Appendix A Compliance Calculations and Design Examples

A.1 General Retention Compliance Calculator

The General Retention Compliance Calculator is an Excel file located on the DDOE website at http://ddoe.dc.gov/swregs.

Each regulated project must use the General Retention Compliance Calculator to demonstrate proper BMP selection and sizing to achieve the required amount of stormwater retention and/or water quality treatment. The completed worksheets from this calculator must be submitted with the Stormwater Management Plan (SWMP). All major regulated projects are required to address the Stormwater Retention Volume (SWRv), and major regulated projects in the Anacostia Waterfront Development Zone (AWDZ) are required to address the Water Quality Treatment Volume (WQTv), as described in Chapter 2.

The General Retention Compliance Calculator can also be used, in addition to other hydrologic methods and models, to demonstrate compliance with detention obligations (see Section 2.6 and Appendix H).

A.2 Instructions for Compliance Calculations

The following guidance explains how to use each of the worksheet tabs in the General Retention Compliance Calculator.

Note: All cells highlighted in blue are user input cells. Cells highlighted in gray are calculation cells, and cells highlighted in yellow are constant values that generally should not be changed.

Site Data Sheet

1. Input the name of the proposed project on **line 9**.
2. Determine if the site is located in the AWDZ and note in **cell E13**.
3. Determine if the site is located in the MS4 and note in **cell E14**.
4. The regulatory rain event for calculation of the SWRv varies depending upon the type of development. For major land-disturbing activities, the SWRv is based upon the 90th percentile depth (1.2 inches). For major substantial improvements, the SWRv is based upon the 80th percentile depth (0.8 inches). If the site is in the AWDZ and undergoing major substantial improvement, the SWRv is based upon the 85th percentile depth (1.0 inches). Choose the type of development on **line 15**. The regulatory rain event for SWRv will be shown on **line 16**, and the regulatory rain event for the WQTv (if applicable) will be shown on **line 17**.

5. For the site, indicate the area (in square feet) of post-development Natural Cover, Compacted Cover, and best management practice (BMP) surface area in **cells D22–D25**. Guidance for various land covers is provided in Table A.1. Efforts to reduce impervious cover on the site and maximize Natural Cover will reduce the required Stormwater Retention Volume (SWRv). Portions of a project located in the public right-of-way should be considered separately from the rest of the site and surface area by cover type should be indicated in **cells E22–E25**.

   Note: This step will be iterative as BMP sizing is performed, and the area of both BMPs and other land cover types are adjusted.

6. From the land cover input, weighted site-runoff coefficients (*Rv*) will be calculated (**line 33**) for both the site and the public right-of-way based upon the land cover *Rv* values of 0.00 for Natural Cover, 0.25 for Compacted Cover, and 0.95 for Impervious Cover.

$$\%N = AN/SA \times 100$$

$$\%C = AC/SA \times 100$$

$$\%I = AI/SA \times 100$$

$$Rv = (\%N \times RvN + (\%C) \times RvC + (\%I) \times RVI$$

where:

$\%N$	=	percent of site in natural cover
AN	=	area of post-development natural cover (ft^2)
$\%C$	=	percent of site in compacted cover
AC	=	area of post-development compacted cover (ft^2)
$\%I$	=	percent of site in impervious cover
AI	=	area of post-development impervious cover (ft^2)
SA	=	total site area (ft^2)
Rv	=	weighted site runoff coefficient
Rv_N	=	runoff coefficient for natural cover (0.00)
Rv_C	=	runoff coefficient for compacted cover (0.25)
Rv_I	=	runoff coefficient for impervious cover (0.95)

7. The SWRv that must be retained on the site and in the PROW will be calculated on **line 37**.

$$SWRv = P/12 \times Rv \times SA$$

where:

SWRv	=	Stormwater Retention Volume (ft^3)
P	=	regulatory rain event (in.)
12	=	conversion from inches to feet
Rv	=	weighted site runoff coefficient
SA	=	total site area (ac)

8. If the site is in the AWDZ, the WQTv that must be treated on site and in the PROW will be calculated on **line 39**. The regulatory rain event for calculation of the WQTv is based upon the 95th percentile depth (1.7 inches).

$$WQTv = P/12 \times Rv \times SA$$

where:

WQTv	=	stormwater treatment volume (ft^3)
P	=	regulatory rain event (1.7 in.)
12	=	conversion from inches to feet
Rv	=	weighted site runoff coefficient
SA	=	total site area (ac)

Table A.1 Land Cover Guidance for General Retention Compliance Calculator, consult Appendix N for more details.

Natural Cover
Land that will remain undisturbed and exhibits hydrologic properties equal to or better than meadow in good condition OR land that will be restored to such a condition. This includes: ▪ Portions of residential yards in forest cover that will NOT be disturbed during construction. ▪ Community open space areas that will not be mowed routinely, but left in a natural vegetated state (can include areas that will be rotary mowed no more than two times per year). ▪ Utility rights-of-way that will be left in a natural vegetated state (can include areas that will be rotary mowed no more than two times per year). ▪ Other areas of existing forest and/or open space that will be protected during construction and that will remain undisturbed. Operational and Management Conditions in Natural Cover Category: ▪ Undisturbed portions of yards, community open space, and other areas that will be considered as forest/open space must be shown outside the Limits of Disturbance (LOD) on an approved Soil Erosion and Sediment Control Plan (SESCP) AND demarcated in the field (e.g., fencing) prior to commencement of construction. ▪ Portions of roadway rights-of-way that will count as natural cover are assumed to be disturbed during construction, and must follow the most recent design specifications for soil restoration and, if applicable, site reforestation, as well as other relevant specifications if the area will be used as a BMP. ▪ All areas that will be considered natural cover for stormwater purposes must have documentation that prescribes that the area will remain in a natural, vegetated state. Appropriate documentation includes: subdivision covenants and restrictions, deeded operation and maintenance agreements and plans, parcel of common ownership with maintenance plan, third-party protective easement, within public right-of-way or easement with maintenance plan, or other documentation approved by DDOE. ▪ While the goal is to have natural cover areas remain undisturbed, some activities may be prescribed in the appropriate documentation, as approved by DDOE: forest management, control of invasive species, replanting and revegetation, passive recreation (e.g., trails), limited bush hogging to maintain desired vegetative community, etc. ▪ Land that will undergo conversion from compacted cover or impervious cover to natural cover must follow the guidelines for compost amended soils in Appendix J.
Compacted Cover
Land disturbed and/or graded for eventual use as managed turf or landscaping. Managed turf comprises of areas that are graded or disturbed, and maintained as turf, including yard areas, septic fields, residential utility connections, and roadway rights of way. Landscaping includes areas that are intended to be maintained in vegetation other than turf within residential, commercial, industrial, and institutional settings.
Impervious Cover
Roadways, driveways, rooftops, parking lots, sidewalks, and other areas of impervious cover. While they are noted separately in the spreadsheet, the surface area of all BMPs, except disconnection areas are included with impervious cover in the spreadsheet's calculations.

Drainage Area Sheets 1–10

If the site has multiple discharge points, or complex treatment sequences, it must be divided into individual drainage areas (DAs). For each DA, a minimum of 50 percent of the SWRv must be retained. In the MS4, if 50 percent of the SWRv cannot be retained, that volume (or equivalent 24-hour storm) must be captured and treated with an accepted TSS treatment practice.

For each DA sheet:

1. Indicate the specific area of post-development Natural Cover, Compacted Cover, Impervious Cover, Vehicular Access, and BMP surface area in **lines 6–10**. The SWRv for the DA will be calculated in **cell G12**, and the WQTv (if in the AWDZ) will be calculated in **cell G17**.

   Note: This step will be iterative as BMP sizing is performed, and the area of both BMPs and other land cover types is adjusted. Vehicular Access Areas are a sub-category of Impervious Cover. Therefore, the Vehicular Access Areas must be included as a part of the total Impervious Cover area.

2. Apply BMPs to the drainage area to address the required SWRv and WQTv by indicating the area in square feet of compacted cover, impervious cover, and vehicular access areas (see not above) to be treated by a given BMP in **columns B, D,** and **F** (or the number of trees in the case of tree preservation or planting). This will likely be an iterative process. The available BMPs include the following:

   - Green Roofs
   - Rainwater Harvesting
   - Simple Disconnection to a Pervious Area (Compacted Cover)
   - Simple Disconnection to a Conservation Area (Natural Cover)
   - Simple Disconnection to Amended Soils
   - Permeable Pavement Systems - Enhanced
   - Permeable Pavement Systems - Standard
   - Bioretention - Enhanced
   - Bioretention - Standard
   - Stormwater Filtering Systems
   - Stormwater Infiltration
   - Grass Channels
   - Grass Channel with Amended Soils
   - Dry Swales
   - Wet Swales
   - Stormwater Ponds
   - Stormwater Wetlands
   - Storage Practices
   - Proprietary Practices
   - Tree Planting
   - Tree Preservation

3. Based upon the area input for a given BMP, the spreadsheet will calculate the Maximum Retention Volume Received by BMP in **column H**. Regardless of the Regulatory Rainfall Event that applies to the site, the volume calculated in **column F** is based on a rainfall depth of 1.7 inches. Therefore, the value in **column H** represents the greatest retention volume for which a BMP can be valued, rather than the volume that must be retained to achieve compliance. In other words, it is possible to “oversize” BMPs in one drainage area and “undersize” others to achieve compliance. However, as noted above, in the MS4, a minimum of 50 percent of the SWRv must be retained in each drainage area. Otherwise, treatment of the remaining runoff to reach 50 percent of the SWRv must be provided by an accepted TSS treatment practice.

$$V_{max} = 1.7/12 \times (Rv_N \times A_N + Rv_C \times A_C + Rv_I \times (A_I + A_{BMP}))$$

where:

V_{max} = volume received by the BMP from 1.7-inch rain event (ft^3)
Rv_N = runoff coefficient for natural cover (0.00)
A_N = area of post-development natural cover (ft^2)
Rv_C = runoff coefficient for compacted cover (0.25)

A_C = area of post-development compacted cover (ft^2)
Rv_I = runoff coefficient for impervious cover (0.95)

A_I = area of post-development impervious cover (ft^2)
A_{BMP} = area of BMP (ft^2)

4. As noted in Chapter 2, for all vehicular access areas, a minimum of 50percent of the SWRv must also be retained or treated. This volume is calculated for each BMP in **column G** as follows:

$$V = RRE/12 \times Rv_I \times Av \times 0.5$$

where:

V = volume received by the BMP from vehicular access areas that must be retained or treated (ft^3)
RRE = Regulatory Rain Event for SWRv (in.)
Rv_I = runoff coefficient for impervious cover (0.95)
Av = area of vehicular access area (ft^2)

5. If more than one BMP will be employed in series, any overflow from upstream BMPs will be accounted for in **column L**, and the total volume directed to the BMP will be summed in **column M**.

