# *Chapter 13*

# *EXAMPLE SITE PLANS*

## *Table of Contents*

### *CHAPTER SECTION HEADINGS*



### *FIGURES*

## *TABLES*

## 13.0 INTRODUCTION

The revisions of the Virginia Stormwater Management Program (VSMP) Regulations represent a significant shift in the way the Department anticipates stormwater runoff will be managed. In the past, the focus of stormwater management (SWM) was to capture runoff in one or more best management practices (BMPs), which removed pollutants from the runoff via various treatment mechanisms. Then, as is often necessary, the runoff would have to be detained and slowly released into the receiving stream channel in order to prevent channel scouring and minor flooding downstream.

Based on the recommendations of a panel of stormwater management experts convened by the National Research Council of the National Academies of Science (NRC, 2008)**,** the new regulatory criteria focus on reducing the volume of runoff generated by the development project, so that more water is kept on the site, greater pollutant removal can be achieved, and impacts on the downstream receiving system will be reduced. This approach relies on design decisions to employ smaller runoff (volume) reduction BMPs distributed around the development site, instead of fewer larger treatment-only structures typically located at the discharge point(s) of the site.

While the choice of BMPs to be used is still up to the designer, local government officials and land developers are concerned about the cost implications of this new strategy and about the implications for long-term inspections and maintenance that will be required to ensure continual performance of these BMPs. As well, the previous edition of this Handbook (1st edition, 1999) provided site design examples only for the traditional approach – a large pond located at or near the site's discharge point. Therefore, this chapter provides a number of example site plan designs focused on the new paradigm – Low Impact Development (LID) BMPs and Environmental Site Design (ESD) sorts of site layout choices.

The examples included here provide explanations about the design decisions, BMP location and sizing, and the associated calculations involved (as explained in **Chapter 11**). The five examples provided represent institutional, residential, commercial/office, and two redevelopment projects.

## 13.1. DESIGN EXAMPLE 1: INSTITUTIONAL SITE PLAN

**Site Description**: This example design (**Figure 13.1** below) is for an *Institutional Use* facility and is comparable to a small hotel or conference center. **Table 1** provides the basic acreage and site hydrology.

**Step 1**: Resource Mapping (see **Chapter 6**) and Environmental Site Assessment
The Site Assessment is the basis for the concept plan and should include at a minimum a written narrative or map identifying the following natural resource features:

1. Wetlands
2. Perennial streams and Intermittent streams
3. Stream buffers
4. Floodplains
5. Forest or other mature and/or native vegetation
6. Steep slopes
7. Soil types (Hydrologic Soil Groups, highly erodible soils)
8. Springs and/or natural seeps
9. Geology (bedrock or karst conditions)
10. Drainage divides

**Step 2:** Site Hydrology and Pollutant Loads

Developing the hydrology for the entire site allows the designer to establish the overall site-scale Post-Development Pollutant Load (TP, lb/yr) and the Total Load (TP) Reduction Required (lb/yr). If the developed portion of the site includes multiple drainage areas, and more importantly, multiple discharge points, the designer will also need to develop the hydrology for each drainage area (Step 3) in order to comply with the Quantity Control requirements.

1. Basic site level hydrology (from NRCS Methods, **Section 4-4** of **Chapter 4**, ***Blue Book***)
   *a.* Pre- and Post developed condition land cover by soil type

   ***NOTE:*** *NRCS CN methods – the NRCS land cover descriptions are not necessarily the same as the RRM Land Cover.*

   *b.* Compute the composite (or weighted) CN.
   *c.* *Tc* (NRCS Methods, **Section 4-4** of **Chapter 4**, ***Blue Book***): This will require topography and site information sufficient to accurately identify drainage divides, *Tc* and *Tt* flow paths and channel geometry, and surface conditions (roughness coefficient, etc.).

   **Table 13.1** provides a summary of the site hydrology. Note that the terminology for what was *meadow* in the pre-developed condition changes to *open space* in the developed condition with the corresponding NRCS Curve Number. NRCS defines open space as lawns, parks, golf courses, etc. These areas will be considered *managed turf* in the VRRM Post-Development Pollutant Load calculation.

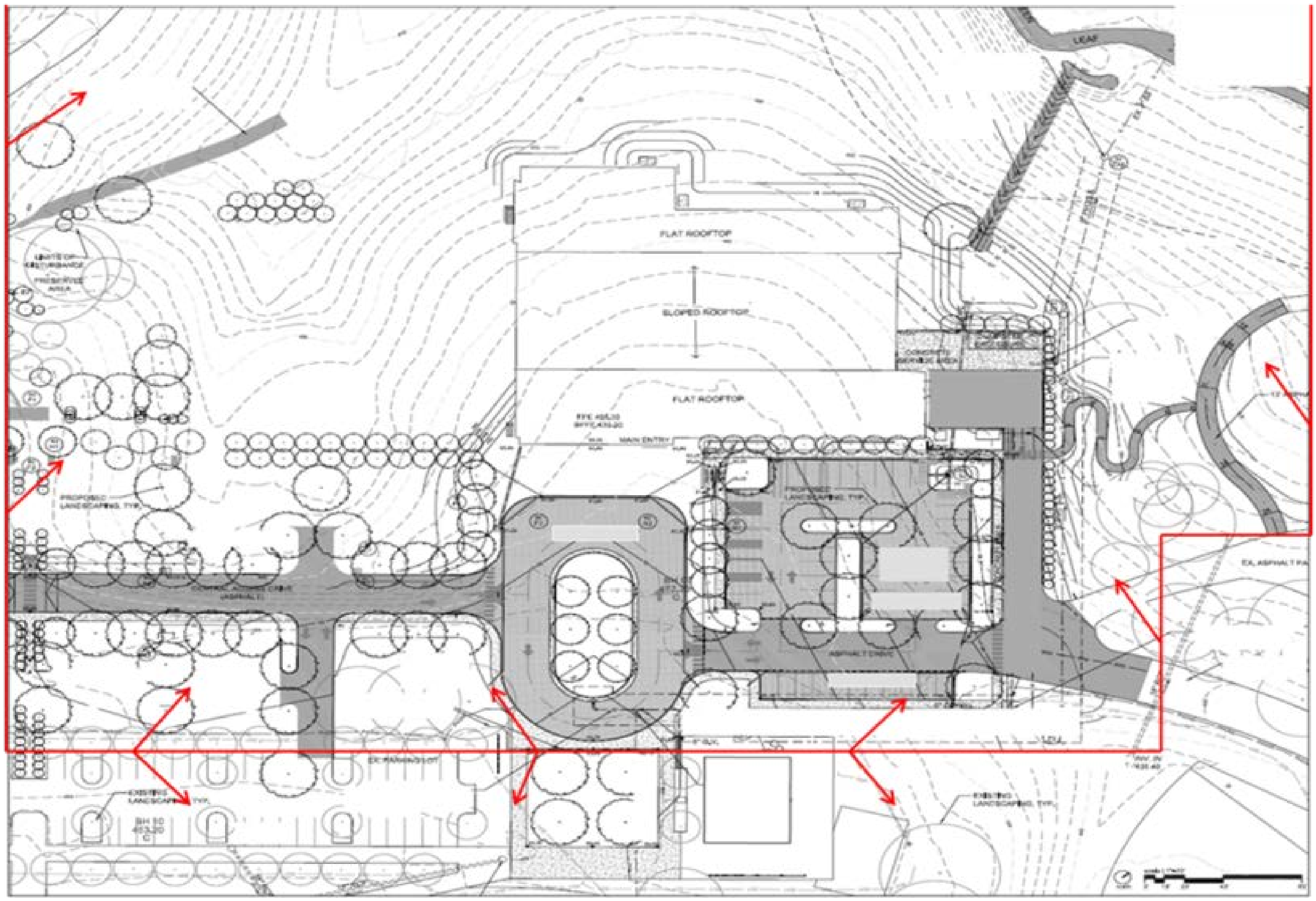


***Figure 13.1. Proposed Institutional Development Site:***
***Site/Parcel Area = 5.97 acres; Developed CN = 76***
*Site Plan Source: Courtesy of Water Street Studio, Charlottesville, VA*

***Table 13.1. Site Hydrology: Entire Institutional Site***

| Pre-Developed | | | | | |
|---|---|---|---|---|---|
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** |
| Meadow | Good | B | 2.05 | 58 | |
| Meadow | Good | C | 2.83 | 71 | |
| Woods | Good | C | 1.09 | 70 | |
| | | **Total** | **5.97** | **66** | **0.35** |
| **Post-Developed** | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc** |
| Open Space | Good | B | 2.05 | 61 | |
| Open Space | Good | C | 0.93 | 74 | |
| Impervious | | C | 1.90 | 98 | |
| Woods | Good | C | 1.09 | 70 | |
| | | **Total** | **5.97** | **76** | **0.21** |

2. Post-Development Pollutant Load (VRRM Compliance Spreadsheet)

   1. The VRRM Compliance Spreadsheet computes the total site composite *Rv,* Post-Development Treatment Volume (*Tv*), Post-Development Pollutant Load (TP and TN), and Total Load Reduction Required (TP) when the Land Cover information is entered into the Site Data Tab. **Table 13.2** below provides the user entered Site Data for this example, and Post-Development Treatment Volume (cf). **Tables 13.5 and 13.6** display the spreadsheet cells for DA's A and B respectively.

***Table 13.2. Land Cover (acres) for Institutional Site: VRRM Compliance Spreadsheet Site Data Tab***

| **Land Cover** | **A** | **B** | **C** | **D** | **Total** |
|---|---|---|---|---|---|
| **Forest** | 0 | 0 | **1.09** | 0 | **1.09** |
| **Turf** | 0 | **2.05** | **0.93** | 0 | **2.98** |
| **Impervious** | 0 | 0 | **1.90** | 0 | **1.90** |
| | | | | **Total** | **5.97** |

**Table 13.3** displays the spreadsheet calculated values (Calculation Cells B46 through B52).

***Table 13.3. Land Cover Summary for Institutional Site: VRRM Compliance Spreadsheet Site Data Tab***

| **Total Site Area (acres)** | **5.97** | | |
|---|---|---|---|
| **Site Rv** | **0.41** | | |
| Post-Development Treatment Volume (acre-ft) | **0.21** | | |
| Post-Development Treatment Volume (cubic feet) | **8,941** | | |
| Post-Development Load (TP) (lb/yr) | **5.62** | (TN) (lb/yr) | **40.19** |
| Total Load (TP) Reduction Required (lb/yr) | **3.17** | | |

**Step 3:** Drainage Area Hydrology, Peak Discharge, and Treatment Volume (*Tv*)

This example includes two distinct discharge points, shown in **Figure 13.2** below. While they discharge into the same stream (or stormwater conveyance channel, as defined in the VSMP regulations), each point of discharge will be required to meet the quantity control requirements (VSMP regulations 9 VAC 25-870-66. Water Quantity).

2. Repeat **Step 2.1** for each Drainage Area (DA);
   a. Compute the composite CN for each DA;
   b. Compute the *Tc* for each DA;
   c. Determine the 24-hour rainfall depth for the appropriate 24-hour design storms as identified in the VSMP regulations (9 VAC 25-870-66), and compute the runoff depth ($Q$) and peak discharge ($q_p$). (Refer to **Chapter 11** of this for guidance on hydrologic methods terminology and symbology.) **Table 13.4** below provides a summary of the pre- and post-development hydrology for Drainage Areas A and B of this example.

3. Enter land cover data into the drainage area tabs on the VRRM Compliance Spreadsheet (**DA-A** and **DA-B** tabs, Land Cover (cells B5 through E7). Calculation cells will provide the total acreage, the Land Cover *Rv* (average for each land cover), and post-development Treatment Volume (*Tv*, in cf). **Tables 13.5 and 13.6** below display the spreadsheet cells for DA's A and B respectively.

**Step 4:** Apply BMPs in DA-A using the VRRM Compliance Spreadsheet:

> ***NOTE**: The spreadsheet is not a BMP design tool other than to provide the designer with a simple tool for selecting BMPs and determining whether the selected BMPs or combinations of BMPs achieves compliance. The spreadsheet can also provide the designer with the treatment volume to the selected BMP ($Tv_{BMP}$ ). This includes the volume generated by the contributing drainage area, as well as any additional (reduced) volume from upstream BMPs. Using basic sizing parameters, the designer can verify the applicability of the practice given the various site constraints (overall footprint, depth, infiltration capacity, etc.). Once the selection of BMPs has been confirmed as adequate for compliance, the designer can then develop the detailed sizing and design of each practice.*

Numerous BMP options are available for this design example; the BMPs selected here represent one of several possible combinations. However, the hierarchy or order of selection is representative of the strategy of the VRRM: start with the site-design related practices, such as sheet flow, protected open space, impervious disconnection, etc.

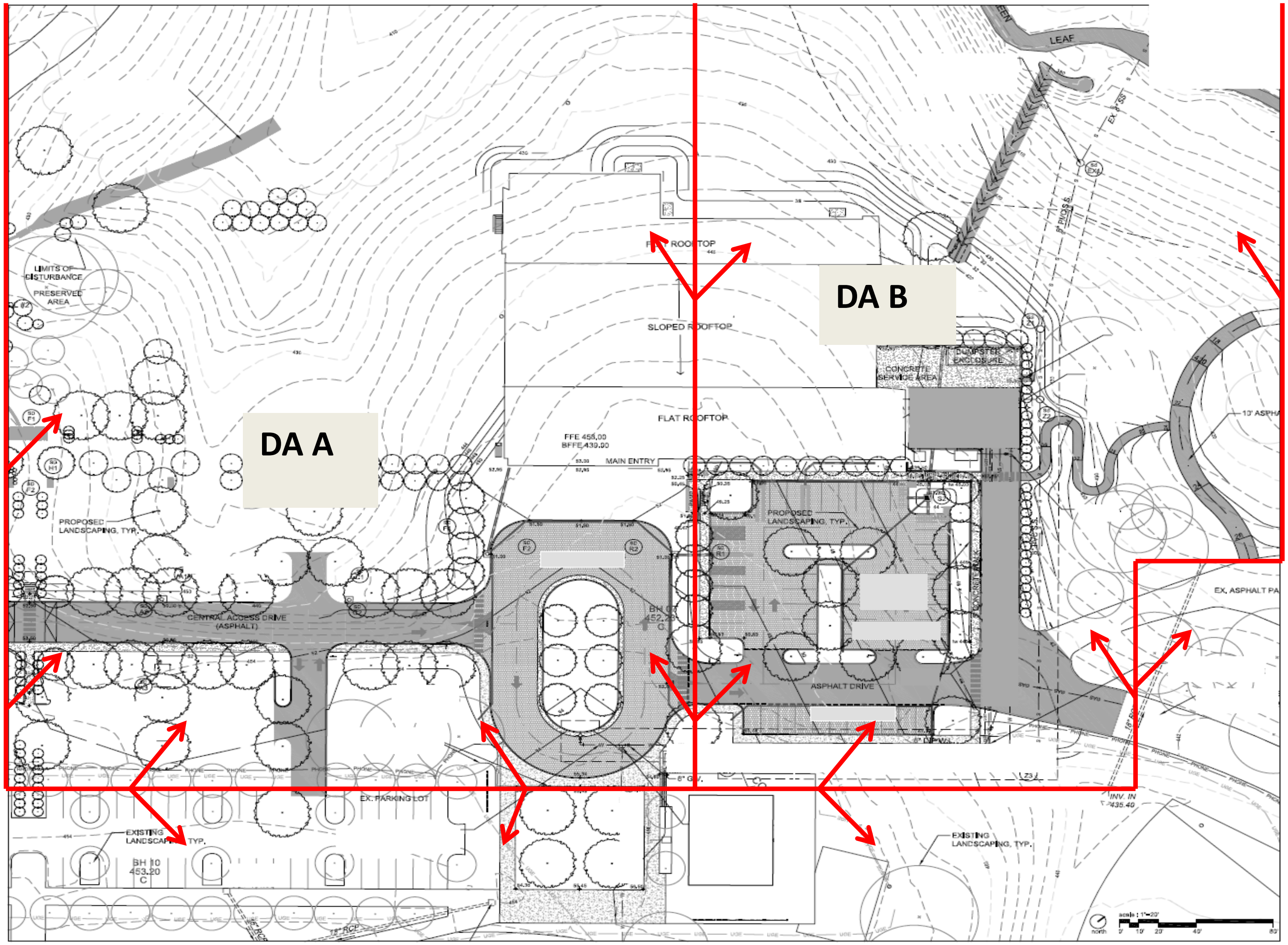


*Figure 13.2. Proposed Institutional Development Site, Drainage Areas A and B*

*Table 13.4. Hydrology for Institutional Site: Drainage Areas A & B*

| Land Use | Condition | HSG | Area (ac) | CN | Tc (hrs) | $Q_1$ (in) | $q_{p1}$ (cfs) | $Q_{10}$ (in) | $q_{p10}$ (cfs) |
|---|---|---|---|---|---|---|---|---|---|
| **Rainfall Depths:** 1-year 24-hour storm: **2.66 inches;** 10-year 24-hour storm: **4.93 inches** | | | | | | | | | |
| ***Drainage Area A*** | | | | | | | | | |
| **Pre-Development DA A** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| Meadow | Good | B | 2.05 | 58 | | | | | |
| Meadow | Good | C | 1.38 | 71 | | | | | |
| Woods | Good | C | 0.50 | 70 | | | | | |
| **Total** | | | **3.93** | **64** | **0.35** | **0.33** | **0.9** | **1.54** | **6.1** |
| **Post-Development DA A** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| Open Space | Good | B | 2.05 | 61 | | | | | |
| Open Space | Good | C | 0.50 | 74 | | | | | |
| Impervious | | C | 0.88 | 98 | | | | | |
| Woods | Good | C | 0.50 | 70 | | | | | |
| **Total** | | | **3.93** | **72** | **0.21** | **0.62** | **2.9** | **2.15** | **11.0** |
| ***Drainage Area B*** | | | | | | | | | |
| **Pre-Development DA B** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| Meadow | Good | C | 1.45 | 71 | | | | | |
| Woods | Good | C | 0.59 | 70 | | | | | |
| **Total** | | | **2.04** | **71** | **0.33** | **0.58** | **1.1** | **2.07** | **4.6** |
| **Post-Development DA B** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$Q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$Q_{p10}$ (cfs)** |
| Open Space | Good | C | 0.43 | 74 | | | | | |
| Impervious | | C | 1.02 | 98 | | | | | |
| Woods | Good | C | 0.59 | 70 | | | | | |
| **Total** | | | **2.04** | **85** | **0.15** | **1.30** | **3.8** | **3.29** | **9.4** |

***Table 13.5. Drainage Area A Land Cover Summary for Institutional Site (VRRM Compliance Spreadsheet DA-A Tab)***

| Drainage Area A Land Cover (acres) | | | | | | |
|---|---|---|---|---|---|---|
| | **A soils** | **B Soils** | **C Soils** | **D Soils** | **Totals** | **Land Cover Rv** |
| Forest/Open Space (acres) | 0 | 0 | 0.50 | 0.00 | 0.5 | 0.04 |
| Managed Turf (acres) | 0 | 2.05 | 0.50 | 0.00 | 2.55 | 0.20 |
| Impervious Cover (acres) | 0 | 0.00 | 0.88 | 0.00 | 0.88 | 0.95 |
| | | | | **Total** | 3.93 | |

| | |
|---|---|
| **Post-Development Treatment Volume (cf)** | 4,995 |

***Table 13.6. Drainage Area B Land Cover Summary for Institutional Site (VRRM Compliance Spreadsheet DA-B Tab)***

| Drainage Area B Land Cover (acres) | | | | | | |
|---|---|---|---|---|---|---|
| | **A soils** | **B Soils** | **C Soils** | **D Soils** | **Totals** | **Land Cover Rv** |
| Forest/Open Space (acres) | 0 | 0 | 0.59 | 0.00 | 0.59 | 0.04 |
| Managed Turf (acres) | 0 | 0 | 0.43 | 0.00 | 0.43 | 0.22 |
| Impervious Cover (acres) | 0 | 0.00 | 1.02 | 0.00 | 1.02 | 0.95 |
| | | | | **Total** | 2.04 | |

| | |
|---|---|
| **Post Development Treatment Volume (cf)** | 3,947 |

**Figure 13.3** below provides the graphic representation of the BMP selections and contributing drainage areas described in this step.

1. **Vegetated Filter Strip**: **0.14 ac** impervious; **0.39 ac** turf

Consider minimum dimensions from specifications (**Sheet Flow BMP Design Specification No. 2**):

- Minimum dimensions:
  - 1% to 4% Slope – Minimum 35 ft. width
  - 4% to 6% Slope – Minimum 50 ft. width
  - **6% to 8% Slope – Minimum 65 ft. width**
  - The first 10 ft. of filter must be 2% or less in all cases

- Maximum flow length:
  - Maximum flow length of 150 ft. from adjacent pervious areas;
  - Maximum flow length of 75 ft. from adjacent impervious areas

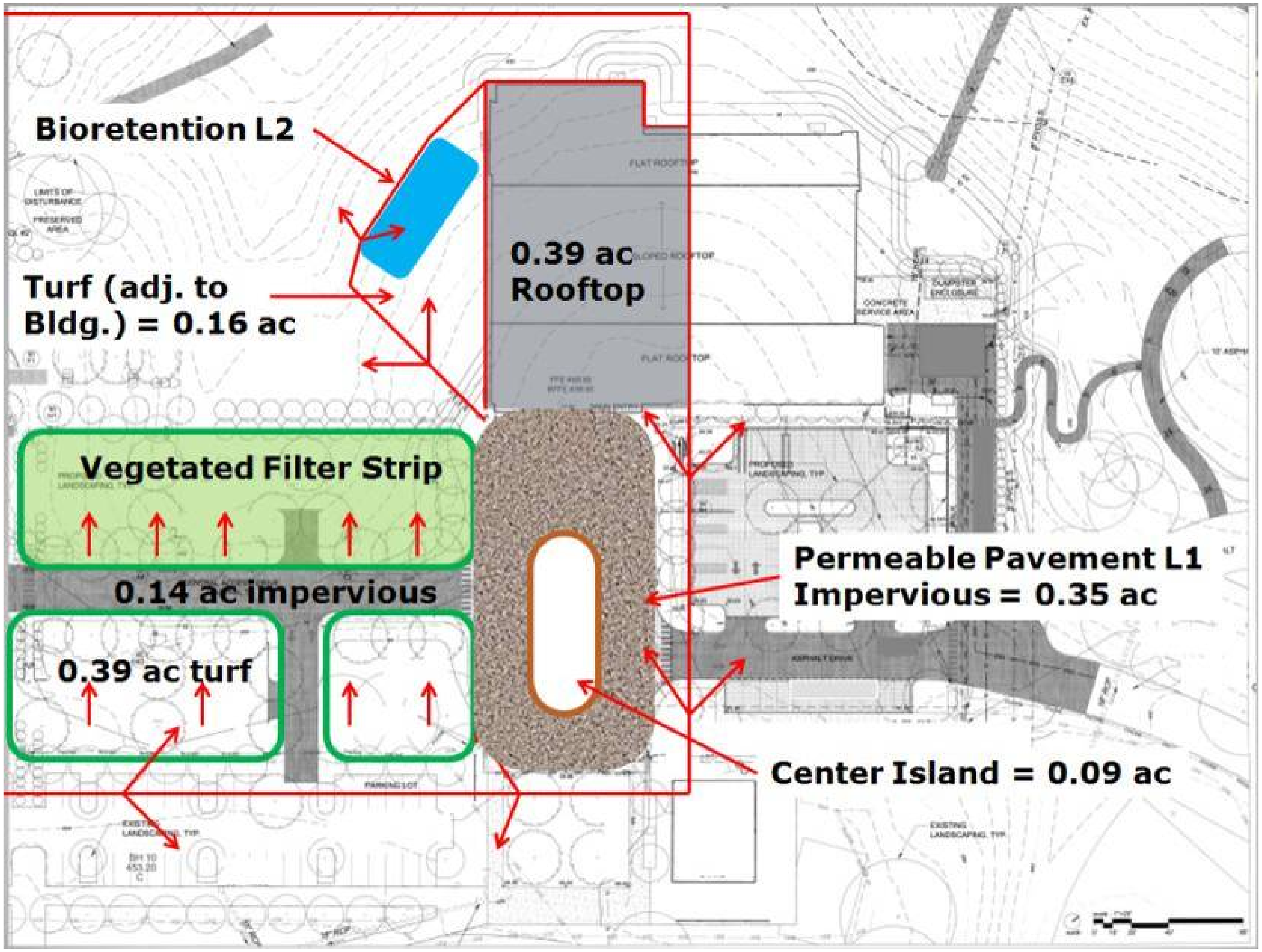


***Figure 13.3: Institutional Site BMP Selections and Areas Contributing Drainage to Drainage Area A***

- Confirm the design of a Vegetated Filter Strip will fit in the selected location:
  - The area of proposed vegetated filter strip that can fit at the desired location is approximately 65 ft wide (direction of flow) and 240 ft long (perpendicular to flow, parallel to the impervious surface);
  - 65' x 240' = 15,600 $ft^2$ (~ 0.35 ac).
  - This area is in B and C soils, so the area of the filter strip will require soil amendments (the design specification allows flexibility for the local plan approving authority to allow filter strips in areas of B soils without soil amendments).

- Select Sheetflow to Vegetated Filter Strip (item 9.c. on the VRRM Compliance Spreadsheet)
  - Enter 0.14 impervious acres and 0.39 turf acres of Credit Area (cells G68 and G69 respectively).
  - No downstream practice is selected at this time; however there appears to be area below the filter strip if needed.

- The 0.35 acres of the filter strip area could be changed from M*anaged Turf* to *Forest/Open Space* in the Land Cover table on the Site Data and D.A. Tab – this would lower the calculated Post-Development Load and Load Reduction Requirement for the site. This can be considered after the Water Quality Compliance Check if necessary.

