet, thereby minimizing short circuiting. It is best to have a basin length to width ratio between 2:1 to 3:1. To achieve this, it may be necessary to modify the inlet and outlet points through the use of pipes, swales or channels to accomplish this.

   Always maximize the distance between the inlet and the outlet.

5. Two-Stage Design — A two-stage design with a pool that fills often with frequently occurring runoff minimizes standing water and sediment deposition in the remainder of the basin. The two stages are as follows:

   A. Top Stage: The top stage should be 2 or more feet deep with its bottom sloped at 1 to 2 percent toward the low flow channel.

   B. Bottom Stage: The active surcharge storage volume of the bottom stage should be 1.0 to 2 feet deep below the bottom of the top stage and store no less than 3.0 percent of the WQCV.

      Provide a permanent micro-pool below the active storage volume of the lower stage in front of the outlet. The pool should be ½ the depth of the top stage depth described above, or 2.5 feet, whichever results in the larger depth.

6. Low-Flow Channel — Conveys low flows from the forebay to the bottom stage. Erosion protection should be provided where the low-flow channel enters the bottom stage. Lining the low flow channel with concrete is recommended. Otherwise line its sides with buried Type VL riprap and bottom with concrete. Make it at least 6-inches deep if concrete lined sides and 9-inches if buried riprap sides are used. At a minimum provide capacity equal to twice the release capacity at the upstream forebay outlet.

7. Basin Side Slopes — Basin side slopes should be stable and gentle to facilitate maintenance and access. Side slopes should be no steeper than 4:1 and the use of flatter slopes is recommended; the flatter, the better and safer.

8. Dam Embankment — The embankment should be designed not to fail during a 100-year <u>and larger storms</u>. Embankment slopes should be no steeper than 3:1, preferably 4:1 or flatter, and planted with turf forming grasses. Poorly compacted native soils should be excavated and replaced. Embankment soils should be compacted to at least 95 percent of their maximum density according to ASTM D 698-70 (Modified Proctor). Spillway structures and overflows should be designed in accordance with local drainage criteria and should consider UDFCD drop-structure design guidelines.

9. Vegetation	Bottom vegetation provides erosion control and sediment entrapment. Pond bottom, berms, and side sloping areas may be planted with native grasses or with irrigated turf, depending on the local setting.
10. Access	All weather stable access to the bottom, forebay, and outlet works area shall be provided for maintenance vehicles. Grades should not exceed 10 percent, and a solid driving surface of gravel, rock, concrete, or gravel stabilized turf should be provided.
11. Inlet	Dissipate flow energy at pond's inflow point(s) to limit erosion and promote particle sedimentation
12. Forebay Design	Provides an opportunity for larger particles to settle out in the inlet in an area that has a solid surface bottom to facilitate mechanical sediment removal. A rock berm should be constructed between the forebay and the main EDB. The forebay volume of the permanent pool should be about 5 percent of the design WQCV. A pipe through the berm to convey water to the main body of the EDB should be offset from the inflow streamline to prevent short circuiting and should be sized to drain the forebay volume in 5 minutes. The floor of the forebay should be concrete or grouted boulder lined to define sediment removal limits.
13. Flood Storage	Combining the water quality facility with a flood control facility is recommended. The 5-year, 10-year, 100-year, or other floods may be detained above the WQCV.
14. Multiple Uses	Whenever desirable and feasible, incorporate the EDB within a larger flood control basin. Also, whenever possible, try to provide for other urban uses such as active or passive recreation, and wildlife habitat. If multiple uses are being contemplated, use the multiple-stage detention basin to limit inundation of passive recreational areas to one or two occurrences a year. Generally, the area within the WQCV is not well suited for active recreation facilities such as ballparks, playing fields, and picnic areas. These are best located above the WQCV level.

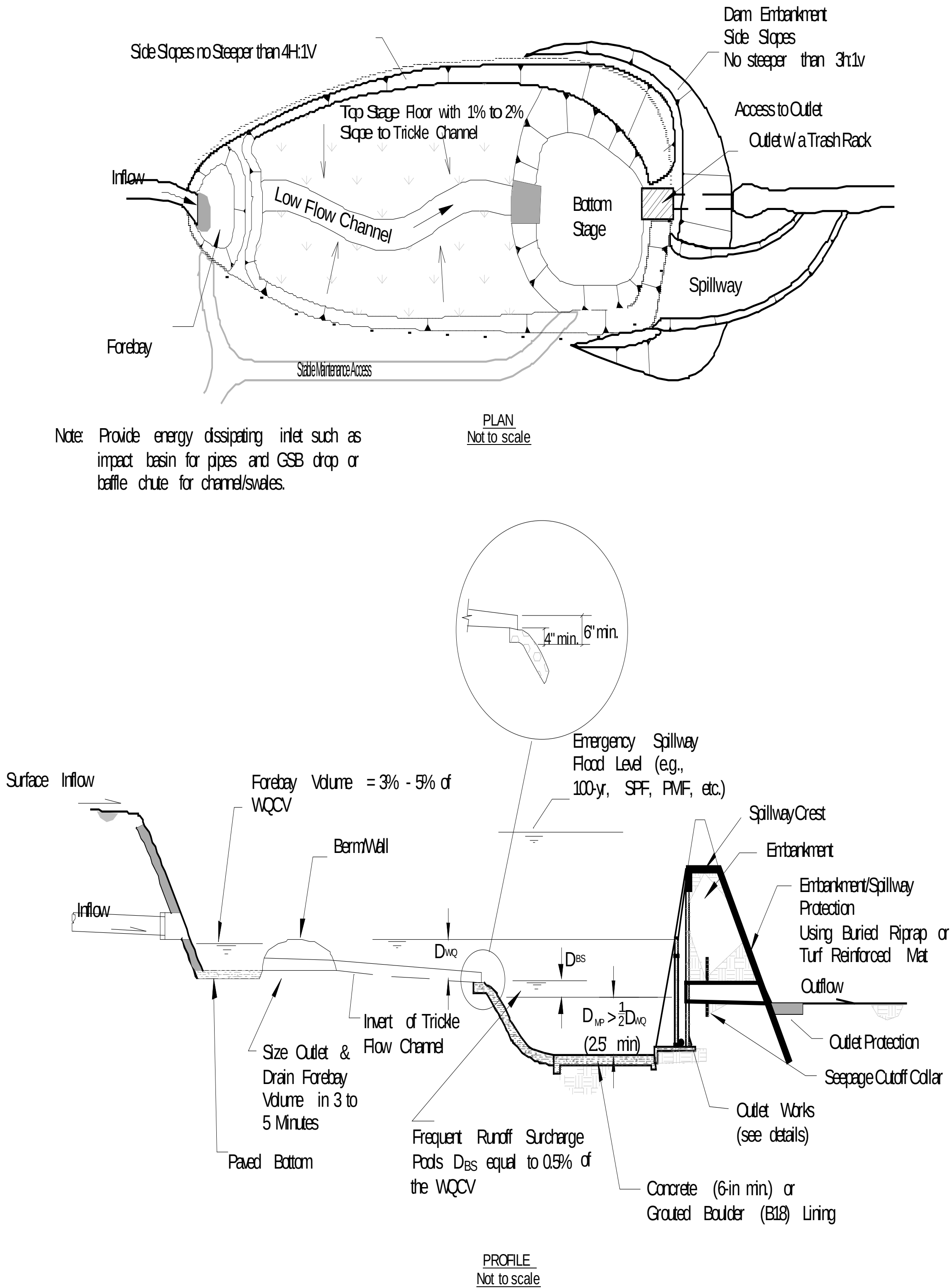


Figure 8.57 Extended Detention Basin Typical Plan and Profile

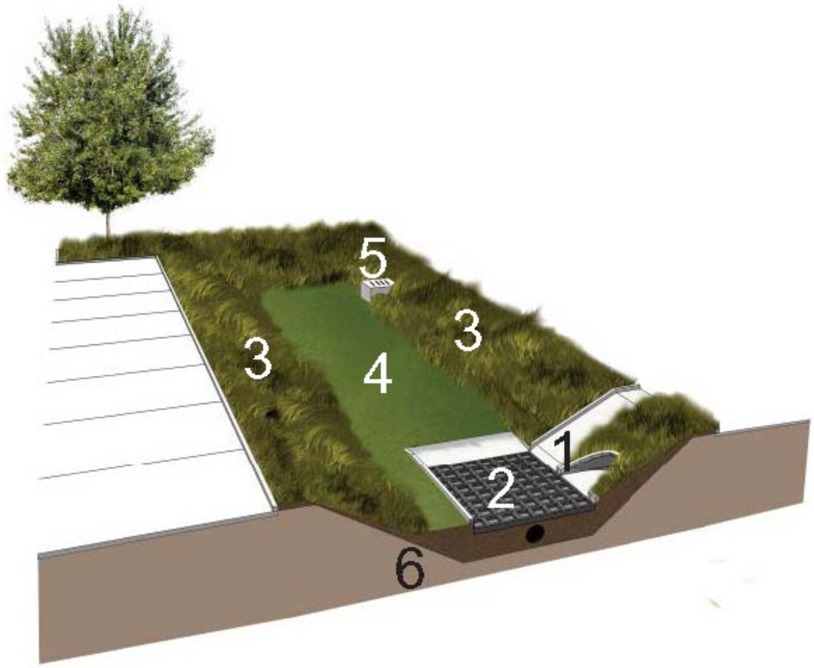


Figure 8.58 Extended Detention Basin Design Sketch

1: Inlet: Dissipate energy at outfalls to prevent erosion and sediment re-suspension.

2: Sediment Trap: Provide forebay for erosion protection and settlement for large particulates in runoff. Provide a pervious hard bottom and access ramp to allow equipment access.

3: Slopes: Side slopes are generally 4:1 or flatter for safety and maintenance.