6. For most BMPs it is necessary to input the surface area of the BMP and/or the storage volume of the BMP in **columns N** and **O**. These should be calculated using the equations provided in Chapter 3.
7. The spreadsheet calculates a retention volume value in **columnP**, based on the value descriptions in **columns I–K**. Regardless of the storage volume of the BMP, the retention volume value cannot be greater than the total volume received by the BMP (**column M**).
8. The Potential Retention Volume Remaining (**column Q**) equals the total volume received by the BMP minus the retention volume value.
9. BMPs that have a less than 100 percent retention value and are accepted TSS treatment practices are assigned additional treatment volume based upon the lesser of the runoff volume received by the BMP and the actual storage volume minus the retention value. This additional treatment volume is indicated in **column R**.
10. Any potential retention volume remaining (**column Q**) can be directed to a downstream BMP in **column S** by selecting from the pull-down menu. Selecting a BMP from the menu will automatically direct the retention volume remaining to **column L** for the appropriate BMP.
11. **Column T** calculates whether or not the vehicular access area directed to each BMP is adequately addressed, via retention or treatment. To do this, the required runoff volume from the vehicular access area is compared to the retention and treatment volumes provided by the BMP, as well as from a downstream BMP, if selected. For each BMP that receives vehicular access runoff, “Yes” or “No” will be displayed. It should be noted that while this column does take downstream BMPs into account, it is not a precise enough check to ensure that all possible design variations are accounted for. Sufficient retention or treatment from vehicular access areas must be clearly shown on the design plans.
12. From the selected BMPs, the total volume retained will be summed in **cell P66**. The retention volume remaining will then be calculated as the difference between the SWRv and the total volume retained in **cell P68** (in cubic feet) and **cell P69** (in gallons). **Cell P71** indicates if at least 50 percent of the SWRv has been retained for the DA.
13. **Cell P72** indicates whether or not all of the vehicular access areas have been adequately addressed. This is accomplished with two checks. First, the cell checks that the entire vehicular access area for the drainage area indicated in **cell B9** has been included in **column F**, by comparing **cell F66** to **cell B9**. Second, the cell checks that sufficient retention or treatment volume has been provided in each BMP by searching for “No’s” in **column T**. As noted above, this check is not precise enough to ensure that all possible design variations are accounted for. Sufficient retention or treatment from vehicular access areas must be clearly shown on the design plans.
14. If in the MS4, if 50 percent of the SWRv has not been retained, **cell P73** indicates that treatment is required.
15. From the selected BMPs, **cell T66** is the sum of the total volume treated. If treatment is required due to a shortage of retention, **cells T68** (cubic feet) and **T69** (gallons) indicate how much more runoff must be treated. If treatment is required because the site is located in the AWDZ, **cells T71** (cubic feet) and **T72** (gallons) indicate how much runoff must be treated to meet WQTv requirements.

16. **Cell P75** will indicate compliance for the DA with a "Yes" or "No," depending on retention and treatment volume provided in the drainage area.

    Note: Since only 50 percent of the SWRv must be retained in any individual DA, compliance in each drainage area does not automatically mean that compliance for the entire site has been achieved.

Public Right-of-Way Sheet

The Public Right-of-Way sheet is functionally identical to the Drainage Area sheet; therefore, Steps 1–16 should be followed as stated above. If SWRv or WQTv is not met, the site may still comply if it follows the Maximum Extent Practicable (MEP) process as described in Appendix B.

Compliance Worksheet Tab

The Compliance worksheet summarizes the stormwater retention and treatment results for each DA as well as the whole site. For all sites, in order to comply with the stormwater management requirements, each DA must indicate that the vehicular access areas volume has been addressed. In the MS4, each DA must either indicate that 50 percent of the SWRv has been retained, or that there are 0 inches of remaining volume to treat 50percent of the SWRv. Key values for each drainage area are described on this worksheet, with site compliance and the public right-of-way summarized at the bottom.

Cell B206 indicates the total volume retained on site. **Cell B208** (cubic feet) and **cell B209** (gallons) indicate the remaining retention volume (if any) to meet the SWRv. If the SWRv has not been fully met, **cell B215** indicates the required Off-site Retention Volume (Offv). The Offv may be addressed through the use of Stormwater Retention Credits (SRCs) and/or payment of an in-lieu fee. If the SWRv has been exceeded, **cell B214** indicates the volume that may be available to generate SRCs

This sheet also summarizes the stormwater retention results from the Public Right-of-Way (PROW) sheet. **Cell B224** indicates the Total Volume Retained on site. **Cells B225** and **B226** show the remaining retention volume (if any) in cubic feet and gallons, respectively. **Cells B232–B235** show the remaining treatment volume (if any) to meet SWRv and WQTv requirements.

Channel and Flood Protection

This sheet assists with calculation of Adjusted Curve Numbers that can be used to calculate peak flows associated with the 2-year storm, 15-year storm, or other storm events.

1. Indicate the appropriate depths for the 1-year, 2-year, and 100-year 24-hour storms (or other storms as needed) on **line 5**.
2. Each cover type is associated with a Natural Resource Conservation Service (NRCS) curve number. **Cells D54, D56, and D58** show the curve number for D.A. 1. Using these curve numbers (or other curve numbers if appropriate), a weighted curve number and the total runoff volume for D.A. 1 is calculated (**cell E58**).

3. **Line 61** calculates the runoff volume without regard to the BMPs employed in D.A. 1. **Line 62** subtracts the storage volume provided by the BMPs in D.A. 1 from these totals.
4. The spreadsheet then determines the curve number that results in the calculated runoff volume with the BMPs. This Adjusted Curve Number is reported on **line 63**.
5. These steps are repeated for Drainage Areas 2–10.

Weighted Curve Number

$$CN = [(AN \times 70) + (AC \times 74) + (AI \times 98)]/SA$$

where:

CN	=	weighted curve number
AN	=	area of post-development natural cover (ft^2)
AC	=	area of post-development compacted cover (ft^2)
AI	=	area of post-development impervious cover (ft^2)
SA	=	total site area (ft^2)

Potential Abstraction

$$S = 1000/(CN\text{-}10)$$

where:

S	=	potential abstraction (in.)
CN	=	weighted curve number

Runoff Volume with no Retention

$$Q = (P - 0.2 \times S)2/(P + 0.8 \times S)$$

where:

Q	=	runoff volume with no BMPs (in.)
P	=	precipitation depth for a given 24-hour storm (in.)
S	=	potential abstraction (in.)

Runoff Volume with BMPs

$$Q_{BMP} = Q - Cv_{DA} \times 12/DA$$

where:

Q_{BMP}	=	runoff volume with BMPs (in.)
Q	=	runoff volume with no BMPs (in.)
Cv_{DA}	=	total storage volume provided by BMPs for the drainage area (ft^3)
12	=	unit adjustment factor, feet to inches
DA	=	drainage area (ft^2)

Adjusted Curve Number

The adjusted curve number is calculated using a lookup table of curve number and runoff volumes so that:

$$CN_{adjusted}, \textit{ so } (P - 0.2 \times S_{adjusted}) \times 2/(P + 0.8 \times S_{adjusted}) = Q_{BMP}$$

$$S_{adjusted} = 1000/(CN_{adjusted} - 10)$$

where:

$CN_{adjusted}$	=	adjusted curve number that will create a runoff volume equal to the drainage area runoff volume including BMPs
P	=	precipitation depth for a given 24-hour storm (in.)
$S_{adjusted}$	=	adjusted potential abstraction based upon adjusted curve number (in.)
Q_{BMP}	=	runoff volume with BMPs (in.)