2. **Permeable Pavement Level 1** in driveway entrance plaza: 0.28 acres of Permeable Pavement and 0.07 acres of impervious run-on, for a total of **0.35 ac** impervious acres (entered in "Credit Area" (column G) of VRRM Compliance Spreadsheet as the "acres of permeable pavement + acres of "external" (up-gradient) impervious pavement").

   Bioretention in the center island (0.09 ac) is an option, however, when considering the space requirements (approximately 5% to 6% of the contributing drainage area to account for 3:1 side slopes, forebay, etc.), makes this a very tight location.

   Consider design criteria from specifications (**Permeable Pavement Level 1 BMP Design Specification No. 7**):

   - Maximum pavement slope < 5%

   - Level 1 ratio of external pavement to permeable pavement (R) ≤ 2.5; with run-on minimized to the extent practicable, or limited to impervious cover.
     - Small portion of pavement immediately adjacent to building will be impervious (regular) pavement = 0.07 ac. Therefore R = 0.07/0.28 = 0.25 (≤ 2.5; OK).
     - Center island is graded with an internal drain to avoid the potential run-on of sediment and landscaping organic solids.

   - Calculate minimum and/or maximum depth of stone reservoir (**Equation 7.1; Design Spec 7**)

- The *minimum* stone reservoir depth required to store the Treatment Volume to the BMP is often less than that needed for adequate pavement bedding (based on soil strength – refer to design specification).
- $Tv_{BMP}$ or Treatment Volume to the practice: 1,207 $ft^3$ from the VRRM Compliance Spreadsheet column I (Runoff Reduction) and column J (Remaining Runoff Volume). The actual pavement stone reservoir depth will be determined by the pavement designer based on subsoil conditions and bearing strength, and will likely exceed the minimum required depth to manage the $Tv_{BMP}$.
- Using Level 1 (with an underdrain) eliminates the need for a *maximum* depth calculation. Increasing the depth of the stone reservoir to capture and store a greater runoff volume with an outlet control for a single-event storm routing as needed may allow the designer to address quantity control requirements. However, increasing the total volume captured and detained does not achieve a greater *annual* runoff volume and pollutant load reduction.

3. **Bioretention Level 2** benched into the slope adjacent to building: **0.39 ac** impervious (rooftop); **0.16** ac turf (adjacent to building); Total acres treated = **0.55 ac**.

   Design and sizing considerations for Bioretention L2 (**Bioretention BMP Design Specification No. 9**):

   - General sizing guidance for Bioretention L2 calls for an overall practice footprint of approximately 6% of the contributing drainage area (6% x 0.55 ac x 43,560 $ft^2$/ac = 1,437 $ft^2$).

   - Entering the contributing turf and impervious *credit area* contributing to the practice into the VRRM Compliance Spreadsheet (column G) reveals the contributing *Tv* from turf and impervious land covers as the sum of column I + column J for each, which when added is the $Tv_{BMP}$ used for BMP sizing = 1,464 $ft^3$.

   - Level 2 Bioretention sizing factor = 1.25 x Tv = 1.25 x 1,464 $ft^3$ = 1,830 $ft^3$

   - Using the sizing rules for storage volume (surface ponding: 1-foot max., required soil media depth: 36-inch min., and infiltration or a gravel reservoir sump: 12-inch min.), and taking into account the grading requirements for benching the practice into the slope adjacent to the building (including area needed for the berm and side slopes), the designer can determine the actual size and depth needed for Bioretention L2. The area adjacent to the building is sufficient for the overall footprint of the practice.

**Step 4A:** Interim compliance check

- The three BMPs in DA-A treat a total of 0.88 acres of impervious cover and 0.55 acres of turf (column G, rows 71 and 72; DA-A Tab).

- The area checks (cell G74); meaning the total treated does not exceed the total in the drainage area. All of the impervious area has been directed to a primary BMP: permeable pavement Level 1 or bioretention Level 2. One of the benefits of the RRM is the ability to use treatment train approach, whereby a downstream BMP can treat not only the adjacent contributing drainage area, but also the discharge from an upstream BMP. The economy of scale in making the downstream BMP slightly larger to accommodate the additional (though "reduced") runoff volume from an upstream BMP may be more efficient than adding a new BMP elsewhere on the site. This is one of the benefits of the VRRM Spreadsheet: the ease at which a designer can consider different BMPs and combinations of BMPs.

  **NOTE**: ***It is important to try to use BMPs with different pollutant removal pathways within a treatment train if possible. While the volume reduction of BMPs in series is cumulative, using the same pollutant removal process more than once in series is not likely to increase the load reduction beyond the capabilities of the first BMP. Further, the pollutant concentration in the runoff may reach an irreducible load, after which any additional load reduction will be the result only of the additional runoff <u>volume</u> reductions achieved.***

- The load reduction achieved with the three BMPs in DA-A can be found in cell I78: 1.51 lb/yr of the required total site reduction 3.17 lb/yr, slightly less than half the required load reduction.

- Since DA-A is larger than DA-B, and since all the impervious area in DA-A has been directed to at least one BMP, it stands to reason that additional BMPs will be needed in this DA, or high performance (Level 2) BMPs will be needed in DA-B.

- Before placing additional BMPs in DA-A, it is recommended to check the potential for BMP implementation in other drainage areas in order to help achieve uniform distribution of BMPs if possible.

**Step 5:** Implement BMPs in DA-B

**Figure 13.4** below provides the graphic representation of the BMP selections and contributing drainage areas described in this step.

1. **Permeable Pavement Level 1** in the parking areas of DA-B: 0.28 acres of Permeable Pavement and 0.08 acres of impervious run-on, total of **0.36 ac** impervious area (entered in "Credit Area" (column G) of VRRM Compliance Spreadsheet as the "acres of permeable pavement + acres of "external" (up-gradient) impervious pavement")

   - The cost of permeable pavement, both materials and installation, is driven by economy of scale. Therefore, since both parking areas are relatively small (areas in both DA-A and DA-B) it makes sense to make both areas permeable pavement.

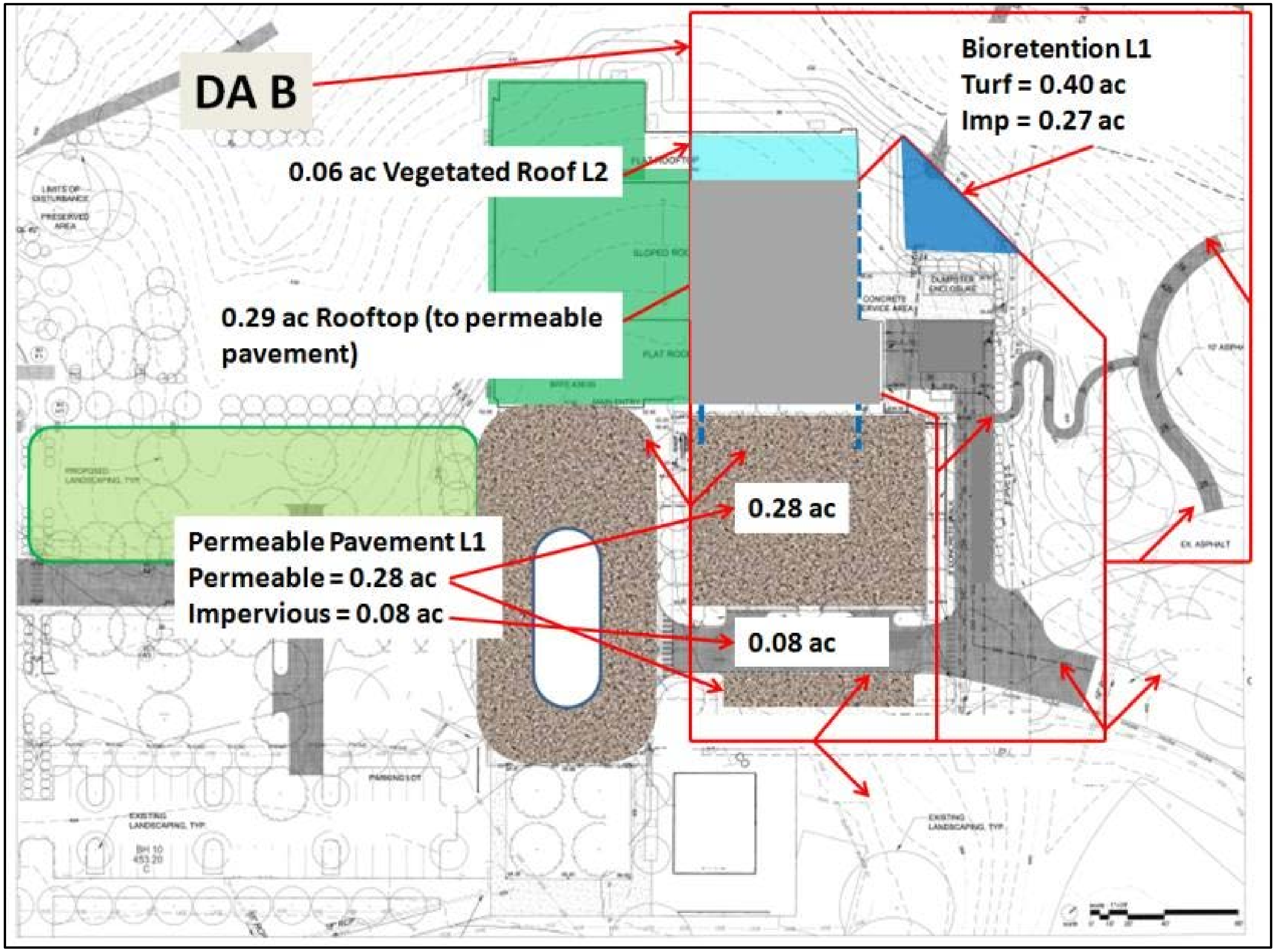


*Figure 13.4: Institutional Site BMP Selections and Areas Contributing Drainage to Drainage Area B*

- The small area of the driveway (0.08 ac.) could easily be constructed of permeable pavement, and actually make construction easier since it would be one consistent application of the selected pavement material. Many designers elect to leave primary or service driveways as a regular or heavy duty pavement since they may experience heavier traffic loads. Designers should consult the manufacturers and contractors familiar with the various permeable pavement materials and design characteristics before finalizing any permeable pavement designs.

  Consider the design and sizing considerations from specifications (**Permeable Pavement BMP Design Specification No. 7**):

- Maximum pavement slope < 5%

- Level 1 ratio of external pavement to permeable pavement (R) ≤ 2.5; with run-on minimized to the extent practicable, or limited to impervious cover.
  - Permeable pavement will be limited to the parking areas (0.28 ac) with the main drive aisle entering the parking (0.08 ac) to be impervious (regular) pavement = 0.08 ac. Therefore R = 0.08/0.28 = 0.29 (≤ 2.5; OK).
  - Using Level 1 (with an underdrain) as in DA-A, eliminates the need for a maximum depth calculation since an underdrain will be used.
  - $Tv_{BMP}$ or Treatment Volume to the practice: 1,242 $ft^3$ (from VRRM Compliance Spreadsheet column I + column J. The actual pavement stone reservoir depth will be determined by the pavement designer based on subsoil conditions and bearing strength, and will likely exceed the minimum required depth to manage the $Tv_{BMP}$.

2. **Rooftop Runoff**: Since the available depth of storage in the permeable pavement is significantly greater than that required for the small drainage area, consider discharging the roof to the permeable pavement.

   - Discharge of the rooftop runoff to the permeable pavement is subject to the maximum R value of 2;

   - Rooftop area is 0.29 ac and the permeable pavement area is 0.28 ac; therefore R = (0.29 + 0.08 ac)/0.28 ac = 1.32 (≤ 2; OK).

   - Critical design element includes the pre-treatment and discharge of the rooftop runoff into the permeable pavement. Pretreatment of rooftop runoff can include gutter screens, surface forebay or filter strip adjacent to the pavement (although a filter strip would be considered a pervious run-on area, which should be avoided or minimized) to capture leaves and other potential debris that would otherwise clog the permeable pavement when discharged at a concentrated outlet (such as the downspout). Discharge of roof drains to permeable pavement could also include sub-grade discharge into the stone reservoir; however this creates possible maintenance challenges. Such a design would require specific screening and cleanout locations for the roof drain pipes.

- With the rooftop area discharged to the permeable pavement, the total "Credit Area" (column G) will be changed to **0.65 ac** impervious area (0.28 ac permeable pavement + 0.29 ac rooftop + 0.08 ac external pavement) and is now entered in "Credit Area" (column G) of VRRM Compliance Spreadsheet as the "acres of permeable pavement + acres of "external" (up-gradient) impervious pavement".

3. **Vegetated Roof Level 2** on the small portion (**0.06 ac**) of the back-side of the building in DA-B.

   - Design considerations for Vegetated Roof Level 2 can be reviewed in **Vegetated Roof BMP Design Specification No. 5.**

   - Generally, the depth of growing media represents the critical design feature. The extremely small area of this rooftop practice may serve to discourage its use; however, Vegetated Roofs can serve as an amenity to the building if there is access or visibility from windows.

   - Enter **0.06** ac into the Credit Area (acres) Column G of VRRM Compliance Spreadsheet.

4. **Bioretention Level 1** can be graded into the slope immediately adjacent to the building and dumpster/Utility connection area: **0.27 ac** impervious; **0.40 ac** turf; Total acreage = **0.67 ac**. Design and sizing considerations for Bioretention L1 (**Bioretention BMP Design Specification No. 9**):

   - General sizing guidance for Bioretention L1 calls for a practice footprint of approximately 6% of the contributing drainage area (6% x 0.67 ac x 43,560 $ft^2/ac$ = 1,751 $ft^2$).
     - $Tv_{BMP}$ or Treatment Volume to the practice: 1,251 $ft^3$ (from VRRM Compliance Spreadsheet column I + column J.

   - Using the Bioretention Level 1 sizing rules for storage volume: surface ponding = 1-foot max., required soil media depth = 24-inch min., and gravel reservoir sump = 12-inch min. Taking into account the grading requirements for benching the practice into the slope adjacent to the building and parking (similar to considerations in DA-A), the designer can determine the actual size and depth needed for Bioretention L1. This area is sufficient for the overall footprint of the practice. The required surface area estimate of 6% of the contributing drainage area is significantly larger than the $Tv_{BMP}$ actually requires, and allows for the possible creation of additional storage for meeting the water quantity criteria.

**Step 5A** Interim Compliance Check

- The three BMPs in DA-B treat a total of 0.98 acres of impervious cover and 0.40 acres of turf (G71 and 72, DA-B Tab).
- The area checks (cell G74); meaning the total acres of impervious and turf treated does not exceed the total in the drainage area.

- The load reduction achieved with the three BMPs in DA-B is 1.34 lb/yr (cell I78 DA-B Tab).

- The Water Quality Compliance Tab indicates that an additional 0.32 lb/yr must be removed in order to comply. Since the site impervious cover has already been managed with BMPs, the designer should investigate opportunities for a treatment train (BMPs in series).

  **NOTE**: ***Another option is to determine the total acreage of BMPs and convert that acreage from turf to "Forest/Open Space" (as defined in the VRRM User's Guide, Section 3.2, Table 1). This would include the vegetated filter strip and bioretention area in DA-A and the bioretention area in DA-B. This change in land cover would be applied to pollutant load and load reduction requirements only, and not the hydrology computations for quantity control.***

  - Vegetated Filter Strip (DA-A) = 0.35 ac
  - Bioretention Level 2 (DA-A) = 1,437 ft2 (0.03 ac)
  - Bioretention Level 1 (DA-B) = 1,251 ft2 (0.03 ac)

  The changes entered into the Site Data Tab are reflected in **Table 13.7**. The changes in post-developed volumes, loads, and load reduction are shown in **Table 13.8** below**.**

  This brings the total site developed load and removal requirement down by approximately 0.16 lb/yr as represented in revised VRRM Compliance Spreadsheet Site Land Cover Data tables below, thereby reducing the additional load reduction requirement from 0.32 lb/yr to 0.16 lb/yr.

***Table 13.7. Institutional Site Revised Land Cover Data – convert area of BMPs to Forest/Open space***

| **Land Cover Summary (Acres)** | | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **Total** |
| Forest/Open | 0 | **0.38** | **~~1.09~~ 1.12** | 0 | **~~1.09~~ 1.50** |
| Turf | 0 | **~~2.05~~ 1.67** | **~~0.93~~ 0.90** | 0 | **~~2.98~~ 2.56** |
| Impervious | 0 | 0 | **1.90** | 0 | **1.90** |
| | | | | **Total** | **5.97** |

***Table 13.8. Institutional Site VRRM Compliance Spreadsheet – computed changes based on Land Cover changes***

| | | | |
|---|---|---|---|
| **Total Site Area (acres)** | **5.97** | | |
| **Site Rv** | **~~0.41~~ 0.40** | | |
| Post-Development Treatment Volume (acre-ft) | **~~0.21~~ 0.20** | | |
| Post-Development Treatment Volume (cubic feet) | **~~8,941~~ 8,687** | | |
| Post-Development Load (TP) (lb/yr) | **~~5.62~~ 5.46** | (TN) (lb/yr) | **~~40.19~~ 39.05** |
| Total Load (TP) Reduction Required (lb/yr) | **~~3.17~~ 3.01** | | |

**Step 6** Consider Additional BMPs in either DA-A or DA-B

1. Additional BMPs can be added downstream of those placed in either drainage area.

    - The Bioretention Basin in DA-A is downstream of the permeable pavement and was determined to have sufficient area to expand for increased volume.

    - The Bioretention Basin in DA-B is more constrained by the steeper slope immediately adjacent to the basin.

    - It is more effective to use a level 2 BMP (DA-A) as a downstream practice due to the greater performance credit.

    Therefore, evaluate the Bioretention Level 2 in DA-A as a practice downstream from the Permeable Pavement.

2. **Permeable Pavement Level 1 in DA-A**

    - Direct the remaining runoff (Column J) to the Bioretention Level 2 by selecting *Bioretention Level 2* in the drop down menu of column P.

3. **Bioretention Level 2 in DA-A**

    - The additional volume from upstream practices is reflected in column H: "Volume from Upstream RR practice."

    - This volume is the reduced volume as discharged from the Permeable Pavement.

    - This additional volume must now be considered when sizing the Bioretention storage components. The total acreage is the 0.55 ac (0.39 impervious, and 0.16 turf) draining directly to the Bioretention basin, plus the 0.35 acres of permeable pavement; total = 0.90 acres.
        - General sizing guidance for Bioretention L2: (6% x 0.90 ac x 43,560 ft2/ac = 2,352 $ft^2$);

- Actual volume requirements based on $Tv_{BMP}$ determined by adding the values for impervious and turf cover in column I + column J:

$$Tv_{BMP} = 1{,}607 + 402 + 95 + 24 = 2{,}128 \text{ ft}^3$$

- Level 2 Bioretention sizing factor = 1.25 x Tv = 1.25 x 1,464 $ft^3$ = 1,830 $ft^3$

**Step 6A** Interim Compliance Check

A summary of the combined volume and total load reduction resulting from the implementation of BMPs in DA-A and DA-B is provided in **Table 13.9** below (excerpted from the VRRM Compliance Spreadsheet Water Quality Compliance Tab). The load reduction requirement has been met.

***Table 13.9. Institutional Site Compliance Check – Water Quality Compliance tab of the VRRM Compliance Spreadsheet***

| | |
|---|---|
| TOTAL TREATMENT VOLUME (cf) | **8,687** |
| TOTAL PHOSPHORUS LOAD REDUCTION REQUIRED (LB/YEAR) | **3.01** |
| | |
| RUNOFF REDUCTION (cf) | **4,264** |
| PHOSPHORUS LOAD REDUCTION ACHIEVED (LB/YR) | **3.13** |

| | |
|---|---|
| REMAINING PHOSPHORUS LOAD REDUCTION (LB/YR) NEEDED | **CONGRATULATIONS!! YOU EXCEEDED THE TARGET REDUCTION BY 0.1 LB/YEAR!!** |

**NOTE**: ***The designer should verify that all the drainage areas check – this includes checks of the DA Tabs (row 74) and the Water Quality Compliance Tab (row 8 and column G) to determine whether more acreage of impervious and/or turf was erroneously directed to a BMP than was available for treatment.***

**Step 7** Quantity Control Requirements – Curve Number Adjustment

The VSMP Channel Protection Criteria are described in **Section 11.6.1** of **Chapter 11**, and the method for calculating the allowable peak discharge to natural channels is described in **Section 11.6.2** of **Chapter 11**, and the method for using the VRRM curve number adjustment is described in **Section 11.6.3** of **Chapter 11**.

- The point of discharge from drainage areas A and B are to a *natural stormwater conveyance system* and therefore the allowable discharge from each drainage area for the 1-year 24-hour design storm must be managed such that the developed condition discharge meets the allowable peak discharge as defined by the "energy balance equation" (**Equation 11.13**):

$$Q_{Developed} \leq I.F.\ x\ (Q_{Pre\text{-}developed}\ x\ RV_{Pre\text{-}Developed}) / RV_{Developed}$$

- The natural channels experience some periodic flooding. Therefore, the VSMP Flooding criteria requires that the post-developed peak flow rate for the 10-year 24-hour storm event is less than the predevelopment peak flow rate (9 VAC 25-870-66 C 2 b).

  The pre- and post-development condition hydrology is required to establish the allowable peak discharge and the corresponding additional detention storage volume requirements.

- **Table 13.10** displays the curve number adjustments computed by the VRRM Compliance Spreadsheet for A-A (Channel and Flood Protection Tab); and

- **Table 13.11** below consolidates the all the relevant hydrology required to compute the quantity control requirements: the 1-year and 10-year 24-hour storm events.

- The reader is encouraged to review the methods for calculating the peak discharge. The development of the Graphical Peak Discharge is described in detail in TR-55 and **Section 4.4.4** of **Chapter 4** of the ***Blue Book***. Numerous hydrologic modeling tools will also generate the peak discharges corresponding to the adjusted curve numbers provided in the VRRM Compliance Spreadsheet.

***Table 13.10. Institutional Site: Drainage Area A Curve Number Adjustment from the VRRM Compliance Spreadsheet***

| | 1-year storm | 2-year storm | 10-year storm |
|---|---|---|---|
| **$RV_{Developed}$ (in) with no Runoff Reduction** | 0.61 | 0.94 | 2.14 |
| **$RV_{Developed}$ (in) with Runoff Reduction** | 0.43 | 0.76 | 1.96 |
| **Adjusted CN** | **67** | **68** | **70** |

1. Compute the allowable peak discharge for the 1-year 24-hour design storm for each drainage area (**Equation 11.13** from **Chapter 11**):

$$Q_{Developed} \leq I.F.\ x\ (Q_{Pre\text{-}developed}\ x\ RV_{Pre\text{-}Developed})\ /\ RV_{Developed}$$

Note that the values for ***$RV_{Developed}$ (in.) with Runoff Reduction*** from the VRRM Compliance Spreadsheet (**Table 13.10** above) are the same term as $Q$ (runoff depth, in.) in **Table 13.11**. Also note that $Q_{developed}$ and $Q_{pre\text{-}developed}$ as written in the VSMP regulations are commonly written as $q_{pDeveloped}$ and $q_{pPre\text{-}developed}$, and are the same term as $q_p$ in **Table 13.11**. Therefore **Equation 11.13** is re-written as:

$$q_{pDeveloped} \leq I.F.\ x\left(q_{pPre-Developed}\ x\ RV_{Pre-Developed}\right) / RV_{Developed}$$

***Table 13.11. Institutional Site: Summary of Hydrology with Adjusted Curve Numbers and Runoff Volumes for Drainage Areas A and B***

| **Rainfall Depths:** 1-year 24-hour storm: **2.66”;** 10-year 24-hour storm: **4.93”** | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***Drainage Area A*** | | | | | | | |
| **Pre-Developed DA A** | | | | | | | |
| | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| **Total** | **3.93** | **64** | **0.35** | **0.33** | **0.9** | **1.54** | **6.1** |
| **Post-Developed DA A** | | | | | | | |
| **Total** | **3.93** | **72** | **0.21** | **0.62** | **2.9** | **2.10** | **11.0** |
| **1-year CN Adjustment w/ RR** | | **67** | | **0.43** | **1.6** | | |
| **10-year CN Adjustment w/ RR** | | **70** | | | | **1.96** | **9.5** |
| ***Drainage Area B*** | | | | | | | |
| **Pre-Developed DA B** | | | | | | | |
| | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| **Total** | **2.04** | **71** | **0.33** | **0.58** | **1.1** | **2.07** | **4.6** |
| **Post-Developed DA B** | | | | | | | |
| **Total** | **2.04** | **85** | **0.15** | **1.30** | **3.8** | **3.28** | **9.4** |
| **1-year CN Adjustment w/ RR** | | **81** | | **1.08** | **2.3** | | |
| **10-year CN Adjustment w/ RR** | | **83** | | | | **3.08** | **6.7** |

The reader should review these terms in **Section 11.6.2** of **Chapter 11**.

- Drainage Area A:
  1-yr $q_{pDeveloped} \leq$ *0.8 x (0.9 x 0.33)/0.43*
  1-yr $q_{pDeveloped} \leq$ ***0.6 cfs***

- Drainage Area B:
  1-yr $q_{pDeveloped} \leq$ *0.8 x (1.1 x 0.58)/1.08*
  1-yr $q_{pDeveloped} \leq$ ***0.5 cfs***

2. Compute the storage volume required to achieve the required 1-year peak discharge reductions.

- In DA-A, the 1-year post-developed peak discharge was reduced from **2.9 cfs** to **1.6 cfs** with the runoff reduction practices. The peak discharge must be further reduced to **0.6 cfs**.

- In DA-B, the 1-year post-developed peak discharge was reduced from **3.8 cfs** to **2.3 cfs** with the runoff reduction practices. The peak discharge must be further reduced to **0.5 cfs**.

There are several alternatives to calculating the storage volume required to achieve the target peak rate reductions. **Section 5-4.2** of **Chapter 5** of the ***Blue Book*** provides a detailed discussion of the TR-55 Storage Volume for Detention Basins (Shortcut Method) – this procedure is also available in various computer program formats. **Section 11.6.4** of **Chapter 11** of this Handbook provides the application of the Shortcut Method in conjunction with the VRRM. There are also numerous hydrologic modeling programs available.