4: Vegetation: Bottom can consist of turf grass if a longitudinal slope is present. For flat ponds, or deep ponds provide a gravel bottom. Side slopes can be planted with native and riparian species. To minimize landscape damage, avoid trees and shrubs in the bottom of the basin where significant sediment deposition is anticipated

5: Outlet/Overflow: Locate an outlet in less visible or screened areas. On larger facilities, locate a micro-pool, trash rack,and emergency spillway in less visible areas

6: Infiltration Matrix: Native soils in all but sand filter basins, which are to be designed with a sand layer and underdrain system in accordance with UDFCD Manual; Volume 3.

Maintenance

Extended detention basins have low to moderate maintenance requirements. Routine and non-routine maintenance is necessary to assure performance, enhance aesthetics, and protect structural integrity. The dry basins can result in nuisance complaints if not properly designed or maintained. Bio-degradable pesticides may be required to limit insect problems. Frequent debris removal and grass-mowing can reduce aesthetic complaints. If a shallow wetland or marshy area is included, mosquito breeding and nuisance odors could occur if the water becomes stagnant. Access to critical elements of the pond (inlet, outlet, spillway, and sediment collection areas) must be provided. The basic elements of the maintenance requirements are presented in **Table 8.13**

Table 8.13 Extended Detention Basin Maintenance Considerations

Required Action	Maintenance Objective	Frequency of Action
Lawn mowing and lawn care	Occasional mowing to limit unwanted vegetation. Maintain irrigated turf grass as 2 to 4 inches tall and non-irrigated native turf grasses at 4 to 6 inches.	Routine – Depending on aesthetic requirements.
Debris and litter removal	Remove debris and litter from the entire pond to minimize outlet clogging and improve aesthetics.	Routine – Following spring runoff and following significant rainfall events.
Sediment removal from forebay and micro-pool	Remove accumulated sediment from the forebay and micro-pool. Dewatering of the micro-pool by pumping onto the EDB's bottom grasses and temporary diversion of all base flows will be needed to remove the accumulated sediment from micro-pool's bottom.	Routine – The sediment accumulations forebay and the micro-pool will need to be cleaned out every one to three years. Cleaning of micro-pool is important for mosquito control.

8.5.3.4 Sand Filter Extended Detention Basin

Figure 8.59 Turf grass over a Sand Filter Extended Detention Basin can serve as an informal play area during most of the year.

Description

A sand filter extended detention basin (SFB) is a stormwater filter that consists of a runoff storage zone underlain by a sand bed with an underdrain system. During a storm, accumulated runoff ponds in the surcharge zone and gradually infiltrates into the underlying sand bed, filling the void spaces of the sand. The underdrain gradually dewaters the sand bed and discharges the runoff to a nearby channel, swale, or storm sewer.

General Application

A SFB is generally suited to offline, onsite configurations where there is no base flow and the sediment load is relatively low.

Advantages/Disadvantages

Primary advantages of SFBs include effective water quality enhancement through settling and filtering. The primary disadvantage is a potential for clogging if a moderate to high level of silts and clays are allowed to flow into the facility. For this reason, it should **not** be put into operation while construction activities are taking place in the tributary catchment. Also, this BMP should not be located close to building foundations or other areas where expansive soils are a concern, although an underdrain and impermeable liner can ameliorate some of this concern.

Physical Site Suitability

Since an underdrain system is incorporated into this BMP, SFB is suited for about any site; presence of sandy sub-soils is not a requirement. This BMP has a relatively flat surface area, so it may be more challenging to incorporate it into steeply sloping terrain.

Pollutant Removal

Although not fully tested to date in the Denver area, the tests on filter vaults in the Denver area and other parts of United States show that the amount of pollutant removed by this BMP should be significant and should at least equal the removal rates by sand filters tested elsewhere.

Cold Weather Considerations

A sand filter will not function when the ground is frozen; therefore, it is important to have an overflow path. Storage volume may be diminished in the spring due to snow accumulation. Sand filters will clog quickly if exposed to moderate to high loads of sediments, so sand filters should not be used to treat areas that are sanded.

Design Procedure and Criteria

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

1.	Basin Storage Volume	Provide a storage volume equal to 130 percent of the *WQCV* calculated using the method described in Section 8.4
2.	Basin Depth/Design	Maximum depth for the *Design Volume* shall be 3 feet.
3.	Filter's Surface Area	Calculate the minimum sand filter area (A_s) of the basin's bottom using: A_s = 2V/9, where V = detention volume
4.	Sand Media	Provide, as a minimum, an 18-inch layer of clean C-33 sand as shown in Figure 8.60. Maintain top surface flat. If side slopes need to be steeper than 3:1 (4:1 or flatter preferred), use vertical walls.
5.	Granular Base and Underdrains	Granular material shall have all fractured faces and meet the technical requirements of AASHTO #3, #4 or #67 aggregate (CDOT 703, #3, 4 or #67).
6.	Impermeable Membrane	When expansive or NRCS Type D soils are present, or when standard percolation tests show percolation drawdown rates exceeding 60 minutes per inch, or potential for groundwater contamination exists, install an impermeable 30 mil thick, or heavier, liner on the bottom and sides of the basin. If vertical walls are permeable or of stacked blocks, extend the impermeable liner behind the walls. Wrap impermeable liners to top of the SFB basin and attach firmly with staples to the soil vertical wall using staples or concrete anchors.

Provide sufficient slack so that the liners are not stretched when rock and sand are placed. If tears are seen or discovered, repair them as recommended by manufacturer with no less than 18 inches of overlap on all sides of the tear.

7.	Outlet Works	When underdrains are needed, the outlet works consists of 4" perforated HDPE pipe to convey water to the overflow outlet structure. Space perforated pipe on 20 foot centers or less. At the outlet of the HDPE pipe into the box, install an orifice sized to empty the WQCV above the sand in no less than 12 hours. Provided an overflow outlet pipe out of the overflow structure to convey flows away from the filter basin when the runoff volume exceeds the *WQCV* at rates required by local jurisdiction to control the flood detention, typically the 10- and the 100-year storm.
8.	Inlet Works	Provide an energy dissipating outlet for all inlet points into the SFB. Use an impact basin for pipes and a baffle chute or grouted sloping boulder drop if a channel or swale is used. Fill all rock voids with filter sand.

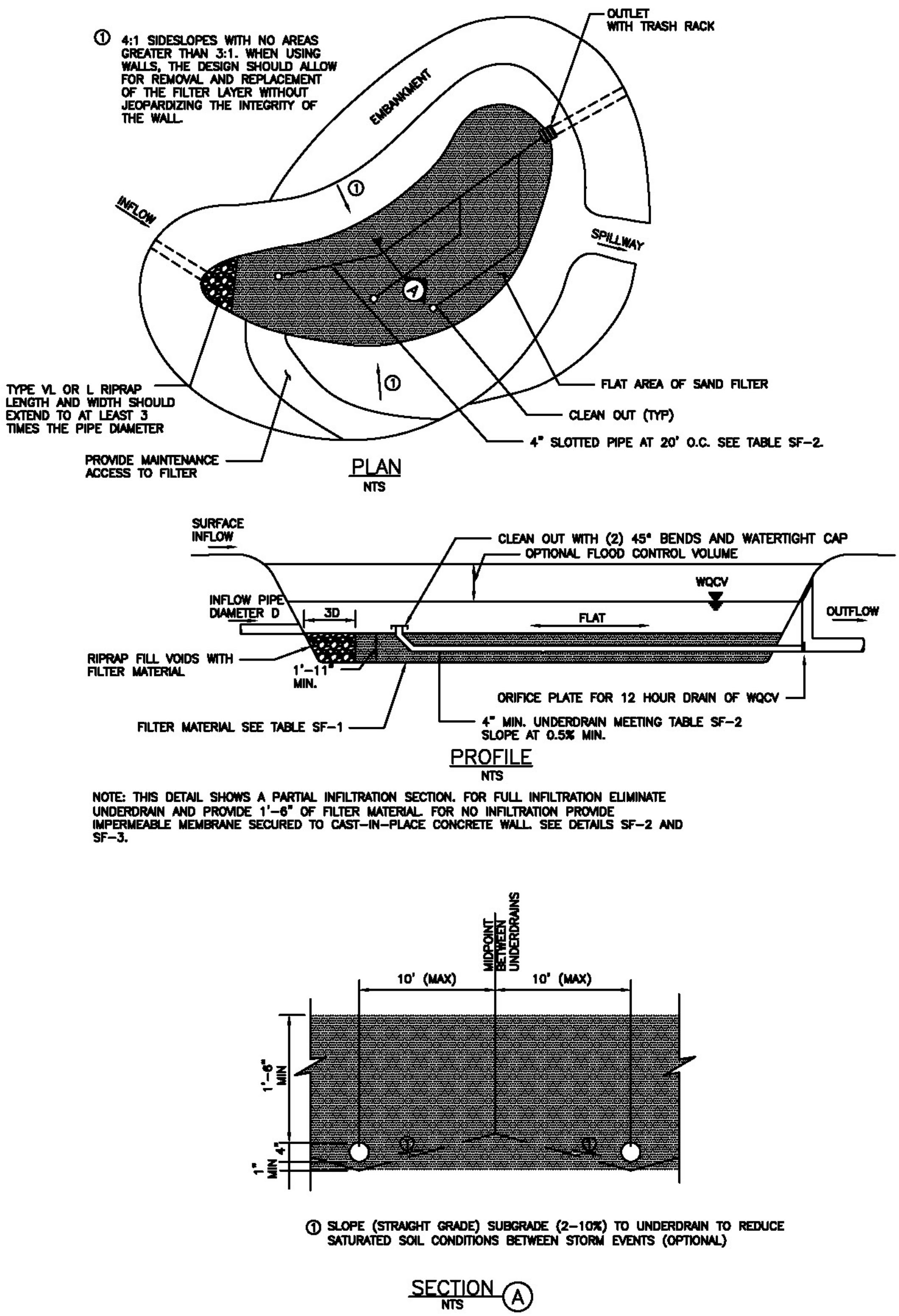


Figure 8.60 Sand Filter Typical Plan and Profile

Maintenance

Table 8.14 provides maintenance recommendations for SFBs.