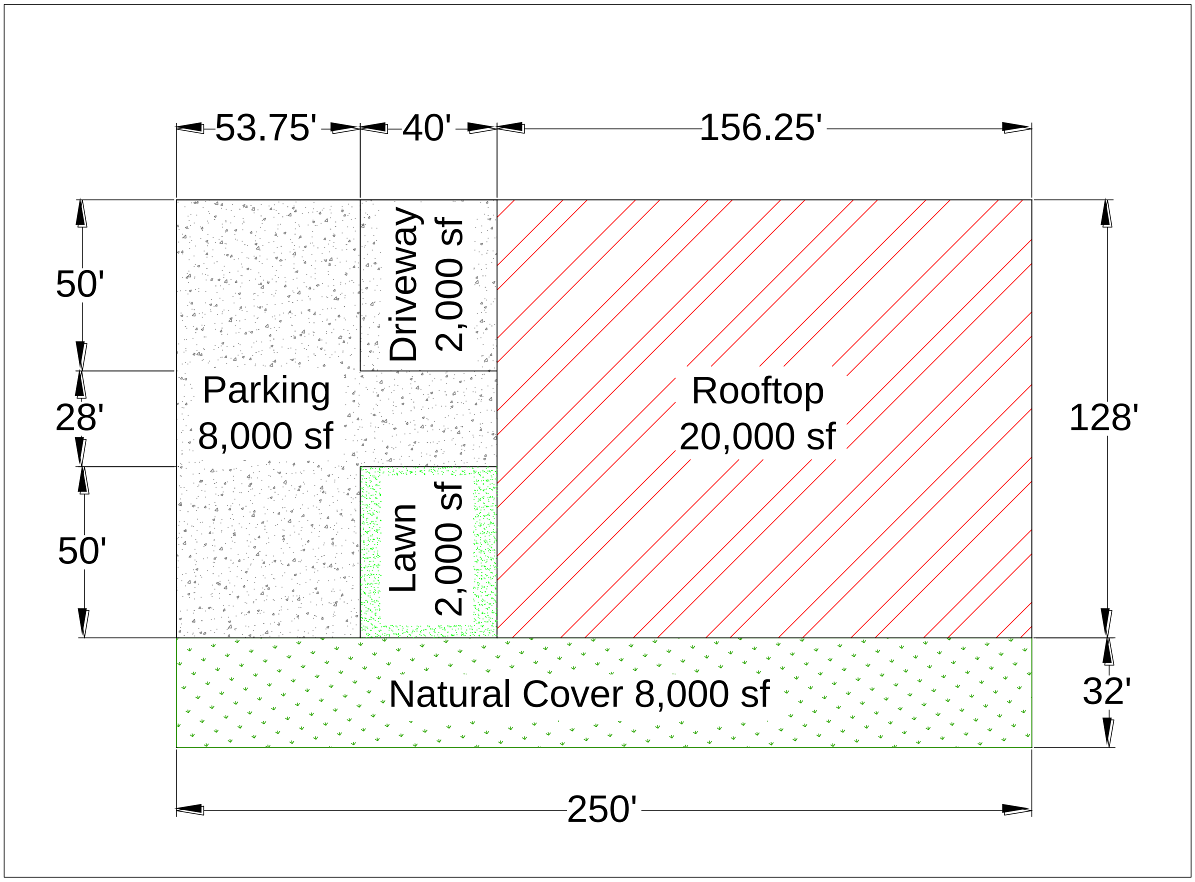
A.3 Design Examples

Design Example 1

Step 1: **Determine Design Criteria.**

Design Example 1 includes the following site characteristics:

Site Name	Anacostia Offices
Total Site Area	40,000 ft^2
Natural Cover Area	8,000 ft^2
Compacted Cover	2,000 ft^2
Impervious Cover	30,000 ft^2
Vehicular Access Areas	10,000 ft^2
Is site located within the AWDZ?	No
Is site located within the MS4?	No
What type of activity is site undergoing?	Major Land Disturbing



Step 2: **Input Design Criteria to Determine the Retention and Treatment Requirements.**

The General Retention Compliance Calculator will calculate a Stormwater Retention Volume (SWRv), once the natural cover, compacted cover, and impervious cover areas are put into **cells D22–D25** on the Site Data sheet.

Based on the design criteria above, Anacostia Offices has the following requirements:

$$SWRv = \textbf{cell D37} = 2{,}900 \text{ ft}^3$$

Step 3: **Identify Site Constraints and BMP Restrictions.**

Key considerations for Anacostia Offices include the following:

- Site soils are contaminated, so infiltration is not allowed, and impermeable liners will be required for most BMPs.
- The commercial land use means that most BMPs are otherwise acceptable.

Step 4: **Select BMPs to Meet the Retention and Treatment Requirements.**

While there are numerous options for treatment of this site, two BMPs were selected: rainwater harvesting (R1) for the rooftop and bioretention (B1) for any remaining rooftop runoff and the rest of the site. Since the site is contaminated, a liner is required and the enhanced bioretention option is not available.

The site will ultimately have one outlet point, and the selected treatment train is relatively simple, so the calculations can be performed on one Drainage Area tab – D.A. 1. Therefore, all of the same values from the Site Data tab for the various cover types (plus the vehicle access area) should be put into **cells B6-B10** on the D.A.1tab.

The first BMP selected is rainwater harvesting for runoff from the rooftop. The Rainwater Harvesting Retention Calculator should be used to determine the cistern size and the associated retention value. In the Rainwater Harvesting Retention Calculator 20,000 square feet should be put in as the Contributing Drainage Area (CDA) (**cell L7**). For utilization of the rainwater, flushing toilets/urinals is selected as the use, and the appropriate values are entered. In this case, 500 people will use the building per day (**cell L21**), Monday through Friday (**cells L30** and **L32**), 8 hours per day (**cell L34)**. On the Results – Retention Value sheet, the retention values are given for various tank sizes. The tables and graphs show that a 30,000 gallon underground tank (or series of tanks) would meet much of the demand and have a very high retention value—94 percent.

The next step is to return to the D.A. 1 tab and input the 20,000-square foot CDA into **cell D25** for rainwater harvesting and input the efficiency (94%) into **cell K25**. The result is that 2,530 cubic feet of runoff are retained and 162 cubic feet remain. Since Standard Bioretention will be the next BMP in the series, it should be selected from the pull-down menu in **cell S25**. The remaining runoff volume will then be directed to this BMP.

In addition to the overflow from the rainwater harvesting BMP, the bioretention area will receive runoff from the rest of the site. Initially, these land uses can be input into **cells B39–D40**. However, the surface area of the bioretention area must be accounted for as well. Through trial and error, it was determined that a 1,000-square-foot bioretention area would be sufficient to meet the retention requirement. This area will be taken from the compacted cover area and will need to be changed on the Site Data Tab as well as at the top of DA. 1. Compacted cover will now be 1,000 square feet, and BMP will be 1,000 square feet. The 8,000 square feet of natural cover will remain. Impervious cover directed to the bioretention area (**cell D39**) will be 10,000 square feet (the remaining impervious area after 20,000 square feet was removed for rainwater harvesting). 1,000 square feet of compacted cover and 1,000 square feet of BMP surface area will also be directed to the bioretention area (**cells B40** and **D40**). Since the 10,000 square feet of impervious cover is made up of driveway and parking area, it is all classified as vehicular access area, so 10,000 should be put into **cell F39** as well.

The vehicular access retention/treatment requirement is 475 cubic feet (**cell G39**), and the total volume directed to the bioretention area, including the “overflow” from the rainwater harvesting BMP, will be 1,677 cubic feet (**cell M39**). Inputting 800 cubic feet for the storage volume in the spreadsheet (**cell O39**) is more than sufficient to address the vehicular access volume and leads to an exceedance of 300 gallons for the SWRv (**cell Q69**). This information is also summarized on the Compliance worksheet tab.

Step 5: Size the BMPs According to the Design Equations.

The size of the rainwater-harvesting cistern was already determined to be 30,000 gallons, although additional volume may be necessary for dead storage for a pump, and/or freeboard.

To meet the bioretention criteria, the bioretention area is sized with 1.5 feet of filter media, 0.75 feet of gravel, and a 0.5-foot ponding depth. The bioretention cell sizing goal is 800 cubic feet.

Step 5.1: Check the Filter Media Depth.

Ensure that the filter media depth does not exceed the maximum in Table 3.21. The ratio of the surface area of the BMP (1,000 ft^2) to the contributing drainage area (32,000 ft^2) is 3.1%. The Rv for the contributing drainage area to the bioretention practice is 0.93. The maximum filter media depth allowed is 5.0 feet. As the bioretention was sized with 1.5 feet of filter media, it passes this check.

Table 3.21 Determining Maximum Filter Media Depth (feet)

SA:CDA (%)	**RvCDA**								
	0.25	**0.3**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**0.95**
0.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
1.0	5.0	5.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
1.5	3.5	4.0	5.0	6.0	6.0	6.0	6.0	6.0	6.0
2.0	2.5	3.0	4.0	5.0	5.5	6.0	6.0	6.0	6.0
2.5	2.0	2.5	3.5	4.0	4.5	5.0	5.5	6.0	6.0
3.0	1.5	2.0	3.0	3.5	4.0	4.5	5.0	5.5	5.5
3.5	1.5	1.5	2.5	3.0	3.5	4.0	4.5	5.0	5.0
4.0	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.5	4.5
4.5	1.5	1.5	2.0	2.5	3.0	3.5	3.5	4.0	4.5
5.0	1.5	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.0
5.5	1.5	1.5	1.5	2.0	2.5	2.5	3.0	3.5	3.5
6.0	1.5	1.5	1.5	1.5	2.0	2.5	3.0	3.0	3.5
6.5	1.5	1.5	1.5	1.5	2.0	2.5	2.5	3.0	3.0
7.0	1.5	1.5	1.5	1.5	1.5	2.0	2.5	3.0	3.0
7.5	1.5	1.5	1.5	1.5	1.5	2.0	2.5	2.5	2.5
8.0	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.5	2.5
8.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.5
9.0	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.0
9.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0
10.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0

