Description

This Fact Sheet provides criteria to quantify stormwater volume reduction when employing runoff reduction practices. The intent of this approach is to avoid the direct connection of impervious areas to the storm drain and instead, guide runoff from pavement and roofs to vegetated areas such as grass buffers and grass swales in a manner that maintains sheet flow conditions.

Photograph RR-1. Disconnecting impervious areas and distributing runoff over grass buffers and swales reduces runoff volume and downstream treatment requirements.

The runoff reduction practices described in this fact sheet can be used to eliminate or reduce the size of volumetric BMPs required for water quality capture volume (WQCV) treatment. For the purpose of stormwater management, the volume of stormwater reduced through runoff reduction using infiltration, depression storage, and evapotranspiration is synonymous to volume treated.

Reducing runoff is the first step of the four-step process for minimizing adverse impacts of urbanization as detailed in Chapter 1, *Stormwater Management and Planning*. Minimizing directly connected impervious areas (MDCIA) by allowing runoff from impervious areas to sheet flow through grass reduces pollutant loading in the receiving water and helps restore predevelopment hydrology.

Runoff Reduction	
Functions	
LID/Volume Red.	Yes
WQCV Capture	Yes
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Good
Total Metals	Good
Bacteria	Good
Other Considerations	
Life-cycle Costs	Low

[3] Based primarily on grass buffer data from the International Stormwater BMP Database (www.bmpdatabase.org).

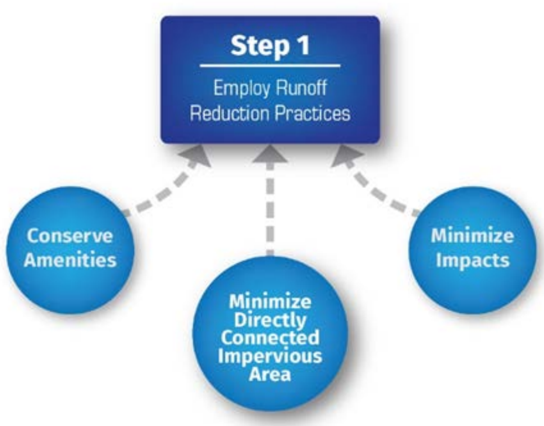


Figure RR-1. Employ runoff reduction practices. The first step in stormwater management is to create less stormwater runoff. We do this through minimizing directly connected impervious areas, conserving amenities such as trees and riparian corridors, and minimizing impacts by not adding more impervious areas than necessary.

Reducing runoff via sheet flow is frequently accomplished using grass buffers (with or without level spreaders) and grass swales where very shallow flow can be maintained. Fact Sheets T-1 and T-2 provide descriptions and additional criteria for grass buffers and swales; however, runoff reduction may be quantified for grass areas meeting criteria in this fact sheet even when all criteria in Fact Sheets T-1 and T-2 are not fully achieved.

Figure RR-2 shows a comparison of conventional stormwater practice to that of runoff reduction and demonstrates terminology used in this factsheet. In the conventional approach (shown left), a directly connected impervious area (DCIA) drains into a storm drain and bypasses the separate pervious area (SPA). In the runoff reduction approach (shown right) unconnected impervious area (UIA) drain to a slotted curb that distributes runoff evenly through a receiving pervious area (RPA).

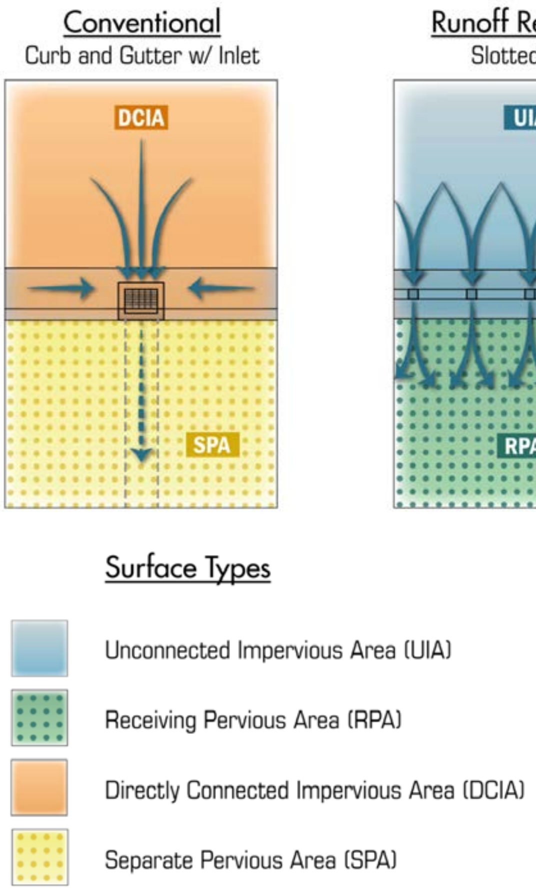


Figure RR-2. Comparison of conventional versus runoff reducing approach.

Benefits

- This practice often makes use of green space already planned as part of a site.
- Low cost.
- Straightforward maintenance requirements that can occur coincident with other landscape maintenance needs.

Limitations

- Frequently damaged by vehicles when adjacent to roadways and unprotected.
- Full vegetative cover, i.e., turf, is required to achieve volume reduction using these criteria.
- High loadings of coarse solids, trash, and debris require pretreatment or more frequent maintenance.
- Space may not be available in ultra-urban areas (lot-line-to-lot-line). In these cases, planters may be an alternative way to disconnect impervious areas

Site Selection

Review all sites to evaluate opportunities for MDCIA. These criteria are recommended where stormwater from impervious areas can be spread out as sheet flow onto pervious turf areas and where grass swales are used for conveyance.

Photograph RR-2. This level spreader accepts and distributes concentrated flow while providing a place for sediment to be removed with a flat shovel. Note: When using this concept for quantifying volume reduction, use a grass RPA and create a free draining condition from the lowest flow point onto the RPA.