Table 8.14 Sand Filter Extended Detention Basin Maintenance Recommendations

Required Action	Maintenance Objectives	Frequency
Debris and litter removal	Remove debris and litter from detention area to minimize clogging of the sand media.	Routine – Depending on aesthetic requirements.
Inspections	Inspect detention area to determine if the sand media is allowing acceptable infiltration. Also inspect the underdrain outlet if one is present, including the orifice plate to make sure it is there and in operating condition.	Routine – Every one to two years inspect for hydraulic performance. If possible, schedule these inspections within 24 hours after a significant rainfall.
Scarify filter surface	Scarify top 3 inches by raking the filter's surface.	Once per year or when needed to promote drainage.
Sand filter removal	Remove the top 3 inches of sand from the sand filter. After a second removal, backfill with 6 inches of new sand to return the sand depth to 18 inches. Minimum sand depth is 15 inches.	If no construction activities take place in the tributary watershed, every 2 to 5 years depending on observed drain times, namely when it takes more than 40 hours to empty 3-foot deep pool. Otherwise more often.

8.5.3.5 Modular Suspended Pavement System

Description

Modular suspended pavement systems (MSPS) provide support and rigidity for paved areas while allowing underneath soils to remain uncompact. A MSPS is a series of modular units or "cells" that are assembled together to create an interconnected skeletal matrix. This subgrade matrix supports concrete, asphalt, or pavers as well as pedestrian and traffic loads. Each cell frame is filled with uncompacted soil. Trees are planted in tree grates or planting strips adjacent to the system. Tree roots are free to move through the cell system without being impeded by dense, compacted soil which is required for traditional pavement subsoil. A healthy tree root network supports healthy, large tree growth. In addition to healthy tree growth, MSPS's can be utilized for stormwater management through a treatment train approach. Through interception, absorption, evapotranspiration and infiltration the system treats stormwater runoff. Stormwater runoff from impervious surfaces enters the MSPS through perforated pipes or permeable pavers. The uncompact soil absorbs the runoff which is then utilized by the adjacent trees. What is not picked up by tree roots infiltrates into deeper subsoils helping to replenish the water table.

General Application

MSPS are utilized to enhance stormwater runoff by treating a portion of the WQCV. A treatment train approach must be applied with MSPS as this BMP is not capable of treating large sediment loads without clogging. Pretreatment is required for the use of MSPS. The MSPS system is in place as a volume storage BMP to contain runoff and promote infiltration. MSPS as a standalone BMP is not applicable for sediment pollutant removal.

Traditional trees surrounded by pavement tend to have a lifespan of approximately 13 years. This is due to the fact that urban trees in tree grates have less than 1/10th of the rooting volume necessary for trees to thrive. With a lifespan of only 13 years the trees die before they can provide significant ecological benefits. Trees planted with sufficient uncompacted soil tend to live upwards of 50 years. This time period allows trees to grow and mature, providing more ecological benefit to the surrounding area.

Advantages/Disadvantages

The advantage of a MSPS system is to treat stormwater runoff while promoting healthy tree growth. The system can be installed in urban areas where pervious area is limited as it resides underneath sidewalks, patios, and roads, thus requiring no additional area. MSPS's have the potential to treat runoff from streets via curb cuts and gutter inlets. Another advantage is tree shade has been correlated with better pavement performance and reduced maintenance.

The disadvantages of MSPS's are if not properly installed or maintained, runoff may not infiltrate causing issues with odor and mosquitoes. MSPS are not effective in high pollutant areas where debris will clog the system and kill the trees and if the system does become clogged it might be difficult and costly to replace. A major disadvantage if fines can easily enter the system and will remain in the system until maintenance is performed. Due to the sediment load constraints MSPS require a pre-filter so as not to clog the system with fines.

Physical Site Suitability

MSPS's are suited for urban areas where impervious area is limited and stormwater management must be done subgrade below pavement. The systems are designed for areas where trees are desired but there is minimal access to uncompacted soils. MSPS's provide an alternative to traditional tree grates which limit root zones and tree growth.

MSPS's can be installed adjacent to streets with curb and gutter. Curb cuts or inlets and perforated pipes provide an access point for street runoff from the gutter to enter the MSPS system. This street runoff is then treated by the system.

MSPS's are utilized is Aspen's downtown area where there is no landscaping strip and where tree grates have traditionally been installed.

Pollutant Removal

Modular suspended pavement systems remove pollutants through soil filtration and plant uptake. Studies show 80% removal of phosphorous, 60% removal of Total Kjeldahl Nitrogen, and 90% removal of heavy metals such as lead, copper, and zinc.

Cold Weather Considerations

The MSPS effectiveness drops significantly during the winter months. When trees go dormant there is little to no water uptake. Without plant uptake the only runoff treatment is accomplished through infiltration. During even colder parts of the year when the ground and system is frozen, there is little infiltration the system effectiveness decreases even more.

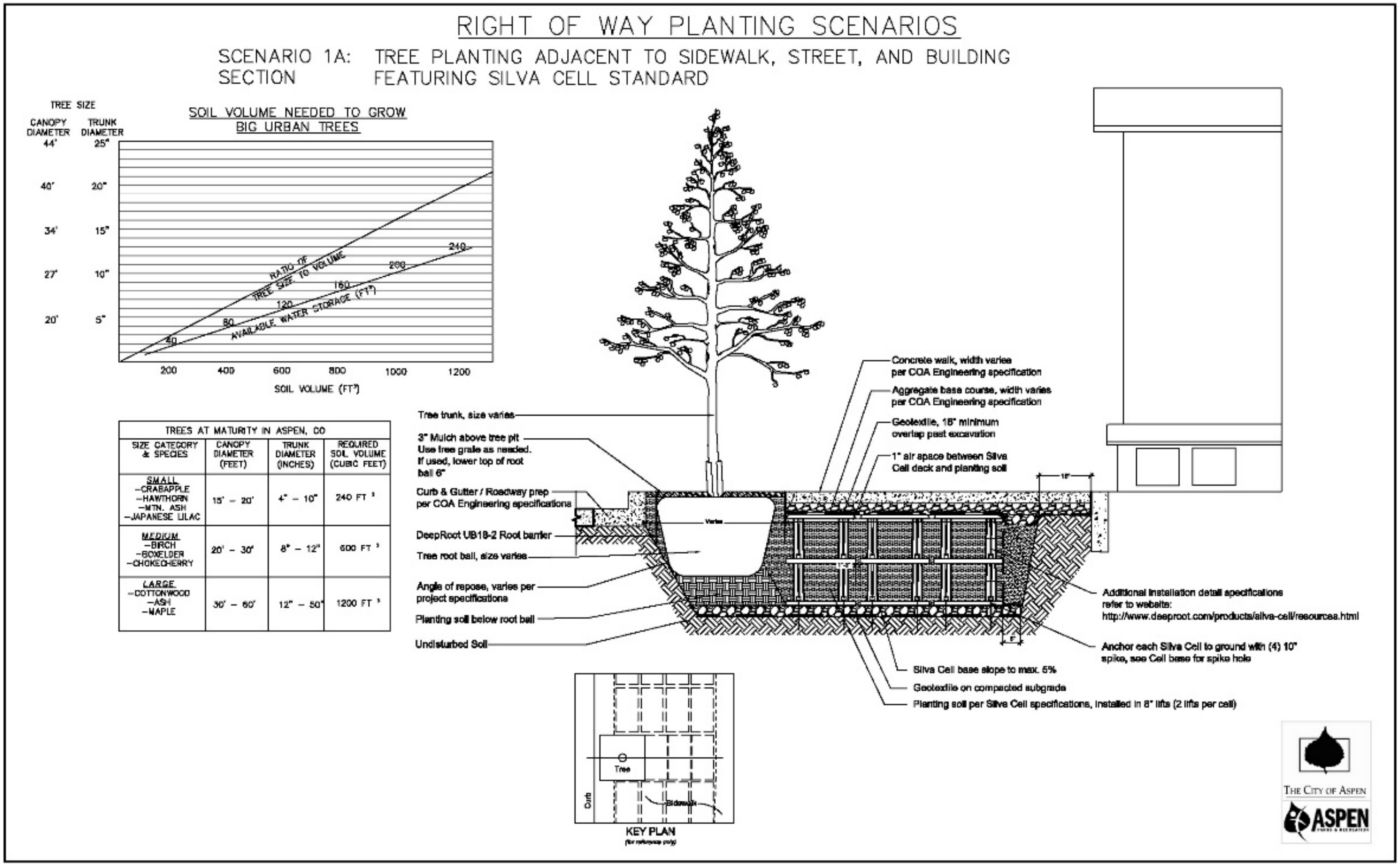
Design Considerations

There are many design considerations and site constraints that should be taken into account for the design of and MSMS system. MSPS's are able to work in conjunction with pervious pavers. Pavers over the system allow runoff to infiltrate over the entire area. If the system is placed in close proximity to a structure, a waterproof liner must be installed along the foundation and extended 10' away from the structure. A perforated underdrain can be placed within the system to distribute runoff throughout. Pipe cleanouts must be provided for any subsurface pipe.

If infiltration rates are low, if the system does not have an outlet, or if the system is located next to a building, a gravel sump pit may be required at the base of the system to provide additional volume area and to draw runoff away from the root zone. If too much water sits in the root zone for an extended period of time there is potential for root rotting.

If a curb inlet is incorporated into the system, and outlet should be provided. This could include tying the system in to another curb inlet further downstream.

A pre-filter is required for all systems with a tributary area high in sediment loading. This includes all streets and gutters. The system shall only be installed in areas where there is no conflict with other utilities. Tree openings should be as large as possible.