***Step 5.2*: Determine Storage Volume.**

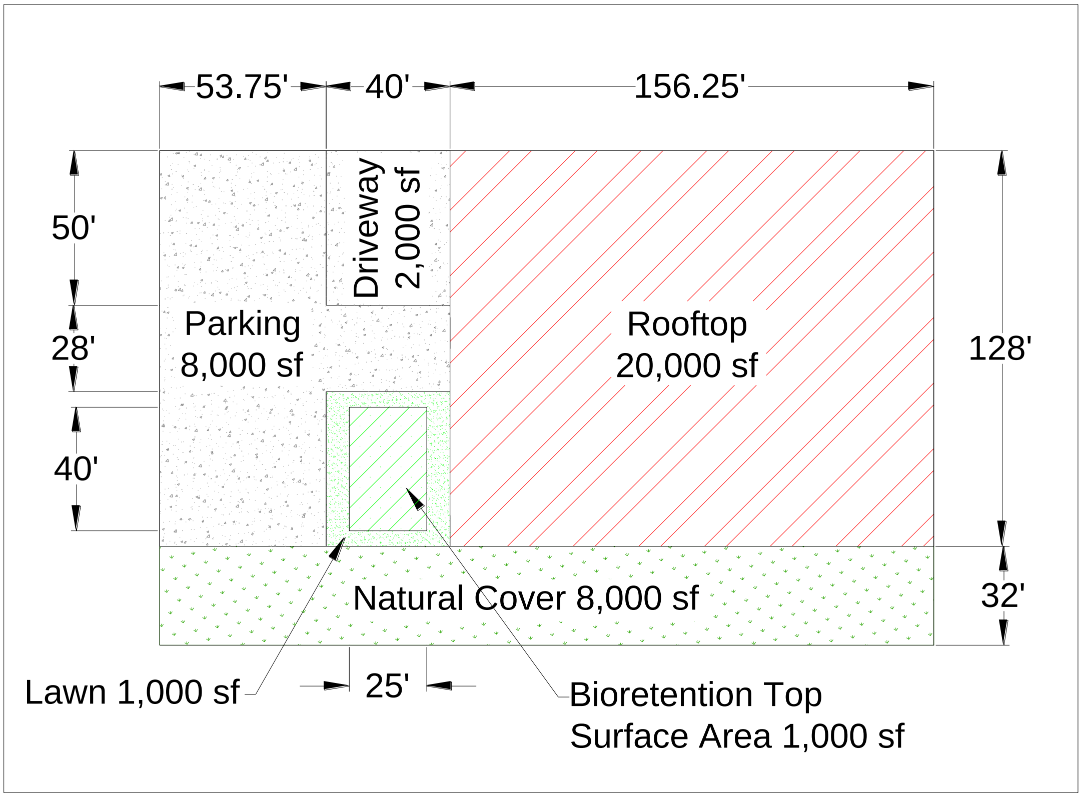
Equation 3.5

$$Sv = SA_{bottom} \times \left[(d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel}) \right] + (SA_{average} \times d_{ponding}) \Big]$$

where:

Sv	=	total storage volume of bioretention (ft^3)
SA_{bottom}	=	bottom surface area of bioretention (ft^2)
d_{media}	=	depth of the filter media (ft)
η_{media}	=	effective porosity of the filter media (typically 0.25)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer(ft)
η_{gravel}	=	effective porosity of the gravel layer (typically 0.4)
$SA_{average}$	=	the average surface area of the bioretention (ft^2) typically, where SA_{top} is the top surface area of bioretention, $SA_{average} = \frac{SA_{bottom} + SA_{top}}{2}$
$d_{ponding}$	=	the maximum ponding depth of the bioretention (ft)

Solving Equation 3.5 often requires an iterative approach to determine the most appropriate bottom surface area and average surface area to achieve the desired *Sv*. In this case, a bioretention with a 40 foot by 25 foot top area and 3:1 side slopes will provide a SA_{top} of 1,000 square feet, a SA_{bottom} of 814 square feet, a $SA_{average}$ of 907 square feet, and achieve a *Sv* of 1,003 cubic feet. This more than meets the goal of 800 cubic feet. If desired, the surface area of the practice could be reduced accordingly, or more SRCs could be generated with the excess volume.



Step 6: **Check Design Assumptions and Requirements.**

Key assumptions and requirements for this site include:

- Based upon the above design, the rainwater harvesting cistern will be 30,000 gallons and the bioretention cell will require at least 1,000 square feet of surface area. The designer would need to ensure that space would be available for these BMPs on the site.
- The contributing drainage area for traditional bioretention must be 2.5 acres or less and this site is less than 1 acre.
- The required head for the above design will be 25 feet, including ponding depth (9 inches), mulch (3 inches), filter media (18 inches), choking layer (about 3inches) , and gravel layer (about 9 inches). (See Figure 3.18). The outlet for the underdrain must be at least this deep.
- The water table must be at least 2 feet below the underdrain, or 5.5 feet below the surface. According to the Soil Survey, Beltsville soils have a 1.5- to 2-foot depth to seasonally high groundwater table, Croom soils have greater than a 5-foot depth, and Sassafras soils have a 4-foot depth. On-site soil investigations will be needed to determine if the 5.5-foot depth to the groundwater table can be met on this site.
- Due to soil contamination and the bioretention area’s proximity to the building (less than 10 feet), an impermeable liner is required.

Since all of these assumptions and requirements can be met in this design example (pending groundwater table investigations), this step is complete.

Step 7: Use the Adjusted Curve Number to Address Peak Flow Requirements.

On the Channel and Flood Protection tab, enter values for C soils in **cells D54, D56**, and **D58** (70 for natural areas, 74 for turf, and 98 for impervious cover, respectively). The original site curve number of 92 is reduced for the 2-year, 15-year, and 100-year storms to 79, 82, and 83, respectively, by the retention provided by the cistern and bioretention cell. These values can be used to help determine detention requirements for this site.

Step 8: Determine Detention Requirements.

Detention is required to reduce the peak discharge rate from the 2-year storm event to the predevelopment (meadow conditions or better) peak discharge rate and to reduce the peak discharge rate from the 15-year storm event to the preproject peak discharge rate. Appendix H includes details on the procedure for calculating the detention volume. In this example, the proposed impervious cover and the proposed runoff curve number is less than the preproject conditions, so detention for the 15-year storm is not required. Detention for the 2-year storm will be required.

The peak inflow (q_{i2}) and the peak outflow (q_{o2}) can be calculated using the WinTR-55 Small Watershed Hydrology program, the area of the site, the time of concentration (Tc), assumed to be 10 minutes), and the curve numbers. The reduced curve of 79, determined above, generates a q_{i2} of 1.61 cubic feet per second (cfs). The curve number for meadow in good condition, 71, generates a q_{o2} of 1.07 cfs.

The ratio of 1.07 cfs to 1.61 cfs equals 0.63. Using Figure H.1, the ratio of storage volume (Vs_2) to runoff volume (Vr_2) is 0.22.

The runoff volume (Vr_2) determined from the General Retention Compliance Calculator is 1.33 inches, which equates to 4,333 cubic feet. Using the calculated ratio of Vs_2/Vr_2, the storage volume required for the site (Vs_2) is 1,020 cubic feet.

With appropriate orifice design to ensure that outflows are properly restricted, this detention volume can be incorporated below the proposed bioretention area or located elsewhere on the site as a standalone detention practice.

Design Example 2

Step 1: **Determine Design Criteria.**

Design Example 2 includes the following proposed design criteria:

Site Name	Downtown Multi-Story Renovation
Total Site Area	15,000 ft^2
Natural Cover Area	0 ft^2
Compacted Cover	0 ft^2
Impervious Cover (Rooftop)	15,000 ft^2
Vehicular Access Areas	0 ft^2
Is site located within the AWDZ?	No
Is site located within the MS4?	Yes
What type of activity is the site undergoing?	Major Substantial Improvement

Step 2: **Input Design Criteria to Determine the Retention and Treatment Requirements.**

The Compliance Calculator Spreadsheet will calculate a Stormwater Retention Volume (SWRv), once the above values are put into the Site Data sheet.

Based on the design criteria above, the Multi-Story Renovation project is required to treat 0.8 inches of rainfall for the SWRv:

SWRv = **cell D37** = 950 ft^3

Step 3: **Identify Site Constraints and BMP Restrictions.**

Key considerations for the Multi-Story Renovation project include the following:

- Since this is a rooftop-only site, very few treatment options are available.
- As a renovation, the structure of the existing roof will be a factor for any rooftop practice.

Step 4: **Select BMPs to Meet the Retention and Treatment Requirements.**

As an initial estimate 75 percent of the rooftop is proposed to be converted to a green roof, with the remaining 25 percent draining to it. Therefore, the land use values need to be changed to account for the green roof: 3,750 square feet should be entered as impervious cover in **cell D24** on the Site Data sheet, and 11,250 square feet should be entered in **cell D25** as “BMP.” As there will be only one drainage area for the site, these same values should be entered into **cells B8** and **B10** on sheet D.A. 1. and as the Green Roof drainage area (**cells D23** and **D24**).

The goal of this design is to capture the entire retention volume (950 ft^3) in the Green Roof. This can be shown on the spreadsheet by entering 950 cubic feet in **cell O23** on sheet D.A. A. **Cell Q69** shows that the SWRv has been met for the site. This information is also summarized on the Compliance worksheet tab.

Step 5: Size the BMPs According to the Design Equations.

The green roof needs to be sized according to Equation 3.1. Since green roofs are typically manufactured systems, several of the parameters, such as the drainage layer depth and maximum water retention of all layers, need to be provided by the manufacturer. The values for the roof used in this design are provided in the variable descriptions below Equation 3.1 (with each layer illustrated in Figure 3.1).

