Appendix K

Introduction

This appendix includes two examples of a typical site design to help guide a manual user through the design process. The examples were created to utilize the manual as a reference for more detailed guidance and information by indicating manual locations where additional information can be found. The **BMP Excel Workbook** referenced within these examples was developed as a guide to help make concept and preliminary design easier on the applicant by automating repetitive calculations of a typical submission within a calculation tool. There may be design instances that do not fit within the typical submission and will need supporting calculations documented outside of the **BMP Excel Workbook**.

K.1. Detailed Calculations Example and LID Calculation Tool (BMP Excel Workbook) – New Office Campus Project

Example 1: New Office Campus Designed for Volume Management (SOV Requirements)
Location: South Chickamauga Watershed
Combined sewer area: No
Parcel size: 8 acres

An owner is proposing to construct a new office complex that includes two new buildings on an 8.0-acre parcel in the South Chickamauga Creek watershed. Development will include construction of two new buildings, parking, and walkway areas on the southern portion of the site.

Step 1 Determine Stormwater Applicability

The site will result in more than 1 acre of land disturbance. As indicated in **Chapter 3, Section 3.3.1, Table 3-1**, the following permits and documentation are required:

- Land Disturbance Permit
- Stormwater Pollution Prevention Plan (SWPPP)
- Performance Method: detailed stormwater calculations must be submitted to the City to demonstrate compliance with requirements for volume management, water quality, safe conveyance of flows, and peak rate mitigation
- Tennessee NPDES Stormwater Construction Permit

The proposed project will be located on a previously undeveloped parcel in the South Chickamauga Creek watershed. Watershed maps to determine a project’s location can be found on the City’s website (***http://www.chattanooga.gov***) under Public Works, City Engineering and Water Quality Program, Public

Education. According to **Chapter 3, Section 3.3.3, Table 3-2**, the rainfall depth that must be managed for new development projects in the South Chickamauga Creek watershed is 1.6 inches, with no discharge to surface waters.

As indicated on the flow chart of **Chapter 3, Section 3.4, Figure 3-1**, if the project design can meet the 1.6-inch SOV requirement for volume management, the water quality requirements will also be assumed to be satisfied. The project design must also meet peak runoff rate control requirements. As described in **Chapter 3, Section 3.4, Item 3**, post-development peak runoff rates must be no greater than pre-development peak runoff rates for the 2-, 5-, 10-, and 25-year, 24-hour storm events. Additionally, the peak runoff rate and maximum water surface elevation must be indicated for peak rate mitigation devices or facilities.

This project does not meet the requirements for any of the incentives listed in **Chapter 3, Section 3.7**. Therefore, the full volume of runoff from the 1.6-inch rainfall must be managed.

CONCEPT PLAN DEVELOPMENT, SUBMISSION, AND REVIEW (Steps 2 through 5)

Step 2 Evaluate the Site

All projects subject to the City of Chattanooga's stormwater management requirements must prepare and submit a concept plan for City review and approval prior to preliminary and final plan submissions. The process for developing a concept plan is indicated in **Chapter 4, Figure 4-1**. The Concept Stormwater Management Plan Review Meeting Application can be found in **Appendix G (Concept Stormwater Management Plan Review Meeting Application)**. The applicant can use the Concept Stormwater Management Plan Checklist found in **Appendix H (Concept, Preliminary, and Final Stormwater Management Plan Checklist)** to assist in the development of the concept plan.

The site is gently sloping (5% to 8%) to the north and is currently in a meadow condition. There are no water bodies, riparian corridors, mapped floodplains, or wetlands. There is no existing tree canopy and there are no existing trees over 6 inches in caliper. There are no existing manmade structures. Review of the soil types (***http://websoilsurvey.nrcs.usda.gov***) indicates that the underlying soils are hydrologic group C, primarily Lobelville cherty silt loam (Lo), and there is no indication of shallow groundwater in the area of proposed development. For concept plan purposes, it is assumed that infiltration BMPs may be employed.

Step 3 Develop Site Layout Plan and Incorporate Protective BMPs

This project will include two new one-story office buildings with a total of 33,250 square feet of office space, and will provide 133 parking spaces. All land development requirements (i.e., setbacks, building heights, etc.) must be met in accordance with the City of Chattanooga Chapter 38 – Chattanooga Zoning Ordinance.