Designing for Maintenance

During design, the following should be considered to ensure ease of maintenance over the long-term:

- Consider a level spreader that allows for removal of sediment such as the one shown in photo RR-2.
- Place the top of the RPA 4 to 6 inches below the adjacent UIA so that growth of vegetation and accumulation of sediment at the edge of the strip does not prevent runoff from entering the buffer.
- Provide temporary or permanent irrigation and adjust as necessary to provide water in amounts appropriate for the selected vegetation. Irrigation needs will change from month to month and year to year.
- Protect the RPA from vehicular traffic when using these criteria adjacent to roadways. This can be done with a slotted curb (or other type of barrier).
- Evaluate potential for sediment loading based on specifics of the site and provide a forebay to facilitate maintenance.

Design Procedure

Table RR-1 provides a summary of criteria and the following steps outline the procedure for quantifying stormwater volume reduction associated with MDCIA. The design example provided later in this Fact Sheet utilizes the *UD-BMP* workbook which performs the below calculations and also provides the composite volume reduction for a site with multiple UIA:RPA pairs as well as DCIA and SPA areas. The workbook tab provides the total volume reduced for the site as well as the percentage of WQCV treated.

Table RR-1. Parameters for quantifying runoff reduction.

Unconnected Impervious Area (UIA)	UIA should be approximately 1-acre or smaller although larger areas may be applicable with proper grading and flow distribution to the RPA. Multiple level spreaders may be needed for larger areas.
Wetted area of the Receiving Pervious Area (RPA) and flow characteristics	RPA must receive evenly distributed flow (sheet flow) from the UIA. Consider only the wetted area when delineating the RPA. Only the area that is directly within the flow path should be considered RPA. For swales, only the bottom width is considered RPA. See the design procedure for additional criteria and considerations for swales and buffers.
Vegetation of RPA	RPA vegetation should be turf grass (from seed or sod) with a uniform density of at least 80%. Dense native turf-forming grasses are recommended where a more natural look is desired. Turf grasses such as Kentucky bluegrass are also an option although require more irrigation. See the *Revegetation* chapter in Volume 2 of this manual with regard to seed mix selection, planting, and ground preparation. Depending on anticipated flows, consider erosion control measures until vegetation has been established.
Interface between UIA and RPA	The RPA must be protected from vehicle traffic and the interface between the UIA and the RPA must provide a vertical step to ensure runoff from UIA to RPA as sediment and grasses build up over time. See conceptual details provided in Figures RR–4 and RR-5.
Length-to Width of UIA:RPA pair	SWMM modeling for the development of this Fact Sheet was limited to a length-to-width ratio of the UIA:RPA pair between 0.06 and 16.0. When using this criteria outside of these limits, results may vary.
Slope of RPA	The slope of the RPA should be no greater than 3:1 (H:V).
UIA/RPA ratio	The recommended maximum UIA/RPA ratio is 10:1. Ratios greater than this may be appropriate with pretreatment and level spreaders in series. Pretreatment should also be considered as the ratio of UIA/RPA increases.
Soil Type and Preparation	These criteria are applicable to all hydrologic soil groups although performance is not equivalent. Conduct agronomic soil tests to determine required soil amendments and consult an ecologist or plant specialist for recommendations specific for the site and type of grass selected.
Underdrains	Analysis conducted for this Fact Sheet did not consider grass swales with underdrains. Data in the International BMP Database indicates presence of an underdrain reduces reduction of the WQCV in bioretention basins (Geosyntec Consultants and Wright Water Engineers, 2012). For this reason, UDFCD recommends these criteria not be used for quantification of volume reduction in bioretention basins (or similar BMPs) with underdrains.
Irrigation	Provide temporary or permanent irrigation systems, depending on the type of vegetation selected. Adjust irrigation application rates and schedules throughout the establishment and growing season as appropriate to meet the needs of the selected plant species. Initially, native grasses require the same irrigation requirements as bluegrass. After the grass is established, irrigation requirements for native grasses can be reduced.

1. **Locate and Delineate all UIA and RPA pairs on the site.** Locate vegetated areas down-gradient of impervious areas to maximize UIA and RPA and minimize DCIA and SPA. Note that lower UIA/RPA ratios provide increased volume reduction and decreased maintenance. It is also effective to break up large areas of UIA to provide a better distribution for the available RPA and reduce UIA flow lengths.

   Calculate the individual areas for each UIA and RPA pair. Determine all remaining DCIA and SPA and calculate individual areas of each.

   a. **Swales:** For UIA draining to a vegetated swale, spread flow the full bottom width of the swale. Discharge from the outlet of a pipe may need a structural measure to ensure flow from the pipe makes contact with the full bottom width of the swale. Consider energy dissipation and use of a forebay to slow and spread pipe discharge while providing a location for sediment removal. See Figure RR-4 for a concept detail of a sediment pad placed upgradient of a grass swale. Note the 4" vertical drop on entry to the sediment pad. This ensures flow will enter the RPA and not pond in the pavement when sediment and grasses build up over time.

   b. **Buffers:** For UIA draining to a vegetated buffer, flow may or may not be concentrated. Provide a level spreader or use the same guidance found in T-1 to assess the need for a level spreader (repeated below for convenience).