Equation 3.1 Storage Volume for Green Roofs

$$Sv = \frac{SA \times [(d \times \eta_1) + (DL \times \eta_2)]}{12}$$

where:

Sv	=	storage volume (ft^3) (goal is 950 ft^3)
SA	=	green roof area (ft^2) (need to determine)
d	=	media depth (in.) (6 in.)
$\eta 1$	=	verified media maximum water retention (0.25)
DL	=	drainage layer depth (in.) (1 in.)
$\eta 2$	=	verified drainage layer maximum water retention (0.4)

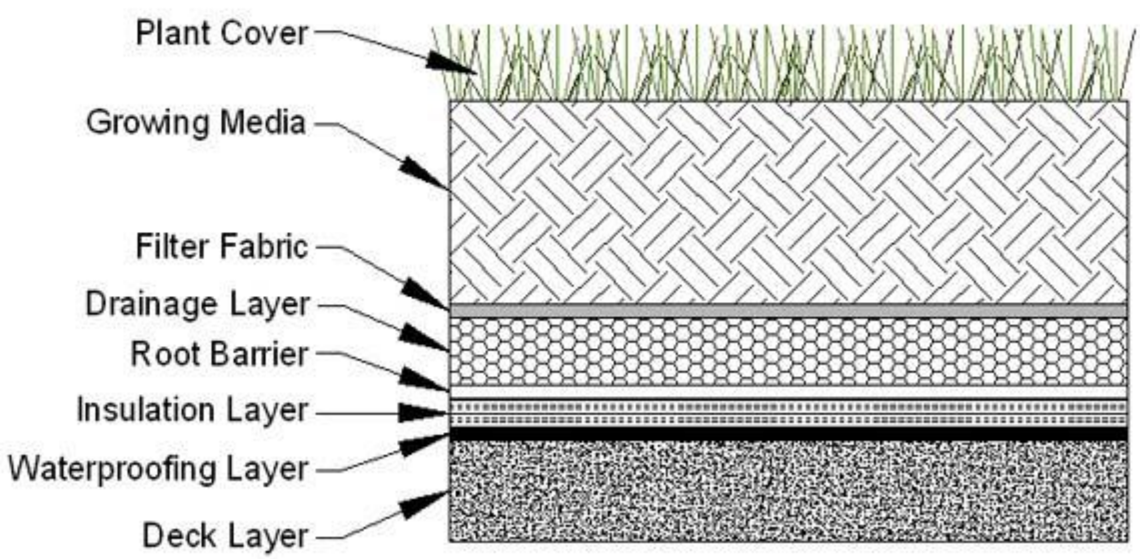


Figure 3.1 Typical layers for a green roof.

Rearranging Equation 3.1 to find the minimum required surface area:

$$SA = Sv/[(d \times \eta\ 1)+(DL \times \eta\ 2)] \times 12$$

or:

$$SA = 950/(6 \times 0.25+1\times 0.4) \times 12$$

$$SA = 6{,}000\ \text{ft}^2$$

Therefore, the green roof must be sized to be at least 6,000 square feet, given the proposed depths. The original assumption was that an 11,250-square-foot roof would be used. Since a smaller roof is feasible, the drainage areas in the spreadsheet may be revised accordingly.

Note: The drainage area to the green roof is only 25 percent larger than the green roof itself, so the maximum additional drainage area to a 6,000-square-foot roof is 1,500 square feet. Alternatively, the larger roof may be utilized, and the increased storage volume can be used to reduce peak flow volume requirements (see Step 8) or sold as Stormwater Retention Credits.

Step 6: Check Design Assumptions and Requirements.

Key assumptions and requirements for this site include:

- A structural analysis of the building is needed to determine that the green roof can be supported by the existing structure.
- Ensure that there is sufficient space on the rooftop (allowing for structures such as vents, steep areas of the roof, and other panels). In this case, the minimum roof area of 6,000 square feet is less than half of the entire roof area and most roofs can accommodate this area.
- At least 1,500 square feet of the rooftop not covered by green roof needs to be designed so that it drains to the green roof without damaging it.

Since all of these assumptions and requirements can be met in this design example, this step is complete.

Step 7: Use the Adjusted Curve Number to Address Peak Flow Requirements.

The initial curve number for this site is 98, but retention provided by the green roof changes this number. The Channel and Flood Protection tab notes the reduced curve numbers for the 2-year, 15-year, and 100-year storms: 90, 91, and 92, respectively. These curve numbers can be used to help determine detention requirements for this site.

Step 8: Determine Detention Requirements.

Detention is required to reduce the peak discharge rate from the 2-year-storm event to the predevelopment (meadow conditions or better) peak discharge rate and to reduce the peak discharge rate from the 15-year storm event to the preproject peak discharge rate. Appendix H includes details on the procedure for calculating the detention volume. In this example, since the proposed land cover is the same as the preproject conditions, detention is not required for the 15-year storm. However, detention is required for the 2-year storm.

The peak inflow, $qi_2$and the peak outflow, q_{o2} can be calculated using the WinTR-55 Small Watershed Hydrology program, the area of the site, the time of concentration (Tc, assumed to be 10 minutes), and the curve numbers. The reduced curve of 90, determined above, generates a qi_2 of 1.00 cubic foot per second (cfs). The curve number for meadow in good condition, 71, generates a q_{o2} of 0.39 cfs.

The ratio of 0.39 cfs to 1.00 cfs equals 0.39. Using Figure H.1, this equates to a ratio of storage volume (Vs_2) to runoff volume (Vr_2) of 0.33.

The runoff volume (Vr_2) determined in the Compliance Calculator spreadsheet is 2.21 inches, which equates to 2,763 cubic feet. Using the calculated ratio of Vs_2/Vr_2, the storage volume required for the site (Vs_2) is912 cubic feet.

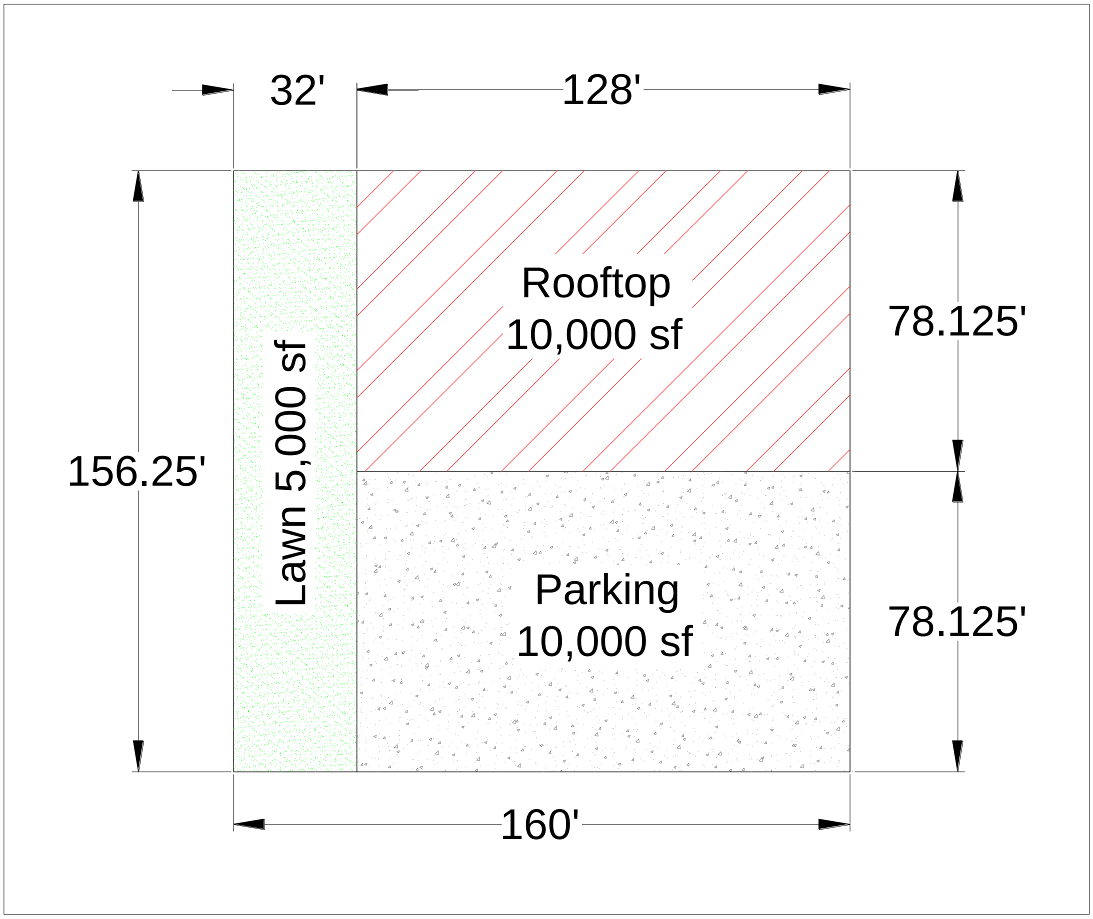
Rooftop Storage (see Appendix I) may be the most cost effective method for achieving this detention volume in this example.

Design Example 3

Step 1: **Determine Design Criteria.**

Design Example 3 includes the following proposed design criteria:

Site Name	Ward 5 Low-Rise Commercial
Total Site Area	25,000 ft^2
Natural Cover Area	0 ft^2
Compacted Cover	5,000 ft^2
Impervious Cover	20,000 ft^2
Vehicular Access Areas	10,000 ft^2
Is site located in the AWDZ?	No
Is site located within the MS4?	Yes
What type of activity is site undergoing?	Major Land Disturbing



Step 2: **Input Design Criteria to Determine the Retention and Treatment Requirements.**

The Compliance Calculator Spreadsheet will calculate a Stormwater Retention Volume (SWRv), once the natural cover, compacted cover, and impervious cover areas are put into **cells D22–D25** on the Site Data sheet.

Based on the design criteria above, the project has the following requirement:

SWRv = **cell D37** = 2,025 ft^3

Step 3: **Identify Site Constraints and BMP Restrictions.**

Key considerations for the project include the following:

- Only a small portion of the compacted cover is available for potential BMPs.
- The Multi-Family Residential site is not restrictive of BMP options.
- The relatively permeable Sunnyside-Sassafras-Muirkirk-Christiana soils on this site allow for infiltration into site soils.

Step 4: Select BMPs to Meet the Retention and Treatment Requirements.

An enhanced bioretention with no underdrain is chosen for this site, primarily to minimize cost. Several other options, such as permeable pavers, would have been acceptable at this site.

The site will ultimately have one outlet point, with only one BMP, so the calculations can be performed on one Drainage Area tab—D.A. 1. Therefore, all of the same values from the Site Data tab for the various cover types (plus the vehicle access area) should be put into **cells B6–B10** on the D.A. 1 sheet.