TREES AT MATURITY IN ASPEN, CO			
SIZE CATEGORY & SPECIES	CANOPY DIAMETER (FEET)	TRUNK DIAMETER (INCHES)	REQUIRED SOIL VOLUME (CUBIC FEET)
SMALL –CRABAPPLE –HAWTHORN –MTN. ASH –JAPANESE LILAC	15' – 20'	4" – 10"	240 FT³
MEDIUM –BIRCH –BOXELDER –CHOKECHERRY	20' – 30'	8" – 12"	600 FT³
LARGE –COTTONWOOD –ASH –MAPLE	30' – 60'	12" – 50"	1200 FT³

Figure 8.61 Right of Way Planting Scenario 1

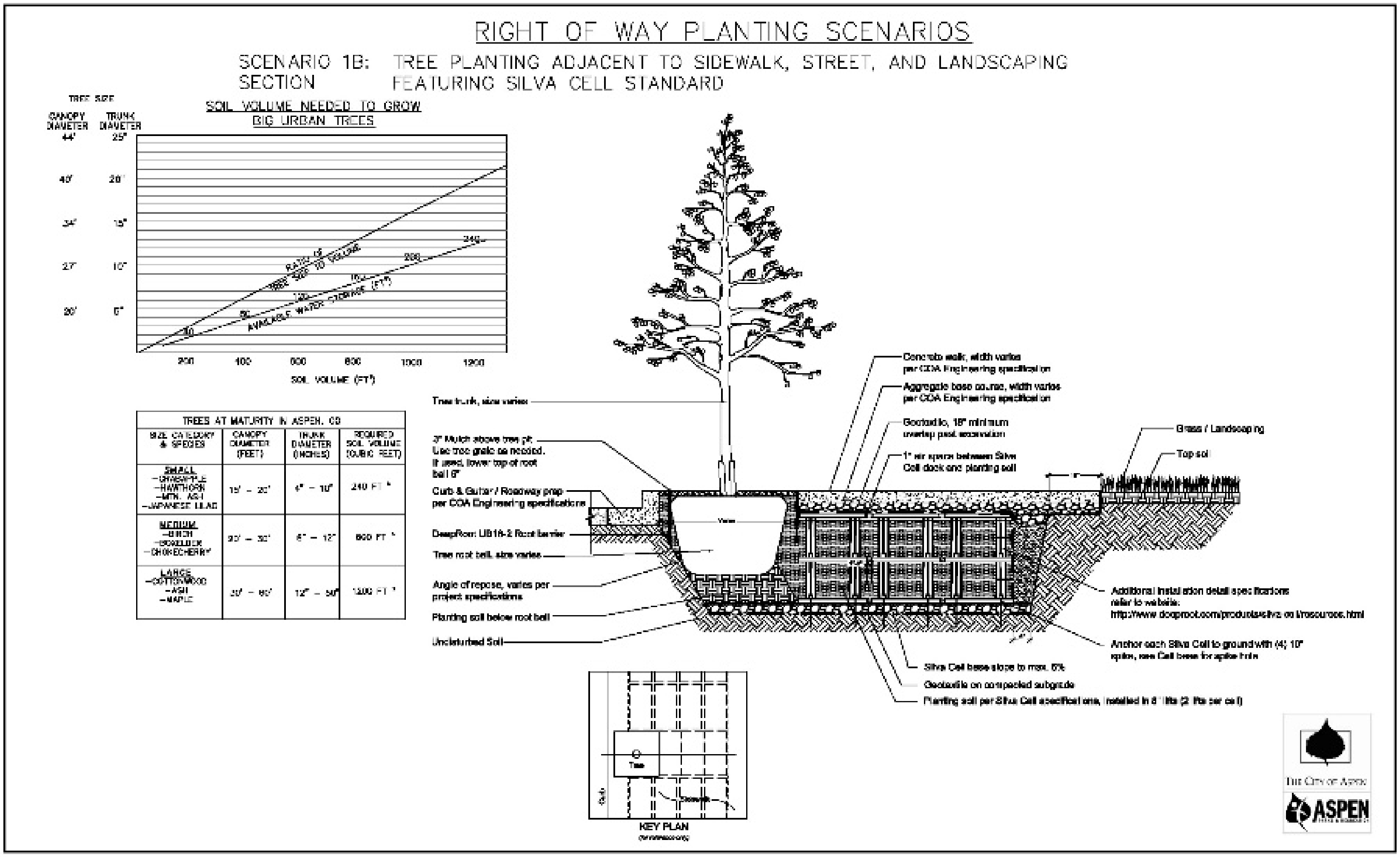


Figure 8.62 Right of Way Planting Scenario 1B

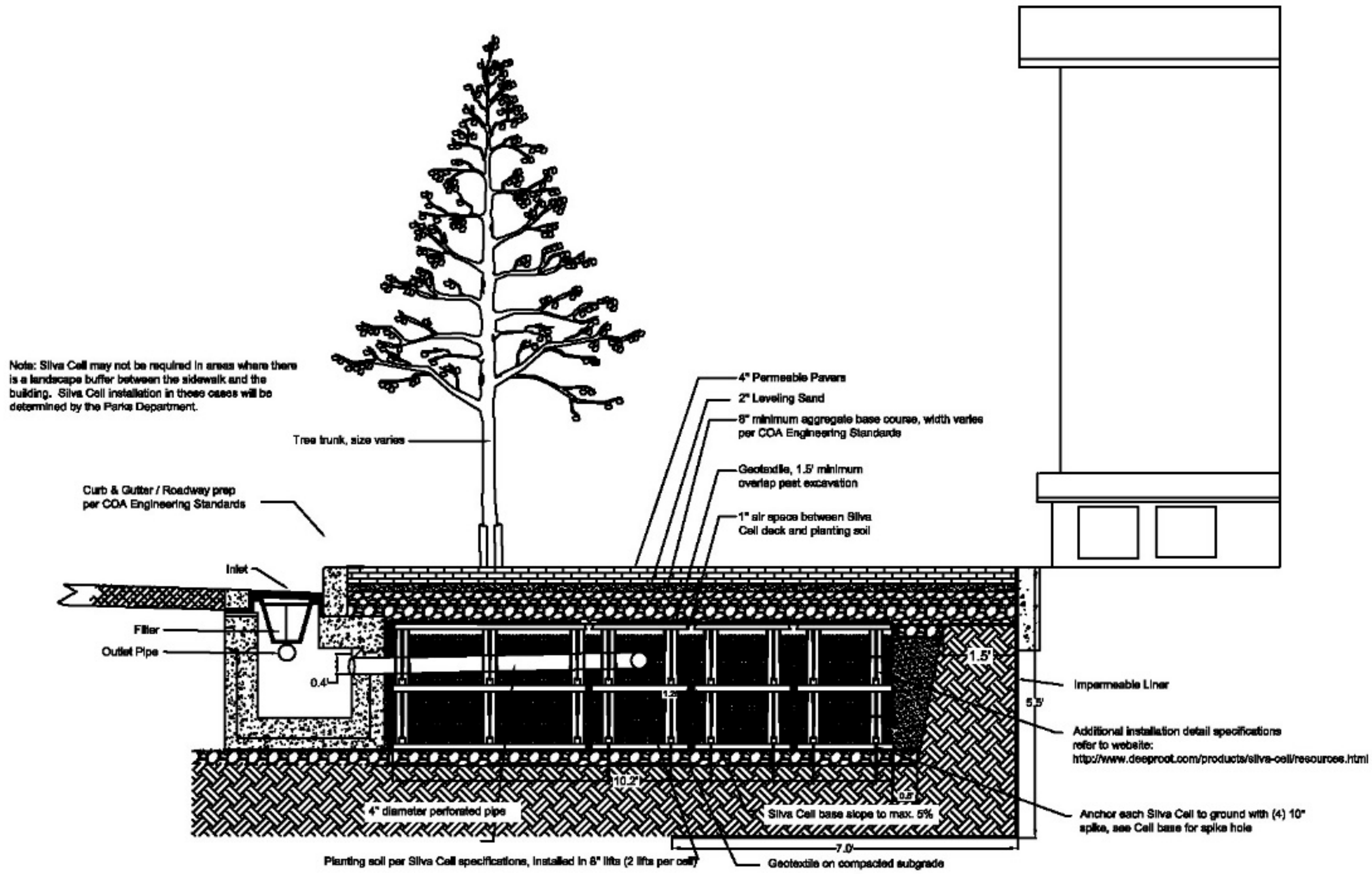


Figure 8.63 MSPS with Inlet

Design Procedure and Criteria

1. Basin Storage Volume - Determine WQCV for tributary area using the procedure described in Section 8.4.
2. System Volume - Determine according to manufacturer's specs the available volume in each MSPS cell. Ensure there are enough MSPS cells to provided adequate volume for the WQCV. Each cell holds 10 cf of soil and able to hold 2 cf of runoff within the void space.
3. Tree placement - Determine the number of trees for the proposed sight. 1,000 cf of soil is recommended for canopy trees while 600 cf is recommended for understory trees. Trees are able to share volume space. It is cost effective to link tree to each other or other soil volumes.
4. Vertical Dimension – MSPS come in a series of cells that can be stacked on top of each other up to three levels. During the design process determine the depth of the system and how many cell levels will be installed. Keep in mind the location of nearby utilities.
5. Structure waterproofing – An impermeable liner must be installed along any foundations of structures within 10' of the MSPS system.
6. Cell Placement – Determine the cell placement. Due to surrounding constraints the proposed plan must show the dimensions and placement of each individual cell in order to avoid spacing conflicts during construction. This also must be done to determine the number of cells to be purchased. It is not adequate to call out MSPS over an overall area.
7. System Uptake – Determine how runoff will enter the system, through modified curb cuts, inlets, piping or pervious pavers. Due to snow plowing operations traditional curb cuts and chases are discouraged within the COA and are not an allowable means to direct street runoff into a MSPS. Modified curb cuts and inlets should be discussed with the COA Engineering Department. Potential designs include smaller and/or reinforced curb openings.
8. Street Runoff Treatment – If runoff treatment for the adjacent street is to be incorporated into the system provide either a modified curb cut or an inlet box and outlet point for the MSPS system. Determine the WQCV of the street tributary basin. Determine the runoff volume that will be treated by the MSPS system and how much runoff will bypass the system. Inlets with a pretreatment filter are the recommended method to direct street runoff into the MSPS system. Direct runoff from the gutter toward curb cuts by placing diagonal cuts within the flowline.
9. Pipe placement– Determine if an underdrain will be utilized to spread runoff throughout the system. If an underdrain is utilized provide a pipe cleanout.
10. Determine if a gravel sump will be necessary beneath the MSPS system. If infiltration rates are low, if the system does not have an outlet, or if the system is located next to a building, a gravel sump pit may be required at the base of the system to provide additional volume area and to draw runoff away from the root zone. If too much water sits in the root zone for an extended period of time there is potential for root rotting.