      Concentrated flows can occur when the width of the watershed (measured perpendicular to flow) differs from that of the grass buffer. Additionally, when the product of the watershed flow length and the interface slope (the slope of the watershed normal to flow at the grass buffer) exceeds approximately one, flows may become concentrated. Use the following equations to determine flow characteristics and reference *T-1 Grass Buffers* for a graphic representation of the variables:

$$\text{Sheet Flow: } \mathrm{FL(SI)} \leq 2 \qquad \text{Equation GB-2 (from Fact Sheet T-1)}$$

$$\text{Concentrated Flow: } \mathrm{FL(SI)} > 2 \qquad \text{Equation GB-3(from Fact Sheet T-1)}$$

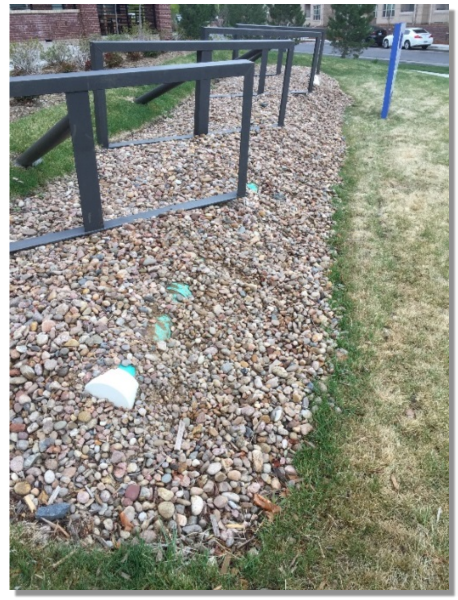
   Where:

   FL = watershed flow length (measured parallel to flow) (ft)

   SI = interface slope (slope of UIA/RPA interface normal to flow from the UIA) (ft/ft)

2. **Delineate the RPA and determine the UIA:RPA ratio:** Only pervious areas receiving flow from the UIA should be included in the calculated RPA. For swales, only the flat bottom width should be included. For buffers, only the area receiving stormwater in a distributed manner such that stormwater wets the entire width of the RPA should be used for this calculation. Land forms or variation in slope that could concentrate flows within the buffer or divert flows to other portions of the buffer should not be included. These criteria assume uniform sheet flow across the buffer.

   A level spreader should be used when flows from the UIA are concentrated. A level spreader can be a slotted drain designed to discharge flow through the slot as shown in Photo RR-2. It could be an exfiltration trench filled with gravel, which allows some stormwater to infiltrate prior to discharging over a level concrete curb. There are many ways to design and construct a level spreader. They can also be used in series when the length of the buffer allows flows to re-concentrate. See conceptual details for level spreaders provided in the T-1 Grass Buffers Fact Sheet.



Photograph RR-2. A perforated pipe packed in gravel receives concentrated flow from the roof top of an office building and discharges the flow to a grass buffer. Photo courtesy SEMSWA.

3. **Protect the UIA:RPA Interface and Provide a Vertical Drop:** The RPA must be protected from vehicular traffic. A slotted curb, as shown in Figure RR–5, can be used for this purpose. To ensure distributed flow across the RPA, place curb openings no more than 2 feet on center. The lip shown on the back side of the curb in Figure RR-5 establishes a vertical drop of 4 inches. This is required to ensure positive drainage from the UIA to RPA. This also provides a location for maintenance. Over time sediment will deposit in this location and the turf of the RPA may start to grow over this lip.

   For grass swales, referred to Figure RR-6. This figure shows a sediment pad at the entrance of the swale and also details a vertical drop of 4 inches.

4. **Characterize on-site topsoil and determine suitability of topsoil for the RPA:** The NRCS Web Soil Survey is a good resource for an initial investigation of site soils. However, only soil sampling and testing will confirm the actual NRCS Hydrologic Soil Group (HSG). Inexpensive lab tests quantify particle size based on sieve and hydrometer analyses to determine sand gradation and percent sand, silt, and clay for texture determination, and include agronomic tests for organic content, pH, salinity, and nutrients.

   UDFCD recommends onsite topsoil sampling and testing as a standard of practice on every project and as a requirement for sites utilizing this Fact Sheet. It is essential that soil conditions be characterized in order to select the most suitable soils for the RPA and determine appropriate amendments (some local governments may also require proof of soil conditions/amendment in landscaped areas for water conservation reasons). Characterization is also required to ensure use of the proper coefficients in equation RR-1.

   Plot the percent sand, silt, and clay of each sample on a USDA soil triangle and use this to confirm soil texture and HSG. Table RR-2 and Figure RR-3 indicate HSG based on percent sand, silt and clay according to the NRCS National Engineering Handbook (USDA, 2009). Based on the results of onsite soil sampling and testing, refer to Table RR-3 to select the most suitable soil from the site for use in the RPA.

See recommendations under Design Step 7, Soil Preparation, for recommendations where soils do not meet criteria for suitability for RPA.

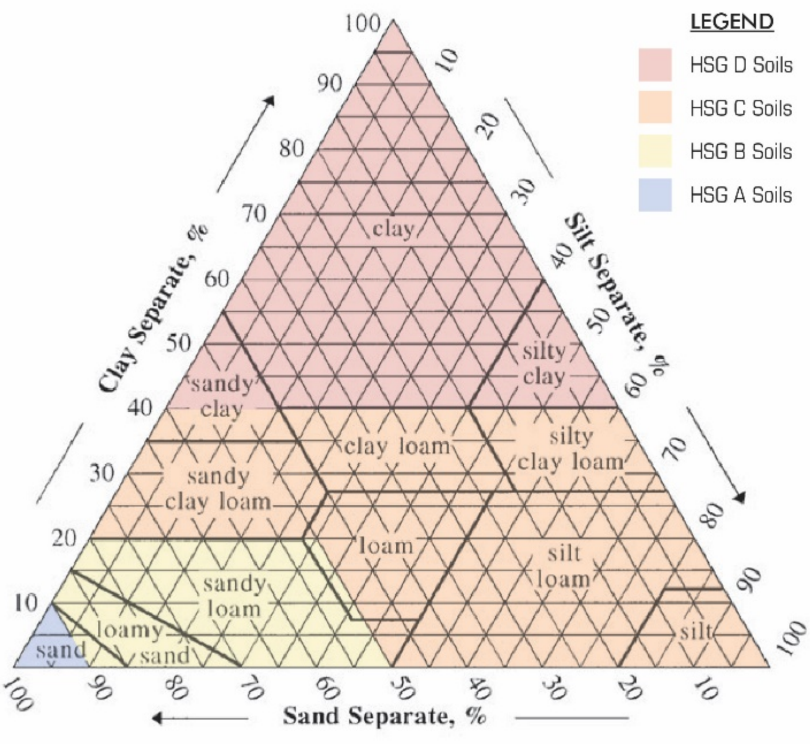


Figure RR-3. USDA Soil Triangle with USDA NRCS Soil Texture Classes overlain by USDA NEH Hydrologic Soil Groups

Table RR-2. Percent Sand, Silt, and Clay for HSG A through D.