It is assumed that the entire site will be directed to the bioretention area, so the same values from the top of the DA1 sheet may be input into **cells B37–F38** (including the 10,000 square feet of vehicle access area in **cell F37**. However, the surface area of the bioretention area must be accounted for as well. It was determined that only 1,000 square feet of compacted cover would be available for a bioretention area. This area will be taken from the compacted cover area, and will need to be changed on the Site Data Tab as well as the top of D.A. 1. Compacted cover will now be 4,000 square feet, and "BMP" will be 1,000 square feet. The rooftop and parking areas will not change. This approach will lead to a total volume of 2,968 cubic feet directed to the BMP.

Since enhanced bioretention receives100 percent retention value, the required storage volume to meet the SWRv is 2,095 cubic feet (this is the required SWRv after changes in land use were made to account for the bioretention surface area). However, the 1,000 square feet available will not be sufficient to provide the entire required storage volume. Through trial and error (see Step 5 below) it was determined that the maximum storage volume is 1,301 cubic feet. This value can be input into **cell O37**. **Cell P68** indicates that there is still 794 cubic feet, or 5,939 gallons (**cell P69**), remaining. This volume will have to be met through the purchase or generation of Stormwater Retention Credits (SRCs) (see Chapter 7 and Step 9 below).

Step 5: Size the BMPs According to the Design Equations.

Assume a filter media depth of 2 feet, a gravel depth of 0.75 feet, and a ponding depth of 1 foot.

Step 5.1**:** Check the Filter Media Depth.

Ensure that the filter media depth does not exceed the maximum in Table 3.21. The ratio of the surface area of the bioretention (1,000 ft^2) to the contributing drainage area (25,000 ft^2) is 4%. The *Rv* was previously determined to be 0.84. The maximum filter media depth allowed is 4.0 feet. As the bioretention was sized with 2 feet of filter media, it passes this check.

Table 3.21 Determining Maximum Filter Media Depth (feet)

SA:CDA (%)	RvCDA								
	0.25	**0.3**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**0.95**
0.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
1.0	5.0	5.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
1.5	3.5	4.0	5.0	6.0	6.0	6.0	6.0	6.0	6.0
2.0	2.5	3.0	4.0	5.0	5.5	6.0	6.0	6.0	6.0
2.5	2.0	2.5	3.5	4.0	4.5	5.0	5.5	6.0	6.0
3.0	1.5	2.0	3.0	3.5	4.0	4.5	5.0	5.5	5.5
3.5	1.5	1.5	2.5	3.0	3.5	4.0	4.5	5.0	5.0
4.0	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.5	4.5
4.5	1.5	1.5	2.0	2.5	3.0	3.5	3.5	4.0	4.5
5.0	1.5	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.0
5.5	1.5	1.5	1.5	2.0	2.5	2.5	3.0	3.5	3.5
6.0	1.5	1.5	1.5	1.5	2.0	2.5	3.0	3.0	3.5
6.5	1.5	1.5	1.5	1.5	2.0	2.5	2.5	3.0	3.0
7.0	1.5	1.5	1.5	1.5	1.5	2.0	2.5	3.0	3.0
7.5	1.5	1.5	1.5	1.5	1.5	2.0	2.5	2.5	2.5
8.0	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.5	2.5
8.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.5
9.0	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.0
9.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0
10.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0

***Step 5.2*: Determine the Storage Volume.**

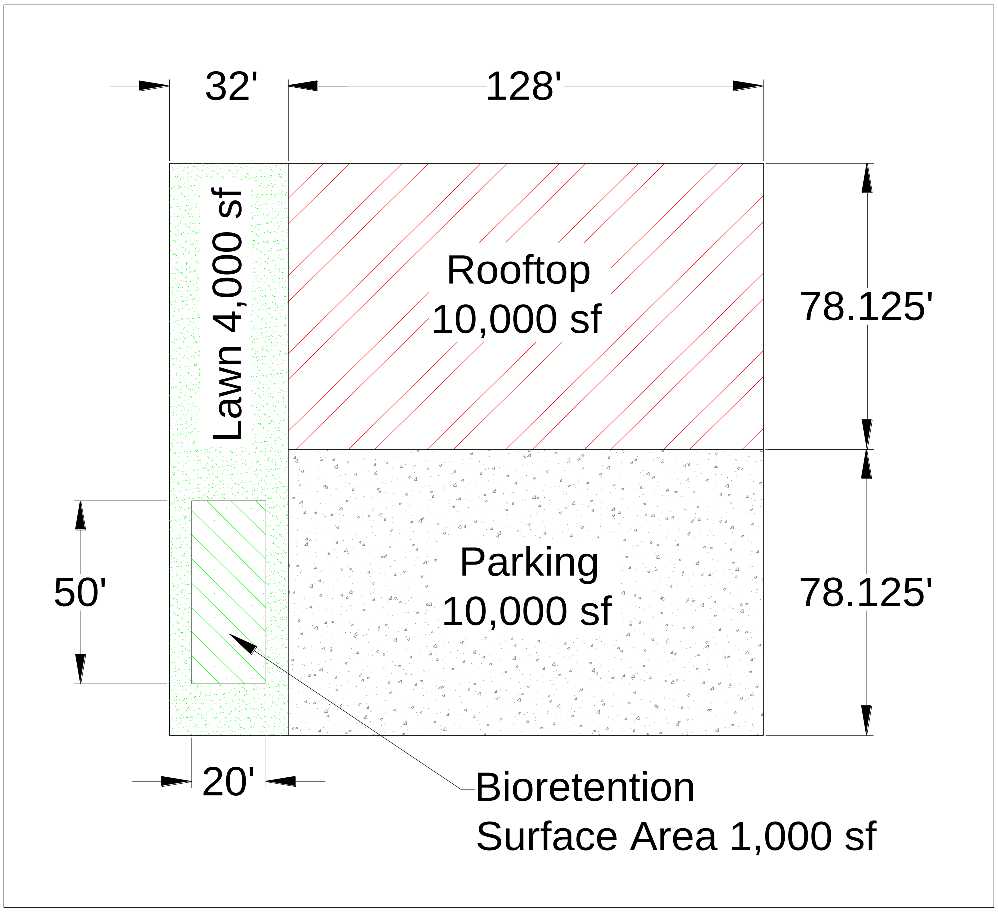
Equation 3.5

$$Sv = SA_{bottom} \times [(d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel})] + (SA_{average} \times d_{ponding})$$

where:

Sv	=	total storage volume of bioretention (ft^3)
SA_{bottom}	=	bottom surface area of bioretention (ft^2)
d_{media}	=	depth of the filter media (ft)
η_{media}	=	effective porosity of the filter media (typically 0.25)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer(ft)
η_{gravel}	=	effective porosity of the gravel layer (typically 0.4)
$SA_{average}$	=	the average surface area of the bioretention (ft^2) typically, where SA_{top} is the top surface area of bioretention, $SA_{average} = \frac{SA_{bottom} + SA_{top}}{2}$
$d_{ponding}$	=	the maximum ponding depth of the bioretention (ft)

Solving Equation 3.5 often requires an iterative approach to determine the most appropriate bottom surface area and average surface area to achieve the desired *Sv*. In this case, a long, narrow practice with a 50 foot by 20 foot top area and 3:1 side slopes was all that would fit on the site. This configuration will provide a SA_{top} of 1,000 square feet, a SA_{bottom} of 616 square feet, a $SA_{average}$ of 808 square feet, and will achieve an *Sv* of 1,301 cubic feet.



Step 6: **Check Design Assumptions and Requirements.**

Key assumptions and requirements for this site include:

- The design will need at least 1,000 square feet of surface area. The designer would need to ensure that this area is available.
- Contributing drainage area for traditional bioretention must be 2.5 acres are less, and this site has a total drainage area of less than 0.5 acres.
- Vehicle access areas must be addressed. The vehicle access retention/treatment requirement of 475 cubic feet is met by this design.
- Head requirements are not likely to be an issue, since this is an infiltration design.

- The water table must be at least 2 feet below the bottom of the bioretention, or 4.25 feet below the surface.
- The measured permeability of the underlying soils must be at least 0.5 inches/hour.
- Additional SRCs will need to be generated or purchased off-site.

Since all of these assumptions and requirements can be met (pending groundwater table and infiltration rate investigations) in this design example, this step is complete.

Step 7: **Use the Adjusted Curve Number to Address Peak Flow Requirements.**

On the Channel and Flood Protection tab, enter values for B soils in **cells D54**, **D56**, and **D58** (55 for natural areas, 61 for turf, and 98 for impervious cover, respectively). The original site curve number of 92 is reduced for the 2-year, 15-year, and 100-year storms to 87, 88, and 89, respectively by the retention provided by the bioretention cell. These curve numbers can be used to help determine detention requirements for this site.

Step 8: **Determine the Detention Requirements.**

Detention is required to reduce the peak discharge rate from the 2-year storm event to the predevelopment (meadow conditions or better) peak discharge rate and to reduce the peak discharge rate from the 15-year storm event to the preproject peak discharge rate. Appendix H includes details on the procedure for calculating the detention volume. In this example, the proposed impervious cover and the proposed runoff curve number is less than the preproject conditions, so detention for the 15-year storm is not required. Detention for the 2-year storm will be required.

The peak inflow (qi_2) and the peak outflow (q_{o2}) can be calculated using the WinTR-55 Small Watershed Hydrology program, the area of the site, the time of concentration (Tc, assumed to be 10 minutes), and the curve numbers. The reduced curve of 87, determined above, generates a qi_2 of 1.50 cubic feet per second (cfs). The curve number for meadow in good condition, 58, generates a q_{o2} of 0.18 cfs.

The ratio of 0.18 cfs to 1.50 cfs equals 0.12. Using Figure H.1, the ratio of storage volume (Vs_2) to runoff volume (Vr_2) is 0.53.

The runoff volume (Vr_2) determined in the Compliance Calculator spreadsheet is 1.84 inches, which equates to 3,833 cubic feet. Using the calculated ratio of Vs_2/Vr_2, the storage volume required for the site (Vs_2) is 2,032 cubic feet.