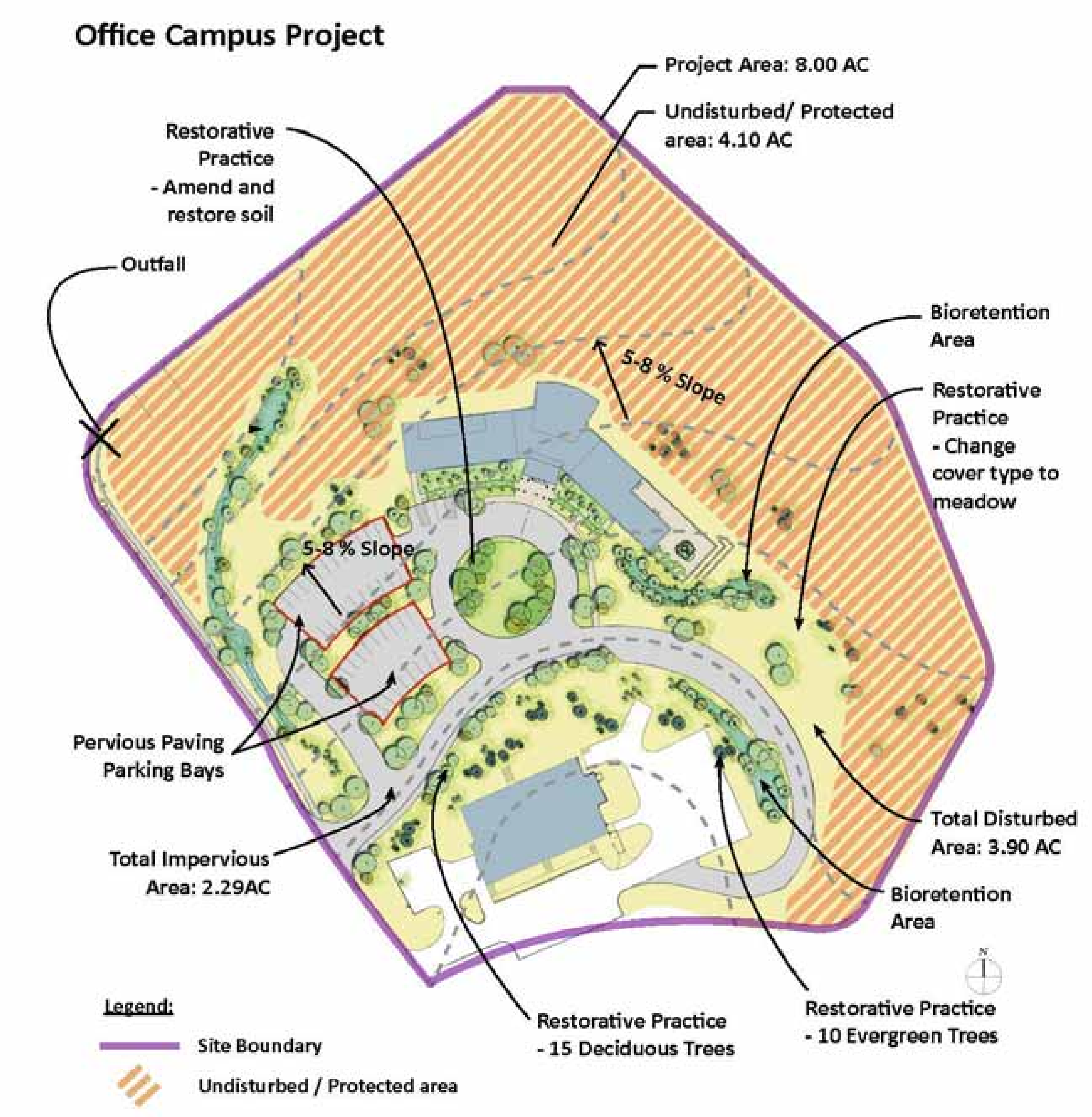

Figure K-1. Concept Project Site Layout Sketch

By orienting the buildings, entrance driveway, and parking lots along the contours of the site, the amount of site disturbance can be reduced. There is opportunity to protect existing soils (**Chapter 5, BMP 5.2.1**) and preserve landforms (**Chapter 5, BMP 5.2.1.1.**). Areas that will be protected and undisturbed during construction, as described in **Chapter 5.2, Damage Prevention and Protection Practices**, may be excluded from stormwater management requirements for volume control as described in **Chapter 7, Section 7.2**. Stormwater from all impervious surfaces and all disturbed portions of the site must be managed for SOV. The **BMP Excel Workbook, Worksheet 1** can be used to estimate the project area protected in accordance with **Chapter 5.2, Damage Prevention and Protection Practices,** and therefore exempt from SOV requirements. This is shown on Figure K-2. Peak rate conveyance requirements must include all drainage areas, including areas addressed by Damage Prevention and Protection Practices, and offsite areas that drain onto a site.

To establish the area of land disturbing activity from which SOV may be calculated, the following steps were taken:

a. Determine the size of the parcel on which the project is to be constructed.
b. Determine the area, if any, of the overall project parcel that will remain undeveloped and where protective BMPs will be applied.

As depicted on Figure K-1, construction will occur within a 3.90-acre project area on the southern portion of the property only. The construction area will be clearly marked with construction fence to ensure that the 4.10 acres to remain undeveloped in the northern portion of the property are not impacted by activities during construction. Soils will be protected in accordance with **Chapter 5, BMP 5.2.1**. A total of 4.10 acres may be omitted from the project area for SOV calculation. This information can be documented using the **BMP Excel Workbook, Worksheet 1** as seen on Figure K-2 and following the formula:

Disturbed Area Requiring Stormwater Management = Total Parcel Area – Total Protected Area
= 8.00 – 4.10
= 3.90 acres

SOV DESIGN RAINFALL =	1.6 in.			

TARGET LOADING RATIO =	8	(See Ch. 5 for details)

Concept Design

Total Parcel Area =	348,480 ft.^{2}	or	8.00 ac
Total Proposed Impervious Area =	99,844 ft.^{2}	or	2.29 ac
Protected Areas			0.00 ac
5.2.1 Area of Protected Undisturbed and Healthy Soils	178,596 ft.^{2}	or	4.10 ac
5.2.1.1 Area of Minimized Land Disturbance	0 ft.^{2}	or	0.00 ac
5.2.1.2 Area of Protected Soils/Steep Slopes	0 ft.^{2}	or	0.00 ac
5.2.2 Area of Protected Natural Flow Paths	0 ft.^{2}	or	0.00 ac
5.2.3 Area of Protected/Enhanced Riparian Corridors	0 ft.^{2}	or	0.00 ac
5.2.4 Area of Protected/Preserved Vegetation	0 ft.^{2}	or	0.00 ac
Total Protected Area	178,596 ft.^{2}	or	4.10 ac
Total Disturbed Area	169,884 ft.^{2}	or	3.90 ac
			0.00 ac
Total Impervious Area	99,844 ft.^{2}	or	2.29 ac
Total Pervious Area	70040 ft.^{2}	or	1.61 ac
Concept Level BMP Area (Based on Proposed Impervious Area)	12,481 ft.^{2}	or	0.29 ac

Disturbed Area Requiring Stormwater Management =	169,884 ft^2	**(A)**
=	3.90 ac	

Figure K-2. Determination of Stormwater Management Area after Implementing Damage Prevention and Protection Practices, BMP Excel Workbook, Worksheet 1

Step 4 Develop Concept Stormwater Management Plan

Project site and development program; determine target area for BMP sizing.

The design professional has a number of options for stormwater management. For this example, the existing information on site conditions indicates that infiltration BMPs may be feasible. The design professional may elect to take all of the runoff to one large BMP, such as a large infiltration bed beneath a pervious parking lot. For concept plan purposes, the design professional is required to demonstrate that enough project area will be available to incorporate the required amount of BMPs, and to indicate the types and sizes of BMPs being considered. BMPs can be adjusted and modified in the detailed design phase when additional project information is available.

The minimum BMP area is a function of:

- The amount of impervious area draining to the BMP. This is referred to as the Loading Ratio.
- The rainfall depth to be managed.

The recommended Loading Ratios as a function of rainfall depth are indicated in **Chapter 5, Section 5.3** in the individual Structural Design Measure sections**.** For a rainfall depth of 1.6 inches, the recommended loading ratio is:

- 8:1 impervious area to BMP area

From Figure K-2, the total impervious area is 2.29 acres, or 99,844 square feet. At an 8:1 Loading Ratio, the minimum BMP area is: 99,844 square feet / 8 = 12,481 square feet Minimum BMP Area.

Therefore, the concept plan must indicate that at least 12,481 square feet of BMP area is available to meet the SOV, and that drainage can be directed to the BMP(s). The location of each BMP, as well as the approximate area of each BMP, must be indicated on the concept plan.

However, the guiding principle of Low-Impact Development is to manage runoff as close as possible to the existing source, and to use soils and vegetation to reduce the volume of runoff. The design professional may elect to add a number of different BMP types, and in different locations, to reduce construction costs or achieve other goals. Efficient LID design professionals will incorporate measures such as landscape restoration and “self-managing” BMPs such as porous pavers to reduce the size and cost of larger BMPs whenever possible. For example, the design professional may decide to limit the depth of stone storage/infiltration beds beneath the parking areas, and instead manage some portion of the runoff in a bioretention area **(Chapter 5, BMP 5.3.4)** to take advantage of cost-effectively using this landscape area for stormwater management. Similarly, construction costs could be reduced by using pervious pavers for the patio and sidewalk that are “self-managing” **(Chapter 5, BMP 5.3.1),** or by “disconnecting” these areas in accordance with **Chapter 5, BMP 5.3.10** so that they are not considered impervious.

For the purposes of this example, a number of additional BMPs are implemented in the detailed design. While a smaller number of BMPs, with greater capacity to receive more runoff, could have been used, more BMPs are shown here for information purposes. These include sidewalks and a patio constructed of pervious pavement (**Chapter 5, BMP 5.3.1**) that will only receive direct rainfall. Two bioretention areas (**Chapter 5, BMP 5.3.4**) will also be included in the stormwater management plan.