HSG Group	% Sand	% Clay	% Silt
A	> 90%	< 10%	0 % < A < 10%
B	50 % < B < 90%	10 % < B < 20%	10 % < B < 50%
C	< 50%	20 % < C < 40%	0 % < C < 100%
D	< 50%	> 40%	0 % < D < 60%

Table RR-3. Topsoil Suitability Criteria for RPA.

Soil Parameter	Suitable	Less Suitable	Marginal	Unsuitable
Electrical Conductivity (EC)	0-4	4-8	8-12	>12
Sodium Adsorption Ratio (SAR)	0-4	4-8	8-13	>13
Exchangeable Sodium % (ESP)	<15		15-20	>20
Saturation Percentage	25-50		20-25 and 50-80	<20 and >80
Calcium Carbonate Percentage	<10%		10-20%	>20%
pH	6.0-8.0	5.0-5.5 and 8.0-8.5	5.0-5.5 and 8.5-9.0	<5.0
Texture	sandy loam, loam	sandy clay loam, silt loam, well-aggregated silty clay loam and clay loam	sandy clay, loamy sand, silty clay,silt, clay (<60%), disggreagated silty clay loam and clay loam	sand, clay (>60%)
Coarse Fragments (gravels, cobbles, boulders)	<25%		25-35%	>35
Nitrate Nitrogen (as accelerant for weed growth)	<10 ppm	10-15 ppm	>15 ppm	
Organic Matter	>2%	1%-2%	<1%	

5. **Calculate Runoff from each UIA:RPA pair:** In the UDFCD region, the precipitation depth associated with the WQCV event is 0.6 inches. For areas outside of the Denver Metro region, the precipitation depth for the WQCV event may differ. It should be noted that the methodology provided below is only valid for WQCV precipitation depths between 0.25 and 0.95 inches. Depths above 0.95 inches start to produce runoff from direct rainfall onto pervious areas which invalidates the methodology described below.

   Calculate the total runoff from each UIA:RPA pair using equation RR-1.

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

   Where:

   Q = Runoff from the total subarea (watershed inches)

   P_2 = Precipitation for 2-hour WQCV event (inches)

   A = total subarea, sum of UIA and RPA (ft^2)

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

   S = average overland slope (ft/ft)

I = subarea imperviousness (percent expressed as a decimal) calculated as (UIA / (UIA+RPA))

Cx = coefficients in Table RR-4 (determined through regression analysis)

Table RR-4. Coefficients for quantifying runoff from a UIA:RPA pair

Soil Type	**Constant** C_0	**Precip, P_2 (in)** C_1	**Area (ac)** C_2	**L:W** C_3	**Slope (ft/ft)** C_4	**%Imp** C_5	**%Imp^2** C_6
A	5.81E-01	-7.79E-01	-3.34E-07	-1.93E-03	7.03E-02	-2.49E+00	2.64E+00
B	-7.77E-02	-9.25E-01	-2.45E-07	-1.45E-03	5.02E-02	-1.36E-02	9.24E-01
C/D	-1.13E-02	-8.99E-01	-2.68E-07	-1.57E-03	5.45E-02	3.55E-01	4.64E-01

The Technical Memorandum entitled *Determination of Runoff Reduction Method Equations (UIA to RPA) based on Multivariable SWMM Analysis*, dated March 15, 2018 documents the derivation of these equations. This is available at www.udfcd.org.

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

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

Where:

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

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

6. **Compare runoff from each UIA:RPA pair to runoff from UIA alone:** For this step *UD-BMP* assumes a depression storage on the UIA of 0.1 inches. Using a WQCV precipitation of 0.6 inches, this equates to 0.5 watershed inches over the area of the UIA. For a runoff volume from the UIA multiply this value by the area of the UIA as shown in equation RR-3.

$$V_{UIA} = \left[\frac{(P_2 - d_{storage})}{12}\right] A_{UIA} \qquad \text{Equation RR-3}$$

Where:

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

P_2 = Precipitation for 2-hour WQCV event (inches)

$d_{storage}$ = impervious depression storage (inches)

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

The difference between this value (V_{UIA}) and that of Equation RR-2 is the volume reduction associated with the UIA:RPA configuration. The percentage of runoff reduction is represented by Equation RR-4.

$$\%\ \text{Runoff Reduction} = \frac{V_{UIA} - V_{UIA:RPA}}{V_{UIA}} \qquad \text{Equation RR-4}$$

Within the UDFCD region (WQCV precipitation depth of 0.60 inches), the runoff reduction percentage is equivalent to the WQCV reduction percentage. However, outside the UDFCD region, these percentages may differ based on the relationship between the 2-hour WQCV precipitation depth and the average runoff producing storm's precipitation depth, d_6 (Figure 3-1 in USDCM Vol. 3) which is used to adjust the calculated WQCV (Equation 3-2 in USDCM Vol. 3).

How much is enough?

When using this BMP as standalone treatment for the WQCV, the MS4 Phase 2 Permit requires reduction of 60% of what the calculated WQCV would be if all impervious area for the applicable development site discharged without infiltration. However, some municipalities may have more stringent requirements. In either case, downstream BMPs may be required and the *UD-BMP* tool can help size those while accounting for volume reduction utilizing this method.

Use Table RR-5 for a quick reference when sizing RPAs to reduce 60% or 100% of the WQCV.