This detention volume, with appropriate orifice design to ensure that outflows are properly restricted, can be incorporated below the proposed bioretention area or located elsewhere on the site, such as underneath the parking lot as a standalone detention practice.

Step 9: **Identify Stormwater Retention Credits.**

Since the SWRv was short of the requirement by 7,615 gallons, 7,615 SRCs will need to be purchased or generated annually for this site to achieve compliance (see Chapter 7 for more details and example calculations).

Design Example 4

Design Example 4 includes the following proposed design criteria:

Site Name	Green St. and Gold St. Intersection
Total Site Area	13,528 ft^2
Natural Cover Area	0 ft^2
Compacted Cover	185 ft^2
Impervious Cover	13,343 ft^2

The site in this design example is a street reconstruction project. Since it is located in the public right-of-way (PROW), the maximum extent practicable (MEP) design process applies (see Appendix B).

Step 1: **Calculate SWRv.**

This intersection includes four stormwater inlets (one at each corner), so it will be divided into four drainage areas. The MEP Verification checklist requires calculation of the contributing drainage area within the limit of disturbance (LOD) as well as calculation of the contributing drainage area outside the LOD.

Drainage Area (DA 1 - N)	Contributing Area (ft^2)		SWRv (gal)	
	within LOD	outside LOD	within LOD	outside LOD
DA1	3,473	1,138	2,371	809
DA2	2,937	987	2,087	701
DA3	5,285	1,747	3,756	1,241
DA4	1,833	1,931	1,303	1,372
DATOTAL	**13,528**	**5,803**	**9,517**	**4,123**

SWRv can be calculated using the Compliance Calculator spreadsheet. In this case, all of the drainage areas were 100 percent impervious, except for DA1, which included 185 square feet of landscaped area within the LOD.

Step 2: **Consider Infiltration.**

This step requires looking at infiltration options by identifying constraints to infiltration, such as a high water table, soil contamination, or poor infiltration rates and locating areas that are well suited for infiltration.

In this example, a high water table and soil contamination were not a concern, The soil had only a moderate to low infiltration rate, making an infiltration sump a possibility as part of another BMP (such as enhanced bioretention) but not feasible as a standalone BMP.

Step 3: Demonstrate Full Consideration of Land-Cover Conversions and Optimum BMP Placement.

Opportunities for BMP placement within and adjacent to the PROW include traffic islands, triangle parks, median islands, cul-de-sacs, paper streets, and traffic calming measures, such as median islands, pedestrian curb extensions, bump outs, chicanes, and turning radius reductions.

As this example is a small intersection project, pedestrian curb extensions are the only feasible location for BMP placement. BMP locations in the pedestrian curb extensions will be possible at three of the four corners of the intersection.

Step 4: Demonstrate Full Consideration of Opportunities Within Existing Infrastructure.

This step requires the assessment and documentation of utility locations, storm sewer depths, right-of-way widths, and exiting trees to determine potential conflicts.

In this example, the difference in elevation between the storm sewer inlets and the invert of the pipes is approximately 5 feet. Other utilities will constrain the space available for the proposed BMPs but will not eliminate the pedestrian curb extension spaces entirely.

Step 5: Locate and Choose BMPs.

Although they may be undersized, enhanced bioretention areas will be selected for 3 of the 4 corners in the space available.

Areas for enhanced bioretention are as follows:

Drainage Area (DA 1 - N)	Contributing Area within LOD (ft^2)	SWRv within LOD (gal)	Available Area for BMP (ft^2)
DA1	3,473	2,371	72
DA2	2,937	2,087	285
DA3	5,285	3,756	190
DA4	1,833	1,303	0
DATOTAL	**13,528**	**9,517**	**N/A**

Step 6: Size BMPs.

Each bioretention area will be designed with a similar cross section: vertical side slopes for the ponding area, a ponding depth of 0.75 feet, a filter media depth of 2 feet, and a gravel depth (including the infiltration sump) of 1.25 feet.

The storage volume is determined with Equation 3.5

Equation 3.5

$$Sv = SA_{bottom} \times \left[(d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel})\right] + (SA_{average} \times d_{ponding})]$$

where:

Sv	=	total storage volume of bioretention (ft^3)
SA_{bottom}	=	bottom surface area of bioretention (ft^2)
d_{media}	=	depth of the filter media (ft)
η_{media}	=	effective porosity of the filter media (typically 0.25)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer(ft)
η_{gravel}	=	effective porosity of the gravel layer (typically 0.4)
$SA_{average}$	=	the average surface area of the bioretention (ft^2) typically, where SA_{top} is the top surface area of bioretention, $SA_{average} = \frac{SA_{bottom} + SA_{top}}{2}$
$d_{ponding}$	=	the maximum ponding depth of the bioretention (ft)

With the cross section dimensions provided above, Equation 3.5 yields the following results:

Drainage Area (DA1–N)	Available Area for BMP (ft^2)	Sv (gal)	Sv (ft^3)
DA1	72	942	126
DA2	285	3,731	499
DA3	190	2,487	332
DA4	0	0	0

The table below indicates that there is a retention deficiency for 3 of the 4 drainage areas with the proposed BMPs.

Drainage Area (DA 1 - N)	Regulated SWRv within LOD (gal)	SWRv Achieved (gal)	Retention Deficiency (gal)	Altered Drainage Profile	
				Y	N
DA1	2,371	942	1,429		X
DA2	2,087	3,731	N/A		X
DA3	3,756	2,487	1,269		X
DA4	1,303	-	1,303		X
DATOTAL	**9,517**	**7,160**			

If there is a retention volume deficiency, the MEP design process notes that the designer should consider sizing BMPs to manage the comingled volume on-site, and/or revisit Design Steps 1 –6 to increase land conversion areas and BMP facilities.

In this case, the proposed bioretention areas in DA2 could treat additional volume, but the proposed bioretention areas in DA1 and DA3 are at capacity. At this point, the designer should review Steps 1 through 6 to ensure that all opportunities for land conversion and BMP facilities have been maximized. If so, this step is complete.

Step 7: **Identify Drainage Areas Where Zero-Retention BMPs are Installed.**

Drainage areas that do not include a retention BMP will require installation of a water-quality catch basin to treat stormwater runoff. This requirement applies only to DA4 in this example.

Design Example 5

Step 1: **Determine Design Criteria.**

Design Example 5 includes the following proposed design criteria:

Site Name	NoMa Office Tower
Total Site Area	65,340 ft^2
Natural Cover Area	0 ft^2
Compacted Cover	0 ft^2
Impervious Cover (Rooftop)	65,340 ft^2
Vehicular Access Areas	0 ft^2
Is site located within the AWDZ?	No
Is site located within the MS4?	Yes
What type of activity is the site undergoing?	Major Land Disturbing

Step 2: **Input Design Criteria to Determine the Retention and Treatment Requirements.**

The Compliance Calculator Spreadsheet will calculate a Stormwater Retention Volume (SWRv), once the impervious cover area is put into **cell D24** on the Site Data sheet.

Based on the design criteria above, the NoMa Office Tower project is required to treat 1.2 inches of rainfall for the SWRv:

SWRv (**cell D37**) = 6,207 ft^3

Identify Site Constraints and BMP Restrictions.

Limitation of space is the key considerations for the NoMa Office tower project. The lot line to lot line construction means there are limited retention and treatment options. A rooftop approach is selected.

Step 3: Select BMPs to Meet the Retention and Treatment Requirements.

As an initial estimate 60 percent of the rooftop is proposed to be converted to a green roof, with an additional 15 percent of the remaining rooftop draining to it. Therefore, the land use values need to be changed to account for the green roof: 26,136 square feet should be entered as rooftop in **cell D24** on the Site Data sheet, and 39,204 square feet should be entered in **cell D25** as "BMP." As there will be only one drainage area for the site, these same values should be entered into **cells B8** and **B10** on sheet DA A. For the Green Roof drainage area (**cells D23** and **D24**), 9801 square feet should be entered as impervious cover, and 39,204 should be entered as BMP surface area.

The goal of this design is to capture the entire retention volume (6,207 ft^3) in the Green Roof. This can be shown on the spreadsheet by entering 6,208 cubic feet (1 extra cubic foot to ensure that any rounding losses are covered) in **cell O23** on sheet DA A. **Cell P68** shows that the SWRv has been met for the site. This information is also summarized on the Compliance worksheet tab.

Step 4: Size the BMPs According to the Design Equations.

The green roof needs to be sized according to Equation 3.1. Note that, since green roofs are typically manufactured systems, several of the parameters, such as the drainage layer depth and maximum water retention of all layers, need to be provided by the manufacturer. In this example, a media depth of 6 inches with a maximum water retention of 0.40 was chosen. The drainage layer has a depth of 1 inch and a maximum water retention of 0.15. These values are indicated in the variable descriptions below Equation 3.1 (with each layer illustrated in Figure 3.1).