Step 5 Concept Plan Submission and Review

Concept Stormwater Management Plan Submission

In accordance with **Chapter 4, Section 4.2.1**, the owner will provide the City with one electronic copy of concept stormwater management plan drawings, as well as one electronic copy of all applicable supporting data and plans for review and comment, and a Stormwater Management Plan Review Meeting Application, found in **Appendix G (Concept Stormwater Management Plan Review Meeting Application)**. Concept stormwater management plans will be prepared using the Concept Stormwater Management Plan Checklist in **Appendix H (Concept, Preliminary, and Final Stormwater Management Plan Checklist)**, ensuring all items listed are shown.

Concept Review Meeting

A concept review meeting with City personnel, attended by the owner and the owner's design professional, is required to discuss the concept stormwater management plan, overall project design, and any other concerns to work toward resolution of potential conflicts. Approval of the concept stormwater management plan is a required prerequisite for preliminary and final approval prior to permitting. **Chapter 4, Section 4.2.1.4** discusses the concept review meeting in further detail.

If the design professional can indicate that consideration has been provided as to the proposed location of SOV-managing BMPs, and that sufficient area will be provided to manage the SOV at the recommended impervious area loading ratio for the depth of SOV rainfall, the concept plan can be considered adequate. The final BMP locations, sizes, and types can be determined in the detailed design for preliminary and final stormwater management plan approval.

PRELIMINARY PLAN DEVELOPMENT, SUBMISSION, AND REVIEW (Steps 6 and 7)

Step 6 Detailed Site Investigation and Testing

Upon receiving approval of the concept stormwater management plan from the City, detailed design of stormwater management measures may proceed. The first step in preliminary stormwater management plan development is to locate the proposed BMPs in accordance with **Appendix A (Protocol 1 Infiltration BMP Setbacks from Structures)** and **Appendix B (Protocol 2 BMP Coordination with Other Utilities)**, and to conduct site testing in accordance with **Appendix C (Protocol 3 Soil Testing)**. For this example, test pits were excavated in the area of each proposed infiltration BMP and infiltration testing was performed at the proposed bottom elevation of each infiltration BMP. Soil testing produced an infiltration rate of 0.4 inches per hour at all locations, confirming the assumptions made during concept stormwater management plan development. In the event that infiltration was not suitable at the proposed locations, but was feasible in other portions of the site, the design professional could adjust the site plan and BMP locations accordingly.

Step 7 Calculation of SOV To Be Managed by Each BMP

In keeping with LID principles, the project BMPs will manage runoff close to where it is generated. Each BMP must be sized to capture the required SOV from the area draining to it. If a BMP can only capture a portion of the required SOV from the area draining to it, a second, downstream BMP must provide the remaining SOV capture. A system of interconnected stormwater management BMPs, or "treatment train," constructed in series must be designed to meet volume reduction, rate reduction, and water quality requirements for all tributary sub-drainage areas. Proper design includes sizing calculations and analysis demonstrating the capture area, SOV for each individual BMP, and capacity of each BMP, as well as the capture area, SOV and capacity of the entire treatment train, and conveyance calculations between BMPs. **Chapter 7, Section 7.4** discusses treatment trains in more detail.

Delineate sub-drainage areas to each BMP and calculate SOV to be managed by each BMP.

For this example, six structural BMPs are being considered and therefore six sub-drainage areas of disturbed area have been delineated, as shown on Figure K-3**.** These sub-areas and land uses are as follows:

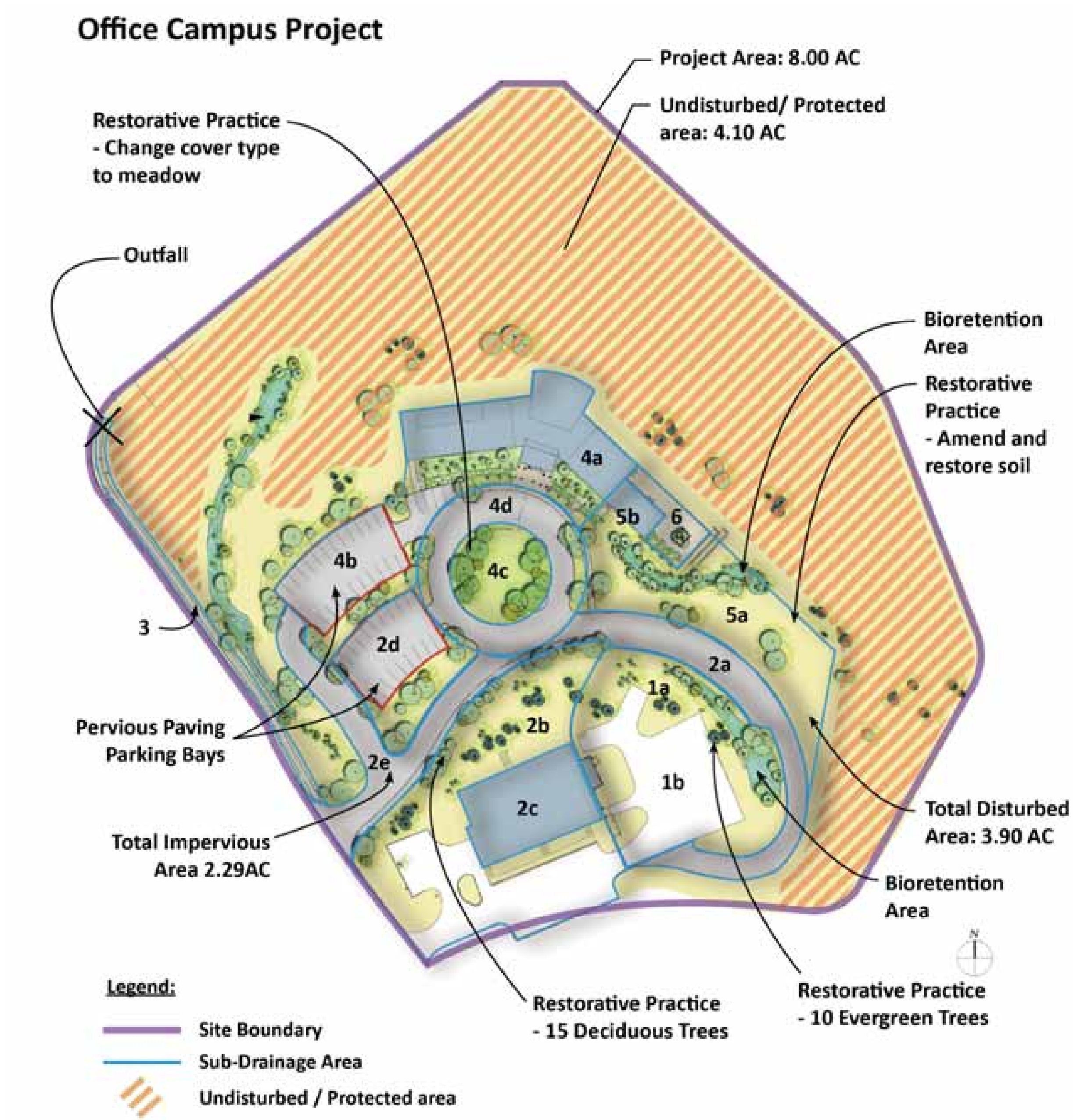

Figure K-3. Delineated Sub-areas

- Sub-area 1 includes lawn and an impervious parking lot. For this example, an unlined bioretention area **(Chapter 5, BMP 5.3.4)** within the landscape plantings is being proposed. Other alternatives, such as directing this runoff to a bed beneath one of the porous parking lots, could also meet requirements. The design professional may select the appropriate BMPs for the site.
- Sub-area 2 includes lawn, two sections of 24-foot-wide driveway, a flat-roofed building, and a pervious parking lot. For this sub-area, an unlined infiltration bed **(Chapter 5, BMP 5.3.2)** beneath the pervious parking lot is proposed.
- Sub-area 3 includes a pervious asphalt sidewalk **(Chapter 5, BMP 5.3.1)**. This pervious pavement will be “self-managing.” That is, the pervious pavement will absorb the rainfall that falls directly onto it without generating runoff for the small rainfall events (up to 1.6 inches based on manual design guidance for pervious sidewalks in **Chapter 5, BMP 5.3.1**) that must be managed for SOV or water quality.
- Sub-area 4 includes lawn, a 24-foot-wide driveway, a flat-roofed building, and a pervious parking lot. For this sub-area, an infiltration bed **(Chapter 5, BMP 5.3.2)** beneath the pervious parking lot is also proposed.
- Sub-area 5 includes a building’s pitched roof and lawn, which will be managed by a bioretention area **(Chapter 5, BMP 5.3.4)**.
- Sub-area 6 includes a building’s outdoor patio. This will be constructed of pervious pavers **(Chapter 5, BMP 5.3.1)**, and like Sub-area 3, will be “self-managing.”
- For each sub-area to a BMP, the land use types, surface areas, and associated SOV can be estimated using the **BMP Excel Workbook, Worksheet 1**, as shown on Figure K-4.

Preliminary Design

INITIAL TARGET BMP AREA = 12,481 ft^2

Sub-Drainage ID per BMP (numbers and lowercase letters only)	Land Use Type	Surface Condition	Disturbed Land Area (ft^2)	Disturbed Land Area (ac)	Rv Value, from Table	Stay on Volume (ft^3)
1a	Typical Urban Soils	Pervious	17,710	0.41	0.15	354
1b	Large Impervious	Impervious	10,000	0.23	0.99	1,320
2a	Small Impervious	Impervious	10,204	0.23	0.79	1,075
2b	Typical Urban Soils	Pervious	15,800	0.36	0.15	316
2c	Flat Roof	Impervious	11,000	0.25	0.88	1,291
2d	Large Impervious	Impervious	10,000	0.23	0.99	1,320
2e	Small Impervious	Impervious	15,190	0.35	0.79	1,600
3	Small Impervious	Impervious	4,000	0.09	0.79	421
4a	Flat Roof	Impervious	20,000	0.46	0.88	2,347
4b	Large Impervious	Impervious	10,000	0.23	0.99	1,320
4c	Typical Urban Soils	Pervious	9,080	0.21	0.15	182
4d	Small Impervious	Impervious	5,200	0.12	0.79	548
5a	Typical Urban Soils	Pervious	27,450	0.63	0.15	549
5b	Pitched Roof	Impervious	2,250	0.05	0.99	297
6	Small Impervious	Impervious	2,000	0.05	0.79	211

Figure K-4. Calculation of SOV by Sub-drainage Area with SSHM Runoff Coefficients, BMP Excel Workbook, Worksheet 1

The required SOV is calculated using the Small Storm Hydrology Method, as described in **Chapter 7, Section 7.3**. Rv values utilized by the Small Storm Hydrology Method are automatically populated within the table based on the user-defined rainfall depth and land use types. These values can be found in the **BMP Excel Workbook, Worksheet 1** or in **Chapter 7, Section 7.3, Table 7-1**, of the manual. The total SOV by sub-area for this example is summarized on Figure K-5 for informational purposes. If using the **BMP Excel Workbook**, it will tabulate the SOV for each sub-area automatically as the design professional adjusts drainage areas and BMP sizes. This information can be found in the **BMP Excel Workbook, Summary Table.**

Sub-Drainage ID	Total Disturbed Area (ft^2)	Total Disturbed Impervious Area (ft^2)	Sub-Drainage Area SOV (ft^3)
1	27,710	10,000	1,674
2	62,194	46,394	5,602
3	4,000	4,000	421
4	44,280	35,200	4,396
5	29,700	2,250	846
6	2,000	2,000	211

Figure K-5. Summary of SOV by Sub-drainage Area, BMP Excel Workbook, Summary Table

Reduce SOV by implementing restorative BMPs.

The design professional may choose to reduce the size of structural BMPs by using landscape restorative measures that reduce runoff volume and provide SOV credit. These include **Chapter 5, BMPs 5.4.1 through 5.4.3**. For each of these restorative BMPs as defined in the **Non-Structural BMP Credits Worksheet, Chapter 7, Section 7.7**, the restorative BMP can be translated into an SOV volume "credit."

The first step is to consider areas within each sub-area where restorative practices may be implemented. For this example, in accordance with the tree planting credits in **Chapter 7, Section 7.2**, this project will include planting 10 evergreen and 15 deciduous trees to reduce the SOV in sub-areas 1 and 2, respectively. The project also proposes to include a 2,000-square-foot area of meadow in sub-area 5 (in lieu of lawn) as part of a required landscape plan. In accordance with **Chapter 5, BMP 5.4.2.1**, this cover type change can also reduce the SOV to be managed by structural BMPs. Additionally, the project will include 5,000 square feet in sub-area 4 where soils disturbed during construction will be restored and amended in accordance with **Chapter 5, BMP 5.4.3**. The SOV volume "credit" of these restorative BMPs can be calculated in accordance with **Non-Structural BMP Credits Worksheet, Chapter 7, Section 7.7**. These credits, and the adjusted SOV as a result of these credits, can also be estimated using the **BMP Excel Workbook, Worksheet 2**, as indicated on Figure K-6. This worksheet provides the adjusted SOV volume by sub-area. As described **in Chapter 7, Section 7.7,** the use of restorative BMPs can only reduce the SOV by a maximum of 25% for each sub-area. **BMP Excel Workbook, Worksheet 2** will not allow the design professional to decrease SOV by more than 25% within each sub-area. Note that the restorative credits are applied to the appropriate BMP sub-areas. In this example, the total SOV volume credit of 336 cubic feet has been achieved through tree planting, meadow planting, and soil restoration done in accordance with the requirements of **Chapter 5, BMPs 5.4.1 through 5.4.3.**

Restorative Volume Credit Worksheet							
Sub-Drainage ID	Sub-Drainage SOV (ft³)	Restorative Practice Credit Type	Area (ft²)	# of Trees	Volume Credit (ft³)	Total Volume Credit (limit to maximum of 25% of SOV) (ft³)	Net Drainage Area SOV (ft³)
1	1,674	Tree Planting - Evergreen		10	100	100	1,574
		None			0		
		None			0		
2	5,602	Tree Planting - Deciduous		15	90	90	5,512
		None			0		
		None			0		
3	421	None			0	0	421
		None			0		
		None			0		
4	4,396	Amend and Restore Disturbed Soils	5,000		104	104	4,292
		None			0		
		None			0		
5	846	Change Cover Type to Meadow	2,000		42	42	804
		None			0		
		None			0		
6	211	None			0	0	211
		None			0		
		None			0		

Figure K-6. Restorative Credits for Tree Plantings and Cover Type Changes, BMP Excel Workbook, Worksheet 2

Determine the BMP area and storage capacity necessary for each sub-drainage area.