Table RR-5. Quick Reference for Sizing RPAs[1]

Soil Type	UIA:RPA Ratio for 60% WQCV Reduction	UIA:RPA Ratio for 100% WQCV Reduction
A	7.2:1	3.7:1
B	3.4:1	1.9:1
C	2:1	1:1

[1]Table RR-5 assumes a WQCV precipitation of 0.6 inch. Ratios are valid for slopes up to 33 percent.

7. **Soil Preparation:** Soil preparation is required in addition to sampling and testing because construction tends to disturb soil horizons, remove organic topsoil, and overly compacted site soils. On the design plans, specify construction practices to achieve desirable soil conditions. If on-site topsoil is suitable as determined by Table RR-3, strip, stockpiled, and reuse it. Note that topsoil falling under the categories of "Less Suitable" and "Marginal" in this table will require amendments. Based on the onsite topsoil sampling and testing, use the most suitable topsoil from the site in the RPA.

   On most development sites, vegetation comprises only a portion of the site; enabling the depth of topsoil placed in these areas to be greater than the average depth stripped over the site. With this in mind, place as much topsoil as available. Where this results in a depth of topsoil less than 12-inches, subgrade soils should be sampled and tested for salinity. Regardless of topsoil thickness, subgrade should be tilled to a depth of at least 18 inches below the finished ground surface. Where topsoil was found to be less suitable or marginal refer to the recommendations of an ecologist or plant specialist and the recommendations listed below.

High salinity. High salinity, in particular excessive sodium, is the most serious problem that can render a soil unsuitable. In this case, alternative sources of topsoil should be located either from the site or from an imported source. However, if an imported source is considered, all the same sampling, testing, and remedial actions described herein for onsite soils are should be undertaken for the proposed source of imported topsoil during the design phase when HSG needs to be determined for use in the workbook tab.

Low pH (acidic soils). The traditional solution for low-pH soils is addition of agricultural lime.

Sand texture. Sand is problematic for use in the RPA due to poor moisture holding capacity to support vegetation and low capacity to adsorb dissolved pollutants. Topsoil comprised of fine sand (at least 70% passing the #35 (0.5 mm) sieve) may be able to be mixed with finer textured topsoil to move into a more suitable texture class). Courser sand (less than 70% passing the #35 (0.5 mm) sieve) is not considered suitable for use in the RPA.

Clay texture. Clay is problematic for use in the RPA due to extremely low infiltration rates and the tendency to lead to boggy conditions in the RPA that are difficult to maintain. Preservation of an aggregated soil structure, if present in onsite topsoil, and avoidance of compaction can help. Addition of weed free Class A compost or light-weight expanded clay products (perlite, vermiculite, and other products made by heating naturally occurring clays) may be useful in improving clayey soil textures, but topsoil with a clay content in excess of 60% is generally unsuitable for use in the RPA regardless of remedial actions. In this case, alternative sources of topsoil should be located either from the site or from an imported source, and any imported source must be thoroughly sampled and tested during the design phase to confirm its suitability for use in the RPA.

High nitrate nitrogen. Because nitrate nitrogen can encourage weed proliferation even at levels considered low by agricultural standards, care is necessary to avoid selecting topsoil with high nitrate nitrogen, and especially to use caution when considering lab results that may recommend application of nitrogen fertilizers, typically based on agricultural considerations.

Low organic matter. Low organic matter can be addressed, at least for the short term via addition of weed-free Class A compost. Another option for addressing low organic matter is the addition of Biosol, a slow-release organic fertilizer.

7. **Vegetation:** This is the most critical component for reduction and improved water quality. These criteria are based on a vegetative cover of approximately 80% (i.e., grass cover). Select durable, dense, and drought tolerant grasses. Turf grasses such as Kentucky bluegrass are often selected due to these qualities[1]. Dense native turf grasses may also be selected where a more natural look is desirable. Once established, these provide the benefit of lower irrigation requirements. See the *Revegetation* chapter in Volume 2 of this manual with regard to seed mix selection, planting and ground preparation. Depending on soils and anticipated flows, consider erosion control measures until vegetation has been established.

[1] Although Kentucky bluegrass has relatively high irrigation requirements to maintain a lush, green aesthetic, it also withstands drought conditions by going dormant. Over-irrigation of Kentucky bluegrass is a common problem along the Colorado Front Range, and it can be healthy, although less lush, with much less irrigation than is typically applied.

8. **Irrigation**: Equip each RPA with an irrigation systems to promote establishment and survival in Colorado's semi-arid environment. Systems may be temporary or permanent, depending on the type of vegetation selected. Irrigation application rates and schedules should be developed and adjusted throughout the establishment and growing season to meet the needs of the selected plant species. Initially, native grasses require the same irrigation requirements as bluegrass. After the grass is established, irrigation requirements for native grasses can be reduced. Irrigation practices have a significant effect on the function of the grass buffer. Overwatering decreases the permeability of the soil, reducing the infiltration capacity and contributing to nuisance baseflows. Conversely, under watering may result in delays in establishment of the vegetation in the short term and unhealthy vegetation that provides less volume reduction and increased susceptibility to rill erosion over the long term.

9. **Outflow Collection**: Provide a means for downstream conveyance of flows in excess of that which will be reduced through infiltration and evapotranspiration. Also note that the *UD-BMP* tool will calculate total volume reduction for the WQCV event as well as percentage of the WQCV treated through reduction. However, it is important to understand that these design points may be in different locations and additional treatment may be required for the remaining WQCV.

Construction Considerations

Success depends not only on a good design and long-term maintenance, but also on construction of the BMP to function as designed. Construction considerations are listed below.

Photograph RR-3. Landscaping in the RPA (the grass swale) is too high to allow stormwater into the vegetation. Ensure a grade differential where UIA meets RPA. Photo courtesy of SEMSWA.