Equation 3.1 Storage Volume for Green Roofs

$$Sv = \frac{SA \times [(d \times \eta_1) + (DL \times \eta_2)]}{12}$$

where:

Sv	=	storage volume (ft^3)
SA	=	green roof area (ft^2)
d	=	media depth (in.) (minimum 3 in.)
η_1	=	verified media maximum water retention
DL	=	drainage layer depth (in.)
η_2	=	verified drainage layer maximum water retention

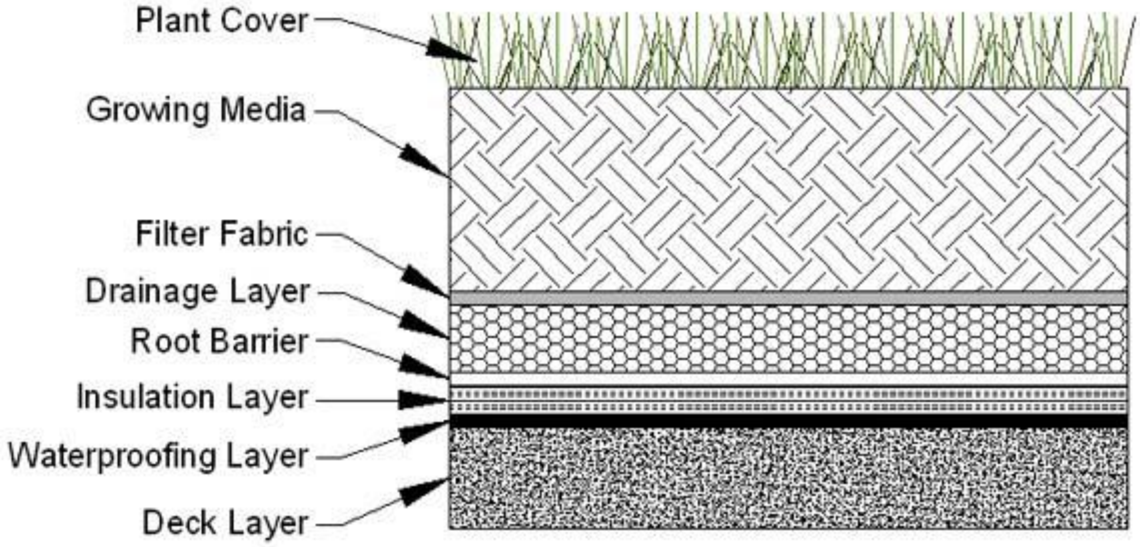


Figure 3.1 Typical layers for a green roof.

Rearranging Equation 3.1 to find the minimum required surface area:

$$SA = Sv/[(\mathrm{d} \times \eta_1)+(DL \times \eta_2)] \times 12$$

or:

$$SA = 6{,}208/(6 \times 0.40 + 1 \times 0.15) \times 12$$

$$SA = 29{,}214 \text{ ft}^2$$

Therefore, the green roof must be sized to be at least 29,214 square feet (45% of the rooftop surface area), given the proposed depths. The original assumption was that a 39,204-square-foot roof would be used. Since a smaller roof is feasible, the drainage areas in the spreadsheet may be revised accordingly. However, the maximum drainage area to a green roof is only 25% more than the green roof itself. If a smaller roof is used, the design must indicate that the water can be conveyed onto the green roof in a non-erosive manner. If the larger green roof area is used, it could be designed with a lower media depth or the increased storage volume could be used to reduce peak flow volume requirements (see Step 8) and/or sold as Stormwater Retention Credits.

Step 5: Check Design Assumptions and Requirements.

Key assumptions and requirements for this site include:

- Ensure that there is sufficient space on the rooftop (allowing for structures such as vents, steep areas of the roof, and other panels). In this case, the green roof area of 29,214 square feet is less than half of the entire roof area.
- At least 19,791 square feet of the rooftop not covered by green roof needs to be designed so that it drains to the green roof without damaging it. This may require level spreaders or other devices.

Since all of these assumptions and requirements can be met in this design example, this step is complete.

Step 6: Use the Adjusted Curve Number to Address Peak Flow Requirements.

The initial curve number for this site is 98, but retention provided by the green roof change this number. The Channel and Flood Protection tab notes the reduced curve numbers for the 2-year, 15-year, and 100-year storms: 86, 88, and 88, respectively. These curve numbers can be used to help determine detention requirements for this site.

Step 7: Determine Detention Requirements.

Detention is required to reduce the peak discharge rate from the 2-year-storm event to the predevelopment (meadow conditions or better) peak discharge rate and to reduce the peak discharge rate from the 15-year storm event to the preproject peak discharge rate. Appendix H includes details on the procedure for calculating the detention volume. In this example, the proposed land cover is the same as the preproject conditions, so detention is not required for the 15-year storm. However, detention is required for the 2-year storm.

The peak inflow, qi_2 and the peak outflow, q_{o2} can be calculated using the WinTR-55 Small Watershed Hydrology program, the area of the site, the time of concentration (Tc, assumed to be 10 minutes), and the curve numbers. The reduced curve of 90, determined above, generates a $qi_2$of 3.80 cubic foot per second (cfs). The curve number for meadow in good condition, 71, generates a q_{o2} of 1.74 cfs.

The ratio of 0.39 cfs to 1.00 cfs equals 0.46. Using Figure H.1, this equates to a ratio of storage volume (Vs_2) to runoff volume (Vr_2) of approximately 0.29.

The runoff volume (Vr_2) determined in the Compliance Calculator spreadsheet is 1.83 inches, which equates to 9,964 cubic feet. Using the calculated ratio of Vs_2/Vr_2, the storage volume required for the site (Vs_2) is 2,890 cubic feet.

Rooftop Storage (see Appendix I) may be the most cost effective method for achieving this detention volume in this example, if space is available, and the design configuration can be created that routes the green roof to the rooftop storage. Alternatively, the required storage could be achieved via a tank located somewhere in the building

Design Example 6

Step 1: Determine Design Criteria

Design Example 6 includes the following proposed design criteria:

Site Name	Connecticut Ave. Complex
Total Site Area	65,340 ft^2
Natural Cover Area	0 ft^2
Compacted Cover	0 ft^2
Impervious Cover (Rooftop)	65,340 ft^2
Vehicular Access Areas	0 ft^2
Is site located within the AWDZ?	No
Is site located within the MS4?	Yes
What type of activity is the site undergoing?	Major Land Disturbing

Step 2: Input Design Criteria to Determine the Retention and Treatment Requirements.

The General Retention Compliance Calculator will calculate a stormwater retention volume (SWRv) once the impervious cover area is entered in **cell D24** on the Site Data sheet.

Based on the design criteria above, the Connecticut Ave. Complex project is required to treat 1.2 inches of rainfall for the SWRv:

SWRv (**cell D37**) = 6,207 ft^3

Step 3: Identify Site Constraints and BMP Restrictions.

Key considerations for the Connecticut Ave. Complex project include the following:

- Since this is a rooftop-only site, very few treatment options are available.

Step 4: Select BMPs to Meet the Retention and Treatment Requirements.

Rainwater harvesting (R-1) is selected as the most appropriate BMP for this site.

The site will ultimately have one outlet point, so the calculations can be performed on one Drainage Area sheet – D.A. 1. Therefore, the impervious cover value from the Site Data tab should be put into **cell B8** on the D.A.1 sheet.

The Rainwater Harvesting Retention Calculator should be used to determine the cistern size and the associated retention value. In the Rainwater Harvesting Retention Calculator 65,340 square feet should be put in as the Contributing Drainage Area (CDA) (**cell L7**). For utilization of the rainwater, flushing toilets/urinals is selected as the use, and the appropriate values are entered. In this case, 1,600 people will use the building per day (**cell L21**), Monday through Friday (**cells**

L30 and **L32**), 8 hours per day (**cell L34)**. On the Results – Retention Value sheet, the retention values are given for various tank sizes. The tables and graphs show that an 80,000 gallon tank would have a 74% retention value. Coincidentally, it would also meet 74% of the annual demand.

The next step is to return to the D.A. 1 tab and input the 65,340-square foot CDA into **cell D25** for rainwater harvesting and input the efficiency (74%) into **cell K25**. The result is that 6,507 cubic feet of runoff are retained and 2,286 cubic feet remain. **Cell P68** shows that the SWRv has been met for the site, and **cell Q69** shows that the SWRv exceedance of 2,244 gallons may be available to generate SRCs.

Step 5: Size the BMPs According to the Design Equations.

The size of the rainwater-harvesting cistern was already determined to be 80,000 gallons, although additional volume may be necessary for detention, as described in Step 8 below, as well as for dead storage for a pump, and/or freeboard.

Step 6: Check Design Assumptions and Requirements.

Key assumptions and requirements for this site include:

- The rainwater harvesting cistern will be at least 80,000 gallons. The designer would need to ensure that space would be available for these BMPs on the site.
- Demand for the water from toilet flushing should be verified.

Since all of these assumptions and requirements can be met in this design example, this step is complete.

Step 7: Use the Adjusted Curve Number to Address Peak Flow Requirements.

The initial curve number for this site is 98, but retention provided by rainwater harvesting changes this number. The Channel and Flood Protection tab notes the reduced curve numbers for the 2-year, 15-year, and 100-year storms: 85, 87, and 88, respectively. These curve numbers can be used to help determine detention requirements for this site.

Step 8: Determine Detention Requirements.

Detention is required to reduce the peak discharge rate from the 2-year-storm event to the pre-development (meadow conditions or better) peak discharge rate and to reduce the peak discharge rate from the 15-year storm event to the pre-project peak discharge rate. Appendix H includes details on the procedure for calculating the detention volume. In this example, the proposed land cover is the same as the pre-project conditions, so detention is not required for the 15-year storm. However, detention is required for the 2-year storm.

The peak inflow, qi_2 and the peak outflow, q_{o2} can be calculated using the WinTR-55 Small Watershed Hydrology program, the area of the site, the time of concentration (Tc, assumed to be 10 minutes), and the curve numbers. The reduced curve of 85, determined above, generates a qi_2 of 3.64 cubic foot per second (cfs). The curve number for meadow in good condition, 71, generates a q_{o2} of 1.74 cfs.

The ratio of 1.74 cfs to 3.64 cfs equals 0.48. Using Appendix H this equates to a ratio of storage volume (Vs_2) to runoff volume (Vr_2) of approximately 0.29.

The runoff volume (Vr_2) determined in the Compliance Calculator spreadsheet is 1.77 inches, which equates to 9,938 cubic feet. Using the calculated ratio of Vs_2/Vr_2, the storage volume required for the site (Vs_2) is 2,795 cubic feet.

Since rainwater harvesting is the selected BMP on this project, the most appropriate means for detaining the 2,795 cubic feet (20,907 gallons) may be to increase the size of the cistern to 13,500 cubic feet (101,000 gallons). Alternatively, if stage-storage routing is performed on the tank for a 2-year storm event, beginning with the average daily volume in the tank, the detention volume may be decreased significantly.