The SOV remaining after restorative credits are applied will be managed by six infiltrating structural BMPs, one in each sub-drainage area. Using the recommended loading ratio for a 1.6-inch rainfall depth, BMPs were located on the site plan. Locations of proposed BMPs with regard to setbacks from structures were considered in accordance with **Appendix A (Protocol 1 Infiltration BMP Setbacks from Structures)**, to avoid potential damage due to water migration. Also, coordination with other utilities, in accordance with **Appendix B (Protocol 2 BMP Coordination with Other Utilities)**, determined that the locations of the proposed BMPs would not conflict with existing or proposed utilities.

A summary of the BMP areas, calculated capture volumes, and impervious to BMP area loading ratios is shown on Figure K-7. The BMPs may be dimensioned using the **BMP Excel Workbook, Worksheet 3**.

The process of sizing and selection of BMPs needs to incorporate site and design knowledge that may not be found in this manual. Site conditions and design requirements need to be considered to determine which BMPs are the most appropriate given specific site conditions and what BMP dimensions will best fit within a site. Dimensioning a BMP can become an iterative process, so utilizing the **BMP Excel Workbook, Worksheet 3** may be helpful.

The **BMP Excel Workbook** provides a designer with the necessary SOV that is required to be captured per sub-drainage area in **BMP Excel Workbook, Worksheet 3** under the column titled, “Net Drainage Area

SOV." This column is the net value of SOV after SOV volume credit has been subtracted for all restorative practices tabulated in **BMP Excel Workbook,Worksheet 2**. In general, a designer will need to know at this point in the design process which areas are available onsite within each sub-drainage area for each BMP and also what volume is needed to be captured in each BMP (**BMP Excel Workbook, Worksheet 3**). Most often this will be indicated by a parking area that may be able to contain an infiltration bed or a landscaped area that could be used for bioretention. These available areas will be the starting point for sizing the necessary BMPs per sub-drainage area.

BMP Excel Workbook, Worksheet 3 can then be used to iteratively adjust which BMPs will be applied to each sub-drainage area and their dimensions. For example, if sub-drainage area 2 has a large parking lot required by City code where an infiltration bed is feasible, a designer might start with the area of the parking lot and adjust the depth of stone storage until the BMP capture volume is greater than the net drainage area SOV. If it appears the entire area of parking is not needed for use as an infiltration bed, the designer can scale down the footprint of the infiltration bed. These design iterations should consider pipe elevations entering and exiting a BMP, pipe cover requirements, and any other site conditions that could influence BMP dimensions. Additional information specific to BMP selection and sizing can be found in **Chapter 5.** Another example might be a situation where a landscape feature such as a bioretention area is desired by the property owner but a maximum amount of ponding is not appropriate. The designer would then have to minimize surface storage in **BMP Excel Workbook, Worksheet 3** for that particular sub-drainage area and provide additional subsurface storage in the form of soil or stone. Using guidance provided in **Chapter 5,** each chosen BMP can be tailored to site requirements using **BMP Excel Workbook, Worksheet 3** to vary BMP area, storage media, and storage media depths per design requirements.

Sub-Drainage ID	BMP Type	Infiltration Rate (in./hr)	Runoff Storage Type	Mid-height Area (ft^2)	Depth of Storage (ft)	Storage Capacity (%)	Storage Volume (ft^3)	BMP Surface Area (ft^2)	BMP Capture Volume (ft^3)	Net Drainage Area SOV (ft^3)	Drawdown Time (hrs)	Loading Ratio
1	**Bioretention**	0.40	Surface	1,200	1	100%	1,200	1,200	1,680	1574	42	8
			Soil	1,200	2	20%	480					
			Stone			0%	0					
2	**Infiltration Bed**	0.40	Surface			0%	0	10,000	6,000	5512	18	5
			Soil			0%	0					
			Stone	10,000	1.5	40%	6,000					
3	**Self-Managing Pervious Pavement**	0.40	Surface			0%	0	4,000	533	421	4	1
			Soil			0%	0					
			Stone	4,000	0.333	40%	533					
4	**Infiltration Bed**	0.40	Surface			0%	0	10,000	5,000	4292	15	4
			Soil			0%	0					
			Stone	10,000	1.25	40%	5,000					
5	**Bioretention**	0.40	Surface	800	0.66	100%	528	800	848	804	32	3
			Soil	800	2	20%	320					
			Stone			0%	0					
6	**Self-Managing Pervious Pavement**	0.40	Surface			0%	0	2,000	266	211	4	1
			Soil			0%	0					
			Stone	2,000	0.333	40%	266					

Figure K-7. Summary of BMP Sizing, BMP Workbook, Worksheet 3

Calculate the total volume managed and confirm that SOV is met.

After sizing the BMPs, the spreadsheet will compute the total SOV managed (using both structural BMPs and restorative practices) and compare the BMP capture volume to the required sub-drainage area SOV. When the total volume managed is equal to the required sub-drainage area SOV, 100% of the SOV has been achieved. As shown on Figure K-8, the structural BMPs combined with the restorative credits in each sub-drainage area have achieved slightly more than 100% of the SOV. Figure K-8 was generated from the **BMP Excel Workbook, Summary Table**.

Project Summary								
Sub-Drainage ID	Total Disturbed Area (ft^2)	Total Disturbed Impervious Area (ft^2)	Sub-Drainage Area SOV (ft^3)	Volume Credit (ft^3)	Net Sub-Drainage Area SOV (ft^3)	Loading Ratio	BMP Capture Volume (ft^3)	Capture > SOV?
1	27,710	10,000	1,674	100	1,574	8	1,680	YES
2	62,194	46,394	5,602	90	5,512	5	6,000	YES
3	4,000	4,000	421	0	421	1	533	YES
4	44,280	35,200	4,396	104	4,292	4	5,000	YES
5	29,700	2,250	846	42	804	3	848	YES
6	2,000	2,000	211	0	211	1	266	YES
Totals	169,884	99,844	13,150	336	12,814		14,327	YES

Figure K-8. Calculate required total volume managed onsite.
If the total volume managed (BMP capture volume) is equal to or greater than the net sub-drainage area SOV, 100% of the SOV has been achieved. BMP Excel Workbook, Summary Table

Develop preliminary infiltration system design.

Proposed infiltration BMP design was evaluated within the guidelines established in **Appendix D (Protocol 4 Infiltration System Design and Construction Guidelines)**, including consideration of drawdown time. Drawdown time was calculated by determining the effective depth of water within the BMP by considering the depth and type of storage that make up the BMP. The effective depth of water is then divided by the infiltration rate to yield the hours of drawdown time. Figure K-9 shows the drawdown times for each BMP summarized from **BMP Excel Workbook, Worksheet 3**. In this case, drawdown times are less than the maximum 72 hours as stipulated by City Code, Chapter 31, Article VIII.

$$Drawdown = \left(\frac{Ponding\ Depth\ (in.) * 1.0 + Soil\ Depth\ (in.) * 0.2 + \ Stone\ Depth\ (in.)\ \ * 0.4}{Infiltration\ Rate\ (\frac{in}{hr})} \right)$$

Drainage Area / BMP	Drawdown Time (hrs.)
1 - Bioretention	42
2 - Infiltration Bed	18
3 - Self-Managing Pervious Pavement	4
4 - Infiltration Bed	15
5 - Bioretention	32
6 - Self-Managing Pervious Pavement	4

Figure K-9. Summary of Drawdown Times for Infiltration BMPs

Adjust Curve Number (CN) for the project site and evaluate peak rate.