- The final grade of the RPA must be lower than the UIA. A grade differential of 4 to 6 inches is recommended to ensure sediment deposit over time does not impede flow into the RPA. Oftentimes, following soil amendment and placement of sod, the final grade is too high to accept sheet flow. The RPA should be inspected prior to placement of seed or sod to ensure appropriate grading.

- Perform soil amending, fine grading, and seeding after tributary areas have been stabilized and utility work crossing the buffer has been completed.

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

- Avoid over compaction of soils during construction to preserve infiltration capacities.

- Erosion and sediment control measures on upgradient disturbed areas must be maintained to prevent excessive sediment loading.

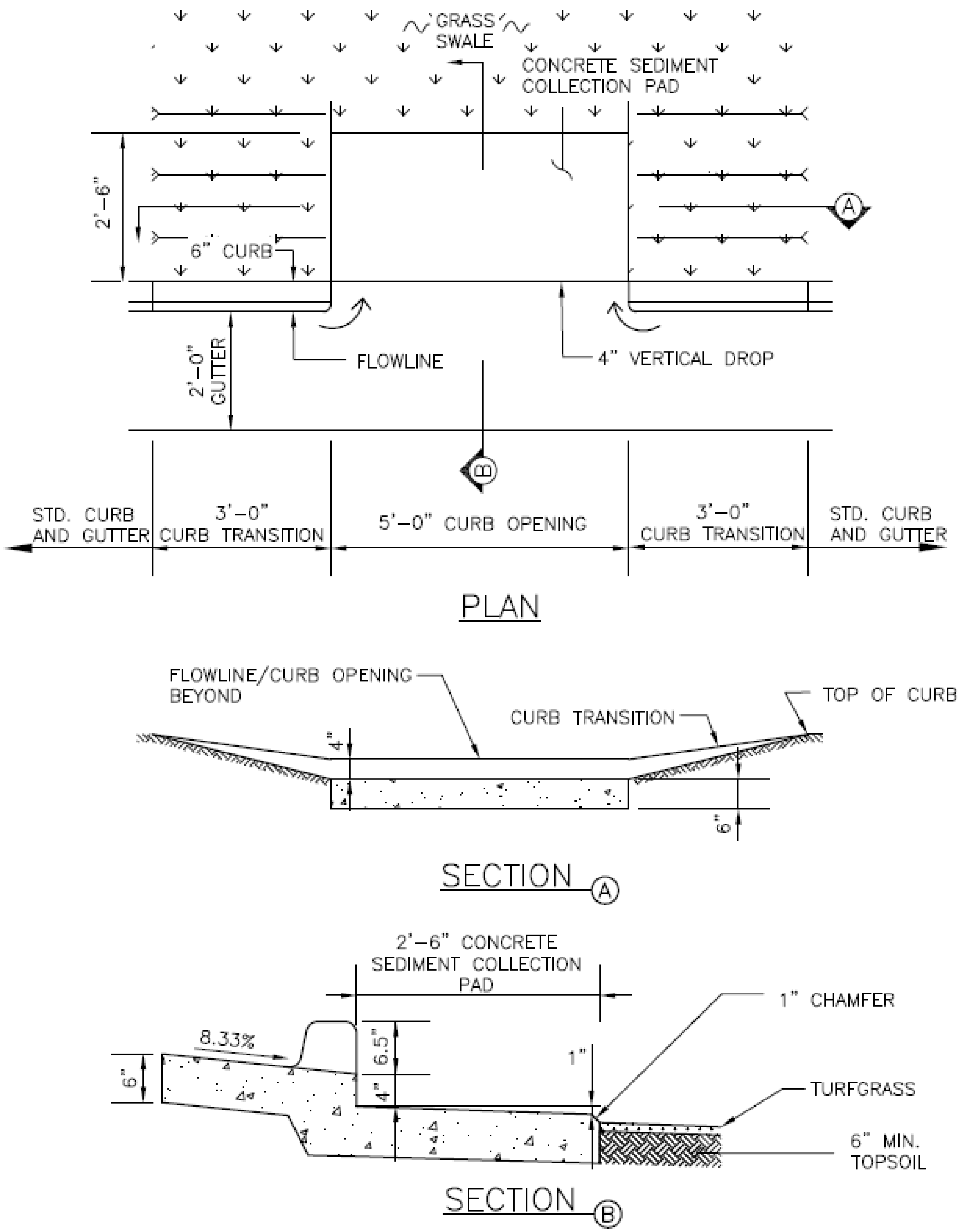


Figure RR-4. Sediment pad for curb opening to grass swale.