Maintenance

Any underdrains must be periodically cleaned by way of the pipe clean out.

Tree grates connected to street gutters via modified curb cuts should be monitored and maintained. Any accumulated sediment and debris should be removed periodically and cleaned out after any big storm events. At least once a year the top layer of soil should be scarified and every few years removed and replaced.

If it is observed that the system is not draining and the soil remains wet for extended periods of time the system may need to be replaced. Excavate down to the existing bottom elevation and scrape the bottom layer to remove any fines in the system.

8.5.3.6 Constructed Wetland Basin

Figure 8.64 Large wetlands can provide regional stormwater treatment and detention as well as create valued habitat. The forebay and pond, shown here, dissipates stormwater velocities and allows larger particles to settle

Figure 8.65 A small wetland pond can be an added amenity to a development.

Description

A constructed wetlands basin (CWB) is a shallow retention pond (RP), which requires a perennial base flow to permit the growth of rushes, willows, cattails, and reeds to slow down runoff and allow time for sedimentation, filtering, and biological uptake. It is a sedimentation basin and a form of a treatment plant.

A CWB differ from "natural" wetlands as they are totally human artifacts that are built to enhance stormwater quality. Sometimes small wetlands that exist along ephemeral drainageways on Colorado's high plains could be enlarged and incorporated into the constructed wetland system. Such action, however, requires the approval of federal and state regulators.

Current regulations intended to protect natural wetlands recognize a separate classification of wetlands constructed for a water quality treatment. Such wetlands generally are not allowed on receiving waters and cannot be used to mitigate the loss of natural wetlands but are allowed to be disturbed by maintenance activities. Therefore, the legal and regulatory status of maintaining a wetland constructed for the primary purpose of water quality treatment, such as the CWB, is separate from the disturbance of a natural wetland. Nevertheless, the U.S. Army Corps of Engineers has established maximum areas that can be maintained under a nationwide permit. Thus, any activity that disturbs a constructed wetland should be first cleared through the U.S. Army Corps of Engineers to ensure it is covered by some form of an individual, general, or nationwide 404 permit.

General Application

A CWB can be used as a follow-up structural BMP in a watershed or as a stand-alone onsite facility if the owner provides sufficient water to sustain the wetland. Flood control storage can be provided above the CWB's water quality capture volume (WQCV) pool to act as a multiuse facility.

Advantages/Disadvantages

A CWB offers several potential advantages, such as natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal. It can also provide an effective follow-up treatment to onsite and source control BMPs that rely upon settling of larger sediment particles. In other words, it offers yet another effective structural BMP for larger tributary catchments.

The primary drawback of the CWB is the need for a continuous base flow to ensure viable wetland growth. In addition, silt and scum can accumulate and unless properly designed and built, can be flushed out during larger storms. In addition, in order to maintain a healthy wetland growth, the surcharge depth for WQCV above the permanent water surface cannot exceed 2 feet.

Along with routine good housekeeping maintenance, occasional "mucking out" will be required when sediment accumulations become too large and affect performance. Periodic sediment removal is also needed for proper distribution of growth zones and of water movement within the wetland.

Physical Site Suitability

A perennial base flow is needed to sustain a wetland, and should be determined using a water budget analysis. Loamy soils are needed in a wetland bottom to permit plants to take root. Exfiltration through a wetland bottom cannot be relied upon because the bottom is either covered by soils of low permeability or because the groundwater is higher than the wetland's bottom. Also, wetland basins require a near-zero longitudinal slope, which can be provided using embankments.

Pollutant Removal

Primary variables influencing removal efficiencies include design, influent concentrations, hydrology, soils, climate, and maintenance. With periodic sediment removal and routine maintenance, removal efficiencies for sediments, organic matter, and metals can be moderate to high; for phosphorous, low to high; and for nitrogen, zero to moderate. Pollutants are removed primarily through sedimentation and entrapment, with some of the removal occurring through biological uptake by vegetation and microorganisms. Without a continuous dry-weather base flow, salts and algae can concentrate in the water column and can be released into the receiving water in higher levels at the beginning of a storm event as they are washed out.

Researchers still do not agree whether routine aquatic plant harvesting affects pollutant removals significantly. Until research demonstrates and quantifies these effects, periodic harvesting for the general upkeep of wetland, and not routine harvesting of aquatic plants, is recommended.

Cold Weather Considerations

Primary cold weather considerations for constructed wetlands are similar to those noted for EDBs. In addition, the shorter growing season in cold climates like Aspen mean a shorter window for biological benefits of these BMPs. Care should be taken in timing the planting of constructed wetlands basins so that plant establishment is successful.

Design Considerations

Figure 8.66 illustrates an idealized CWB. An analysis of the water budget is needed to show the net inflow of water is sufficient to meet all the projected losses (such as evaporation, evapotranspiration, and seepage for each season of operation). Insufficient inflow can cause the wetland to become saline or to die off.

Design Procedure and Criteria

The following steps outline the design procedure for a CWB.

1. Basin Surcharge Storage Volume — Calculate the WQCV based on the guidance provided in **Section 8.4**.

2. Wetland Pond Depth and Volume — The volume of the permanent wetland pool shall be no less than 75% of the WQCV found in Step 1.

   Proper distribution of wetland habitat is needed to establish a diverse ecology. Distribute pond area in accordance with the following:

Components	Percent of Permanent Pool Surface Area	Water Design Depth
Forebay, outlet and free water surface areas	30% to 50%	2 to 4 feet deep
Wetland zones with emergent vegetation	50% to 70%	6 to 12 inches deep*
*One-third to one-half of this zone should be 6 inches deep.		

3. Depth of Surcharge WQCV — The surcharge depth of the WQCV above the permanent pool's water surface shall not exceed 2.0 feet.

4. Outlet Works — Provide outlet works that limit WQCV depth to 2 feet or less. Use a water quality outlet that is capable of releasing the WQCV in no less than a 12-hour period. Refer to the Volume 3 of the UDFCD Urban Storm Drainage Criteria Manual for schematics pertaining to structure geometry; grates, trash racks, and screens; outlet type: orifice plate or perforated riser pipe; cutoff collar size and location; and all other necessary components.

5. Trash Rack — Provide a trash rack of sufficient size to prevent clogging of the primary water quality outlet. Size the rack so as not to interfere with the hydraulic capacity of the outlet. Refer to the Volume 3 of the UDFCD Urban Storm Drainage Criteria Manual for trash rack criteria.

6. Basin Use — Determine if flood storage or other uses will be provided for above the wetland surcharge storage or in an upstream facility. Design for combined uses when they are to be provided for.

7. Basin Shape — Shape the pond with a gradual expansion from the inlet and a gradual contraction to the outlet, thereby limiting short circuiting. Try to achieve a basin length to width ratio between 2:1 to 4:1. It may be necessary to modify the inlet and outlet point through the use of pipes, swales, or channels, to accomplish this. Always maximize the distance between the inlet and outlet.

8. Basin Side Slopes — Basin side slopes are to be gentle and stable to facilitate maintenance and access. Side slopes should be no steeper than 4:1, preferably 5:1 or flatter.

9. Base Flow — A net influx of water must be available throughout the year that exceeds all of the losses. The following equation and parameters can be used to estimate the net quantity of base flow available at a site:

$$Q_{net} = Q_{Inflow} - Q_{Evap} - Q_{Seepage} - Q_{E.T.}$$

Where:

Q_{Net}	=	Net quantity of base flow (acre-ft/year)
Q_{Inflow}	=	Estimated base flow (acre-ft/year) (Estimate by seasonal measurements and/or comparison to similar watersheds)
Q_{Evap}	=	Loss attributed to evaporation less the precipitation (acre-ft/year) (Computed for average water surface)
$Q_{Seepage}$	=	Loss (or gain) attributed to seepage to groundwater (acre-ft/year)
$Q_{E.T.}$	=	Loss attributed to plant evapotranspiration (computed for average plant area above water surface, not including the water surface)

10. Inlet/Outlet Protection — Provide a means to dissipate flow energy entering the basin to limit sediment resuspension. Outlets should be placed in an outlet bay that is at least 3 feet deep. The outlet should be protected from clogging by a skimmer shield that starts at the bottom of the permanent pool and extends above the maximum capture volume depth.

11. Forebay Design — Provide the opportunity for larger particles to settle out in an area that has a solid driving surface bottom for vehicles to facilitate sediment removal. The forebay volume of the permanent pool should be 5 to 10 percent of the design water quality capture volume.

12. Vegetation — Refer to **Appendix E** for general planting criteria and plant species specific to Aspen and BMPs

13. Maintenance Access — Provide vehicle access to the forebay and outlet area for maintenance and removal of bottom sediments. Maximum grades should not exceed 10 percent, and a stabilized, all-weather driving surface needs to be provided. Provide a concrete or grouted boulder lined bottom and side-slopes under water in the forebay area to define sediment removal limits and permit heavy equipment to operate within them.

Maintenance

Table 8.15 provides maintenance recommendations for CWBs.

Table 8.15 Maintenance Recommendations for Constructed Wetlands Basin

Required Action	Maintenance Objective	Frequency of Action
Lawn mowing and lawn care	Mow occasionally to limit unwanted vegetation. Maintain irrigated turf grass at 2 to 4 inches tall and non-irrigated native turf grasses at 4 to 6 inches.	Routine – Depending on aesthetic requirements.
Debris and litter removal	Remove debris and litter from entire pond to minimize outlet clogging and aesthetics. Include removal of floatable material from the pond's surface.	Routine – Including just before annual storm seasons (that is, in April and May) and following significant rainfall events.
Sediment removal	Remove accumulated sediment and muck along with much of the wetland growth. Re-establish growth zone depths and spatial distribution. Revegetate with original wetland species.	Non-routine – Every 10 to 20 years as needed by inspection if no construction activities take place in the tributary watershed. More often if they do. Expect to clean out forebay every 1 to 5 years.
Aquatic plant harvesting	Cut and remove plants growing in wetland (such as cattails and reeds) to remove nutrients permanently with manual work or specialized machinery.	Non-routine until further evidence indicates such action would provide significant nutrient removal. In the meantime, perform this task once every 5 years or less frequently as needed to clean the wetland zone out.
Inspections	Observe inlet and outlet works for operability. Verify the structural integrity of all structural elements, slopes, and embankments.	Routine – At least once a year, preferably once during one rainfall event resulting in runoff.