Once the storage volume requirements are determined, the designer may elect to create small detention facilities below the runoff reduction practices. Or, the designer may incorporate more storage into the various runoff reduction practices, such as:

- Additional storage in the stone reservoir of the permeable pavement by increasing the depth of stone;
- A perforated pipe within the permeable pavement stone reservoir;
- Additional surface ponding storage above the bioretention basins (the area of surface storage may be increased beyond the surface area of the soil media in accordance with the Bioretention Design Specification No. 9).

In all cases, the designer will have to verify that an outlet control structure is designed to achieve the sage-storage-discharge relationship that is assumed by the shortcut method. This can be achieved through routing of the 1-year design storm.

3. Compute the storage volume required to achieve the required 10-year peak discharge reductions:

In D.A.A, the 10-year post-developed peak discharge was reduced from **11.0 cfs** to **9.5 cfs** with the runoff reduction practices. The peak discharge must be further reduced to the pre-developed peak rate of **6.1 cfs**.

- In DA-B, the 10-year post-developed peak discharge was reduced from **9.4 cfs** to **6.7 cfs** with the runoff reduction practices. The peak discharge must be further reduced to **4.6 cfs**.

The designer may elect to increase the storage volume and rate controls built into either the runoff reduction practices or the detention structures developed with Step 2 above.

## 13.2. DESIGN EXAMPLE 2: RESIDENTIAL SUBDIVISION SITE PLAN

**Site Description:** This design example (**Figure 13.5** below) is for a *residential subdivision*. The design of the road and utility infrastructure is dependent on the zoned lot yield. The example includes an analysis of the stormwater benefits associated with cluster development – same lot yield on a smaller overall footprint.

**Step 1**: Resource Mapping (see **Chapter 6**) and Environmental Site Assessment

The Site Assessment is the basis for the stormwater concept plan and should include at a minimum include a written narrative or map identifying the following natural resource features:

1. Wetlands
2. Perennial streams and Intermittent streams
3. Stream buffers
4. Floodplains
5. Forest or other mature and/or native vegetation
6. Steep slopes
7. Soil types (Hydrologic Soil Groups, highly erodible soils)
8. Springs and/or natural seeps
9. Geology (bedrock or karst conditions)
10. Drainage divides

Attention to the location of the environmental features will help in reducing the impacts of the development infrastructure as well as the lot configurations during the initial layout of the development. If it is preferred to keep BMPs off of individual lots, then areas of highly permeable soils or natural drainage collection areas should be identified in order to establish out-parcels or open space in order to facilitate the implementation of runoff reduction practices. **Figure 13.5** shows a typical mapping of environmental features as applied to the residential development parcel for this example.

This example illustrates the VRRM site design credits. In general, higher density development is considered to create less impervious cover over the entire parcel as a result of less roadway infrastructure and shorter driveways (due to shorter house setbacks), while also creating opportunities to protect open space that would otherwise be on lots, and require protective easements on private property. **Figure 13.6** below illustrates this 15 acre parcel divided up into 25 half-acre lots; note that the lots cover the entire parcel. **Figure 13.7** below illustrates this same parcel utilizing 25 quarter-acre lots in a cluster development pattern; note that areas of steep slopes, buffers, woods, and other environmental site features have been carved out as open space within the development parcel.

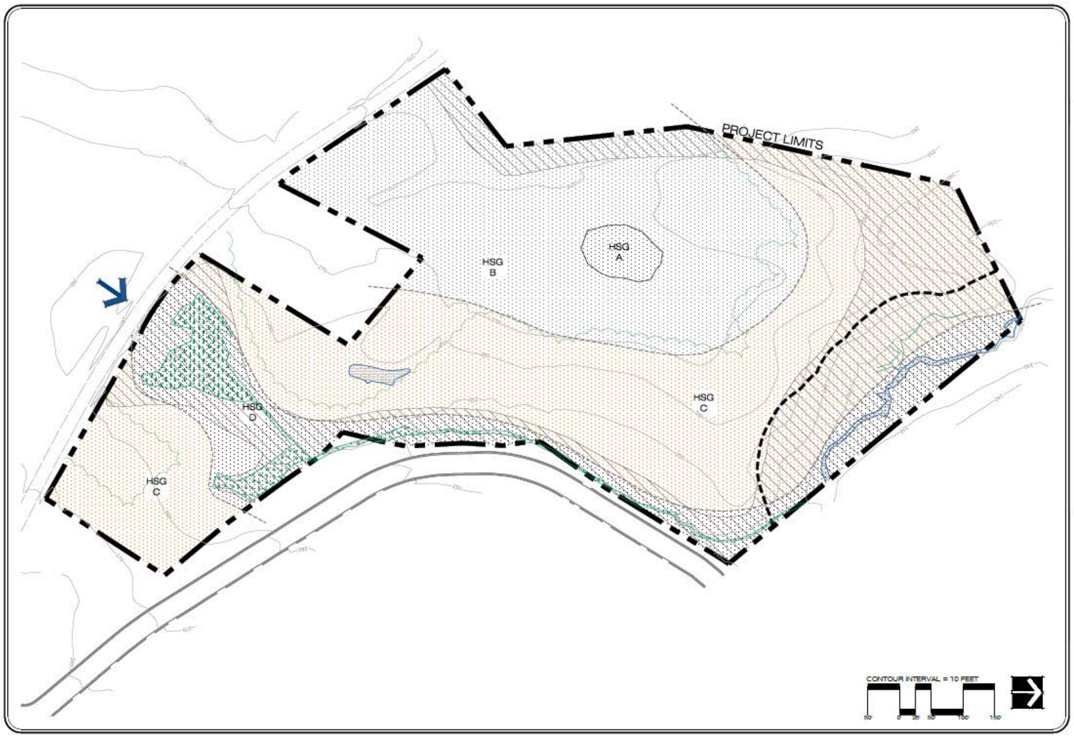


*Figure 13.5. Residential Site Environmental Assessment: soil types, steep slopes, wetlands, streams, aquatic buffers, mature vegetation (trees)*

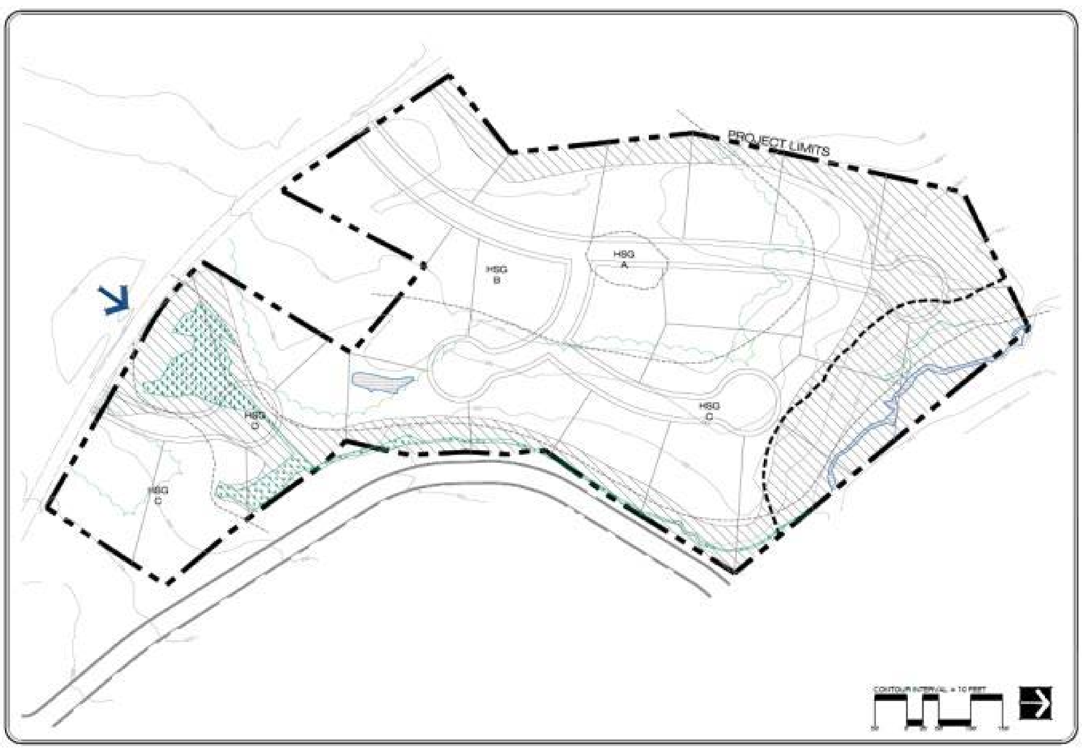


*Figure 13.6. 15-acre Residential Development with 25 half-acre Lots*

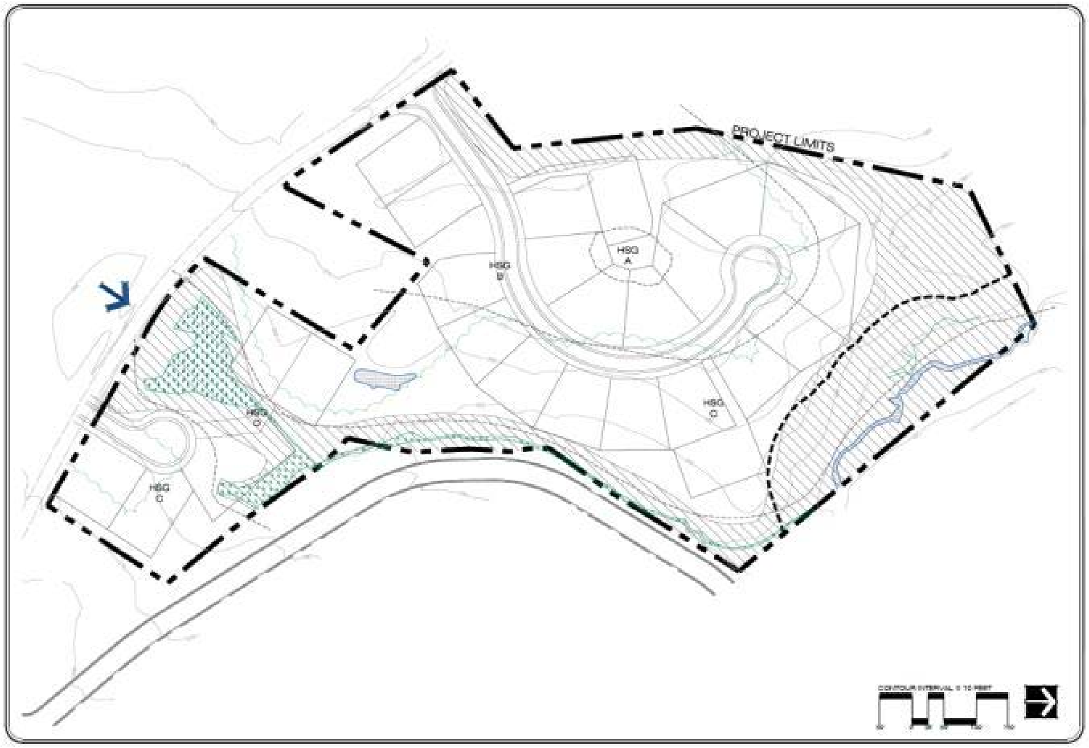


***Figure 13.7. 15-acre Residential Development with 25 quarter acre lots***

**Table 13.12** and **Table 13.13** below provide the summary of the Land Cover and the corresponding Treatment Volume and Pollutant Load (TP) Reduction requirements for the two development scenarios, ½-acre and ¼-acre lots respectively. The VRRM site design incentives associated with minimizing the grading and disturbance of soil, preservation of wooded open space, and the minimization of turf cover represent a 22% decrease in the post-development treatment volume (18,362 ft3 reduced to 14,317 ft3) and a 32% reduction in the Total Load (TP) Reduction requirement (5.39 lb/yr reduction from 11.54 lb/yr is reduced to 2.85 lb/yr reduction from 9.0 lb/yr).

***Table 13.12. Residential Site Land Cover Summaries for ½-Acre and ¼-Acre Lot Development***

| Land Cover | ½ Acre Lots | ¼ Acre Lots |
|---|---|---|
| Forest | 1.32 | 5.70 |
| Turf | 10.88 | 6.97 |
| Impervious | 2.80 | 2.33 |
| **Total** | **15.0** | **15.0** |

***Table 13.13. Residential Site: Treatment Volume and Pollutant Load Reduction Requirements for ½-Acre and ¼-Acre Lot Development***

| | **½-Acre Lots** | **¼-Acre Lots** |
|---|---|---|
| Site Rv | **0.34** | **0.26** |
| Post-Development Treatment Volume (acre-ft) | **0.42** | **0.33** |
| Post-Development Treatment Volume (cubic feet) | **18,362** | **14,317** |
| Post-Development Load (TP) (lb/yr) | **11.54** | **9.00** |
| Total Load (TP) Reduction Required (lb/yr) | **5.39** | **2.85** |

**Step 2:** Site Hydrology and Pollutant Loads

Developing the hydrology for the entire site allows the designer to establish the overall site-scale Post-Development Pollutant Load (TP, lb/yr) and the Total Load (TP) Reduction Required (lb/yr). If the developed portion of the site includes multiple drainage areas, and more importantly, multiple discharge points, the designer will also need to develop the hydrology for each drainage area (Step 3) in order to comply with the Quantity Control requirements.

3. Basic site level hydrology (NRCS Methods-Chapter 4-4 Blue Book)

    *a.* Pre- and Post developed condition land cover by soil type

    **NOTE:** ***NRCS CN methods - note that the NRCS land cover descriptions are not necessarily the same as the RRM Land Cover.***

    *b.* Compute the composite (or weighted) CN.

    *c.* Tc (NRCS Methods-Chapter 4-4 Blue Book): This will require topography and site information sufficient to accurately identify drainage divides, $T_c$ and $T_t$ flow paths and channel geometry, and surface conditions (roughness coefficient, etc.).

    **Table 13.14** below provides a summary of the site hydrology. Note that the terminology for what was *meadow* in the pre-developed condition changes to *open space* in the developed condition with the corresponding NRCS Curve Number. NRCS defines open space as lawns, parks, golf courses, etc. These areas will be considered *managed turf* in the VRRM Post-Development Pollutant Load calculation.

***Table 13.14. Residential Site Hydrology: Whole Site***

| Pre-Developed | | | | | |
|---|---|---|---|---|---|
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** |
| Meadow | Good | B | 1.89 | 58 | |
| Meadow | Good | C | 4.15 | 71 | |
| Woods | Good | C | 8.96 | 70 | |
| | | **Total** | **15.00** | **69** | **0.60** |
| **Post-Developed** | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc** |
| Open Space | Good | B | 1.54 | 61 | |
| Open Space | Good | C | 5.43 | 74 | |
| Impervious | | C | 2.33 | 98 | |
| Woods | Good | C | 5.70 | 70 | |
| | | **Total** | **15.00** | **75** | **0.32** |

4. Post Developed Pollutant Load (VRRM Compliance Spreadsheet)

The VRRM Compliance Spreadsheet computes the total site composite *Rv,* Post-Development Treatment Volume (*Tv*), Post Development Pollutant Load (TP and TN), and Total Load Reduction Required (TP) when the Land Cover information is entered into the Site Data Tab. **Table 13.15** provides the user entered Site Data for this example, and **Table 13.16** displays the spreadsheet calculated values (Calculation Cells B46 through B52).

***Table 13.15. Residential Site Land Cover (acres):***
***VRRM Compliance Spreadsheet Site Data Tab: ¼ -acre Lots***

| Land Cover | A | B | C | D | Total |
|---|---|---|---|---|---|
| Forest | 0 | 0 | **5.70** | 0 | **5.70** |
| Turf | 0 | **1.54** | **5.43** | 0 | **6.97** |
| Impervious | 0 | **0.35** | **1.98** | 0 | **2.33** |
| | | | | **Total** | **15.00** |

***Table 13.16. Residential Site Land Cover Summary:***
***VRRM Compliance Spreadsheet Site Data Tab – ¼ -acre Lots***

| **Total Site Area (acres)** | **15.00** | | |
|---|---|---|---|
| **Site Rv** | **0.26** | | |
| Post-Development Treatment Volume (acre-ft) | **0.33** | | |
| Post-Development Treatment Volume (cubic feet) | **14,317** | | |
| Post-Development Load (TP) (lb/yr) | **9.00** | (TN) (lb/yr) | **64.35** |
| Total Load (TP) Reduction Required (lb/yr) | **2.86** | | |

**Step 3:** Drainage Area Hydrology, Peak Discharge, and Treatment Volume (Tv)

Drainage Area A generally consists of the small cluster of lots (5 lots) on the southern edge of the property, and Drainage Area B consists of the larger portion to the north (the north arrow is pointing to the right of the page). Drainage Area B parallels the stream valley along the eastern property line and has several potential discharge locations between lots. Alternatively, the road can serve as a stormwater collection and conveyance corridor and direct all the runoff to a single discharge point at the end of the cul-de-sac. **Figure 13.8** shows the general drainage divide of the developed area discharge to the receiving *stormwater conveyance system.* The downstream The discharge of stormwater from the proposed development is not necessarily at pre-defined low points, and the designer may be able to influence the developed condition drainage patterns to maximize the use of non-structural runoff reduction practices and treatment trains.

Each point of discharge into the stormwater conveyance channel as defined in the VSMP regulations will be required to address the quantity control requirements (VSMP regulations, 9 VAC 25-870-66. Water Quantity,).

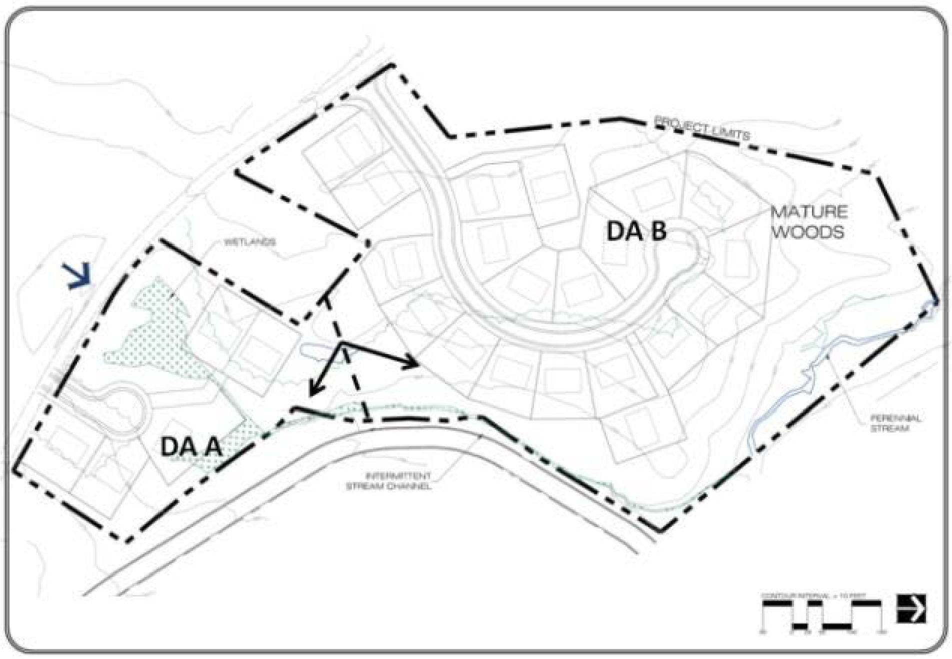


***Figure 13.8. Residential Site Drainage Areas A and B***

4. Repeat **Step 2.1** for each DA.

    a. Compute the composite CN for each DA.

    b. Compute the Tc for each DA.

    c. Determine the 24-hour rainfall depth for the appropriate 24-hour design storms as identified in the VSMP regulations (9 VAC 25-870-66), and compute the runoff depth ($Q$) and peak discharge ($q_p$). [Refer to **Chapter 11** (*Hydrologic Methods and Computations*) for guidance on hydrologic methods terminology and symbology.] **Table 13.17** below provides a summary of the Pre- and Post-development hydrology for Drainage Areas A and B of this example.

**Step 4:** Apply BMPs in DA-A using the VRRM Compliance Spreadsheet.

> **NOTE**: ***The spreadsheet is not a BMP design tool other than to provide the designer with a simple tool for selecting BMPs and determining whether the selected BMPs or combinations of BMPs achieve compliance. The spreadsheet can also provide the designer with the treatment volume to the selected BMP (**$Tv_{BMP}$**). This includes the volume generated by the contributing drainage area, as well as any additional (reduced) volume from upstream BMPs. Using basic sizing parameters, the designer can verify the applicability of the practice given the various site constraints (overall footprint, depth, infiltration capacity, etc.). Once the selection of BMPs has been confirmed as adequate for compliance, the designer can then develop the detailed sizing and design of each practice.***

There are numerous BMP options available to manage the runoff from the houses, driveways, and the roadway. The designer should pay particular attention to the opportunities to use treatment trains. **Figure 13.9** below provides the graphic representation of the BMP selections and approximate locations.

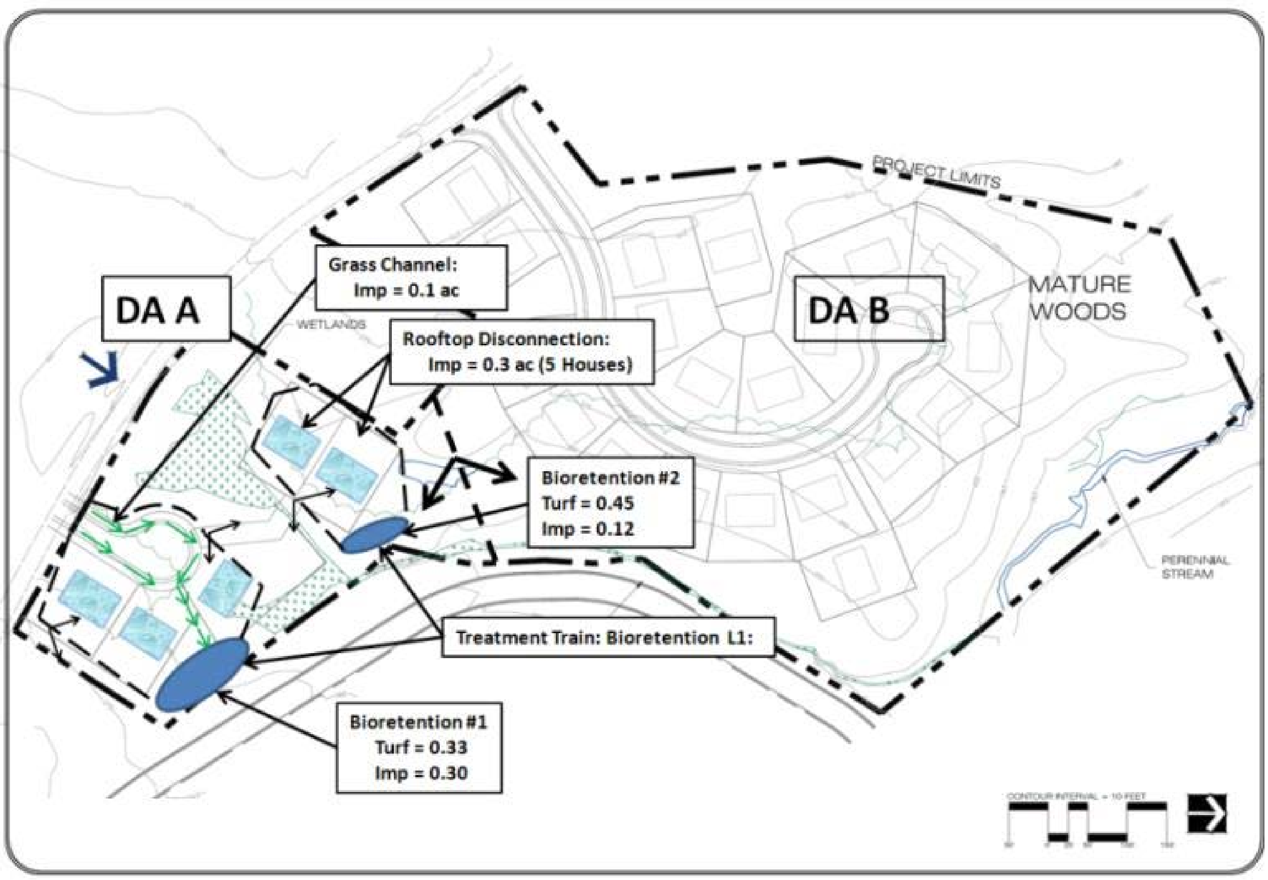


***Figure 13.9. Residential Site BMP Selections and Areas Contributing Drainage to Drainage Area A***

1. **Simple Rooftop Disconnection**: 5 houses; approximate total = **0.3 ac** impervious. Consider the minimum criteria for Simple disconnection (**Impervious Disconnection BMP Specification No. 1**):

   ➢ Drainage Area Criteria:
   - Maximum slope < 2%; or < 5% w/ turf reinforcement
   - Longest contributing impervious area flow path ≤ 75 ft.
   - Maximum contributing drainage area (rooftops): CDA ≤ 1000 sf per disconnection

***Table 13.17. Residential Site Hydrology: Drainage Areas A & B***

| **Rainfall Depths:** 1-year 24-hour storm: **2.66”;** 10-year 24-hour storm: **4.93”** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ***Drainage Area A*** | | | | | | | | | |
| **Pre-Development DA A** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| Meadow | Good | C | 1.20 | 71 | | | | | |
| Woods | Good | C | 2.35 | 70 | | | | | |
| | | **Total** | **3.55** | **70** | **0.45** | **0.54** | **1.4** | **1.98** | **6.5** |
| **Post-Development DA A** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| Open Space | Good | C | 1.71 | 74 | | | | | |
| Impervious | | | 0.45 | 98 | | | | | |
| Woods | Good | C | 1.39 | 70 | | | | | |
| | | **Total** | **3.55** | **75** | **0.21** | **0.75** | **3.3** | **2.40** | **11.2** |
| ***Drainage Area B*** | | | | | | | | | |
| **Pre-Developed DA B** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| Meadow | Good | B | 1.89 | 58 | | | | | |
| Meadow | Good | C | 2.95 | 71 | | | | | |
| Woods | Good | C | 6.61 | 70 | | | | | |
| | | **Total** | **11.45** | **68** | **0.60** | **0.46** | **3.0** | **1.83** | **15.8** |
| **Post-Developed DA B** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$Q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$Q_{p10}$ (cfs)** |
| Open Space | Good | B | 1.54 | 61 | | | | | |
| Open Space | Good | C | 3.72 | 74 | | | | | |
| Impervious | | | 1.88 | 98 | | | | | |
| Woods | Good | C | 4.31 | 70 | | | | | |
| | | **Total** | **11.45** | **75** | **0.32** | **0.75** | **8.9** | **2.40** | **30.7** |

***Table 13.18. Residential Site Drainage Area A Land Cover Summary (VRRM Compliance Spreadsheet D.A. A Tab)***

| **Drainage Area A Land Cover (acres)** | | | | | | |
|---|---|---|---|---|---|---|
| | **A soils** | **B Soils** | **C Soils** | **D Soils** | **Totals** | **Land Cover Rv** |
| Forest/Open Space (acres) | 0 | 0 | **1.39** | 0.00 | 1.39 | 0.04 |
| Managed Turf (acres) | 0 | 0 | **1.71** | 0.00 | 1.71 | 0.22 |
| Impervious Cover (acres) | 0 | 0.00 | **0.45** | 0.00 | 0.45 | 0.95 |
| | | | | **Total** | **3.55** | |

| **Post Development Treatment Volume (cf)** | **3,119** |
|---|---|

***Table 13.19. Residential Site Drainage Area B Land Cover Summary (VRRM Compliance Spreadsheet D.A. B Tab)***

| **Drainage Area B Land Cover (acres)** | | | | | | |
|---|---|---|---|---|---|---|
| | **A soils** | **B Soils** | **C Soils** | **D Soils** | **Totals** | **Land Cover Rv** |
| Forest/Open Space (acres) | 0 | 0 | **4.31** | 0.00 | 4.31 | 0.04 |
| Managed Turf (acres) | 0 | **1.54** | **3.72** | 0.00 | 5.26 | 0.21 |
| Impervious Cover (acres) | 0 | **0.35** | **1.53** | 0.00 | 1.88 | 0.95 |
| | | | | **Total** | **11.45** | |

| **Post Development Treatment Volume (cf)** | **11,198** |
|---|---|

- Disconnection minimum dimensions:
  - Length (parallel to flow): 40 ft. min.
  - Width (perpendicular to flow): 10 ft. min.