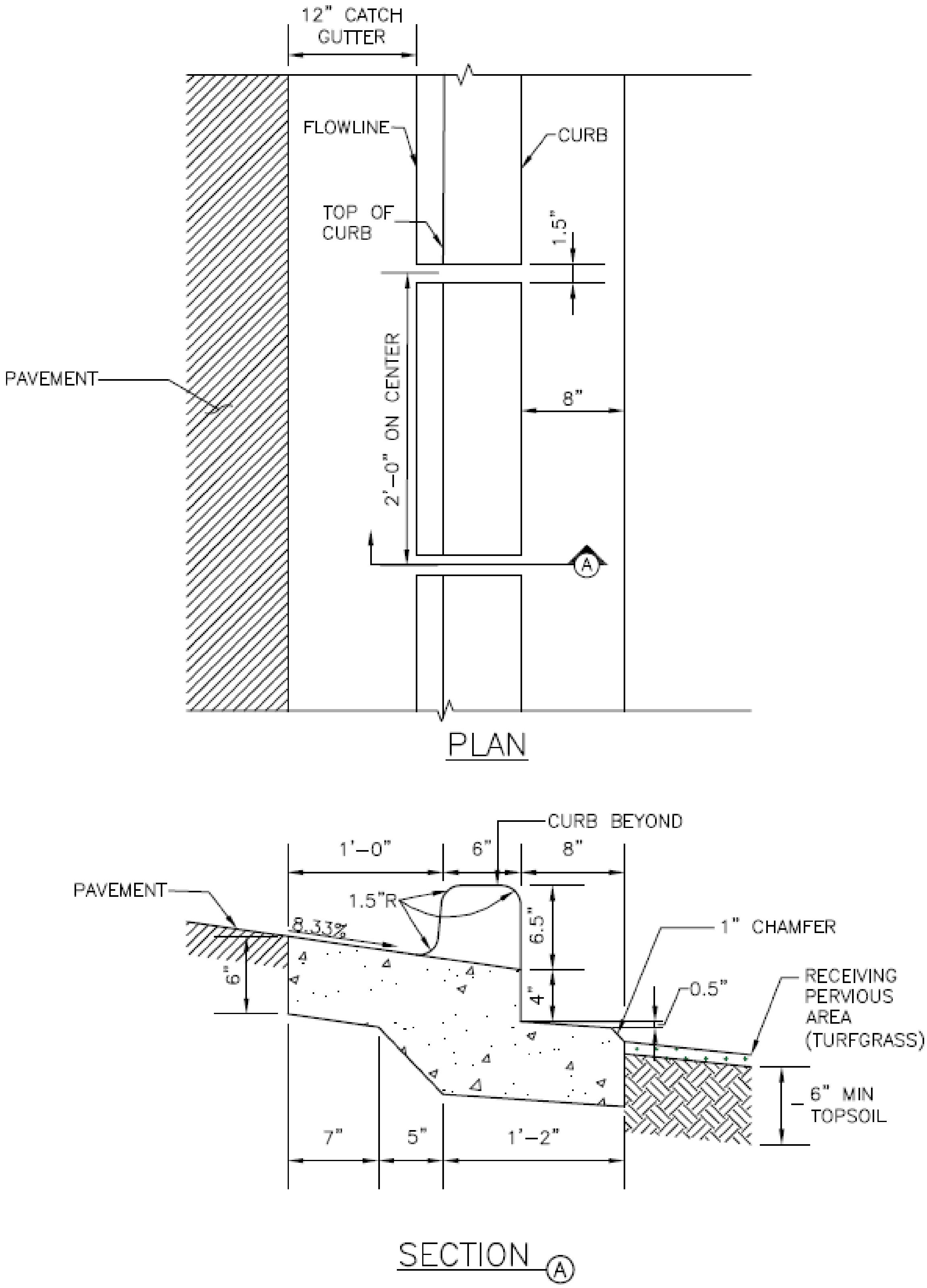


Figure RR-5. Slotted curb.

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.UDFCD.org. This section provides a completed design form from this workbook as an example.

A small commercial property has been divided into UIA:RPA pairs, DCIA and SPA. Soil type for all RPA and SPA is HSG C/D. Note that not all grassed areas can be counted as RPA, in the case of a buffer or grass swale, sheet flow must be maintained. What percentage of the WQCV can be treated by quantifying volume reduction associated with the UIA:RPA configuration?