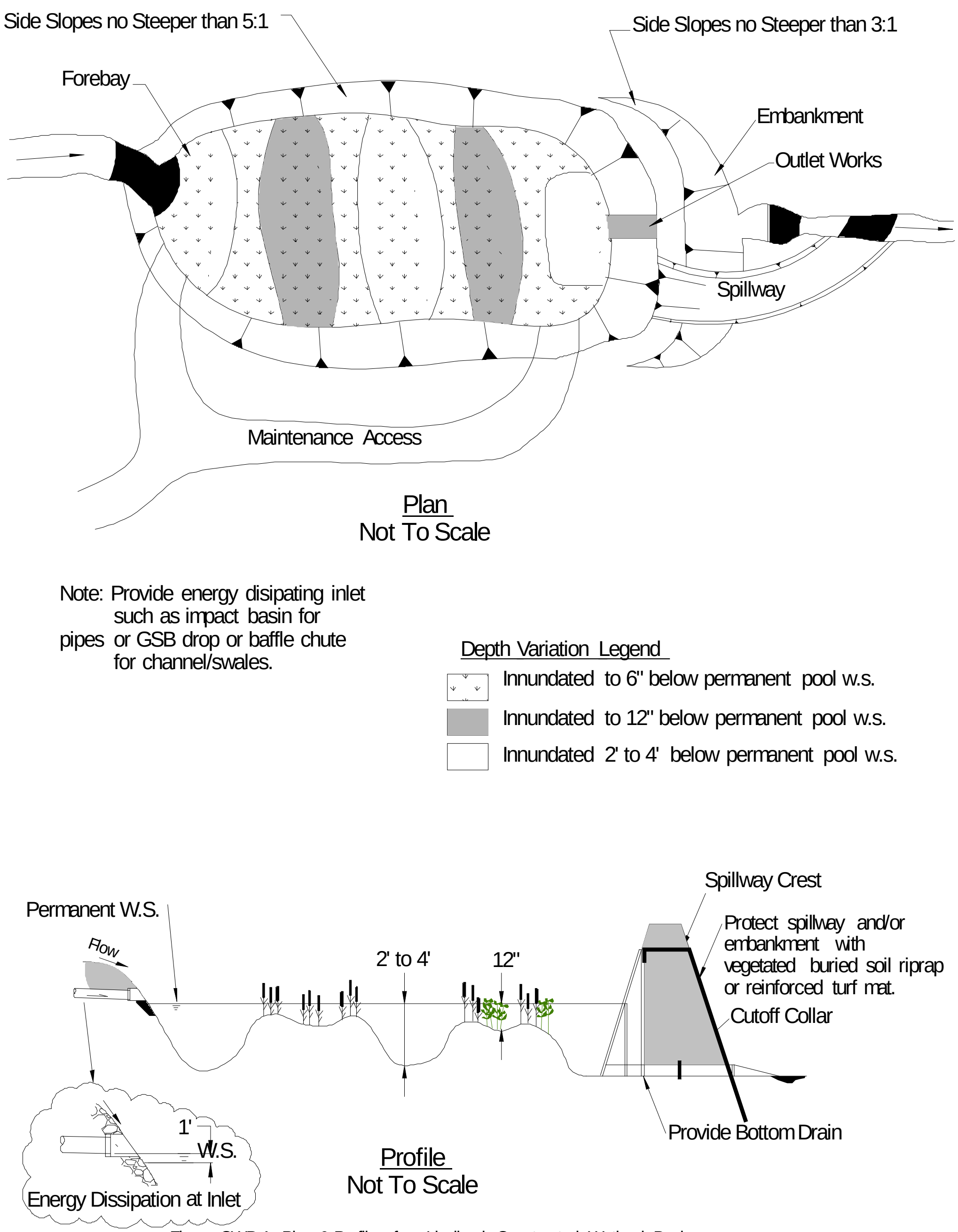


Figure CWB-1 Plan & Profile of an Idealized Constructed Wetland Basin

Figure 8.66 Constructed Wetland Basin – Plan and Cross-Section

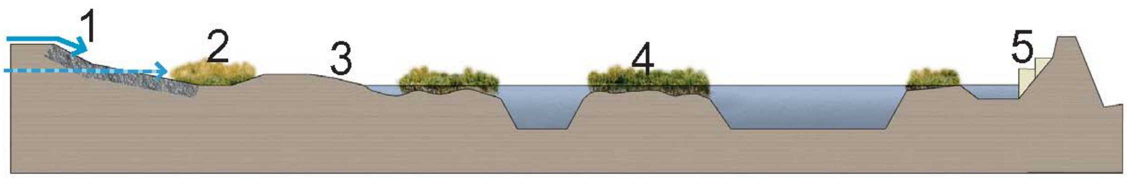


Figure 8.67 Typical Constructed Wetland Basin Design Sketch

1: Inlet: Dissipate energy at inlets to prevent erosion and sediment re-suspension.

2: Sediment Trap: Provide a sediment forebay to remove larger sediment particles. Provide access for routine maintenance

3: Slopes: Side slopes are generally 4:1 or flatter for safety and maintenance. Provide a safety bench slope at 10:1 to a depth of 18" below normal water level for ponds.

4: Vegetation: Should consist of native grasses, rushes, willows, cattails and reeds. Refer to Appendix E for a list of appropriate plant species.

5: Outlet/Overflow: Provide a micropool, outlet structure, and overflow weir designed to withstand necessary flow velocities.

6: Infiltration Matrix: Infiltration through pond areas is not appropriate; requires soils with low permeability. In areas with permeable soils, and impervious linear may be necessary to retain stormwater

8.5.4 Sub-surface BMPs

The general policy of the City of Aspen is that subsurface BMPs are acceptable as long as they meet the City's water quality criteria of 80^{th} percentile treatment and > 90 percent removal of particles 60 microns and larger. Subsurface BMPs designed and sized in accordance with methods above for volume-based BMPs will be presumed to meet this objective. Inspection and maintenance for sub-surface BMPs must be rigorous (minimum yearly requirement) with reporting to City.

For proprietary BMPs, design engineers and/or manufacturers must provide actual field data to substantiate performance if they do not meet the volume and drain time requirements in this Chapter.

8.5.4.1 Subsurface Sedimentation/Filtration Vaults

Subsurface sedimentation/filtration vaults that meet the criteria in Section 8.4 for the WQCV and allowable drain time may be used for water quality treatment in Aspen provided that they are inspected and maintained yearly at a minimum. Because underground systems may be pumped and because historically, there have been problems with re-suspension of sediments in underground vault systems, a multi-chambered treatment approach is required. Biological/vegetation based BMPs are not feasible underground, limiting options for storage-based BMPs to extended detention and sand-filtration. Because of the potential to pump out or scour bottom sediments, sand-filtration is the primary recommended non-proprietary underground treatment method for the City of Aspen.

At a minimum, an underground sand filter shall meet the following requirements:

1. A pretreatment chamber for removal of course sediments with a volume equivalent to 0.30 times the WQCV calculated according to Section 8.4 must be provided. This must be separated from the sand filter chamber by baffling.

2. The sand filter chamber shall have a surcharge (i.e. above the filter media) volume equivalent to the WQCV.

3. Material specifications, depth and area parameters shall be the same as for an above ground sand filter basin (**Section 8.5.3.4**).

4. Where discharges from the BMP will be pumped, a separate outlet chamber is required from which the water passing through the filter layer can be pumped. The outlet pump shall be sized to discharge at a rate not to exceed the WQCV/12 hours.

5. If detention storage is also provided underground, it shall be in a separate vault. A diversion shall be sized so that flows in excess of the WQCV are diverted to the detention chamber and the underground sand filter is not surcharges (in terms of depth or hydraulic grade line) beyond the WQCV maximum elevation.

6. Maintenance access must be provided to each chamber. Access must be sufficient to allow complete removal of the filter material, if necessary.

Figure 8.68 illustrates a typical underground sand filter.

Table 8.16 provides maintenance requirements for underground sand filters.

Table 8.16 Underground Sand Filter Maintenance Requirements

Required Action	Maintenance Objective	Frequency of Action
Inspection	Monitor water level and accumulation of sediments in chambers.	Quarterly and following all rainfall events >0.25 inches.
Scarify filter surface	Scarify top 3 inches by raking the filter's surface.	Once per year or when needed to promote drainage.
Sand filter removal	Remove the top 3 inches of sand from the sand filter. After a second removal, backfill with 6 inches of new sand to return the sand depth to 18 inches. Minimum sand depth is 15 inches.	If no construction activities take place in the tributary watershed, every 2 to 5 years depending on observed drain times, namely when it takes more than 12 hours to empty 3-foot deep pool. Otherwise more often.