- The lot area in this section of t he development is relatively flat and is well suited to simple disconnection.

- The actual size and footprint of the house may vary based on the building permit. The initial subdivision plan generally uses an average house size and location (within the setbacks). The builder should provide a house location survey or other graphic representation to show that the actual design and proposed construction of the disconnection (or the alternative practice) meets the performance goal established by the original common plan of development.

- Select Simple Disconnection to C/D Soils (item 2.b. on the VRRM Compliance Spreadsheet)
  - Enter 0.3 acres of Credit Area (cell G18).

- The site plan indicates adequate space downstream of the houses to capture the rooftop runoff in a Bioretention Level 1; **Figure 13.9** below.
- Direct the remaining runoff to the downstream BMP by selecting *Bioretention Level 1* in the drop down menu of column P.

2. **Grass Channels –** Direct the roadway runoff **0.10 ac** impervious to open section grass channels adjacent to the pavement. Consider the minimum criteria for Simple disconnection (**Impervious Disconnection BMP Specification No. 1**):

➢ Channel dimensions and slope:
- The bottom width of the channel: 4 ft to 8 ft wide. (This criterion may be reduced to a minimum of 2 ft if the combination of flow depth and channel slope maintain the maximum flow velocity of 1 ft/sec).
- The channel side-slopes: 3H:1V or flatter.
- The longitudinal slope of the channel should be no greater than 4%. (Check dams may be used to reduce the effective slope in order to meet the limiting velocity requirements.)
- Maximum contributing drainage area to any individual grass channel of 5 acres
- Combined slope and geometry to maintain max Retention Volume flow velocity: ≤ 1 ft/sec

➢ Select Grass Channel C/D Soils (item 4.c. on the VRRM Compliance Spreadsheet)
- Enter 0.10 acres of impervious acres of Credit Area (cell G36), and no turf area.
- Similar to the simple disconnection, Direct the remaining runoff to the downstream BMP by selecting *Bioretention Level 1* in the drop down menu of column P.

3. **Bioretention Level 1** can be added in two locations as shown on **Figure 13.9.** Additional area draining directly to the Bioretention L1: 2 driveways (**0.02 ac** impervious) and yard area (**0.78 ac** turf); and a total contributing drainage area of 1.2 acres (0.4 acres from upstream practices). Design and sizing considerations for Bioretention L1 (**Bioretention BMP Design Specification No. 9**):

➢ General sizing guidance for Bioretention L1 calls for a practice footprint of approximately 6% of the contributing drainage area (6% x 1.20 ac x 43,560 $ft^2$/ac = 3,136 $ft^2$).

➢ As discussed in the previous example, the VRRM Compliance Spreadsheet can provide the designer with the actual Treatment Volume to the BMP for design purposes ($Tv_{BMP}$). In this case:
- $Tv_{BMP}$ = 1,778 $ft^3$ (from VRRM Compliance Spreadsheet column I (462 + 249 $ft^3$) + column J (693 +374 $ft^3$).

**NOTE:** ***the Level 1 Bioretention being sized in this step is actually two Bioretention practices within the same drainage area. The designer can approximate the relative runoff volume contribution to each practice by splitting the runoff volume from Upstream RR Practice (Column H) and the volume from***

***the Credit Area (Column I + Column J – Column H) proportionally according the relative drainage area to each of the two practices.***

- For this design example:
  - Runoff contribution from the rooftop disconnection based on the relative contributing drainage area is 60% to Bioretention #1 (466 $ft^3$), and 40% to Bioretention #2 (310 $ft^3$).
  - Runoff contribution from the road and grass swale goes to Bioretention #1 (310 $ft^3$).
  - Runoff contribution from the Credit Area impervious and turf acres draining directly to the two bioretention areas based on the relative contributing drainage areas are 332 $ft^3$ to Bioretention #1 and 361 $ft^3$ to Bioretention #2.
  - The total $Tv_{BMP}$ to Bioretention 1 = 466 + 310 + 332 = 1,108 $ft^3$.
  - The total $Tv_{BMP}$ to Bioretention 2 = 310 + 361 = 671 $ft^3$.

- Using the Bioretention Level 1 sizing rules for storage volume: surface ponding – 1’ max., required soil media depth – 24” min., and underdrain and gravel reservoir layer – 12” min., and the corresponding values of porosity for each layer, the designer can determine the minimum surface ponding and soil media surface areas:
  - Bioretention #1 = 583 $ft^2$ .
  - Bioretention #2 = 353 $ft^2$.

  **NOTE**: ***The designer must consider the overall footprint as was incorporated into the 6% sizing rule-of-thumb: 3:1 side slopes on the ponding surface area to include freeboard, 3:1 slopes on the embankment (if needed), the flow path geometry, inlet forebay, etc***.

**Step 4A**: Interim compliance check

- The treatment train of the Simple Disconnection, Grass Channel, and Bioretention L1 treat a total of 0.42 acres of impervious cover and 0.78 acres of turf (column G, rows 71 and 72; DA-A Tab). The only untreated areas are those that would require significant clearing and grading to drain to the BMP locations (the “pan-handle” driveways and yard areas).

- The area checks (cell G74); meaning the total treated does not exceed the total in the drainage area.

- The load reduction achieved with the three BMPs in DA A can be found in cell I78: 0.81 lb/yr of the required total site reduction 2.85 lb/yr.

**Step 5:** Implement BMPs in DA-B

**Figure 13.10** below provides the graphic representation of the BMP selections and contributing drainage areas described in this step. It is important to note that the acreages listed for each practice in Figure 6 do not include the acreages from upstream runoff reduction practices.

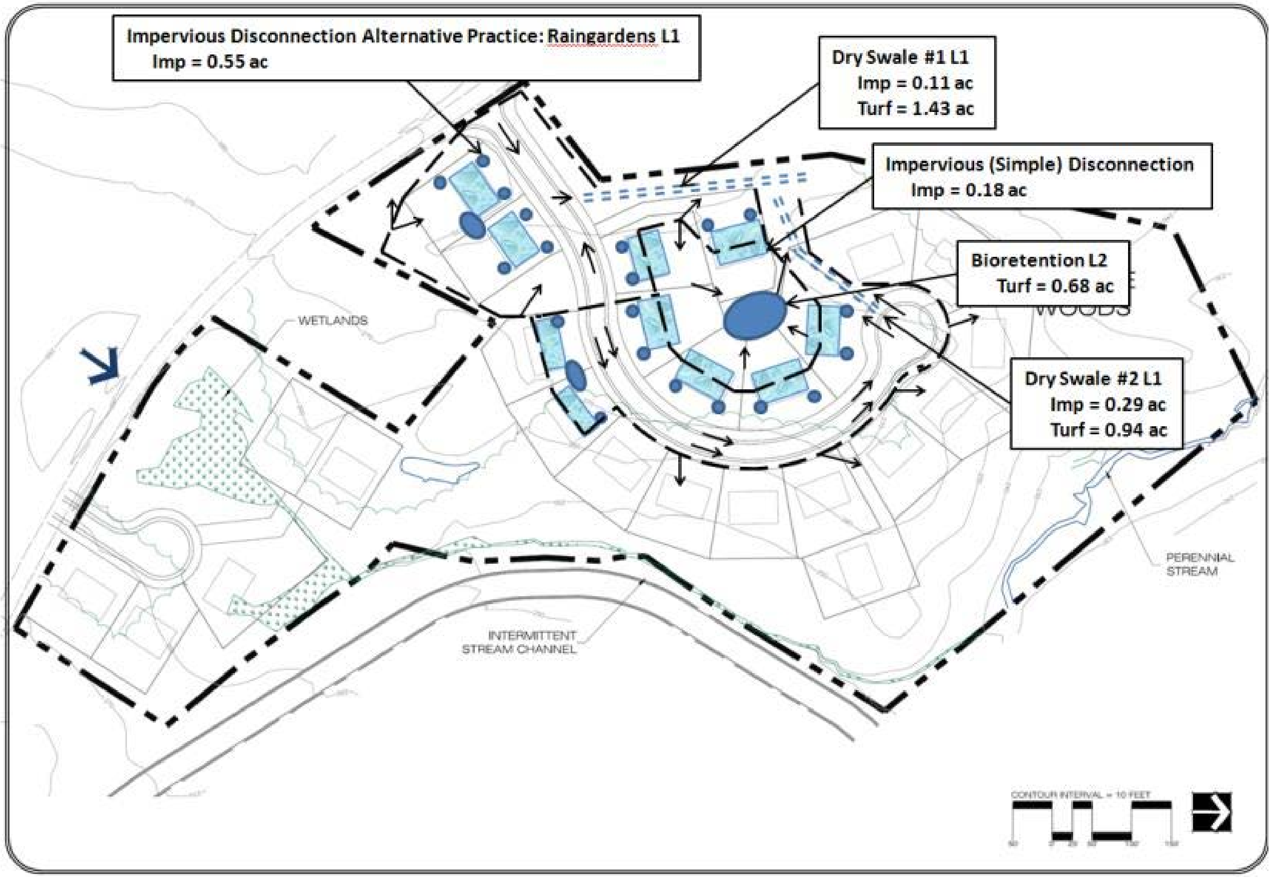


***Figure 13.10. Residential Site BMP Selections and Areas Contributing Drainage to Drainage Area B***

1. **Impervious Disconnection – Alternative Practices: Rain Garden L1 (Micro-Bioretention)** is proposed for the houses and driveways near the entrance to the development and along the front-side of the houses where the yards are readily drained to the street. These lots are relatively small and would make simple disconnection very difficult to accommodate (simple disconnection length = 40 ft.). Also, the houses along the outside of the curve (right side as you travel into the development) do not include impervious disconnection because the yards are relatively steep (slopes greater than 5%).

   The total acreage of disconnection includes all or part of 10 houses and accompanying driveways, for a total of **0.55 ac** impervious area (entered in "Credit Area" (column G) of VRRM Compliance Spreadsheet. Since these houses will not all drain to the same downstream practice, the designer may elect to break Drainage Area B into multiple sub-areas, using a different VRRM Compliance Spreadsheet D Tab for each sub-area. For example, if impervious disconnected houses shown at the top of the drawing (near the entrance) drain to the downstream practice: Dry Swale #1 (Level 1 design), and the remaining disconnected houses were to drain to a Bioretention or other practice, the two sub-areas of houses would require separate spreadsheet D.A. Tabs since the remaining runoff volume and pollutant load can't be directed to different downstream practices in the drop-down menu (Column P).

In this particular case, the downstream practice happens to be a Dry Swale Level 1 for both sub-areas, so they can in fact be combined in one tab; however, the designer will have to carefully evaluate the $Tv_{BMP}$ going to each practice in order to size them correctly. **0.31 ac** of impervious disconnection will drain to Dry Swale #1, and **0.24 ac** of impervious disconnection will drain to Dry Swale #2.

**NOTE:** ***Using two tabs for sub-areas draining to different downstream practices makes the determination of the Tv<sub>BMP</sub> for each downstream practice relatively straight forward, and certainly simpler than analyzing the remaining volume and manually splitting it to different downstream practices. However, the use of sub-areas within a larger drainage area on a relatively small site (site scale vs watershed scale) will make the assessment of the quantity control requirements more difficult since the VRRM Compliance Spreadsheet curve number adjustments on the Channel and Flood Protection Tab are computed for each D.A. Tab. One option would be to work with two spreadsheets – one for design of the runoff reduction BMPs, and the other to analyze the Curve Number Adjustment and site scale compliance.***

Consider the design and sizing considerations from specifications (**Impervious Disconnection - BMP Design Specification No. 1**):

- Alternative Practice: Micro-Bioretention Level 1
  - Maximum contributing drainage area = 1,000 ft$^2$
  - Surface area = 3% of contributing drainage area
  - Soil depth minimum = 18 inches

- Design is based on the typical house rooftop area of 2,400 ft$^2$, and assumed to have a minimum of four downspouts (approximately 600 ft$^2$ contributing area, each rain garden surface area is approximately (3% x 600 ft$^2$) = 18 ft$^2$

- Driveways are assumed to be approximately 400 ft$^2$ (based on a house setback of 25 ft and the width of 16 ft). Sizing approximately (3% x 400 ft$^2$) = 12 ft$^2$

- Final design of the micro-bioretention will be based on final lot plan showing actual house footprint, downspout locations, and driveway size and grade.

2. **Dry Swale Level 1** located along the western property line (top of **Figure 13.10** above **–** labeled **Dry Swale #1 L1**) will capture the remaining runoff volume and pollutant load from the disconnected houses and driveways, and the direct discharge from the adjacent turf area of **1.43 ac**. and adjacent impervious road area of **0.11 ac** (Credit Area Column G). A second Dray Swale (labeled **Dry Swale #2 L1**) will collect the remaining runoff from the disconnected houses and driveways, and the direct discharge from the adjacent turf area of **0.94 ac**. and impervious roadway and cul-de-sac area of **0.29** ac. Consider the design and sizing considerations from specifications (**Dry Swale Level 1 – BMP Design Specification No. 10**):

- Maximum effective swale slope: 2% (check dams or other grade control structures can be used to achieve this design parameter).

- Minimum soil media depth = 18 inches

- The $Tv_{BMP}$ for Dry Swale #1 is 1,998 $ft^3$ (from VRRM Compliance Spreadsheet column I + column J).
  - The designer can select a range of swale widths and/or lengths to accommodate the design $Tv_{BMP}$. Using the sizing rules for soil depth (18 inches at porosity $\eta$ = 0.4), gravel/underdrain layer (12 inches at $\eta$= 0.25), and surface ponding (12"maximum at $\eta$= 1), and 3:1 side slopes on the surface ponding yields an effective storage volume per foot of dry swale width.
  - Select a trial Dry Swale width of 6 ft. The effective storage depth of the swale is 1.8 ft, and the corresponding effective storage volume is 13.8 $ft^2$ per linear foot of length. Therefore, estimate the required length:

$$1{,}998\ ft^3 / 13.8\ ft^2/ft = 145 \text{ linear feet}$$

  - Try Dry Swale width = 4 ft. The corresponding effective storage volume is 10.2 $ft^2$ per linear foot of length. Therefore, estimate the required length:

$$1{,}998\ ft^3 / 10.2\ ft^2/ft = 196 \text{ linear feet}$$

  - Using 3:1 side slopes on the 12" surface ponding plus 6" of freeboard, an approximate width of 15 ft is required to accommodate the 6 ft bottom width dry swale. An approximate corridor of 25 ft wide and 250 ft long is available for the Dry Swale, which allows adequate space to include check dams or grade control structures as needed (Dry Swale design can include the creation of multiple cells that establish near level flow segments with overflow inlets or weirs). The designer can select the geometry that best suits the site; the volume of soil, stone, excavation, etc., will be comparable.

- The $Tv_{BMP}$ for Dry Swale #2 is 2,247 $ft^3$ (from VRRM Compliance Spreadsheet column I + column J).
  - The available space for Dry Swale #2 is less than for #1, so the designer will be required to consider a different geometry (dry swale width). Using the same design logic as for Dry Swale #1 described above and a design width on the soil layer of 6 ft, a minimum dry swale length of approximately 162 ft. would be required. However, only approximately 185 linear feet is available, and the available width may require easements or an adjustment of the lot lines.

  **NOTE:** ***Depending on the local VSMP Authority requirements, impervious disconnection on private lots may not be an accepted option. In this case, the site can easily be re-worked with different or additional BMPs in lieu of the***

***rain garden and simple disconnection. However, the additional runoff volume that was reduced by the disconnection would increase the $Tv_{BMP}$ to the Dry Swales and increase the overall footprint and cost. In the case of Dry Swale #2, it would likely not be a practical BMP choice given the available space for the BMP.***

**Step 5A**: Interim Compliance Check

- The combined performance of the impervious disconnection and the two Dry Swales treat a combined 1.13 acres of impervious cover, and 3.05 acres of turf (G71 and 72, DA-B Tab).
- The area checks (cell G74); meaning the total acres of impervious and turf treated does not exceed the total in the drainage area.
- The load reduction achieved with the three BMPs in DA-B is 2.47 lb/yr (cell I78 DA-B Tab).
- Combined with DA-A, the total impervious area treated is 1.55 acres (out of a possible 2.33 acres), and the total turf area treated is 3.83 (out of a possible 6.97 acres).
- A summary of the combined volume and total load reduction resulting from the implementation of BMPs in DA-A and DA-B is provided in **Table 13.20** (excerpted from the VRRM Compliance Spreadsheet Water Quality Compliance Tab). The load reduction requirement has been met.

***Table 13.20. Residential Site Compliance Check –***
***Water Quality Compliance tab of the VRRM Compliance Spreadsheet***

| | |
|---|---|
| TOTAL TREATMENT VOLUME (cf) | **14,317** |
| TOTAL PHOSPHORUS LOAD REDUCTION REQUIRED (LB/YEAR) | **2.85** |
| | |
| RUNOFF REDUCTION (cf) | **4,153** |
| PHOSPHORUS LOAD REDUCTION ACHIEVED (LB/YR) | **3.28** |

| | |
|---|---|
| REMAINING PHOSPHORUS LOAD REDUCTION (LB/YR) NEEDED | **CONGRATULATIONS!! YOU EXCEEDED THE TARGET REDUCTION BY 0.4 LB/YEAR!!** |

**NOTE:** ***The designer should verify that all the drainage areas check – this includes checks on the D.A. Tabs (row 74) and the Water Quality Compliance Tab (row 8 and column G) to verify that more acreage of impervious and/or turf was erroneously directed to a BMP than was available for treatment.***

**Step 6** Quantity Control Requirements – Curve Number Adjustment

The VSMP Channel Protection Criteria are described in **Section 11.6.1** of **Chapter 11**, and the method for calculating the allowable peak discharge to natural channels is described in **Section**

**11.6.2** of **Chapter 11**, and the method for utilizing the VRRM curve number adjustment is described in **Section 11.6.3** of **Chapter 11**.

- The point of discharge from drainage areas A and B are to a *natural stormwater conveyance system* and therefore the allowable discharge from each drainage area for the 1-year 24-hour design storm must be managed such that the developed condition discharge meets the allowable peak discharge as defined by the "energy balance equation" (**Equation 11.13**):

$$Q_{Developed} \leq I.F. \; x \; (Q_{Pre\text{-}developed} \; x \; RV_{Pre\text{-}Developed}) \,/\, RV_{Developed}$$

- The natural channels downstream experience some periodic flooding. Therefore, the VSMP Flooding criteria requires that the post-developed peak flow rate for the 10-year 24-hour storm event is less than the predevelopment peak flow rate (9 VAC 25-870-66 C 2 b).

The pre- and post-development condition hydrology is required to establish the allowable peak discharge and the corresponding additional detention storage volume requirements.

- **Table 13.21** displays the curve number adjustments computed by the VRRM Compliance Spreadsheet for DA-A and DA-B (Channel and Flood Protection Tab); and

- **Table 13.22** below consolidates all the relevant hydrology required to compute the quantity control requirements: the 1-year and 10-year 24-hour storm events.

***Table 13.21. Residential Site Drainage Area A Curve Number Adjustment from the VRRM Compliance Spreadsheet***

| **Drainage Area A** | | | |
|---|---|---|---|
| | **1-year storm** | **2-year storm** | **10-year storm** |
| **$RV_{Developed}$ (in) with no Runoff Reduction** | 0.75 | 1.20 | 2.39 |
| **$RV_{Developed}$ (in) with Runoff Reduction** | 0.67 | 1.12 | 2.31 |
| **Adjusted CN** | **73** | **74** | **74** |
| **Drainage Area B** | | | |
| | **1-year storm** | **2-year storm** | **10-year storm** |
| **$RV_{Developed}$ (in) with no Runoff Reduction** | 0.75 | 1.20 | 2.39 |
| **$RV_{Developed}$ (in) with Runoff Reduction** | 0.67 | 1.12 | 2.32 |
| **Adjusted CN** | **73** | **74** | **74** |

***Table 13.22. Residential Site Summary of Hydrology with Adjusted Curve Numbers and Runoff Volumes for Drainage Areas A and B***

| |
|---|
| **Rainfall Depths:** 1-year 24-hour storm: **2.66";** 10-year 24-hour storm: **4.93"** |

| *Drainage Area A* | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Pre-Developed DA A** | | | | | | | |
| | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| **Total** | **3.55** | **70** | **0.45** | **0.54** | **1.4** | **1.98** | **6.5** |
| **Post-Developed DA A** | | | | | | | |
| **Total** | **3.55** | **75** | **0.21** | **0.75** | **3.3** | **2.40** | **11.2** |
| **1-year CN Adjustment w/ RR** | | **73** | | **0.67** | **2.8** | | |
| **10-year CN Adjustment w/ RR** | | **74** | | | | **2.31** | **10.8** |
| *Drainage Area B* | | | | | | | |
| **Pre-Developed DA B** | | | | | | | |
| | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| **Total** | **11.45** | **68** | **0.60** | **0.46** | **3.0** | **1.83** | **15.8** |
| **Post-Developed DA B** | | | | | | | |
| **Total** | **11.45** | **75** | **0.32** | **0.75** | **8.9** | **2.40** | **30.7** |
| **1-year CN Adjustment w/ RR** | | **73** | | **0.67** | **7.6** | | |
| **10-year CN Adjustment w/ RR** | | **74** | | | | **2.31** | **29.5** |

1. Compute the allowable peak discharge for the 1-year 24-hour design storm for each drainage area (**Equation 11.13** from **Chapter 11**):

   $$Q_{Developed} \leq I.F.\ x\ (Q_{Pre\text{-}developed}\ x\ RV_{Pre\text{-}Developed}) / RV_{Developed}$$

   Note that the values for ***$RV_{Developed}$ (in) with Runoff Reduction*** from the VRRM Compliance Spreadsheet (**Table 13.21** above) are the same term as $Q$ (runoff depth, in.) in **Table 13.22**. Also note that $Q_{developed}$ and $Q_{pre\text{-}developed}$ as written in the VSMP regulations are commonly written as $q_{pDeveloped}$ and $q_{pPre\text{-}developed}$, and are the same term as $q_p$ in **Table 13.22**. Therefore **Equation 11.13** is re-written as:

   $$q_{pDeveloped} \leq I.F.\ x \left(q_{pPre-Developed}\ x\ RV_{Pre-Developed}\right) / RV_{Developed}$$

   The reader should review these terms in **Section 11.6.2** of **Chapter 11**.

   - Drainage Area A:
     1-yr $q_{pDeveloped} \leq 0.8\ x\ (1.4\ x\ 0.54)/0.67$
     1-yr $q_{pDeveloped} \leq$ ***0.9 cfs***

   - Drainage Area B:
     1-yr $q_{pDeveloped} \leq 0.8\ x\ (3.0\ x\ 0.46)/0.67$
     1-yr $q_{pDeveloped} \leq$ ***1.6 cfs***

2. Compute the storage volume required to achieve the required 1-year peak discharge reductions.

- In D.A. A, the 1-year post-developed peak discharge was reduced from **3.3 cfs** to **2.8 cfs** with the runoff reduction practices. The peak discharge must be further reduced to **0.9 cfs**.

- In D.A. B, the 1-year post-developed peak discharge was reduced from **8.9 cfs** to **7.6 cfs** with the runoff reduction practices. The peak discharge must be further reduced to **1.6 cfs**.