After acquiring infiltration rates and completing preliminary infiltration system design to manage 100% of SOV, the design professional is required to evaluate the project for peak rates of runoff. To account for the impacts on peak rate reduction through the application of LID measures on a project site, an adjustment may be made to the CN values assigned to disturbed areas managed by an LID BMP. The method for adjusting CN values is provided in **Chapter 7, Section 7.6**. The modified CN value gives the design professional credit for the volume stored in the BMPs and for the volume that is infiltrated from the BMPs. The infiltration volume is limited to the amount infiltrated during 12 hours of the 24-hour storm.

The first step is to determine a weighted CN for both the pre-development and post-development conditions. Because the predevelopment condition is a single land cover throughout, the weighted CN value for this area will be 71, since the area consists of meadow with “C” soils as the existing condition. A weighted CN value will be necessary to determine peak rates from both the pre-development and post-development conditions but only the post-development weighted CN will be adjusted since volume capture will only take place within the post-development BMPs. The CN weighting procedure is equivalent to dividing the total sum of each land use area times its corresponding CN value by the total area. The calculation method would be the same for determining the pre-development CN if multiple land covers were present in the pre-development condition. A summary of area, land cover descriptions, and associated CNs is shown on Figure K-10. See **Chapter 7, Section 7.6, Table 7-5** for recommended CN values.

Land Cover Description	Area (ft.^{2})	CN
Lawn	70,040	74
Buildings and Driveways	63,844	98
Pervious Parking, Patio, and Sidewalk	26,000	75
Impervious Parking	10,000	98

Total Area = 169,884 ft.^{2}

Figure K-10. Summary of Area, Land Cover, and Corresponding CN for Use in Weighted CN Calculation

$$Weighted\ CN = \frac{\sum(Land\ cover\ area\ x\ CN)}{Total\ land\ cover\ area} = \frac{14{,}369{,}672}{169{,}884} = 84.59\ (rounded\ to\ 85)$$

After determining the post-development weighted CN, calculate the potential retention, *S*, for the project site using the weighted CN value and TR-55 Eqn. 2-4 from **Chapter 7, Section 7.6**.

$$S = \frac{1000}{CN} - 10 = \frac{1000}{85} - 10 = 1.76\ \ inches$$

Once the potential retention is determined, use that value to calculate the runoff volume, *Q*, for the 2-year, 5-year, 10-year, 25-year, and 100-year storms using equation TR-55 2-3 from **Chapter 7, Section 7.6** and the design rainfall depths, *P*, for each storm shown in **Chapter 7, Section 7.5, Table 7-4**.

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$For\ the\ 10year\ storm, Q_{10} = \frac{(5.1 - 0.2 \times 1.76)^2}{(5.1 + 0.8 \times 1.76)} = 3.46\ inches$$

Similarly, using the same equation, Q_2 = 2.19 inches, Q_5 = 2.91 inches, Q_{25} = 4.30 inches, and Q_{100} = 5.64 inches.

The reduction volume, *R*, is the sum of all volumes stored (SOV) and infiltrated by the BMPs on the project site over 12 hours of the 24-hour storm. Soils testing in the vicinity of each proposed BMP showed the in-situ soils were capable of infiltrating at a rate of 0.4 inches per hour. Infiltration volume can be determined by multiplying the BMP bottom area (ft^2) by the infiltration rate (in/hr), which takes into account unit conversion and amount of infiltration allowed. SOV and infiltration volumes for each BMP are summarized on Figure K-11.

Drainage Area / BMP	SOV (ft.^{3})	Infiltration Volume (ft.^{3})
1 - Bioretention	1,680	480
2 - Infiltration Bed	6,000	4000
3 - Self-Managing Pervious Pavement	533	1600
4 - Infiltration Bed	5,000	4000
5 - Bioretention	848	320
6 - Self-Managing Pervious Pavement	266	800
Total =	14,327	11,200

Figure K-11. Summary of SOV and Infiltration Volumes Provided by Each BMP

$$R = \frac{\sum_{n=1}^{i}\left[(SOV + Infiltration\ Volume)_n\ (in\ cubic\ feet)\right]}{Total\ land\ cover\ area\ (in\ square\ feet)} \times \frac{12inches}{1foot}$$

$$R = \left(\frac{14{,}327ft^3 + 11{,}200ft^3}{169{,}884ft^2}\right) \times \frac{12inches}{1foot} = 1.80\ inches$$

Using the runoff volume, *Q*, minus the reduction, *R*, recalculate the potential retention, *S*, for each storm (2-, 5-, 10-, 25-, and 100-year), using modified equation 2-3 from **Chapter 7, Section 7.6**.

$$Q - R = \frac{(P - 0.2S_{mod})^2}{(P + 0.8S_{mod})}$$

$$For\ the\ 10year\ storm, Q_{10} - R = (3.46 - 1.80) = 1.66\ inches = \frac{(5.1 - 0.2S_{mod})^2}{(5.1 + 0.8S_{mod})}$$

Solve for S to obtain $S_{10,mod}$ = 5.59 (calculated within the background of BMP Excel Workbook, Worksheet 4)

Similarly, using the same equation, $S_{2,mod}$ = 8.43 inches, $S_{5,mod}$ = 6.28 inches, $S_{25,mod}$ = 5.00 inches, and $S_{100,mod}$ = 4.52 inches.

After the potential retention is determined for each storm, these values are used in rearranged equation 2-4 from **Chapter 7, Section 7.6** to calculate the adjusted CN for each storm.

$$CN_{adj} = \frac{1000}{S_{mod} + 10}$$

$$For\ the\ 10year\ Storm, CN_{10,adj} = \frac{1000}{S_{10,mod} + 10} = \frac{1000}{(5.59 + 10)} = 64$$

Similarly, using the same equation, $CN_{2,adj}$ = 54, $CN_{5,adj}$ = 61, $CN_{25,adj}$ = 67, and $CN_{100,adj}$ = 69.

The adjusted CNs were used in WinTR-55, along with the calculated time of concentration (Tc), to evaluate the peak rate of runoff from the developed site with the designed BMPs and compared to the peak rate of runoff from the pre-developed site. The adjusted CN for the 2-, 5-, 10-, 25-, and 100-year design storms are shown on Figure K-12. The peak rates of runoff for these design storms in the pre-developed, developed/unmanaged, and developed/managed conditions are shown on Figure K-13.