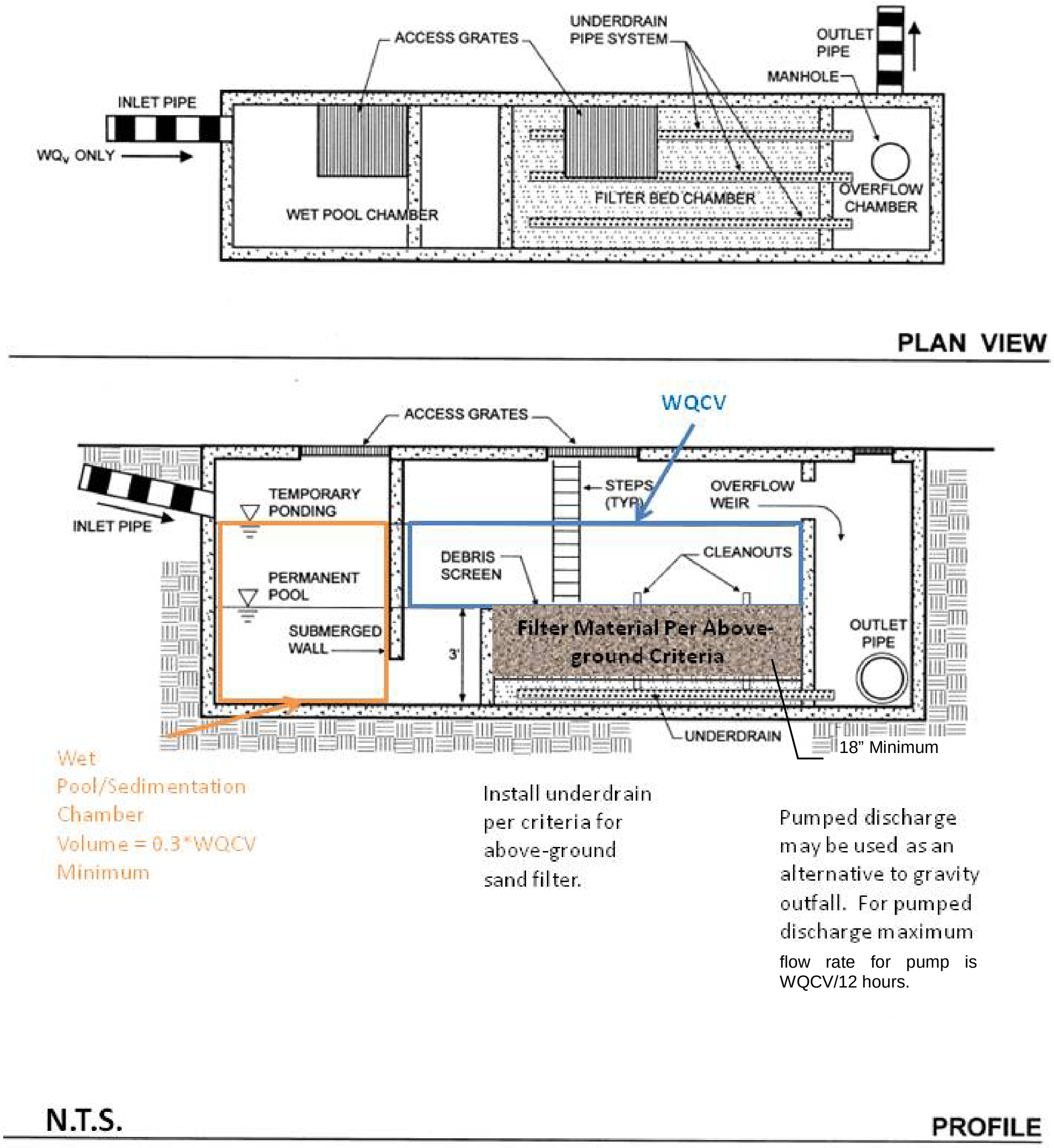


Figure 8.68 Typical plan and Profile for Underground Sand Filter (Source: Center for Watershed Protection with modifications)

8.5.4.2 Dry Wells

Description

Dry wells may be used to collect, detain, and percolate runoff for individual residences and for commercial development for which a standard detention pond or discharge to the City's stormwater collection system is infeasible. The applicant will need to provide evidence of such infeasibility to the City Engineer for review. Dry wells typically collect runoff from the entire impervious area of a new development. Therefore, the dry well is a type of storm management practice that can satisfy the goal of maintaining the predevelopment runoff characteristics of a drainage basin. However, dry wells may also create groundwater contamination problem. Dry wells cannot be used in conjunction with certain land uses and activities that may produce soluble pollutants, such as chloride, nitrate, copper, dissolved solids and some polycyclic aromatic hydrocarbons.

General Application

Dry wells should be considered a BMP of last resort. In areas where other BMPs are infeasible, dry wells may be considered. They are not appropriate for treating runoff containing moderate to high levels of sediment. They may be acceptable for treatment of runoff from roofs, and un-sanded sidewalks drives and pedestrian areas.

Advantages/Disadvantages

In general, dry wells have the following advantages:

- Dry well facilities have an ability to capture surface water runoff and filter it through the ground.
- Dry well facilities will improve or increase ground water recharge capacity.
- Dry well facilities will reduce thermal impacts on fisheries.
- Dry well facilities will augment low flow stream conditions.

The disadvantages of dry wells are well known include the following:

- Since dry wells rely on infiltration into the surrounding soils, clogging can be a major problem. As a dry well or the surrounding soils becomes clogged, the dry well will exhibit decreased ability to infiltrate water. Signs of reduced infiltration include longer periods of standing water in the well and overflow from the well from smaller than expected events. Sediment loads to dry wells should be closely managed since this is the primary cause of clogging. Runoff with sediment concentrations that are moderate to high should be excluded from dry wells (for example, runoff from landscape areas, roads and/or areas with ground disturbance.

- Because of the potential for clogging over time, conservative criteria must be used for sizing of dry wells. **When sizing a drywell to capture WQCV, the volume must be calculated at 1.5 times the WQCV**. **If a drywell is to be utilized for detention in addition to water quality, the entire runoff volume of the design storm shall be captured.** Refer to the Design Procedure and Criteria for proper drywell detention sizing

- Frequent inspection and maintenance are necessary to maintain performance and to preemptively detect changes in performance.

- Dry wells may not be used in areas that receive runoff from areas with pollutants that have the potential to contaminate groundwater including many dissolved constituents.

Physical Site Suitability

Dry wells remain a viable treatment option in Aspen in areas where soils have high infiltration capacity. Restrictions on use of dry wells include the following:

- Dry wells may not be used if seasonal high groundwater is less than 5 feet below the bottom of the well.
- Dry wells may not be used in areas where sanding occurs.
- Suitable sources of runoff for dry wells include roofs, residential lots, un-sanded drives and sidewalks.
- Pre-treatment for sediment removal is required (see Street BMPs in **Section 8.5.2**).
- Dry wells are not applicable in areas where pollutant loadings have potential for groundwater contamination. Dry wells are considered Class V Injection Wells under the Environmental Protection Agency Underground Injection Control Program. Appropriate permitting, which typically includes providing documentation of the dry well location and characteristics, is the responsibility of the applicant proposing the dry well.
- Dry wells may not be used where the infiltration surface is on top of fill.
- Dry wells must be located at least 10 feet from building foundations. The design engineer shall evaluate potential impacts of infiltrated runoff on nearby foundations even when spacing from the foundation is greater than 10 feet.
- Use of a dry well is limited to areas with soils with minimum percolation rate of 3 inches per hour. Slower percolating soils are not suitable or practical for drywell systems.

Pollutant Removal

Performance data for dry wells is not widely available. There have been instances of documented groundwater contamination when runoff with soluble pollutants has been directed to dry wells. A properly designed and maintained dry well, sited with due attention to underlying soils and groundwater, can be a very effective runoff reduction BMP.

Cold Weather Considerations

Dry wells will not infiltrate runoff as designed if the surrounding ground is frozen; therefore, it is essential that the infiltration portion of the dry well be located below the frost line. In addition, dry wells have the potential to introduce very cold air into the underground chamber in the winter, creating the potential for freezing underground water and sewer lines if adequate separation is not provided.

Design Considerations

Figure 8.57 shows a typical dry well. Dry wells must be a minimum of 10 feet deep and the water level from the design storm runoff must not rise above 6 inches below the ground surface. The bottom section of the well casing, conventionally known as the barrel section, is perforated concrete wall surrounded by gravel backfill and filter fabric. A percolation or hydraulic conductivity test must be submitted to the City showing that the soil will drain the runoff volume in 24 hours.

The expected fluctuation in ground water levels must also be submitted to show that a normal rise in ground water will not impede the infiltration of runoff through the dry well.

Overflow pipes may be incorporated into a drywell detention design. The lot or property must be graded to allow possible overflows to drain to a local conveyance facility without crossing adjacent properties or damaging property.

Runoff from vehicular areas must be pretreated before entering drywell.

Drywells are not permitted in parking lots, garages, or interior drains.

Design Procedure and Criteria

1. Dry Well Volume

   *Note: The COA will permit the void space of gravel up to 2' surrounding a drywell to count towards drywell volume. Gravel which is installed beyond 2' of the drywell shall not be counted as additional drywell volume.

   Water Quality Capture Volume:

   Drywells designed to capture and treat the WQCV of a tributary area should use the WQCV times a factor of safety of 1.5.

   Detention Volume:

   A drywell without a controlled outlet, utilized for detention, must capture the entire storm runoff volume. The design storm runoff volume shall be conservatively estimated by multiplying the one hour design storm depth by the total impervious area tributary to the drywell.

   A drywell with a controlled outlet shall use the FAA method as described in Chapter 5 to determine the required detention volume. Drywells without controlled outlet flow rates shall not utilize the FAA method.

2. Minimum Diameter

   The minimum dry well diameter is whatever is deemed necessary by the design engineer to allow for maintenance of the drywell.

3. Minimum Depth

   The percolation zone of the dry well must be below the maximum freezing depth of the surrounding soil.

4. Percolation Area

   The minimum percolation rate for soils surrounding the dry well is 3 inches per hour. If, based on evaluation of hydraulic conductivity data by a Registered Professional Engineer, the percolation rate around or beneath a proposed drywell is believed to be less than 3 inches per hour, a dry well is not a suitable BMP. The bottom section of the well casing, conventionally known as the barrel section, is perforated (1-inch diameter holes) concrete wall surrounded by gravel backfill.

   Area shall be calculated using the following equation:

   $AP = (Vr)/(K)(43,200)$

   Where:

   AP = Total area of the sides of the percolation area, square feet

Vr = Runoff volume, cubic feet
K = Hydraulic conductivity of soil, feet/second based off the most conservative percolation or hydraulic conductivity test results provided by a certified geotechnical engineer.

The above equation is a rearranged Darcy Equation for groundwater flow assuming a 24-hour drain time, a hydraulic gradient of 1.0 and a 50% clogging factor. Since the bottom of the dry wells must be constructed 5 feet above the maximum ground water elevation, the hydraulic gradient (I) can be assumed to equal 1. In addition, the soil around the dry well may clog with time. Therefore, it is important to reduce the value of hydraulic conductivity with a safety factor. The hydraulic conductivity shall be determined by a Registered Professional Engineer.