- **D.A. A:**

  $q_{p1Allowable}$ = 0.9 cfs
  $q_{p1Developed}$ = 2.8 cfs
  $Q_{1Developed} = RV_1 = Vr$ (TR55) = 0.67 inches

  Using **Figure 13.11 below (or Figure 11.7** of **Chapter 11** (or Figure 6-1, TR-55) and the ratio of the allowable discharge out to the discharge in:

$$\left({q_o}/{q_i}\right) \text{ or } \left({q_{p1Allowable}}/{q_{p1Developed}}\right) = \left({0.9\ cfs}/{2.8\ cfs}\right) = 0.32$$

$${Vs}/{Vr} = 0.37$$

Solve for *Vs*: $Vs = Vr * \left({Vs}/{Vr}\right)$

Where:
*Vs* = volume of storage required
*Vr* = developed condition runoff depth, in watershed-inches, expressed as Q or in the VRRM as $RV_1$ (step 9 above) = 0.43 watershed-inches

From **Figure 13.11** below or **Figure 11.7** (or Figure 6-1, TR-55): ${Vs}/{Vr} = 0.37$

$$Vs = Vr * 0.37 = 0.67 * 0.37 = 0.25 \text{ watershed-inches}$$

0.25 watershed inches x 3.55 ac x (3,630 $ft^3$/ac-in) = **3,221 $ft^3$** of storage required

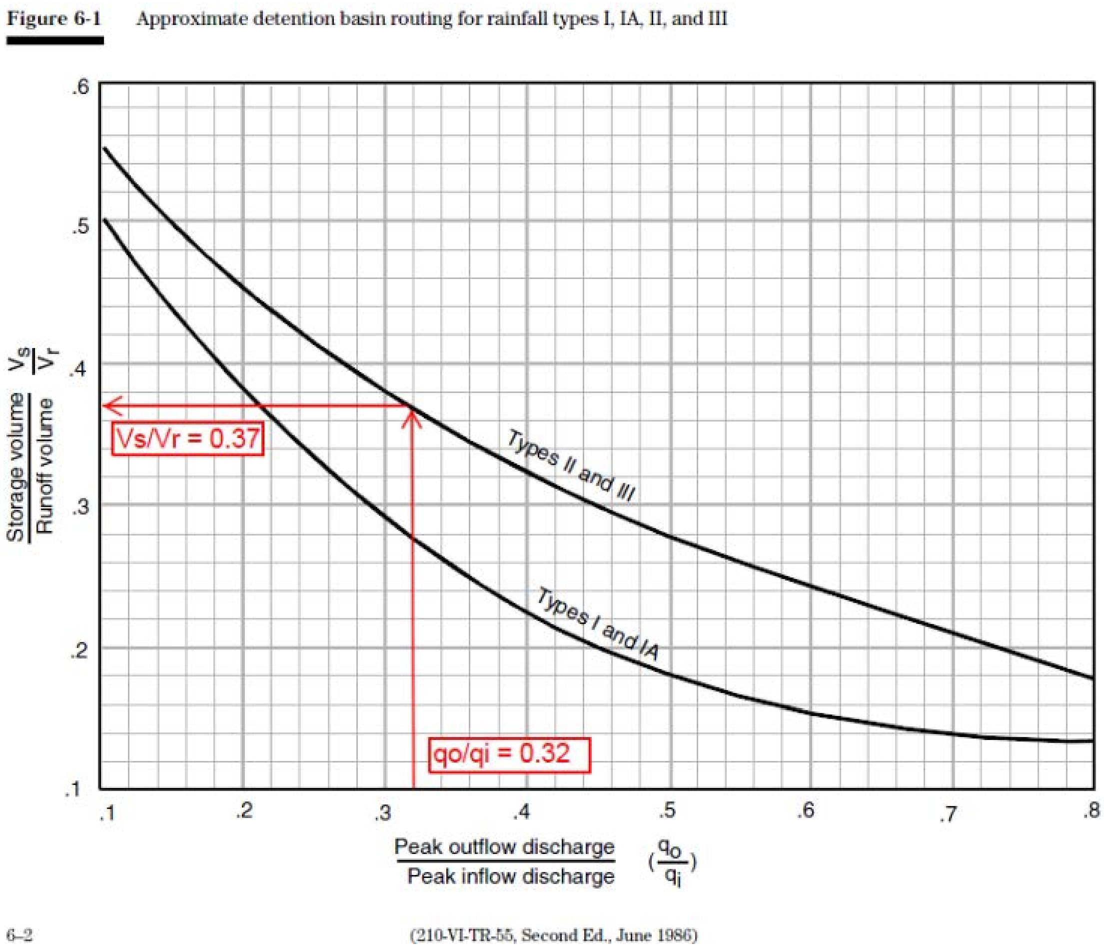


***Figure 13.11. Residential Site: Approximate Detention Basin Routing DA A. (TR55 Figure 6-1)***

- DA-B: Following the same computational procedures outlined in Chapter 11 and for DA-A above, the storage volume required in DA-B:

$$\left({}^{q_o}/_{q_i}\right) = \left({}^{1.6\ cfs}/_{7.6\ cfs}\right) = 0.21$$

From **Figure 13.11** or Figure 6-1, TR-55: ${}^{Vs}/_{Vr} = \ 0.45$

$$Vs = Vr * 0.45 = 0.67 * 0.45 = 0.30 \text{ watershed-inches}$$

0.30 watershed inches x 11.45 ac x (3,630 $ft^3$/ac-in) = **12,469 $ft^3$** of storage required

There are several alternatives to calculating the storage volume required to achieve the target peak rate reductions. The method used above, TR-55 Storage Volume for Detention Basins (Shortcut Method), is described in detail in **Section 5-4.2** of **Chapter 5** of the ***Blue Book*** provides a detailed discussion. This procedure, as well as numerous others based on storage indication routing, are readily available and can be applied once the designer computes the developed condition peak rate of runoff (as reduced using the VRRM) and the allowable peak outflow (allowable discharge calculated using the VSMP "energy balance" method).

3. Compute the storage volume required to achieve the required 10-year peak discharge reductions.

   The computational procedures required for computing the 10-year design storm storage requirements are identical to those used above. The peak rates of runoff (cfs) and the runoff depth (in) for the pre- and post-developed condition are provided in **Table 13.22** above (the post-developed peak rate and runoff depth reduced accordingly by the runoff reduction practices).

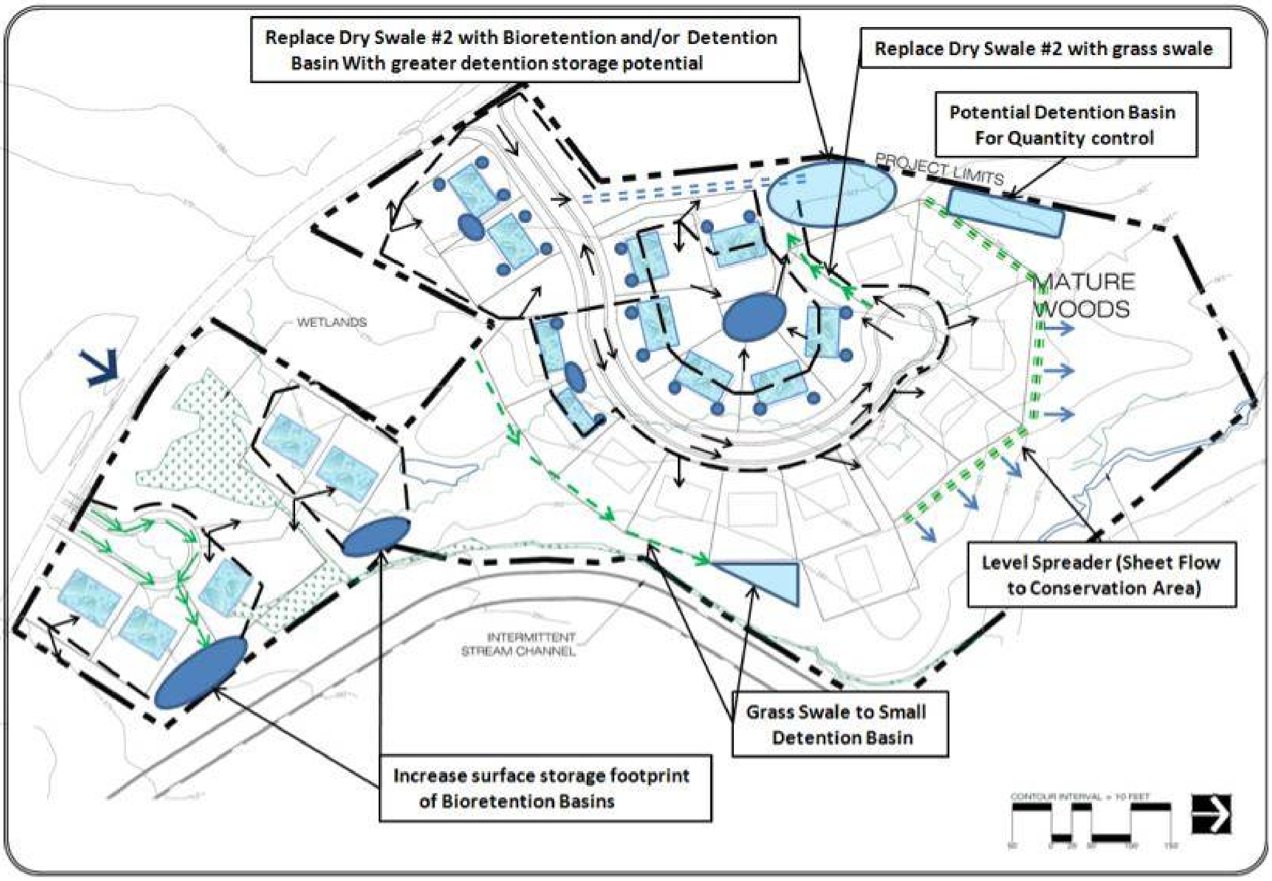


***Figure 13.12. Residential Site: Additional Storage Volume Design Options***

**Step 8**: Design Additional Detention Storage

There are several alternatives for creating storage on this residential development. The following provides a few of the suggestions offered by designers that reviewed this project during DCR the design charrettes held in 2008-2009:

1. Increase the surface storage of the two bioretention basins in DA-A to the maximum allowable surface area (as a function of the soil media surface area) in order to possibly eliminate the need to locate an additional basin in this portion of the site.

2. Modify the Runoff Reduction design as follows:
   a. Replace Dry Swale #2 with a grass swale since: i) the available space for a grass swale is limited; and ii) the grade and limited space reduce the opportunity to add additional detention storage.
   b. Add a bioretention/detention basin at the end of the grass swale (as shown on **Figure 13.12** above). This practice will provide comparable volume reduction and pollutant removal credit as the dry swale while also allowing grater opportunity for additional detention storage.

3. Add additional storage as needed in the form of a detention basin for quantity control below the bioretention/detention basin described above.

4. Install a level spreader along the rear property line of lots leading up to the cul-de-sac (**Figure 13.12**) for Sheet Flow to Conservation Area (**BMP Design Specification No. 2**). This will provide treatment for one of the few impervious and turf areas of the site that are not being treated. (The designer should consider this option as an inexpensive way to reduce the Water Quantity storage requirements. **Most importantly, this provides a treatment option that is not on the lots, and also avoids the clearing of mature trees**.

5. Install a grass swale along the rear lot lines on the lower-left of DA-B. The grass swale can be used to convey the drainage area to a small detention basin. This location could be used as a sediment basin during construction; however, the designer should be aware that sediment controls could be installed closer to the houses (and further away from the stream) and this location, if used for a permanent detention basin will require an access easement.

## 13.3. DESIGN EXAMPLE 3: OFFICE/COMMERCIAL SITE PLAN

**Site Description**: This example is for a small multi-story office/commercial zoned property.

**Step 1**: Resource Mapping (**see Chapter 6**) and Environmental Site Assessment
The Site Assessment is the basis for the stormwater concept plan and should include at a minimum include a written narrative or map identifying the following natural resource features:

1. Wetlands
2. Perennial streams and Intermittent streams
3. Stream buffers
4. Floodplains
5. Forest or other mature and/or native vegetation
6. Steep slopes
7. Soil types (Hydrologic Soil Groups, highly erodible soils)
8. Springs and/or natural seeps
9. Geology (bedrock or karst conditions)
10. Drainage divides

The grades on this site are relatively gentle sloping towards the perimeter. An area of woods and wetlands are located along the northern and western property lines. **Figure 13.13** below shows the overall layout of the development.

**Step 2:** Site Hydrology and Pollutant Loads

Developing the hydrology for the entire site allows the designer to establish the overall site-scale Post-Development Pollutant Load (TP, lb/yr) and the required Total Load (TP) Reduction (lb/yr). If the developed portion of the site includes multiple drainage areas, and more importantly, multiple discharge points, the designer will also need to develop the hydrology for each drainage area (**Step 3**) in order to comply with the Quantity Control requirements.

1. Basic site level hydrology (from NRCS Methods, **Section 4-4** of **Chapter 4**, ***Blue Book***)
   *a.* Pre- and Post developed condition land cover by soil type

   **NOTE:** ***NRCS CN methods – note that the NRCS land cover descriptions are not necessarily the same as the RRM Land Cover.***

   *b.* Compute the composite (or weighted) CN.
   *c.* $T_c$ (NRCS Methods. **Section 4-4** of **Chapter 4**, ***Blue Book***): This will require topography and site information sufficient to accurately identify drainage divides, $T_c$ and $T_t$ flow paths and channel geometry, and surface conditions (roughness coefficient, etc.).

   **Table 13.23** below provides a summary of the site hydrology. Note that the terminology for what was *meadow* in the pre-developed condition changes to *open space* in the developed condition with the corresponding NRCS Curve Number. NRCS defines open space as lawns, parks, golf courses, etc. These areas will be considered *managed turf* in the VRRM Post-Development Pollutant Load calculation.

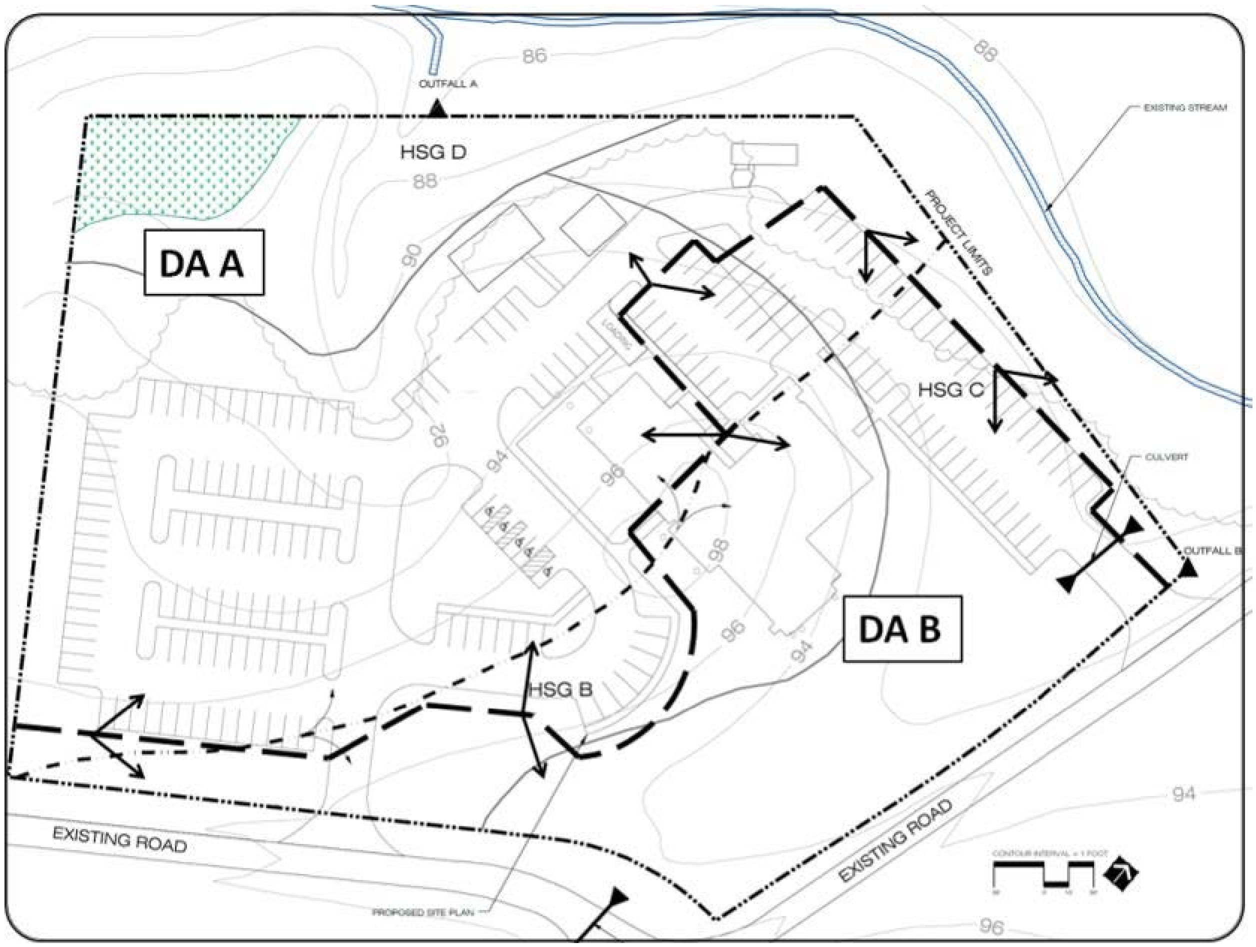


*Figure 13.13. Office/Commercial Site Drainage Areas A and B*

*Table 13.23. Office/Commercial Site Hydrology: Whole Site*

| Pre-Development | | | | | |
|---|---|---|---|---|---|
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** |
| Meadow | Good | B | 3.00 | 58 | |
| Meadow | Good | C | 1.50 | 71 | |
| Woods | Good | C | 0.20 | 70 | |
| Woods | Good | D | 0.90 | 77 | |
| | | **Total** | **5.60** | **65** | **0.54** |
| **Post-Development** | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc** |
| Open Space | Good | B | 1.10 | 61 | |
| Open Space | Good | C | 1.20 | 74 | |
| Impervious | | C/B | 2.20 | 98 | |
| Woods | Good | C | 0.20 | 70 | |
| Woods | Good | D | 0.90 | 77 | |
| | | **Total** | **5.60** | **81** | **0.26** |

2. Post-Development Pollutant Load (VRRM Compliance Spreadsheet)

   The VRRM Compliance Spreadsheet computes the total site composite *Rv,* Post-Development Treatment Volume (*Tv*), Post-Development Pollutant Load (TP and TN), and Total Load Reduction Required (TP) when the Land Cover information is entered into the Site Data Tab. **Table 13.24** provides the user-entered Site Data for this example. **Table 13.25** displays the spreadsheet-calculated values (Calculation Cells B46 through B52).

***Table 13.24. Office/Commercial Site Land Cover (acres): VRRM Compliance Spreadsheet Site Data Tab***

| Land Cover | A | B | C | D | Total |
|---|---|---|---|---|---|
| Forest | 0 | 0 | **0.20** | 0.9 | **1.10** |
| Turf | 0 | **1.10** | **1.20** | 0 | **2.30** |
| Impervious | 0 | **1.90** | **0.30** | 0 | **2.20** |
| | | | | **Total** | **5.60** |

***Table 13.25. Office/Commercial Site Land Cover Summary: VRRM Compliance Spreadsheet Site Data Tab***

| | | | |
|---|---|---|---|
| **Total Site Area (acres)** | **5.60** | | |
| **Site Rv** | **0.47** | | |
| Post-Development Treatment Volume (acre-ft) | **0.22** | | |
| Post-Development Treatment Volume (cubic feet) | **9,536** | | |
| Post-Development Load (TP) (lb/yr) | **5.99** | (TN) (lb/yr) | **42.86** |
| Total Load (TP) Reduction Required (lb/yr) | **3.70** | | |

**Step 3:** Drainage Area Hydrology, Peak Discharge, and Treatment Volume (*Tv*)

The drainage area divide shown in **Figure 13.13** above represents the major drainage divide in terms of the discharge outfall locations: DA drains to the outfall at the top of the figure, and DA-B discharges to the driveway culvert at the site's northern entrance.

1. Repeat **Step 2.1** for each DA:
   a. Compute the composite CN for each DA
   b. Compute the $T_C$ for each DA
   c. Determine the 24-hour rainfall depth for the appropriate 24-hour design storms as identified in the VSMP regulations (9 VAC 25-870-66), and compute the runoff depth (*Q*) and peak discharge ($q_p$). (Refer **to Chapter 11** (*Hydrologic Methods and Computations*) for guidance on hydrologic methods terminology and symbology.) **Table 13.26** below provides a summary of the pre- and post-development hydrology for Drainage Areas A and B of this example.

2. Post Developed Land Cover and Treatment Volume for DA's.

Enter Land Cover data into the drainage area tabs on the VRRM Compliance Spreadsheet (DA-A and DA-B tabs (cells B5 through E7). Calculation cells will provide the total acreage, the Land Cover *Rv* (average for each land cover), and Post-Development Treatment Volume (cf). **Tables 13.27** and **13.28** below display the spreadsheet cells for DA-A and DA-B respectively.

***Table 13.26. Office/Commercial Site Hydrology: Drainage Areas A & B***

| **Rainfall Depths:** 1-year 24-hour storm: **2.66"; ** 10-year 24-hour storm: **4.93"** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ***Drainage Area A*** | | | | | | | | | |
| **Pre-Development DA-A** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| Meadow | Good | B | 1.87 | 58 | | | | | |
| Woods | Good | C | 0.2 | 70 | | | | | |
| Woods | Good | D | 0.9 | 77 | | | | | |
| | | **Total** | **2.97** | **65** | **0.46** | **0.36** | **0.6** | **1.61** | **4.2** |
| **Post-Development DA-A** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| Open Space | Good | B | 0.4 | 61 | | | | | |
| Impervious | | | 1.47 | 98 | | | | | |
| Woods | Good | C | 0.2 | 70 | | | | | |
| Woods | Good | D | 0.9 | 77 | | | | | |
| | | **Total** | **2.97** | **85** | **0.21** | **1.31** | **5.1** | **3.30** | **12.7** |
| ***Drainage Area B*** | | | | | | | | | |
| **Pre-Development DA-B** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$q_{p10}$ (cfs)** |
| Meadow | Good | B | 1.13 | 58 | | | | | |
| Meadow | Good | C | 1.50 | 71 | | | | | |
| | | **Total** | **2.63** | **65** | **0.60** | **0.36** | **0.5** | **1.61** | **3.1** |
| **Post-Development DA-B** | | | | | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** | **$Q_1$ (in)** | **$Q_{p1}$ (cfs)** | **$Q_{10}$ (in)** | **$Q_{p10}$ (cfs)** |
| Open Space | Good | B | 0.70 | 61 | | | | | |
| Open Space | Good | C | 1.20 | 74 | | | | | |
| Impervious | | | 0.73 | 98 | | | | | |
| | | **Total** | **2.63** | **77** | **0.32** | **0.84** | **2.4** | **2.56** | **7.6** |

***Table 13.27. Office/Commercial Site: Drainage Area A Land Cover Summary (VRRM Compliance Spreadsheet DA-Tab)***

| Drainage Area A Land Cover (acres) | | | | | | |
|---|---|---|---|---|---|---|
| | A soils | B Soils | C Soils | D Soils | Totals | Land Cover Rv |
| Forest/Open Space (acres) | 0 | 0 | **0.20** | **0.90** | 1.10 | 0.05 |
| Managed Turf (acres) | 0 | **0.40** | 0 | 0.00 | 0.40 | 0.20 |
| Impervious Cover (acres) | 0 | **1.47** | 0 | 0.00 | 1.47 | 0.95 |
| | | | | **Total** | **2.97** | |

| | |
|---|---|
| **Post-Development Treatment Volume (cf)** | **5,552** |

***Table 13.28. Office/Commercial Site: Drainage Area B Land Cover Summary (VRRM Compliance Spreadsheet DA-B Tab)***

| Drainage Area B Land Cover (acres) | | | | | | |
|---|---|---|---|---|---|---|
| | A soils | B Soils | C Soils | D Soils | Totals | Land Cover Rv |
| Forest/Open Space (acres) | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| Managed Turf (acres) | 0 | **0.70** | **1.20** | 0.00 | 1.90 | 0.21 |
| Impervious Cover (acres) | 0 | **0.43** | **0.30** | 0.00 | 0.73 | 0.95 |
| | | | | **Total** | **2.63** | |

| | |
|---|---|
| | |
| **Post-Development Treatment Volume (cf)** | **3,984** |

**Step 4:** Apply BMPs in DA-A using the VRRM Compliance Spreadsheet:

> **NOTE:** ***The spreadsheet is not a BMP design tool other than to provide the designer with a simple tool for selecting BMPs and determining whether the selected BMPs or combinations of BMPs achieves compliance. The spreadsheet can also provide the designer with the treatment volume to the selected BMP ($Tv_{BMP}$). This includes the volume generated by the contributing drainage area, as well as any additional (reduced) volume from upstream BMPs. Using basic sizing parameters, the designer can verify the applicability of the practice given the various site constraints (overall footprint, depth, infiltration capacity, etc.). Once the selection of BMPs has been confirmed as adequate for compliance, the designer can then develop the detailed sizing and design of each practice.***

The designer should pay particular attention to the opportunities to use runoff reduction BMPs within the existing infrastructure and avoid impacting the adjacent woods and other open areas outside the limits of disturbance. **Figures 13.14** thru **13.16** below provide the graphic representation of the BMP selections and approximate locations.

1. **Permeable Pavement Level 1** in the large parking area of Drainage Area A. For this example, the drive aisles are to be constructed of traditional pavement, and the parking stalls constructed of a permeable pavement. (There may be an economy of scale in terms of construction costs

to construct the entire parking area with permeable pavement – depending on the pavement material selected.)

The total area of impervious cover of the parking lot consists of 14,600 $ft^2$ (0.33 ac) of permeable pavement and 15,680 $ft^2$ (0.36 ac) of regular pavement (including curbs, gutters, and islands), for a total of **0.69 ac** impervious acres (entered in "Credit Area" (column G) of VRRM Compliance Spreadsheet as the "acres of permeable pavement + acres of "external" (up-gradient) impervious pavement".