Weighted CN	Storm Frequency	Rainfall (in)	S	Q (in)	BMP Capture Volume (ft^3)	Infiltration Volume (12 hrs) (ft^3)	Total BMP Volume Reduction (ft^3)	Q minus Total Volume Reduction (in)	Adjusted CN
85	2	3.70		2.19				0.39	54
	5	4.50		2.91				1.11	61
	10	5.10	1.76	3.46	14,327	11,200	25,527	1.66	64
	25	6.00		4.30				2.50	67
	100	7.40		5.64				3.83	69

Figure K-12. Adjusted Curve Numbers for the 2-, 5-, 10-, 25-, and 100-Year Design Rainfall Events, BMP Excel Workbook, Worksheet 4

Condition	CN	Tc (hr)	2-Yr Peak Rate (cfs)	5-Yr Peak Rate (cfs)	10-Yr Peak Rate (cfs)	25-Yr Peak Rate (cfs)	100-Yr Peak Rate (cfs)
Predeveloped	71	0.32	5.06	7.93	9.62	12.8	18.04
Developed/Unmanaged (No BMPs)	85	0.29	10.12	13.76	15.8	19.49	25.24
Developed/Managed	69	0.29	4.69	7.55	9.29	12.52	17.81

Figure K-13. Peak Rates of Runoff in the Pre-Developed, Developed/Unmanaged, and Developed/Managed Conditions. Implementation of appropriate volume management BMPs (structural and restorative) may result in a design that does not require additional detention measures.

Depending on conditions and the extent of LID, the adjusted post-development CN may be lower than the pre-development CN, negating the requirement for additional peak rate attenuation structures. It is important to note that the designer must confirm that the time of concentration (Tc in hours) is not shorter after development before assuming that peak rates have not been altered. This case can be seen in the example. Peak rates for all storms in the Developed/Managed condition with LID BMPs are lower than the pre-development peak rates. The SOV abstracted from the runoff by these BMPs is accounted for so that additional peak rate mitigation is not necessary. This limits the construction and maintenance of stormwater facilities that are oversized by ignoring the value of SOV capture and infiltration.

If peak rate mitigation was not achieved during the initial BMP design, this would be the point to modify BMP dimensions or add additional facilities to the system for peak rate control. Note that from previous sections of this example, some BMPs have a lower loading ratio than the 8:1 guideline, meaning that these BMPs may have capacity for additional stormwater management. At this point, the design professional may elect to use the BMPs for peak rate control as well as SOV, eliminating other detention BMP requirements if peak rate requirements are not met with the initial BMP sizing. This decision will depend on proposed BMP dimensions, site conditions, and BMP guidance found in **Chapter 5** of this manual. If current BMP dimensions are optimized for site conditions and can only be used for SOV capture, other facilities may be needed to manage peak rates if calculations show peak rate mitigation is necessary. An alternative to separate facilities would be to increase the dimensions of the BMP to accommodate peak rate control within the system as long as SOV storage and retention are maintained along with BMP design guidance found in **Chapter 5.** Porous parking lots are an example of a BMP well-suited to providing both volume and rate management.

Complete a stormwater management plan narrative.

A stormwater plan narrative must be prepared and submitted with preliminary stormwater management plans for approval by the City. The stormwater management plan narrative must include documentation of the calculations performed above, as well as construction specifications of materials to be used in the proposed stormwater management measures.

Prepare an Operations and Maintenance Plan.

An Operations and Maintenance Plan must be prepared in accordance with **Chapter 8, Section 8.2**.

Submit preliminary stormwater management plan.

In accordance with **Chapter 4, Section 4.2.2**, the owner will provide the City with one hard copy and one electronic copy of preliminary stormwater management plan drawings, as well as of all applicable supporting data, plans, and calculations (i.e., soil testing reports, stormwater calculations, etc.) for the City's review and comment.

The Preliminary Stormwater Management Plan Checklist in **Appendix H (Concept, Preliminary, and Final Stormwater Management Plan Checklist)** provides additional details on the required components of a preliminary stormwater management plan submission, including both stormwater management plan narrative and drawings.

FINAL PLAN DEVELOPMENT, SUBMISSION AND REVIEW (Steps 8 and 9)

Step 8 Submit Final Plan Documents and Obtain Permits

Following approval of preliminary stormwater management plans, final plans may be submitted to the City. In accordance with **Chapter 4, Section 4.2.3**, the owner will provide the City with three hard copies of the final stormwater management plan drawings, and one hard copy of all applicable supporting data, plans, and calculations (i.e., soil testing reports, stormwater calculations, etc.) for review and approval. An electronic submission of all materials is also required.

Inspection and Maintenance Agreements, prepared in accordance with **Chapter 8, Section 8.3**, must also be filed for each project, as directed by the City and submitted to the Land Development Office, with the final plan submission.

No final plan will be approved by the City until all applicable state and federal permits have been obtained and all applicable bonds have been posted.

Step 9 Construct and Inspect

Construction Oversight

During construction, the licensed professional responsible for the design of stormwater management BMPs must oversee the construction of subsurface stormwater management BMPs. The Construction Oversight Certification for Stormwater Management BMPs in **Appendix I (Construction Oversight Certification for Stormwater Management BMPs)** must be completed and submitted to the City prior to building or site occupancy.

Inspection and Certification

The City of Chattanooga will conduct a Final Inspection of the stormwater management practices associated with this project. The Final Inspection will include inspection of all surface BMPs to ensure consistency with the City approved plans and details. The Post-Construction Inspection and Certification for Stormwater Management BMPs, outlined in **Appendix J (Post-Construction Inspection and Certification for Stormwater Management BMPS),** must be included with as-built drawings, as required.

As Built Drawings

As stated in **Chapter 4, Section 4.2.3.4**, the City's current procedures, requirements, and content regarding as-built drawings are applicable as identified on the City's webpage at http://www.chattanooga.gov/public-works/land-development-office/forms-and-permits.

Annual Reporting

The inspection checklists provided in **Chapter 8, Section 8.4** will be submitted to the City's Water Quality Department annually.

END OF EXAMPLE 1

K.2. Detailed Calculations Example and LID Calculation Tool (BMP Excel Workbook) – New Office Campus Project

Example 2: New Office Campus Designed for Water Quality Management (WQ Requirements)
Location: South Chickamauga Watershed
Combined sewer area: No
Parcel size: 8 acres

This example is identical to the first example for the concept phase. However, during the site testing of the detailed design, excavation of test pits revealed that the onsite soils have an infiltration rate of 0.05 inches/hour, which is less than the minimum infiltration rate of 0.2 inches/hour required for BMPs without underdrainage, thus rendering infiltration infeasible. Other volume-reducing BMPs, such as cisterns for reuse **(Chapter 5, BMP 5.3.9)** or green roofs **(Chapter 5, BMP 5.3.8)**, cannot provide enough SOV capacity on this site to meet project needs. Therefore, the BMPs are sized for the Water Quality Volume (WQv) of 2.1 inches. This means that the BMPs must have the capacity to store and slowly release, in accordance with the requirements of **Chapter 7, Section 7.4**, the total volume of runoff from the 2.1-inch rainfall event.