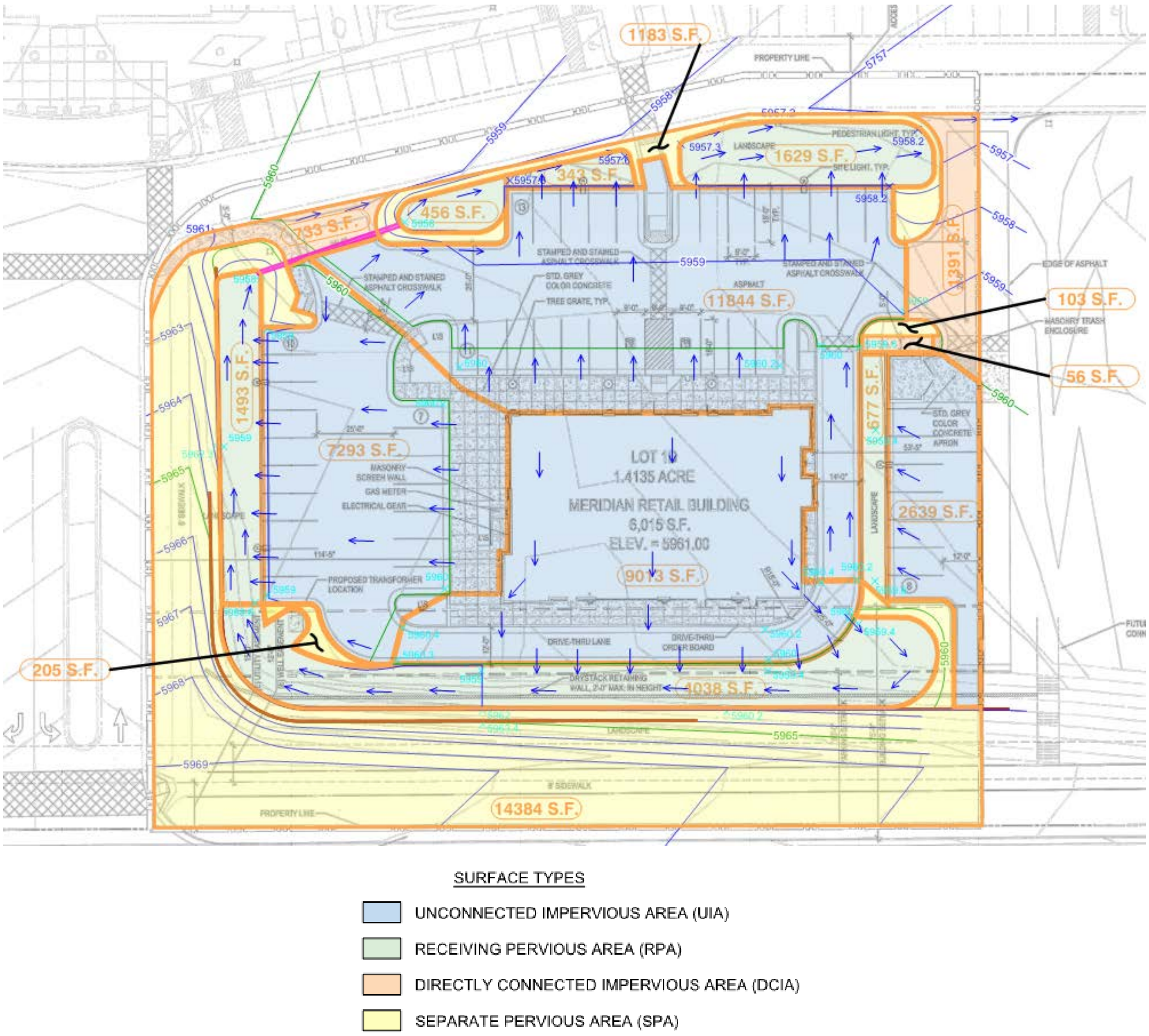


Figure RR-6. Example site runoff reduction configuration.

Step 1. Input Site Information (depending on "Area Type" the user will populate blue fields). Use the *Downstream Design Point ID* field to identify a common location where individual sub areas (separate columns) meet. In this example, some areas flow directly offsite (columns 1 through 3) while the remainder (columns 4 through 9) are all directed to an outfall at the northeast corner of the site.

SITE INFORMATION (User Input in Blue Cells)

WQCV Rainfall Depth	0.60	inches
Depth of Average Runoff Producing Storm, d_6 =	0.43	inches (for Watersheds Outside of the Denver Region, Figure 3-1 in USDCM Vol. 3)

Area Type	DCIA	DCIA	SPA	SPA	SPA	UIA:RPA	UIA:RPA	UIA:RPA	UIA:RPA	
Area ID	1	2	3	4	5	6	7	8	9	
Downstream Design Point ID	offsite	offsite	offsite	NE corner	NE corner	NE corner	NE corner	NE corner	NE corner	
Downstream BMP Type	None	None	None	None	None	None	None	None	None	
DCIA (ft^2)	733	1,391	--	--	--	--	--	--	--	
UIA (ft^2)	--	--	--	--	--	9,013	7,293	11,844	2,639	
RPA (ft^2)	--	--	--	--	--	4,038	1,493	2,428	677	
SPA (ft^2)	--	--	14,589	1,183	103	--	--	--	--	
HSG A (%)	--	--	0%	0%	0%	0%	0%	0%	0%	
HSG B (%)	--	--	0%	0%	0%	0%	0%	0%	0%	
HSG C/D (%)	--	--	100%	100%	100%	100%	100%	100%	100%	
Average Slope of RPA (ft/ft)	--	--	--	--	--	0.050	0.050	0.050	0.050	
UIA:RPA Interface Width (ft)	--	--	--	--	--	154.00	88.00	105.00	78.00	

Step 2. Calculate Runoff Results for each sub-area (no additional data entry required)

CALCULATED RUNOFF RESULTS

Area ID	1	2	3	4	5	6	7	8	9
UIA:RPA Area (ft^2)	--	--	--	--	--	13,051	8,786	14,272	3,316
L / W Ratio	--	--	--	--	--	0.55	1.13	1.29	0.55
UIA / Area	--	--	--	--	--	0.6906	0.8301	0.8299	0.7958
Runoff (in)	0.50	0.50	0.00	0.00	0.00	0.14	0.29	0.29	0.25
Runoff (ft^3)	31	58	0	0	0	151	210	339	70
Runoff Reduction (ft^3)	0	0	729	59	5	224	94	154	40

Step 3. Calculate WQCV Results for each sub-area (no additional data entry required)

CALCULATED WQCV RESULTS

Area ID	1	2	3	4	5	6	7	8	9
WQCV (ft^3)	31	58	0	0	0	376	304	494	110
WQCV Reduction (ft^3)	0	0	0	0	0	224	94	154	40
WQCV Reduction (%)	0%	0%	0%	0%	0%	60%	31%	31%	37%
Untreated WQCV (ft^3)	31	58	0	0	0	151	210	339	70

Step 4. Calculate reduction and WQCV results for each design point (no additional data entry required)

CALCULATED DESIGN POINT RESULTS (sums results from all columns with the same Downstream Design Point ID)

Downstream Design Point ID	offsite	NE corner						
DCIA (ft^2)	2,124	0						
UIA (ft^2)	0	30,789						
RPA (ft^2)	0	8,636						
SPA (ft^2)	14,589	1,286						
Total Area (ft^2)	16,713	40,711						
Total Impervious Area (ft^2)	2,124	30,789						
WQCV (ft^3)	89	1,283						
WQCV Reduction (ft^3)	0	512						
WQCV Reduction (%)	0%	40%						
Untreated WQCV (ft^3)	89	771						

Step 5. Calculate reduction and WQCV results for the site (no additional data entry required)

CALCULATED SITE RESULTS (sums results from all columns in worksheet)

Total Area (ft^2)	57,424
Total Impervious Area (ft^2)	32,913
WQCV (ft^3)	1,371
WQCV Reduction (ft^3)	512
WQCV Reduction (%)	37%
Untreated WQCV (ft^3)	859

Summary and Discussion. Using MDCIA at this site, we treat 37 percent of the WQCV. A small bioretention basin could be placed at the northeast corner of the site to treat remaining flows at the “NE corner” design point. To do this, return to Step 1 and use the pull-down menu to select a BMP in the *Downstream BMP Type* field. The spreadsheet will size treatment volume based on the drain time of the BMP (while still accounting for the volume reduction). BMP sizing is detailed in Chapter 3 of the manual.

True site configuration and grading were used for this example. Site grading limited how much of the site could be used for RPA versus SPA. If more of the SPA could be converted to RPA, WQCV requirements could be satisfied with this method alone, even with Type C\D soils. Note that using this same example with Type B and Type A soils results in treatment of 57 percent and 86 percent respectively.

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