5. Structural Backfill — ¾-inch screened rock shall be provided to transition from the dry well to the surrounding native soil. The minimum thickness of this layer shall be 18-inches surrounding the dry well. The COA will permit the void space of gravel up to 2' surrounding a drywell to count towards drywell volume. Gravel which is installed beyond 2' of the drywell shall not be counted as additional drywell volume.

6. Dry Well Bottom — The bottom of the dry well shall be considered impervious due to likely clogging from sediment accumulation over time.

Maintenance

Dry wells must be inspected and maintained yearly to remove sediment and debris that is washed into them. A maintenance plan shall be submitted to the City in the Drainage Report describing the maintenance schedule that will be undertaken by the owners of the new residence or building. Minimum inspection and maintenance requirements include the following:

- Inspect dry wells as annually and after every storm exceeding 0.5 inches.
- Dispose of sediment, debris/trash, and any other waste material removed from a dry well at suitable disposal sites and in compliance with local, state, and federal waste regulations.
- Routinely evaluate the drain-down time of the dry well to ensure the maximum time of 24 hours is not being exceeded. If drain-down times are exceeding the maximum, drain the dry well via pumping and clean out the percolation area (the percolation barrel may be jetted to remove sediment accumulated in perforations). Consider drilling additional perforations in the barrel. If slow drainage persists, the system may need to be replaced.

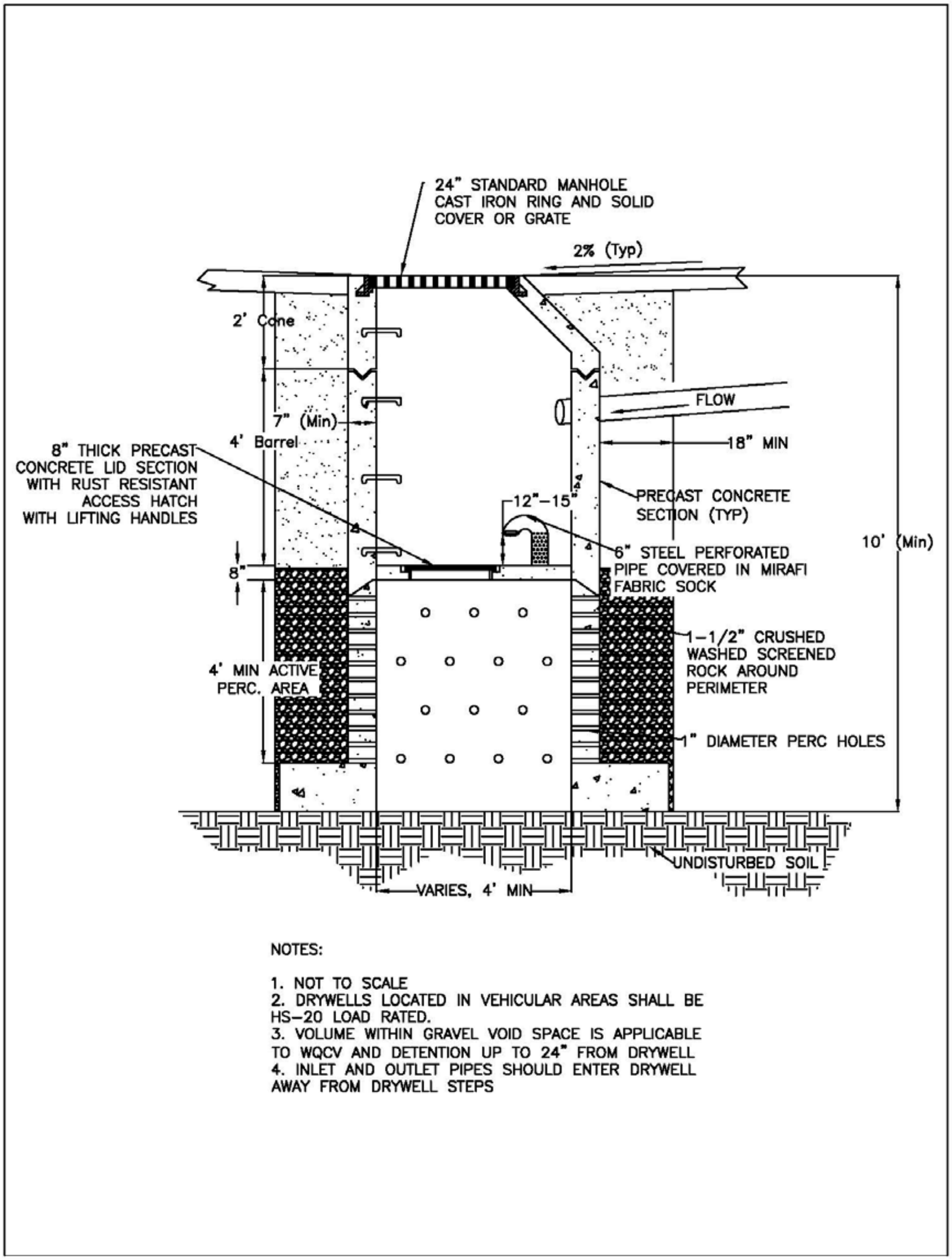
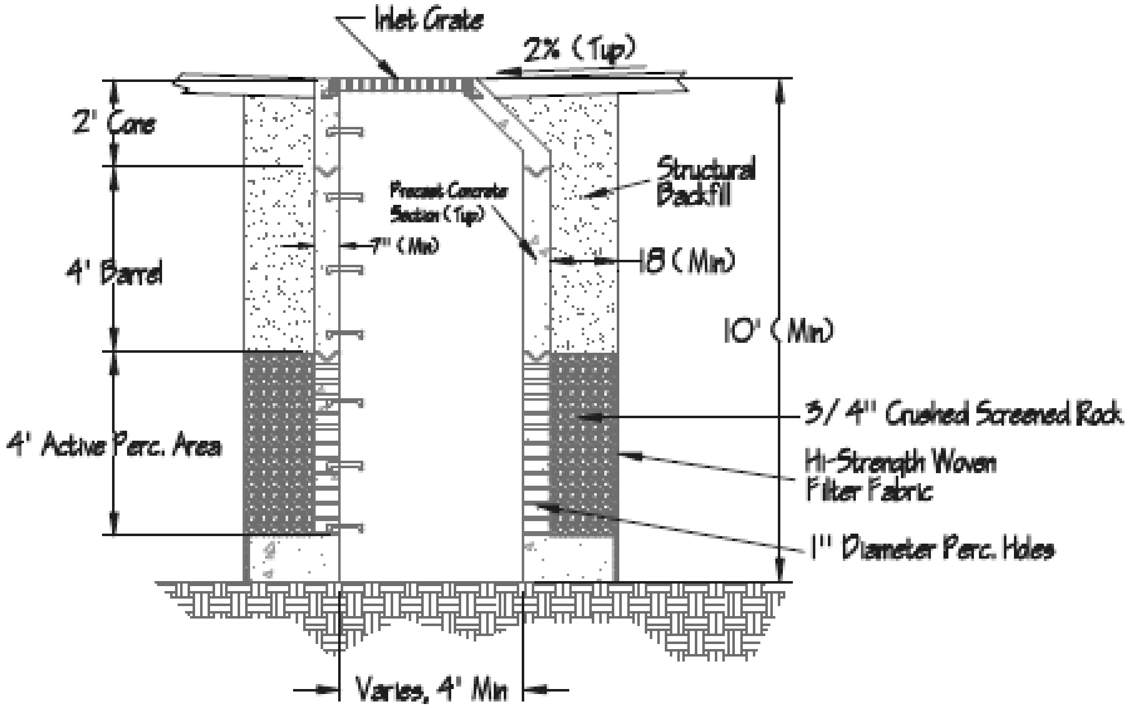


Figure 8.69 Typical WQCV Dry Well



Notes:

1. Drywell design is to be considered when other drainage options prove unfeasible.
2. Drywell diameter and depth must be based on professional hydraulic calculations (taking into account runoff volume and the surrounding soil's percolation rate).
3. Drywells may not be placed in City ROW or in City Easements.
4. Drywells must be cleaned periodically and as often as necessary to keep them performing at maximum capacity.
5. $\frac{3}{4}$" screened rock (wrapped in woven filter geotextile) is required to transition from drywell to native fill.

Figure 8.70 Typical "Detention Only" Dry Well

8.5.4.3 Proprietary Underground Treatment Devices

Proprietary underground treatment devices are allowable in Aspen as long as they meet the treatment objectives described in **Section 8.4** (90 percent removal of total suspended solids 60 microns and coarser for 80 percent of runoff events on an annual basis). It is the responsibility of the applicant to provide documentation that the BMP will meet this criterion. The City reserves the right to not accept any proprietary BMP proposed.

Documentation of performance must meet the following criteria:

1. Testing must consist of field data collected in substantial compliance with the Technology Acceptance and Reciprocity Partnership (TARP). Laboratory studies will not be considered. Information on the TARP program can be found in several locations on the internet including http://www.dep.state.pa.us/dep/deputate/pollprev/techservices/tarp/.

2. Data collected in environments similar to Aspen (i.e. high-mountain, cold climates). Data from other climates may be considered; however, the City may deem data collected in dissimilar locations (e.g. Florida) unacceptable.

Many studies have been conducted over the past decade to document the performance of proprietary BMPs. Sources of data that may be used to support using a proprietary BMP include the following:

- International Stormwater BMP Database (www.bmpdatabase.org).

- University of Massachusetts Amherst Stormwater Technologies Clearinghouse (www.mastep.net).

Other data sources may also be acceptable, provided they meet the documentation criteria above.

Maintenance of any underground BMP, proprietary or not, is of utmost importance. For proprietary BMPs, manufacturers' recommended maintenance shall be followed. Where frequency of inspection and maintenance activities vary from the requirements described above for dry wells, the stricter (more frequent) schedule shall be followed.

8.6 References

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