The parking islands on the upstream side of the permeable pavement (**Figure 13.14** below) are proposed to be impervious (decorative pavers or similar). Alternatively, the designer may elect to eliminate the islands in favor of a continuous section of permeable pavement with wheel-stops to facilitate pavement construction, or the islands can be increased in size to facilitate green space or another runoff reduction practice; however the location of the parking area is set between the roadway setback and mature woods. It is more advantageous to sacrifice the parking island space in favor of preserving the adjacent wooded area.

Consider design criteria from specifications (**Permeable Pavement Level 1, BMP Design Specification No. 7**):

- Maximum pavement slope < 5%

- The Level 1 ratio of external pavement to permeable pavement (*R*) may not exceed 2.5:1, with run-on minimized to the extent practicable, or limited to impervious cover.
  - The grading of the parking drive aisles slopes toward the adjacent permeable pavement as indicated by the flow arrows (**Figure 13.14** below). Therefore, some areas will have no "run-on" while other areas will capture the adjacent drive aisle.
  - For the areas with run-on, the ratio $R$ = 2,880 $ft^2$/1,782 $ft^2$ = 1.6 (less than 2.5:1, OK).

- Calculate minimum and/or maximum depth of stone reservoir (**Equation 7.1, Design Specification No. 7**)
  - Each section of permeable pavement will require sizing of the stone reservoir based on the surface area and contributing impervious area using **Equation 7.1**. However, the *minimum* stone reservoir depth required to store the Treatment Volume to the BMP ($T_{vBMP}$) is often less than that needed for adequate pavement bedding (based on soil strength – refer to **Design Specification No. 7**).
  - $T_{vBMP}$, or Treatment Volume to the total practice = 2,380 $ft^3$ from the VRRM Compliance Spreadsheet, column I (Runoff Reduction) and column J (Remaining Runoff Volume).
  - Using a Level 1 practice (with an underdrain) eliminates the need for a *maximum* depth calculation. Increasing the depth of the stone reservoir to capture and store a greater runoff volume with an outlet control for a single-event storm routing, as needed, may allow the designer to address quantity control requirements. However, increasing the total volume captured and detained does not achieve a greater *annual* runoff volume and pollutant load reduction.

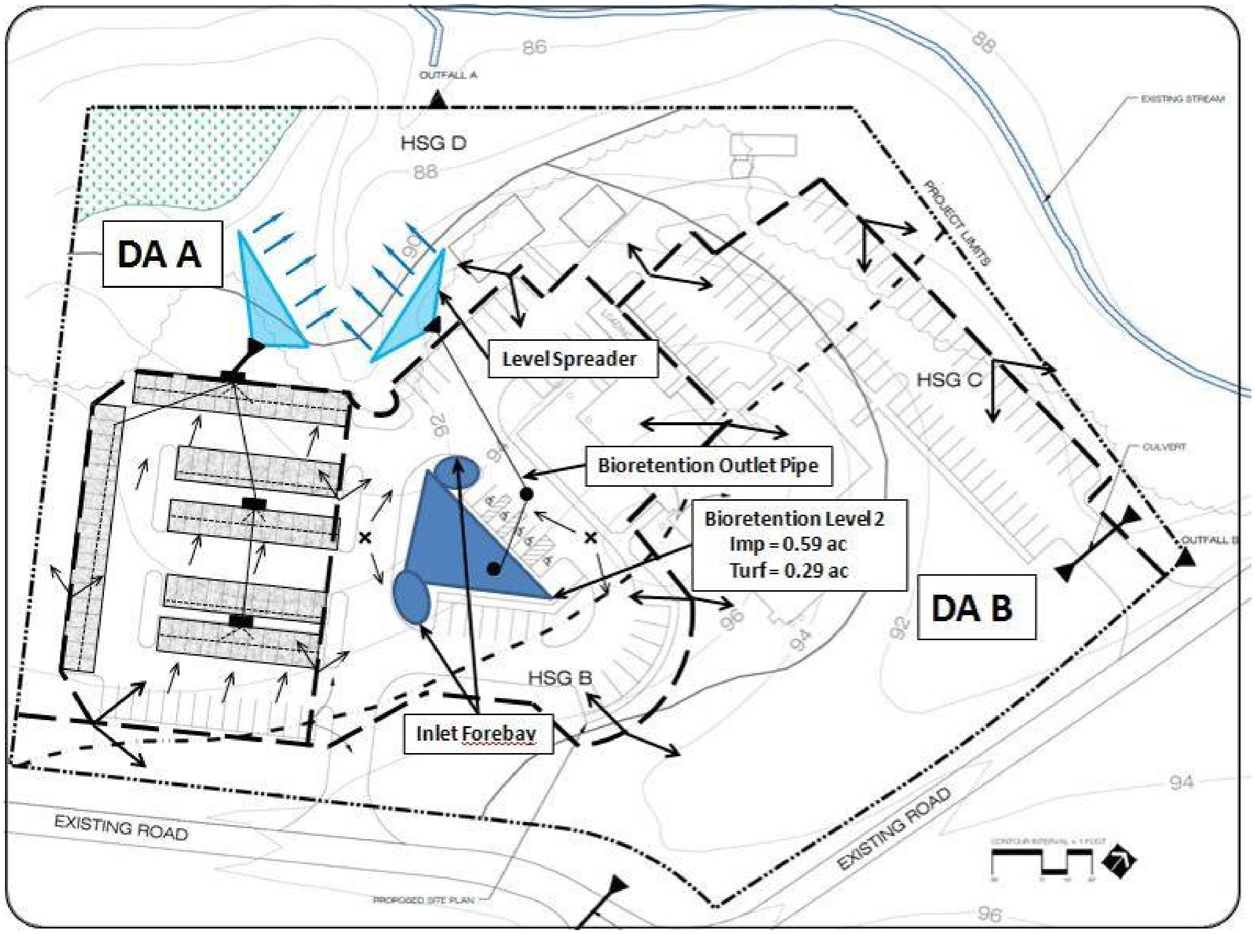


*Figure 13.14. Office/Commercial Site: Permeable Pavement in Drainage Area A*

- **Equation 7.1**, minimum depth of reservoir layer, $d_{stone}$:

$$d_{stone} = \frac{(P \times A_I \times Rv_I) + (P \times A_P)}{\eta_r \times A_P}$$

$$d_{stone} = \frac{\left(0.08ft \times 2{,}880\ ft^2 \times 0.95\right) + \left(0.08ft \times 1{,}782ft^2\right)}{0.4 \times 1{,}782ft^2} = 0.51ft = 6.1\ inches$$

- The design is simplified here for illustrative purposes. If the permeable pavement area were one large parking area with a run-on *R* value of 1.6, the required stone reservoir depth to manage the 1-inch rainfall would be 6.1 inches. The actual stone depth below the pavement will be determined as required to achieve structural stability, and in this case will be greater than 6.1 inches, thus providing an opportunity to increase storage to meet the Water Quantity requirements.
- The design will include underdrains that connect to adjacent curb inlets, as shown in **Figure 13.14** above**.**

- The curb inlets serve as the overflow for large storm events. A drainage system connects the inlets to the outfall.

➢ **Downstream Practice**: The outfall of the underdrain collection system is directed towards the wooded area (near the top of **Figure 13.14** above), designated as a Conservation Area. Select *Sheetflow to Conservation Area* with C/D soils as the downstream practice to which discharge is directed from the Permeable Pavement drains (Column P in the VRRM Compliance Spreadsheet).

2. **Bioretention Level 2** can be constructed in the oversized traffic island in the main driveway. This location picks up the flow from the main driveway and a portion of the rooftop (**0.59 ac** impervious and **0.29 ac** turf); Total acres treated = **0.88 acres**.

   Design and sizing considerations for Bioretention Level 2 (**Bioretention, BMP Design Specification No. 9**):

➢ General sizing guidance for Bioretention Level 2 calls for an overall practice footprint of approximately 6% of the contributing drainage area (6% x 0.59 ac x 43,560 $ft^2$/ac = 1,542 $ft^2$). The area of the traffic island is approximately 4,500 $ft^2$.

➢ $Tv_{BMP}$ (or Treatment Volume to the total practice) = 2,380 $ft^3$, from the VRRM Compliance Spreadsheet column I (Runoff Reduction) and column J (Remaining Runoff Volume).

➢ Bioretention Level 2 requires a treatment volume = 1.25 x $T_{vBMP}$ = 1.25 x 2,380 $ft^3$ = **2,975 $ft^3$**.

➢ The available space of the traffic island must include the 3:1 side slopes for the surface ponding and freeboard (required to convey the large storms out of the traffic island), and inlet forebays (volume inclusive of the *Tv*). The drainage area is split in order to maximize the effectiveness of the two forebays (see **Figure 13.15** below).

➢ Using the Bioretention Level 1 sizing rules for storage volume:
- Surface ponding = 1-foot max.
- Required soil media depth = 36 inches min.
- Gravel reservoir sump = 12 inches min. (or use infiltration if soil tests verify the infiltration rate of the soil to be at least 0.5"/hr with corresponding values of porosity for each layer)

The designer can determine the minimum surface ponding and soil media surface areas: **1,384 $ft^2$**.

➢ The outfall of the overflow system can be directed to the rear of the property towards the wooded area (top of **Figure 13.15** below), designated as a conservation area. Select *Sheetflow to Conservation Area* with C/D soils as the downstream practice to which discharge f is directed from the Bioretention Area (Column P in the VRRM Compliance Spreadsheet).

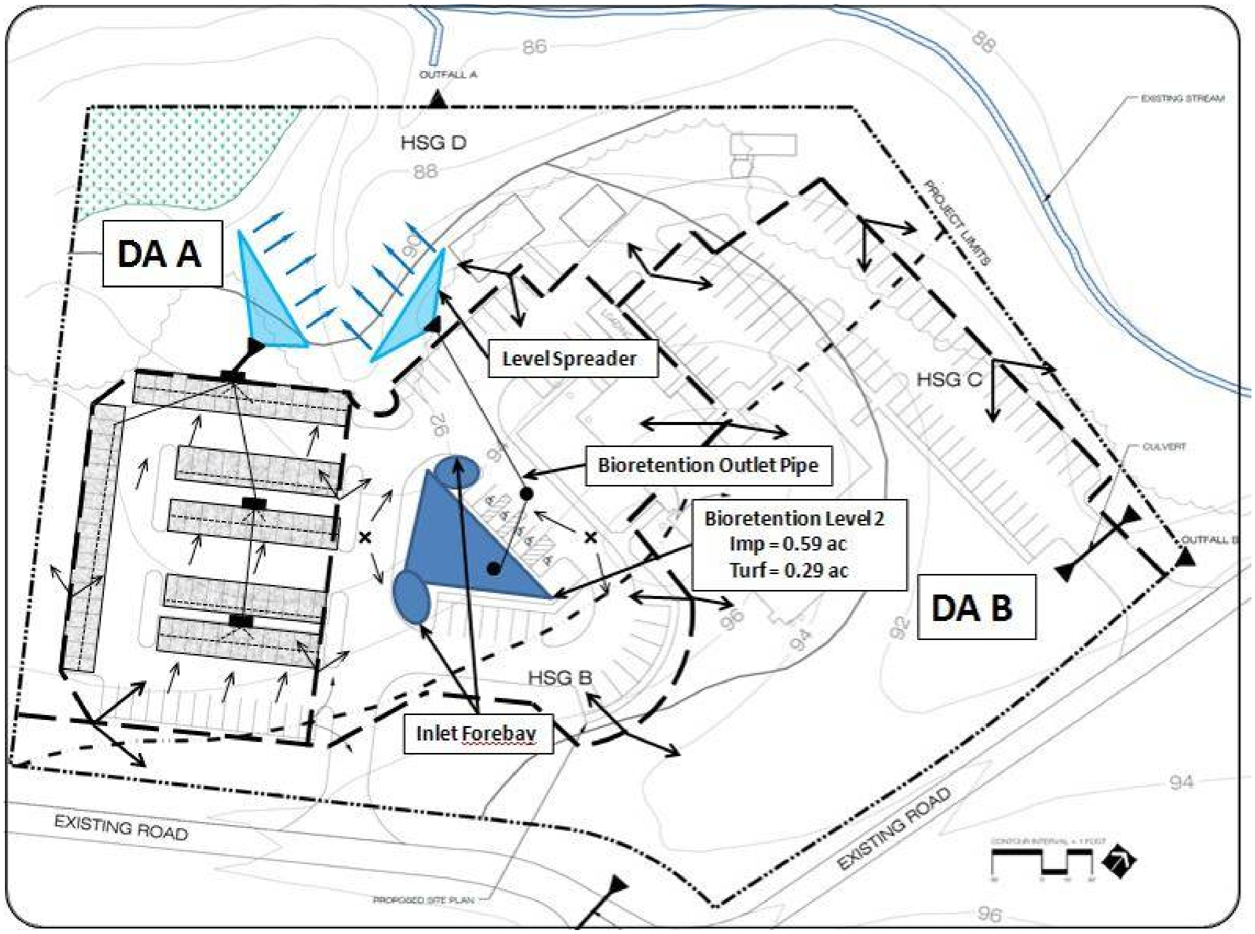


*Figure 13.15. Office/Commercial Site: Level 2 Bioretention in Drainage Area A*

**Step 4A**: Interim compliance check

1. The combination of the Permeable Pavement Level 1 and Bioretention Level 2 treats a total of 1.28 acres of impervious cover and 0.29 acres of turf (column G, rows 71 and 72, DA-A Tab).

2. The area checks (cell G74); meaning the total area treated does not exceed the total area in DA-A.

3. The load reduction achieved with the two BMPs in DA-A, found in cell I78, is 2.15 lb/yr of the required total site reduction of 3.70 lb/yr.

**NOTE:** ***The area of the Bioretention Basin in DA-A can be converted to Forest/Open Space on the Site Data Tab and the D.A. Tab – this will reduce the load requirement.***

**Step 5:** Implement BMPs in DA-B

Several different options can be considered in DA-B. The rooftop area of the building can be captured in Micro-Bioretention, and there is adequate area to configure a large bioretention practice, dry swale, constructed wetland or wet pond, etc. The VRRM Compliance Spreadsheet allows the designer to consider the relative performance of these strategies; however, equally important, the designer must also consider the BMP design criteria, including the difference between Level 1 and Level 2 design specifications, in order to determine if the practice will fit in the designated location.

1. **Impervious Disconnection, BMP Design Specification No. 1 – Alternative Practices: Rain Garden Level 2 (Micro-Bioretention).** While there is likely enough space to provide simple disconnection (sheet flow) across B soils, the potential runoff volume and load reduction credit associated with Micro-Bioretention is much greater, and it is further justified by the desire to place aesthetic BMPs in the highly visible location around the front and entrance area of the building.

   - The rooftop is relatively large for the typical scale of simple or alternative practice disconnection (1,000 $ft^2$ per disconnection), so the designer must coordinate with the architect to ensure that the downspouts will be placed in the preferred locations to provide maximum visibility to the rain gardens, and that there is enough room for the required surface area. Consider the Rain Garden design and sizing considerations from **Design Specifications No. 9**.

   (**Impervious Disconnection, BMP Design Specification No. 1**):

   - Alternative Practice: *Micro-Bioretention Level 1*
     - Maximum contributing drainage area = 1,000 $ft^2$
     - Surface area = 3% of contributing drainage area
     - Soil depth minimum = 18 inches

   - Alternative Practice: *Micro-Bioretention Level 2* (the design and sizing criteria is similar, but with a different required surface area and soil media depth.
     - Maximum contributing drainage area = 1,000 $ft^2$
     - Surface area = 4% of contributing drainage area
     - Soil depth minimum = 24 inches

   - The portion of the rooftop that meets the criteria for a highly visible location for the Rain Garden(s) is approximately 3,000 $ft^2$ or **0.07 ac.** impervious). Therefore, three separate rain gardens are required, with each treating a maximum of 1,000 $ft^2$.

   - The available head (or depth) to discharge to an underdrain must be coordinated with the final grading plan. In this case, based on the large drainage feature along the front of the parcel, a Level 2 (24-inch soil media depth) Micro-bioretention practice is proposed.

- See #3 below for a possible downstream practice(s) to be employed (Column P in the VRRM Compliance Spreadsheet).

2. **Grass Channel.** The largest land cover feature in DA-B is the parking area and driveway, consisting of **0.55 ac** of impervious cover. The grades on the site allow for the parking to be graded to sheet flow across to a Grass Channel running the length of the parking lot (**Figure 13.16**) between the parking lot and the building. The Grass Channel then connects to a Dry Swale. Consider the *Grass Channel* design and sizing considerations from specifications (**Grass Channels, BMP Design Specification No. 3**):

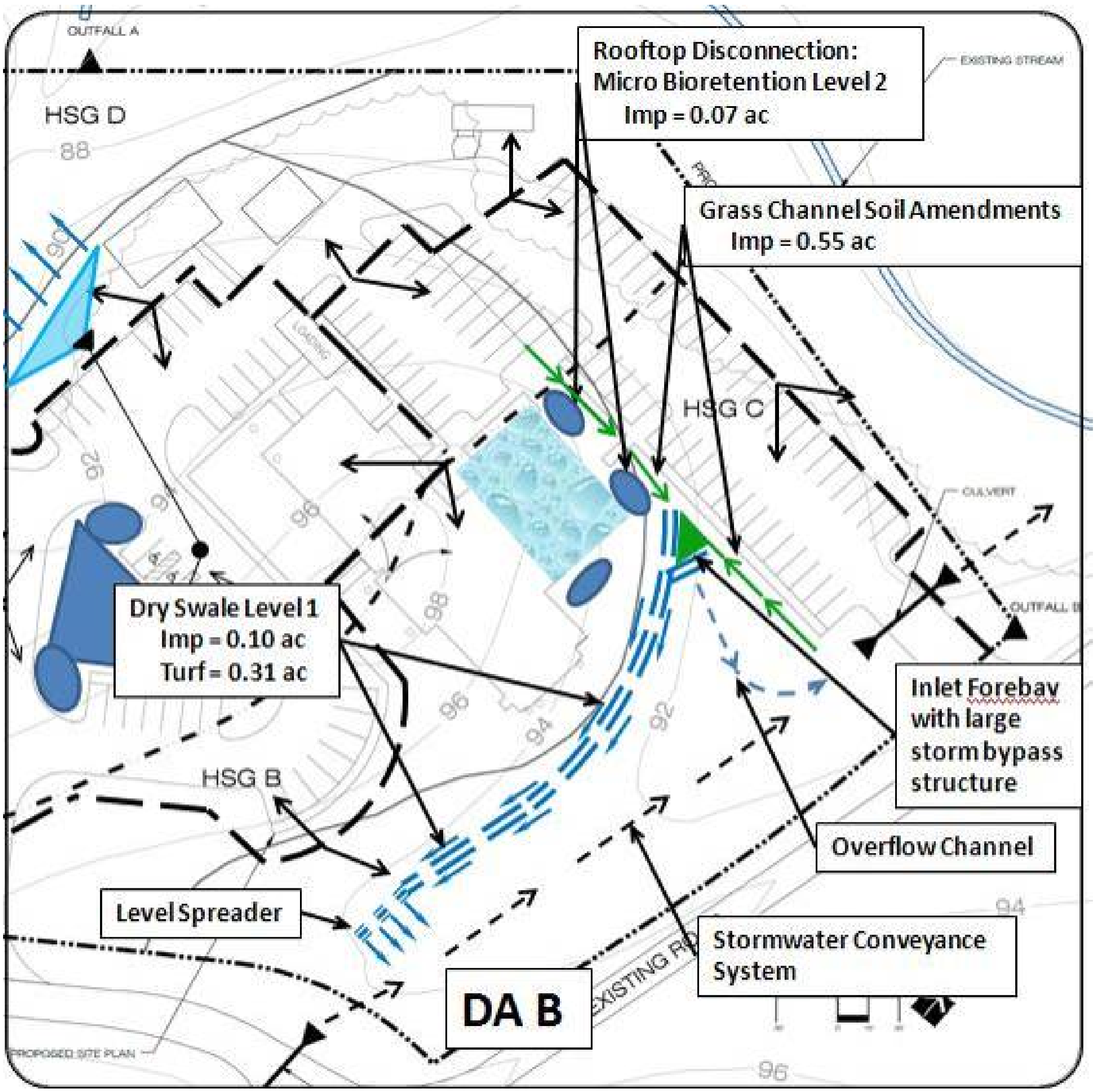


*Figure 13.16. Office/Commercial Site: Micro-Bioretention and Dry Swale in D.A. B*

- Maximum contributing drainage area to any individual grass channel = 5 acres.

- The bottom width of the channel: 4 ft to 8 ft wide (or as needed to ensure that, combined with the slope, the channel maintains the maximum *Tv* (Retention Volume) peak velocity at less than 1 ft/sec) .
  - The channel side-slopes: 3H:1V or flatter.
  - The longitudinal slope of the channel should be no greater than 4%. (Check dams may be used to reduce the effective slope in order to meet the limiting velocity requirements.)

- The Grass Channel is primarily on C soils. To maximize the performance credit, the channel will be enhanced with soil amendments.

- Grade channel from each end of the parking area to the center for connection to the Dry Swale. Construct an overflow or bypass structure designed to divert the flow in excess of the *Tv* peak rate (**Section 11.5.3 of Chapter 11**).

- Enter **0.55** impervious acres in 4.c. (*Grass Channel with Compost Amended Soils*), cell G36.

- See #3 below for a downstream practice to be employed (Column P in the VRRM Compliance Spreadsheet).

3. A **Dry Swale Level 1** will extend from the grass channel across the grass area as shown in **Figure 13.16** above. The alignment parallels the contour in order to maintain a longitudinal slope as flat as possible.

   - The designer should verify if the available hydraulic head between the Dry Swale location and the drainage feature along the front of the parcel will accommodate the depth requirements of a Level 2 Dry Swale. For purposes of this example, we will assume that there is insufficient head available, so a Level 1 Dry Swale will be used.
     - Select Dry Swale Level 1 as the downstream practice to be employed for the Grass Swale (Column P in the VRRM Compliance Spreadsheet – see #2 above).
     - Additional impervious area drains to the Dry Swale from the rooftop disconnection draining into the Micro-Bioretention practices. Select Dry Swale Level 1 as the downstream practice to be employed for this sequence as well (Column P in the VRRM Compliance Spreadsheet – see #1 above.
     - Additional impervious area drains to the Dry Swale from the rooftop areas that are *not* currently managed by an upstream BMP. This rooftop area was determined to be too large to meet the Micro-Bioretention criteria (< 1,000ft$^2$). Therefore, add **0.10 ac** of impervious area draining to the Dry Swale, entered in the Credit Area (Column G) for the Dry Swale Level 1.
     - Additional turf acres drain to the Dry Swale. Add **0.31 ac** of turf area draining to the Dry Swale, entered in the Credit Area (Column G) for the Dry Swale Level 1.

Consider the design and sizing considerations from specifications (*Dry Swale Level 1*, **BMP Design Specification No. 10**):

- Maximum effective swale slope: 2% (minimal check dams are needed, since the alignment is set so as to minimize the longitudinal grade of approximately 0.5%.

- Minimum soil media depth = 18 inches

- The $Tv_{BMP}$ for the Dry Swale #1 is 1,960 $ft^3$ (from the VRRM Compliance Spreadsheet, column I + column J).
  - The designer can select a range of swale widths and/or lengths to accommodate the design $Tv_{BMP}$. Using the sizing rules for soil depth (18 inches at a porosity of $\eta$ = 0.4), a gravel/underdrain layer (12 inches at $\eta$ = 0.25), surface ponding (12 inches maximum at $\eta$= 1), and 3:1 side slopes, the surface ponding yields an effective storage volume per foot of dry swale width.
  - Therefore, choosing a Dry Swale width = 4 ft, the corresponding effective storage volume is 10.2 $ft^2$ per linear foot of length. Therefore, estimate the required length:

$$1{,}960 \text{ ft}^3 / 10.2 \text{ ft}^2/\text{ft} = 192 \text{ linear feet}$$

  - An approximate width of 14 ft is required to accommodate the dry swale: 4 ft bottom width, 3:1 side slopes on the 12-inch surface ponding, plus 6 inches of freeboard. An approximate corridor 260 ft long is available with almost unlimited width. The additional width and length allows adequate space to include check dams or grade control structures as needed (Dry Swale design can include the creation of multiple cells that establish near-level flow segments with overflow inlets or weirs). The designer can select the geometry that best suits the site; the volume of soil, stone, excavation, etc., will be comparable.

- The dry swale discharges to the drainage feature across the front of the parcel – between the road and the building – through a level spreader sized according to the procedure outlined in **Section 11.5.3 (Calculation of the Treatment Volume peak flow rate $q_{pTv}$) of Chapter 11**:
  - Step 1: Calculate the adjusted CN (**Equation 11.10**):

$$CN = \frac{1000}{[10 + 5P + 10Q_a - 10(Q_a^2 + 1.25Q_aP)^{0.5}]}$$

$$Q_a = {}^{Tv_{BMP}}/_{DA} = {}^{1{,}960\ ft^3}\Big/\left(1.03\ ac \times 43{,}560\ {}^{ft^2}/_{ac}\right)$$

$$Q_a = 0.52"$$

$$CN = \frac{1000}{\left[10 + 5(1") + 10(0.52") - 10\left((0.52")^2 + 1.25(0.52")(1")\right)^{0.5}\right]}$$

*CN = 94*

- Step 2: Compute the drainage area Time of Concentration (*Tc*). By definition, the *Tc* is the longest flow path in the drainage area. However, the longest flow path in DA-B does not reflect the hydrologic time of concentration of the drainage area contributing to the Dry Swale. Recomputing the *Tc* for the parking lot (sheet flow and shallow concentrated flow) generates a much different (shorter) *Tc* = 0.11 hr.
- Step 3: $q_{pTv}$

  $I_a = 200/CN - 2$ = 0.128 inch

  $I_a/P$ = 0.128 in./1 in. = 0.128

  $q_u$ = 950 csm/in. [see **Figure 13.17** below:TR55 Exhibit 4-II Unit peak discharge ($q_u$)] for NRCS (SCS) type II rainfall distribution; *Tc* = 0.11 hr, $I_a/P$ = 0.128)

  $$q_{pTv} = q_u \times A \times Q_a$$
  $$q_{pTv} = 950\frac{csm}{in.} \times \frac{1.03ac}{640\ {}^{ac}/_{mi^2}} \times 0.52\ in.$$
  $$q_{pTv} = 0.8\ cfs$$

The level spreader at the end of the Dry Swale is sized based on a Treatment Volume peak discharge $q_{pTv}$ = 0.8 cfs. This design is predicated on a diversion structure that diverts any flow in excess of 0.8 cfs away from the Dry Swale, and directly to the stormwater conveyance system.

**Step 5A**: Interim Compliance Check

- The combined performance of the Micro-Bioretention disconnection and the Dry Swale treats a combined 0.72 acres of impervious cover, and 0.31 acres of turf (G71 and 72, DA-B Tab).

- The area checks (cell G74) (i.e., the total acres of impervious and turf treated does not exceed the total in the drainage area.

- The load reduction achieved with the three BMPs in DA-B is 1.19 lb/yr (cell I78 DA-B Tab).

- Combined with DA-A, the total impervious area treated is 2 acres (out of a possible 2.2 acres), and the total turf area treated is 0.6 (out of a possible 2.3 acres).

- A summary of the combined volume and total load reduction resulting from the implementation of BMPs in DA-A and DA-B is provided in **Table 13.29** below (excerpted from the VRRM Compliance Spreadsheet Water Quality Compliance Tab). The load reduction requirement has been met.

**Exhibit 4-II** Unit peal discharge ($q_u$) for NRCS (SCS) type II rainfall distribution

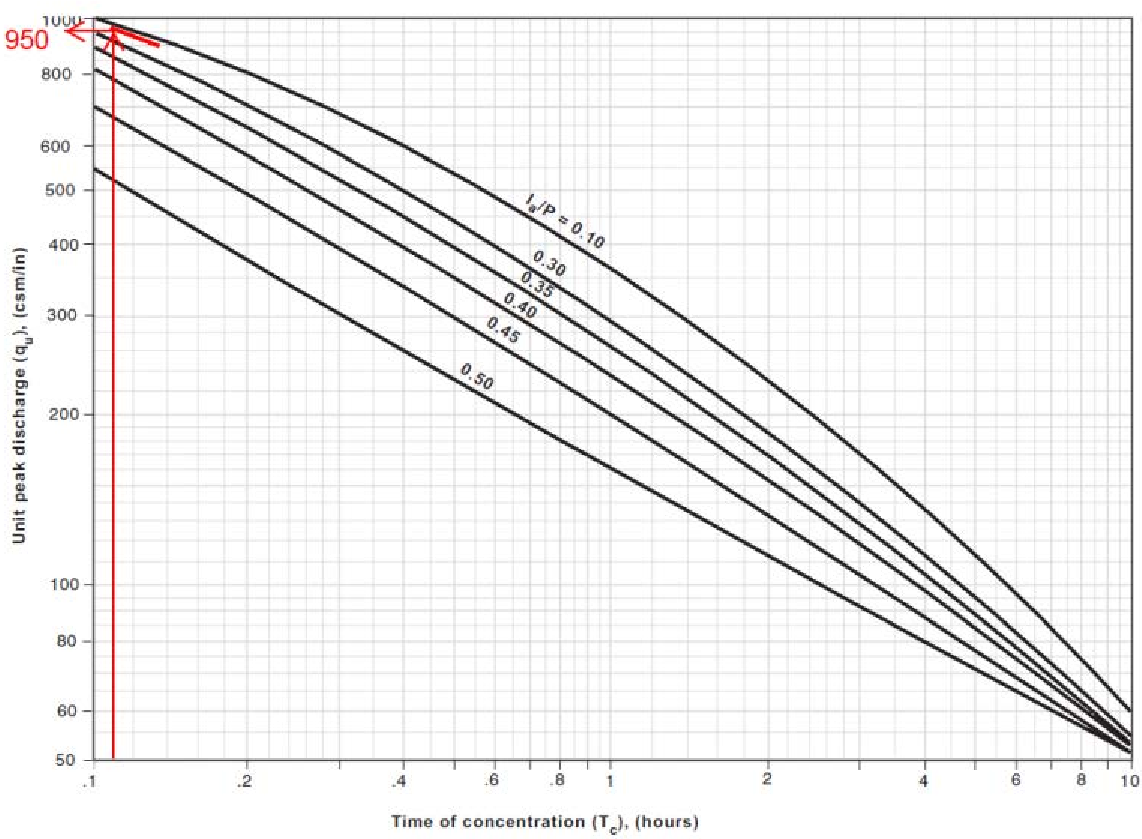


***Figure 13.17. Exhibit 4-II from TR-55***

***Table 13.29. Office/Commercial Site Compliance Check –***
***Water Quality Compliance Tab of the VRRM Compliance Spreadsheet***

| | |
|---|---|
| TOTAL TREATMENT VOLUME (cf) | 9,536 |
| TOTAL PHOSPHORUS LOAD REDUCTION REQUIRED (LB/YEAR) | **3.70** |
| | |
| RUNOFF REDUCTION (cf) | **5,292** |
| PHOSPHORUS LOAD REDUCTION ACHIEVED (LB/YR) | **2.28** |

| | |
|---|---|
| REMAINING PHOSPHORUS LOAD REDUCTION (LB/YR) NEEDED | **CONGRATULATIONS!! YOU EXCEEDED THE TARGET REDUCTION BY 0 LB/YEAR!!** |

**NOTE**: ***The designer should verify that all the drainage areas check – this includes checks on the D.A. Tabs (row 74) and the Water Quality Compliance Tab (row 8 and column G) to verify that no more acreage of impervious and/or turf was directed to a BMP than was actually available for treatment.***

**Step 7** Quantity Control Requirements – Curve Number Adjustment

The VSMP Channel Protection Criteria are described in **Section 11.6.1 of Chapter.** The method for calculating the allowable peak discharge to natural stormwater conveyance systems is described in **Section 11.6.2**, and the method for using the VRRM curve number adjustment is described in **Section 11.6.3**.

- The point of discharge from DA-A is to a *natural stormwater conveyance system* and therefore the allowable discharge from each drainage area for the 1-year 24-hour design storm must be managed such that discharge for the developed condition does not exceed the allowable peak discharge, as defined by the “energy balance equation” (**Equation 11.13**):

$$Q_{Developed} \leq I.F.\ x\ (Q_{Pre\text{-}developed}\ x\ RV_{Pre\text{-}Developed})\ /\ RV_{Developed}$$

- The natural *stormwater conveyance system* immediately downstream does not currently experience flooding.

- This condition must be analyzed to the required limits of analysis, in accordance with **9 VAC 25-870-66 C 3. Water quantity**:
  - The site's contributing drainage area is less than or equal to 1% of the total watershed area draining to a point of analysis; or
  - Based on peak flow rate, the site's peak flow rate from the 10-year 24-hour storm event is less than or equal to 1% of the existing peak flow rate prior to the implementation of any stormwater quantity control measures; or
  - The stormwater conveyance system enters a mapped floodplain.

- The total site area (combined drainage areas of DA-A and DA-B is 5.6 acres. DA-A discharges directly to an adjacent stormwater conveyance system, while DA-B discharges to a small man-made stormwater conveyance system designed to convey the 10-year storm flow within the system, before discharging into the same natural stormwater conveyance system as DA-A. Therefore, the analysis of the point of discharge should consider the entire site. The contributing drainage area (CDA) of the natural stormwater conveyance system is determined to be 628 acres to the point of discharge for DA-A. Therefore, the site's CDA is less than 1% of the total watershed area. Also, the stream is in a mapped floodplain. Therefore, 10-year storm flood control is not required.

**Channel Protection**: Hydrological data for the pre- and post-development site conditions is necessary to establish the allowable peak discharge and the corresponding additional detention storage volume requirements.

- **Table 13.30** below displays the curve number adjustments computed by the VRRM Compliance Spreadsheet for DA-A and DA- B (Channel and Flood Protection Tab);

- **Table 13.31** below consolidates all the relevant hydrologic data required to compute the quantity control requirements for the 1-year 24-hour storm event.

11. Compute the allowable peak discharge for the 1-year 24-hour design storm for each drainage area (**Equation 11.13** from **Chapter 11**):

$$Q_{Developed} \leq I.F.\ x\ (Q_{Pre\text{-}developed}\ x\ RV_{Pre\text{-}Developed})\ /\ RV_{Developed}$$

Note that the values for ***$RV_{Developed}$ (in.) with Runoff Reduction*** from the VRRM Compliance Spreadsheet (**Table 13.30**) is the same term as $Q$ (runoff depth, in.) in **Table 13.31**. Also note that $Q_{developed}$ and $Q_{pre\text{-}developed}$ as written in the VSMP regulations are commonly written as $q_{pDeveloped}$ and $q_{pPre\text{-}developed}$, and are the same term as $q_p$ in **Table 13.31**. Therefore **Equation 11.13** is re-written as:

$$q_{pDeveloped} \leq I.F.\ x\ \left(q_{pPre-Developed}\ x\ RV_{Pre-Developed}\right)\ /\ RV_{Developed}$$

The reader should review these terms in **Section 11.6.2** of **Chapter 11**.

- Drainage Area A:

1-yr $q_{pDeveloped} \leq 0.8\ x\ (0.6\ x\ 0.36)/0.68$

1-yr $q_{pDeveloped} \leq$ ***0.3 cfs***

- Drainage Area B:

1-yr $q_{pDeveloped} \leq 0.8\ x\ (0.5\ x\ 0.36)/0.68$

1-yr $q_{pDeveloped} \leq$ ***0.2 cfs***

*Table 13.30. Office/Commercial Site: Drainage Area A Curve Number Adjustment from the VRRM Compliance Spreadsheet*

| Drainage Area A | | | |
|---|---|---|---|
| | 1-year storm | 2-year storm | 10-year storm |
| $RV_{Developed}$ (in) with no Runoff Reduction | 1.31 | 1.89 | 3.30 |
| $RV_{Developed}$ (in) with Runoff Reduction | 0.96 | 1.54 | 2.96 |
| Adjusted CN | **79** | **80** | **81** |
| **Drainage Area B** | | | |
| | 1-year storm | 2-year storm | 10-year storm |
| $RV_{Developed}$ (in) with no Runoff Reduction | 0.84 | 1.32 | 2.56 |
| $RV_{Developed}$ (in) with Runoff Reduction | 0.68 | 1.16 | 2.40 |
| Adjusted CN | **73** | **74** | **75** |

*Table 13.31. Office/Commercial Site Hydrology Summary, with Adjusted Curve Numbers and Runoff Volumes for Drainage Areas A and B*

| **Rainfall Depths:** 1-year 24-hour storm: **2.66"** | | | | | |
|---|---|---|---|---|---|
| ***Drainage Area A*** | | | | | |
| **Pre-Developed DA A** | | | | | |
| | Area (ac) | CN | Tc (hrs) | $Q_1$ (in) | $q_{p1}$ (cfs) |
| Total | 2.97 | 65 | 0.46 | 0.36 | 0.6 |
| **Post-Developed DA A** | | | | | |
| Total | 2.97 | 85 | 0.21 | 1.31 | 5.1 |
| 1-year CN Adjustment w/ RR | | 79 | | 0.96 | 3.6 |
| ***Drainage Area B*** | | | | | |
| **Pre-Developed DA B** | | | | | |
| | Area (ac) | CN | Tc (hrs) | $Q_1$ (in) | $q_{p1}$ (cfs) |
| Total | 2.63 | 65 | 0.60 | 0.36 | 0.5 |
| **Post-Developed DA B** | | | | | |
| Total | 2.63 | 77 | 0.32 | 0.84 | 2.4 |
| 1-year CN Adjustment w/ RR | | 73 | | 0.68 | 1.7 |

12. Compute the storage volume required to achieve the required 1-year peak discharge reductions.

- In D.A. A, the 1-year post-developed peak discharge was reduced from **5.1 cfs** to **3.6 cfs** with the runoff reduction practices. The peak discharge must be further reduced to **0.3 cfs**.

- In D.A. B, the 1-year post-developed peak discharge was reduced from **2.4 cfs** to **1.7 cfs** with the runoff reduction practices. The peak discharge must be further reduced to **0.2 cfs**.

- Follow the same procedures as outlined in Design Example 2.

**NOTE:** ***The designer should be aware of the challenges in designing a control structure to manage a design release rates below 1 cfs. In many cases, it may be more feasible to add storage to practices such as Permeable Pavement,***

***Bioretention, Dry Swale, and others that have an actual storage component and a discharge structure.***

## 13.4. DESIGN EXAMPLE 4: DEVELOPMENT ON PRIOR DEVELOPED LAND

**Site Description**: This example design (**Figure 13.18**) is for an ultra-urban development on prior developed land, referred to hereafter as redevelopment. This redevelopment project proposes converting a small commercial/retail building and adjacent parking into a multi-story apartment/condominium. **Table 13.32** provides the basic acreage and site hydrology.

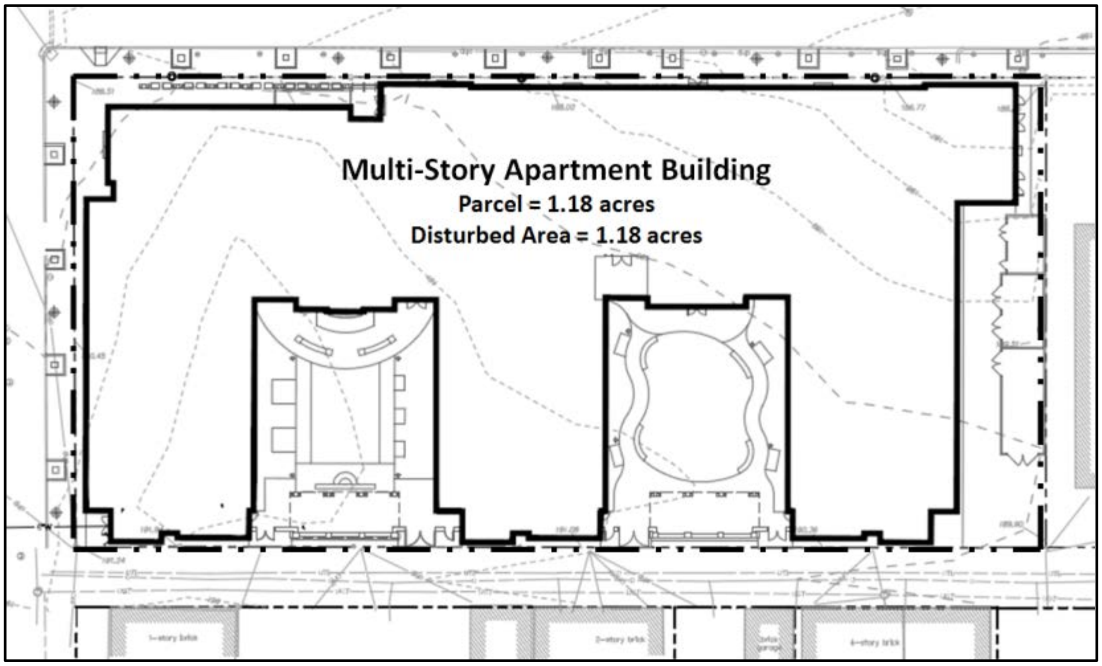


***Figure 13.18. Proposed Redevelopment Site***

***Table 13.32. Pre- and Post-redevelopment Site Hydrology***

| Pre-Redevelopment | | | | | |
|---|---|---|---|---|---|
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc (hrs)** |
| Open Space | Good | D | 0.38 | 80 | |
| Impervious | | D | 0.80 | 98 | |
| | | **Total** | **1.18** | **92** | **0.10** |
| **Post-Redevelopment** | | | | | |
| **Land Use** | **Condition** | **HSG** | **Area (ac)** | **CN** | **Tc** |
| Open Space | Good | D | 0.13 | 80 | |
| Impervious | | D | 1.05 | 98 | |
| | | **Total** | **1.18** | **96** | **0.10** |

**Step 1**: Resource Mapping (see **Chapter 6**) and Environmental Site Assessment

The Environmental Site Assessment is the basis for the concept plan and will typically include a map identifying natural resource features. Since this is an ultra-urban redevelopment site, the Environmental Site Assessment may include a very different set of features and/or investigations (i.e., Level 1 or Phase 1).

Another important item for urban redevelopment sites is the soils investigation. The usual sources of preliminary information on soils will often reference urban or impacted soils. Designers should not assume that this means that the soils are not suitable for infiltration or retention storage. There have been many examples of permeable soils below the existing or pre-redevelopment construction impact, revealing permeable soils for incorporation into the stormwater BMP strategy.

**Step 2:** Site Hydrology and Pollutant Loads

The site hydrology for this highly impervious urban redevelopment project is straightforward due to the relatively small size and consistent land cover. Computing the site pollutant load (TP) and pollutant load reduction requirement for redevelopment projects will require that the pre- and post-redevelopment loads be calculated. The required load reduction will be a 10% or 20% reduction from the pre-redevelopment site TP load. Where the redevelopment project results in a net increase in impervious cover, the total required TP load reduction will include the reduction for the new (additional) impervious acreage, which must meet the *new* development site-based TP load limit of 0.41 lb/ac/yr.

1. Basic site level hydrology, using either the NRCS or the Rational Method, may be acceptable to the VSMP Authority.
   a. Pre- and post-redevelopment land cover. **NOTE: *When using the NRCS CN methods, remember that the NRCS land cover descriptions are not necessarily the same as the RRM Land Cover descriptions*.**
   b. Compute the composite (or weighted) CN or Modified Rational “C” value.
   c. Determine the $T_c$ (refer to the NRCS Methods in **Section 4-4** of **Chapter 4**, ***Blue Book***). This will require topography and site information sufficient to accurately identify drainage divides, $t_c$ and $T_t$ flow paths, and surface conditions (roughness coefficient, etc.).

   **Table 13.32** above provides a summary of the site hydrology. Note that the terminology for what was *meadow* in the pre-developed condition changes to *open space* in the developed condition with the corresponding NRCS Curve Number. NRCS defines open space as lawns, parks, golf courses, etc. These areas will be considered *managed turf* in the VRRM Post-Development Pollutant Load calculation.

   The corresponding computation of the peak discharge is provided in **Step 3** below for each drainage area using the Rational Method, since compliance with the quantity control requirements is determined by the adequacy of the existing manmade stormwater conveyance system. The individual drainage areas are defined by the points of discharge to the stormwater conveyance system.

2. Determine the pre- and post-redevelopment pollutant Loads (using the VRRM Redevelopment Compliance Spreadsheet).

   Based on user input for the Total Disturbed Acreage and the Pre- and Post-Redevelopment Land Cover on the Site Data tab (**Table 13.33** below), the VRRM Redevelopment Compliance

Spreadsheet computes the Pre- and Post-Redevelopment Land Cover Summary, which includes the site composite *Rv,* Treatment Volume (*Tv*), and Pollutant Loads (TP and TN). This redevelopment project also results in a **net increase of 0.25 acres of impervious cover**; therefore the spreadsheet will also compute the *Adjusted* Pre-Redevelopment Land Cover Summary, and the Post-Redevelopment *New Impervious* Land Cover Summary (upper cells of **Table 13.34**).

***Table 13.33. Disturbed Acreage and Pre- and Post-Redevelopment Land Cover (acres): VRRM Redevelopment Compliance Spreadsheet Site Data Tab***

**Total Disturbed Acreage** **1.18**

**Pre*Redevelopment Land Cover**

| Land Cover | A | B | C | D | Total |
|---|---|---|---|---|---|
| Forest | 0 | 0 | 0 | 0 | **0** |
| Turf | 0 | 0 | **0.38** | 0 | **0.38** |
| Impervious | 0 | 0 | **0.80** | 0 | **0.80** |
| | | | | **Total** | **1.18** |

**Post*Redevelopment Land Cover**

| Land Cover | A | B | C | D | Total |
|---|---|---|---|---|---|
| Forest | 0 | 0 | 0 | 0 | **0** |
| Turf | 0 | 0 | **0.13** | 0 | **0.13** |
| Impervious | 0 | 0 | **1.05** | 0 | **1.05** |
| | | | | **Total** | **1.18** |

***Table 13.34. Land Cover Summary: Pre-Redevelopment (Listed and Adjusted) Post-Redevelopment, and New Impervious Load Reduction Requirements: from the VRRM Redevelopment Compliance Spreadsheet, Site Data Tab***

| Land Cover Summary Pre-Redevelopment | Listed | Adjusted | Post-Redevelopment | New Impervious |
|---|---|---|---|---|
| Total Site Area (acres) | 1.18 | 0.93 | 0.93 | 0.25 |
| Site Rv | 0.72 | 0.85 | 0.85 | 0.95 |
| Post-Development Tv (acre-ft) | 0.0713 | 0.0660 | 0.0660 | .0198 |
| Post-Development Tv (cubic feet) | 3,104 | 2,877 | 2,877 | 862 |
| Post-Development Load (TP) (lb/yr) | 1.95 | 1.81 | 1.81 | 0.54 |

| | | |
|---|---|---|
| Maximum % Reduction below Pre-Redevelopment Load | 20% | |
| TP Load Reduction Requirement (lb/yr) | 0.36 | 0.44 |
| Total Load Reduction Required (lb/yr) | 0.80 | |
| Post-Development Load (TN) | 16.81 | |

3. Load Reduction Requirement

The total load reduction requirements (percent reduction from pre-redevelopment plus the reduction required for the *new* (additional) impervious cover to meet the new development load limit (0.41 lb/ac/yr) are also computed on the Site Data tab, and are shown in the lower cells of **Table 13.34** above.

**NOTE:** The following items are incorporated within the Site Data tab Land Cover Summary computation cells:

- The Pre-Redevelopment (**Listed**) Land Cover Summary reflects the acreages of pervious and impervious areas for the existing site condition (prior to redevelopment).
- The Pre-Redevelopment (**Adjusted**) Land Cover Summary reflects the existing site condition acreage **minus** the pervious area proposed for new impervious cover.
- The Post-Redevelopment Land Cover Summary reflects the post-redevelopment condition **minus** the net acreage of new impervious cover.
- The Post-Redevelopment *New* Impervious Land Cover Summary reflects the net acreage of new (additional) impervious cover.
- The Adjusted and Post-Redevelopment Land Cover Summary columns are used to compute the 10% or 20% load reduction requirement, based on the acreage of actual land disturbance: < 1 ac, or ≥ 1 ac, respectively).
- The New Impervious Land Cover Summary is used to compute the load reduction requirement to meet the new development load limit of 0.41 lb/ac/yr.
- If there is no net increase in impervious cover, the *Listed, Adjusted,* and *Post-Redevelopment* columns will be identical (with the exception of any changes in managed turf or open space cover) and the *New Impervious* column will be zero.

The computation performed in cell F65 on the Site Data tab of the VRRM Redevelopment Compliance Spreadsheet includes the following:

- The **Maximum % Reduction below Pre-Redevelopment Load** (10% or 20%) is determined from the user input regarding the total disturbed acreage: < 1 ac or ≥ 1 ac, respectively);
- If there is no new impervious cover (determined from the Land Cover input cells), the total **TP Load Reduction Requirement** is the result of the computation of the 10% or 20% reduction from the pre-redevelopment land cover.
- If there *is* new impervious cover, the **TP Load Reduction Requirement** for each of the two computations is displayed: the percent reduction from the pre-redevelopment condition *and* the reduction required for the new impervious to meet the new development load limit (shown as 0.36 and 0.44 lb/yr respectively);
- The **Total Load Reduction Required** is **0.80 lb/yr**, the sum of the two pollutant load reduction requirements.
- A check is also computed to verify that the Total Load Reduction Required does not exceed that which would be required to meet the new development TP load limit. If it does, the lesser load limit is displayed.

**Step 3:** Drainage Area Hydrology, Peak Discharge, and Treatment Volume (*Tv*)

**Figure 13.19** displays the proposed drainage divides as defined by the roof drain system. The green area within each courtyard corresponds to the managed turf listed in the Post-Redevelopment Land Cover of **Table 13.33** above.

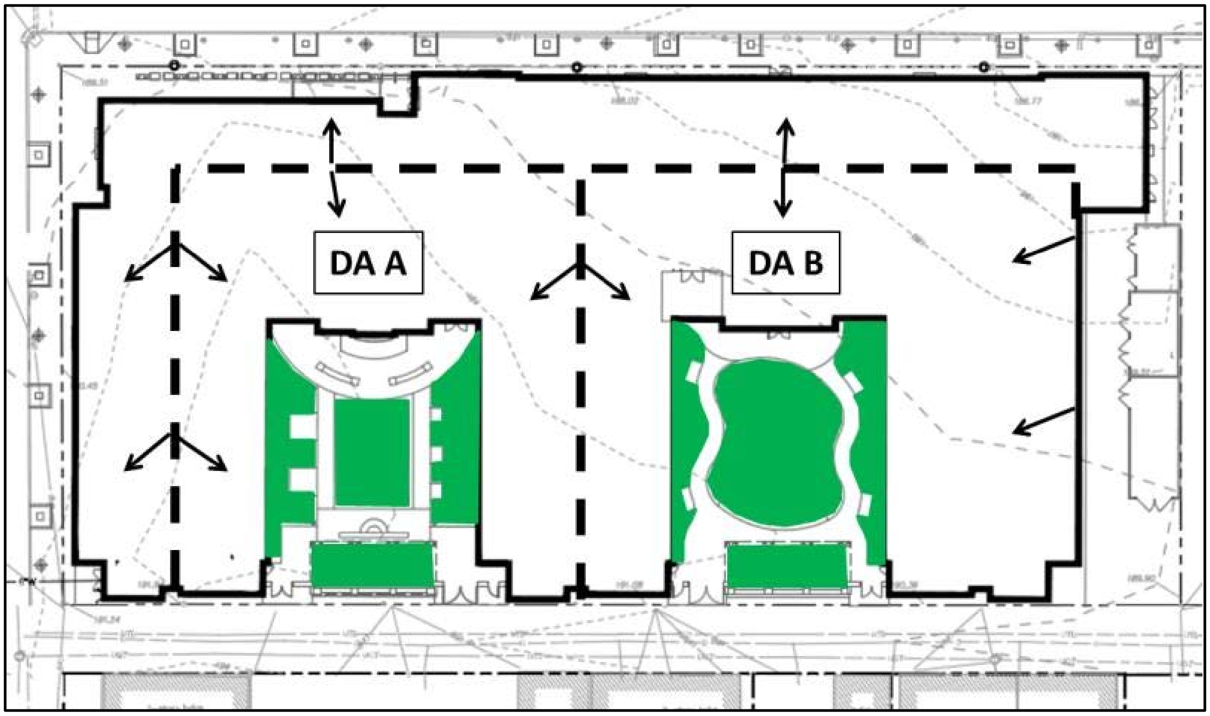


***Figure 13.19. Redevelopment Site Drainage Areas A and B***

1. The drainage area hydrology and peak discharge for demonstrating compliance with the quantity control requirements are determined using the Rational Method. The downstream stormwater conveyance system is a man-made storm drain system designed for 10-year storm capacity.

$$Q = CIA$$

Where:

Q = Rational Method peak discharge (cfs)
C = Rational Method runoff coefficient (Appendix 6E-1, VDOT Drainage Manual);
$C_{impervious}$ = 0.9; $C_{urban\ turf}$ = 0.35
Weighted C (whole site) = 0.84
Weighted C (DA A) = 0.80
Weighted C (DA B) = 0.83
I = Rainfall intensity (in/hr) (Appendix 6C-1, VDOT Drainage Manual)

$$I_{10} = \frac{B}{(t_c + D)^E}\ ;\ B_{10}=47.91;\ D_{10}=9.25;\ E_{10}=0.72$$

$$I_{10} = 7.07 \text{ in/hr}$$

A = Drainage Area
DA-A = 0.34 ac.

DA-B = 0.44 ac.
DA-A: $Q_{10}$ = (0.80)(7.07in/hr)(0.34 ac) = 1.9 cfs
DA-B: $Q_{10}$ = (0.83)(7.07in/hr)(0.44 ac) = 2.6 cfs

**NOTE: *Drainage Areas A and B could possibly be combined into one area, depending on the configuration of the receiving stormwater conveyance system or on how the runoff reduction practices are implemented (i.e., comparable BMP selection, or BMP treatment trains that allow the results of the BMP implementation to be aggregated in the VRRM Redevelopment Compliance Spreadsheet). However, designers may find it helpful to split the areas in order to more readily determine the $Tv_{BMP}$ to each BMP in order to ensure adequate sizing.***

3. Post-Development Land Cover and Treatment Volume for the Drainage Areas.

Enter the land cover data into cells B5 through E7 on the drainage area tabs (D.A. A and D.A. B) on the VRRM Compliance Spreadsheet. Calculation cells will provide the total acreage, the Land Cover *Rv* (average for each land cover), and Post-Development Treatment Volume (*Tv*, in cf). **Tables 13.35** and **13.36** display the spreadsheet cells for DA-A and DA-B, respectively.

***Table 13.35. Drainage Area A Land Cover Summary (VRRM Redevelopment Compliance Spreadsheet D.A. A Tab)***

| **Drainage Area A Land Cover (acres)** | | | | | | |
|---|---|---|---|---|---|---|
| | **A soils** | **B Soils** | **C Soils** | **D Soils** | **Totals** | **Land Cover Rv** |
| Forest/Open Space (acres) | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Managed Turf (acres) | 0 | 0 | 0 | **0.06** | 0.06 | 0.25 |
| Impervious Cover (acres) | 0 | 0 | 0 | **0.28** | 1.28 | 0.95 |
| | | | | **Total** | **0.34** | |

| | |
|---|---|
| **Post Development Treatment Volume (cf)** | **1,020** |

***Table 13.36. Drainage Area B Land Cover Summary (VRRM Redevelopment Compliance Spreadsheet D.A. B Tab)***

| **Drainage Area B Land Cover (acres)** | | | | | | |
|---|---|---|---|---|---|---|
| | **A soils** | **B Soils** | **C Soils** | **D Soils** | **Totals** | **Land Cover Rv** |
| Forest/Open Space (acres) | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| Managed Turf (acres) | 0 | 0 | 0 | **0.06** | 0.06 | 0.25 |
| Impervious Cover (acres) | 0 | 0 | 0 | **0.38** | 0.38 | 0.95 |
| | | | | **Total** | **0.44** | |

| | |
|---|---|
| **Post Development Treatment Volume (cf)** | **1,365** |

**Step 4:** Apply BMPs in DA-A and DA-B using the VRRM Redevelopment Compliance Spreadsheet:

Several options (e.g., vegetated roof, rainwater harvesting, offsite compliance options pursuant to 9 VAC 25-870-69, etc.) are viable for achieving the redevelopment load reduction requirement for an ultra-urban or highly-constrained redevelopment site. Within the two courtyards, this redevelopment project includes centrally located green space that will be considered for treatment options.

1. **Permeable Pavement Level 1** is applied to the walkways and pedestrian plaza areas of the courtyard. Total area of permeable pavement:
   - Courtyard DA A = 2,620 $ft^2$ = 0.06 acres
   - Courtyard DA B = 2,650 $ft^2$ = 0.06 acres

   Consider criteria from the BMP design specifications (**Permeable Pavement Level 1, BMP Design Specification No. 7**):

   - ➢ Maximum pavement slope < 5%

   - ➢ For Permeable Pavement Level 1, the ratio of external pavement to permeable pavement (R) $\leq$ 2.5, with run-on minimized to the extent practicable or at least limited to run-on from impervious cover only. Both courtyards are graded so that there is no run-on onto the permeable pavers.

   - ➢ Calculate the minimum and/or maximum depth of the stone reservoir (**Equation 7.1, BMP Design Specification No. 7**). Since there is no run-on, the equation for the minimum design depth, $d_{stone}$, reduces to the rainfall depth (1-inch = 0.08 ft) divided by the porosity of the stone reservoir ($\eta_r$ = 0.4):

     $$d_{stone} = 0.08 \text{ ft} / 0.4 = 0.2 \text{ ft} = 2.4 \text{ inches.}$$

     The minimum stone depth below the permeable pavers will ultimately be determined by the structural stability of the soils and by the paver manufacturer; however, it will most likely be greater than 2.4 inches, based simply on constructability. This will ultimately provide for additional storage volume, if needed for quantity control.

   - ➢ No downstream practice is selected

2. **Bioretention Level 1** can be constructed within each of the courtyards in the central green spaces bounded by the walkways, to manage the rooftop runoff. Determine the total area draining to the proposed courtyard bioretention areas:
   - Courtyard DA-A = Rooftop (Impervious Area): 9,600 $ft^2$ = 0.22 acres
     Courtyard turf area: 1,300 $ft^2$ = 0.03 acres
   - Courtyard DA-B = Rooftop (Impervious Area): 14,000 $ft^2$ = 0.32 acres
     Courtyard turf area: 1,350 $ft^2$ = 0.03 acres

   Since these are highly constrained areas, the designer must ensure that there is adequate surface area for the full design elements – a forebay or other pre-treatment, ponding area side slopes no steeper than 3H:1V, and sufficient storage volume available to contain the total $Tv_{BMP}$. The surface area available within the two courtyards is:

- Courtyard DA-A = 690 $ft^2$
- Courtyard DA-B = 1,530 $ft^2$

Design and sizing considerations for Bioretention L1 (**Bioretention BMP Design Specification No. 9**):

- General sizing guidance for Bioretention Level 1 calls for an overall practice footprint of approximately 3% to 6% of the contributing drainage area (CDA):
  - Courtyard DA-A = 6% x 0.25 ac x 43,560$ft^2$/ac = 653 $ft^2$ (< 690 $ft^2$)
  - Courtyard DA-B = 6% x 0.35 ac x 43,560$ft^2$/ac = 915 $ft^2$ (< 1,530 $ft^2$)

  The surface area available in each courtyard should be adequate to provide bioretention sized appropriately for the contributing drainage areas. **Figure 13.20** illustrates the application of Permeable Pavement and Bioretention in the courtyards in DA-A and DA-B.

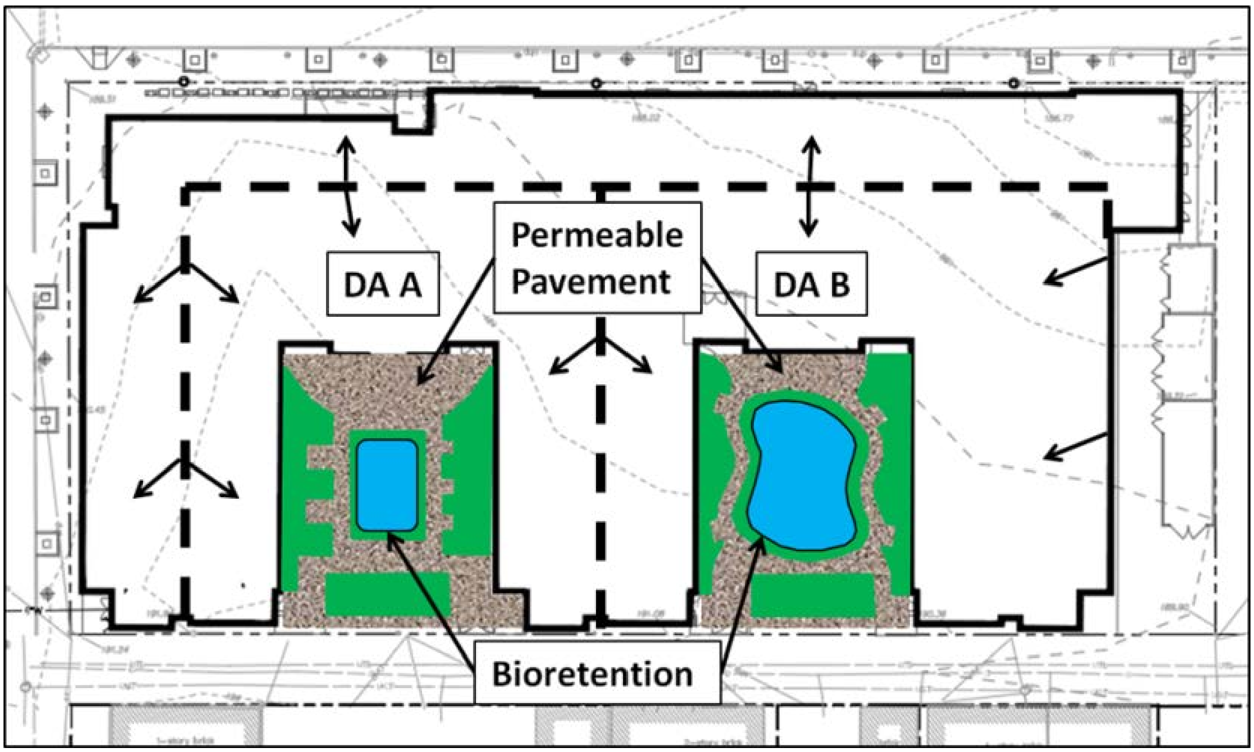


***Figure 13.20. Proposed Permeable Pavement and Bioretention within Courtyards in DA-A & DA-B***

- Entering the contributing drainage areas into Tabs D.A. A & D.A. B, respectively, in the VRRM Redevelopment Compliance Spreadsheet will provide the actual $Tv_{BMP}$ needed to size each practice.
  - $Tv_{BMP}$ for the Bioretention in Courtyard DA-A = 785 $ft^3$
  - $Tv_{BMP}$ for the Bioretention in Courtyard DA-B = 1,130 $ft^3$

The $Tv_{BMP}$ is determined by summing the Runoff Reduction and Remaining Runoff Volume (columns I and J on the Drainage Area Tabs of the VRRM Redevelopment Compliance Spreadsheet) for the impervious and turf acres draining to Bioretention (rows 46 and 47). If there were an upstream practice contributing to the Bioretention basin, the $Tv_{BMP}$ would include the volume listed in column H as well.

- Apply the Bioretention Level 1 sizing rules to determine the storage volume –
  - Surface ponding depth = 1-foot max.
  - Required soil media depth = 24-inches min.
  - Gravel reservoir depth (12 inches) and the corresponding values of porosity for each layer

The designer can either work backwards using the $Tv_{BMP}$ and determine the minimum area necessary, or maximize the available surface area and determine the volume available.

- Available *Tv* volume Courtyard DA-A = 826 $ft^3$ (>785 $ft^3$)
- Available *Tv* volume Courtyard DA-B = 2,285 $ft^3$ (>1,130 $ft^3$)

**Step 4A**: Interim compliance check

- The combination of the Permeable Pavement Level 1 and Bioretention Level 1 within the two courtyards treats a total of 0.78 acres as follows:
  - Courtyard DA-A:
    - Permeable Pavement: Impervious area = 0.06 acres
    - Bioretention: Impervious area = 0.22 acres
      Turf area = 0.03 acres
  - Courtyard DA B:
    - Permeable Pavement: Impervious area = 0.06 acres
    - Bioretention: Impervious area = 0.32 acres
      Turf area = 0.03 acres

- The area checks (cell G74) for both drainage areas, meaning the total area treated does not exceed the total area of the drainage area.

- The load reduction achieved with the two BMPs in DA-A = 0.35 lb; and in DA-B = 0.47 lb (cells I-78)

  - The total volume reduction achieved is 407 $ft^3$ in DA-A and 545 $ft^3$ in DA-B (cells I-77).

  - The Water Quality Compliance Tab indicates that the drainage areas check (the acreage treated within each drainage area does not exceed the total acreage of each drainage area.

**Step 5:** Quantity Control Requirements

The VSMP Channel Protection Criteria are described in **Section 11.6.1** of **Chapter 11**, including provisions for discharging to a man-made conveyance system. The receiving system is a pipe drainage system that will not be eroded by the 2-year design discharge (9 VAC 25-870-66). The system was originally designed to carry the 10-year design storm runoff, and it does not *currently* experience flooding during the 10-year design storm. However, the designer must ensure that the system will flood in the future as a result of this redevelopment project.

The site $T_c$ (and the corresponding design intensity, $I_{10}$, in inches/hour) does not change as a result of the redevelopment project. However, there is an increase in impervious cover, resulting in an increase in the Rational Method runoff coefficient (i.e., the weighted *C* for the site increases from 0.72 to 0.84). There is no direct computational procedure to measure the effect of the VRRM runoff volume reduction in the Rational Method, so the designer should verify the capacity and hydraulic grade line of the stormwater conveyance system to ensure that the 10-year design flow stays within the system.

The following computation is performed to ensure that an adequate volume of retention storage is provided to generate the same Curve Number (*CN*) as in the pre-redevelopment condition, in order to meet the criteria of the VSMP regulations for quantity control.

1. Determine the Pre- and Post-Redevelopment CNs and the adjusted CN (based on the runoff volume reduction).

   An analysis of the pre-redevelopment hydrology (**Table 13.32**, page 13-65 above) and the post-redevelopment hydrology from the Channel and Flood Protection tab indicates the following:
   - Pre-redevelopment *CN* = 92; $R_{v10Pre\text{-}redevelopment}$ = 4.24 inches
   - Post-redevelopment *CN* = 96; $R_{v10Post\text{-}redevelopment}$ = 4.68 inches
   - Adjusted Post-redevelopment *CN* = 94; Adjusted $R_{v10Post\text{-}redevelopment}$ = 4.46 inches

2. Determine the retention storage required to mimic the pre-redevelopment *CN*.

   The retention volume goal is (4.46" - 4.24" = 0.22 watershed inches). This equates to 942 ft$^3$:

$$0.22" \times 1.18\, acres \times \left(3{,}560\, {ft^2}/{ac}\right)\left({ft}/{12"}\right) = 942 ft^3$$

3. The area of the DA-B courtyard has a surface area of 1,530 ft$^2$ proposed for Bioretention. This area can accommodate a maximum 2,285 ft$^3$ of retention storage (based on a 12-inch surface ponding depth, a 24-inch soil media depth, and a 12-inch deep stone layer), which exceeds the required $Tv_{BMP}$ of 1,130 ft$^3$. The additional storage volume (1,155 ft$^3$) can be used to ensure that the 10-year adjusted *CN* for the post-redevelopment condition matches the pre-redevelopment condition. Matching the pre-development *CN* for the required design storm should be sufficient to ensure that the redevelopment site will not cause flooding.

## 13.5. DESIGN EXAMPLE 5: DEVELOPMENT ON PRIOR DEVELOPED LAND

This example establishes the pollutant reduction requirements for a development project on prior developed land (*redevelopment*) within an urban business campus. This example does not follow through with BMP design and compliance; rather, the goal is to illustrate the selection of the parameters to enter into the spreadsheet in order to determine the pollutant load reduction requirements for the dual standard of new development and redevelopment.

**Site Description:** This land disturbing activity (**Figure 13.21**) proposes to renovate one existing building and construct one new building and two new parking lots with associated sidewalk improvements. The project area is **4.0 acres** within an urban campus of approximately 45 acres.

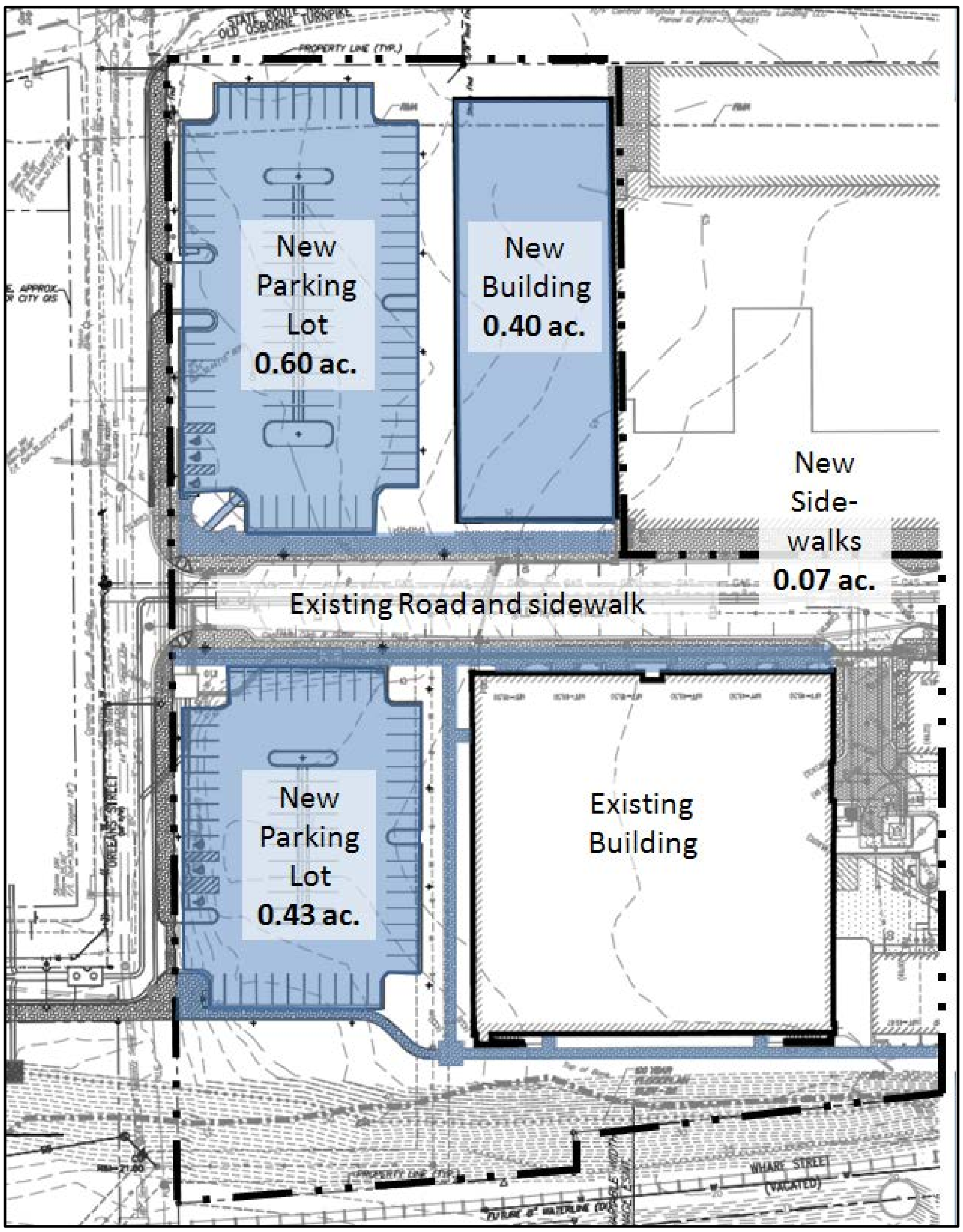


***Figure 13.21. Proposed Redevelopment Site***

**Step 1:** Resource Mapping (see **Chapter 6**) and Environmental Site Assessment

Resource Mapping and an Environmental Site Assessment should enable the designer to identify available locations for runoff reduction and/or pollutant removal practices on urban redevelopment projects, within the existing and proposed site infrastructure, prior to establishing a final design and grading plan. The proposed micro-topography and resulting drainage divides can often be manipulated to direct runoff to these locations without significant impacts to the overall site design.

The designer can implement stormwater management BMPs to achieve the pollutant load reduction requirement by treating the new, redeveloped, or existing site areas *within the limits of the project* (as defined by the project site). In this case, the project site is a 4.0 acre area that incorporates all of the improvements (including the existing building renovation) and areas necessary for construction. Since this project site is very limited in terms of available space for surface BMPs, the designer may elect to increase the project site within the larger campus (previously this was defined as a planning area). However, the land cover data entered into the VRRM Redevelopment Compliance Spreadsheet must include the entire project site.

**Step 2:** Site Hydrology and Pollutant Loads

1. Determine the basic site-level hydrology using the NRCS or Rational Methods, as accepted by the VSMP Authority.

2. Determine the Pre- and Post-redevelopment Pollutant Loads (VRRM Redevelopment Compliance Spreadsheet).

   The area of disturbance is determined to be **2.0 acres** and includes the area of the new construction (building, parking lots, sidewalk improvements), and the area necessary for access to the site and the staging of construction materials and equipment (including those needed for the existing building renovation). The *area of new impervious cover* includes the two parking lots, the new building and the new sidewalks, as shown in **Figure 13.21** above. The net increase in impervious cover is determined to be **1.50 acres**. The data is entered into the Site Data tab of the VRRM Redevelopment Compliance Spreadsheet (blue cells) as shown in **Table 13.36** below.

3. Load Reduction Requirement

   The total load reduction requirements for this land disturbing activity include the percent reduction from Pre-redevelopment Land Cover, plus the reduction required for the new impervious cover to meet the new development load limit (0.41 lb/ac). This is computed on the Site Data tab. The input shown above is computed on the Site Data tab to calculate the Listed and Adjusted Pre-redevelopment, the Post-redevelopment and the New Impervious Land Cover Summaries, shown in **Table 13.37** below.

   A description of the computations performed in these cells is provided in **Section 13.4 (Design Example 4)** above, and a detailed tabulation is provided in **Chapter 12**, the spreadsheet user's guide.

*Table 13.36. Disturbed Acreage and Pre- and Post-ReDevelopment Land Cover (acres): VRRM Redevelopment Compliance Spreadsheet Site Data Tab*

**Total Disturbed Acreage** **2.00**

**Pre-** ReDevelopment Land Cover

| Land Cover | A | B | C | D | Total |
|---|---|---|---|---|---|
| Forest | 0 | 0 | 0 | 0 | 0 |
| Turf | 0 | 0 | 0 | **2.50** | **2.50** |
| Impervious | 0 | 0 | 0 | **1.50** | **1.50** |
| | | | | **Total** | **4.00** |

**Post-** ReDevelopment Land Cover

| Land Cover | A | B | C | D | Total |
|---|---|---|---|---|---|
| Forest | 0 | 0 | 0 | 0 | **0** |
| Turf | 0 | 0 | 0 | 1.00 | **1.00** |
| Impervious | 0 | 0 | 0 | 3.00 | **3.00** |
| | | | | **Total** | **4.00** |

*Table 13.37. Land Cover Summary: Pre-Redevelopment (Listed and Adjusted), Post-Redevelopment, and New Impervious and Load Reduction Requirement: VRRM Redevelopment Compliance Spreadsheet Site Data Tab*

| Land Cover Summary Pre-Redevelopment | Listed | Adjusted | Post-Redevelopment | New Impervious |
|---|---|---|---|---|
| Total Site Area (acres) | 4.00 | 2.50 | 2.50 | 1.50 |
| Site Rv | 0.51 | 0.67 | 0.67 | 0.95 |
| Post-Development Tv (acre-ft) | 0.1708 | 0.1396 | 0.1396 | .1188 |
| Post-Development Tv (cubic feet) | 7,442 | 6,080 | 6,080 | 5,173 |
| Post-Development Load (TP) (lb/yr) | 4.68 | 3.82 | 3.82 | 3.25 |

| | | |
|---|---|---|
| Maximum % Reduction below Pre-Redevelopment Load | 20% | |
| TP Load Reduction Requirement (lb/yr) | 0.76 | 2.64 |
| Total Load Reduction Required (lb/yr) | 3.40 | |
| Post-Development Load (TN) | 50.58 | |

The completion of the remaining steps for demonstrating compliance with the water quality and water quantity requirements is covered in previous examples and is not repeated in this example.

## 13.6 REFERENCES

National Research Council (NRC). 2008. Water and Science Technology Board, Division of Earth and Life Studies. "Chapter 3 Hydrologic, Geomorphic, and Biological Effects of Urbanization on Watersheds." *Urban Stormwater Management in the United States*. Washington, DC: National Academies Press. 109+. URL: http://www.nap.edu/catalog.php?record_id=12465#toc.