STEPS 1 THROUGH 5 – SAME AS EXAMPLE 1

PRELIMINARY PLAN DEVELOPMENT, SUBMISSION, AND REVIEW (Steps 6 and 7)

Step 6 Detailed Site Investigation and Testing

Upon receiving approval of the concept stormwater management plan from the City, detailed design of stormwater management measures may proceed. The first step in preliminary stormwater management plan development is to locate the proposed BMPs in accordance with **Appendix A (Protocol 1 Infiltration BMP Setbacks from Structures)** and **Appendix B (Protocol 2 BMP Coordination with Other Utilities)**, and to conduct site testing in accordance with **Appendix C (Protocol 3 Soil Testing)**. For this example, test pits were excavated in the area of each proposed infiltration BMP. During the excavation of the test pits, it was discovered that infiltration would not be feasible on the site. In the event that infiltration was not suitable at the proposed locations, but was feasible in other portions of the site, the design professional could adjust the site plan and BMP locations accordingly.

In keeping with LID principles, the project includes BMPs that will manage runoff close to the source. Each BMP must be sized to capture the required WQv from the area draining to it. If a BMP can only capture a portion of the required WQv from the area draining to it, a second, downstream BMP must provide the remaining WQv capture.

<u>Delineate sub-drainage areas to each BMP and calculate WQv required for each sub-area.</u>

For this example, four structural BMPs are being considered for five sub-drainage areas of disturbed area delineated, as referenced to Figure K-3. These sub-areas and land uses are as follows:

- Sub-area 1 includes lawn and an impervious parking lot. For this example, an underdrained bioretention area **(Chapter 5, BMP 5.3.4)** within the landscape plantings is being proposed. Other alternatives, such as directing this runoff to a bed beneath one of the porous parking lots, could also meet requirements. The design professional may select the appropriate BMPs for the site.
- Sub-area 2 includes lawn, two sections of 24-foot-wide driveway, a flat-roofed building, and a pervious parking lot. For this sub-area, an underdrained infiltration bed **(Chapter 5, BMP 5.3.2)** beneath the pervious parking lot is proposed.
- Sub-area 3 includes an impervious sidewalk that will directly discharge to the outfall shown on Figure 3. WQv for the entire site, however, will be met by capturing an equivalent volume in sub-area 2.
- Sub-area 4 includes lawn, a 24-foot-wide driveway, a flat-roofed building, and a pervious parking lot. For this sub-area, an underdrained infiltration bed **(Chapter 5, BMP 5.3.2)** beneath the pervious parking lot is also proposed.
- Sub-area 5 includes a building's pitched roof and lawn, and outdoor patio (sub-area 6 on Figure K-3 and in Example 1), which will be managed by an underdrained bioretention area **(Chapter 5, BMP 5.3.4)**.

For each sub-area to a BMP, the land use types, surface areas, and associated SOV can be estimated using the **BMP Excel Workbook, Worksheet 1**, as shown on Figure K-14.

Preliminary Design

INITIAL TARGET BMP AREA =	12,481 ft^2

Sub-Drainage ID per BMP (numbers and lowercase letters only)	Land Use Type	Surface Condition	Disturbed Land Area (ft^2)	Disturbed Land Area (ac)	Rv Value, from Table	Stay on Volume (ft^3)
1a	Typical Urban Soils	Pervious	17,710	0.41	0.18	558
1b	Large Impervious	Impervious	10,000	0.23	0.99	1,733
2a	Small Impervious	Impervious	10,204	0.23	0.85	1,518
2b	Typical Urban Soils	Pervious	15,800	0.36	0.18	498
2c	Flat Roof	Impervious	11,000	0.25	0.90	1,733
2d	Large Impervious	Impervious	10,000	0.23	0.99	1,733
2e	Small Impervious	Impervious	15,190	0.35	0.85	2,260
3	Small Impervious	Impervious	4,000	0.09	0.85	595
4a	Flat Roof	Impervious	20,000	0.46	0.90	3,150
4b	Large Impervious	Impervious	10,000	0.23	0.99	1,733
4c	Typical Urban Soils	Pervious	9,080	0.21	0.18	286
4d	Small Impervious	Impervious	5,200	0.12	0.85	774
5a	Typical Urban Soils	Pervious	27,450	0.63	0.18	865
5b	Pitched Roof	Impervious	2,250	0.05	0.99	390
5c	Small Impervious	Impervious	2,000	0.05	0.85	298

Figure K-14. Calculation of WQv by Sub-drainage Area with SSHM Runoff Coefficients, BMP Workbook, Worksheet 1

The required WQv is calculated using the Small Storm Hydrology Method, as described in **Chapter 7, Section 7.3**. Rv values utilized by the Small Storm Hydrology Method are automatically populated within the table based on the user-defined rainfall depth and land use types. These values can be found in the **BMP Excel Workbook, Worksheet 1** or in **Chapter 7, Section 7.3, Table 7-1**, of the manual. The total SOV by sub-area for this example is summarized on Figure K-15 for informational purposes. If using the **BMP Excel Workbook**, it will tabulate the SOV for each sub-area automatically as the design professional adjusts drainage areas and BMP sizes. This information can be found in the **BMP Excel Workbook, Summary Table**. In this case where the 2.1 volume is required, the designer may select this value from the dropdown menu of the **BMP Excel Workbook, Worksheet 1**. Rv values appropriate for the 2.1 volume are updated by the spreadsheet as well.

Sub-Drainage ID	Total Disturbed Area (ft^2)	Total Disturbed Impervious Area (ft^2)	Sub-Drainage Area SOV (ft^3)
1	27,710	10,000	2,290
2	62,194	46,394	7,740
3	4,000	4,000	595
4	44,280	35,200	5,942
5	31,700	4,250	1,552

Figure K-15. Summary of WQv by Sub-drainage Area, BMP Excel Workbook, Summary Table

Reduce WQv by implementing restorative BMPs.

The design professional may choose to reduce the size of structural BMPs by using landscape restorative measures that reduce runoff volume and provide WQv credit. These include **Chapter 5, BMPs 5.4.1 through 5.4.3**. For each of these restorative BMPs as defined in the **Non-Structural BMP Credits Worksheet, Chapter 7, Section 7.7**, the restorative BMP can be translated into a WQv "credit" volume. The first step is to consider areas within each sub-area where restorative practices may be implemented. For this example, in accordance with the tree planting credits in **Chapter 7, Section 7.2**, this project will include planting 10 evergreen and 15 deciduous trees to reduce the WQv in sub-areas 1 and 2, respectively. The project also proposes to include a 2,000-square-foot area of meadow in sub-area 5 (in lieu of lawn) as part of a required landscape plan. In accordance with **Chapter 5, BMP 5.4.2.1**, this cover type change can also reduce the SOV to be managed by structural BMPs. Additionally, the project will include 5,000 square feet in sub-area 4 where soils disturbed during construction will be restored and amended in accordance with **Chapter 5, BMP 5.4.3**. The WQv "value" of these restorative BMPs can be calculated in accordance with **Non-Structural BMP Credits Worksheet, Chapter 7, Section 7.7**. These credits, and the adjusted WQv as a result of these credits, can also be estimated using the **BMP Excel Workbook, Worksheet 2**, as indicated on Figure K-16. This worksheet provides the adjusted WQv by sub-area. As described **in Chapter 7, Section 7.7,** the use of restorative BMPs can only reduce the WQv by a maximum of 25%. **BMP Excel Workbook, Worksheet 2** will not allow the design professional to decrease WQv by more than 25%. Note that the restorative credits are applied to the appropriate BMP sub-areas. In this example, the total SOV volume credit of 336 cubic feet has been achieved through tree planting, meadow planting, and soil restoration done in accordance with the requirements of **Chapter 5, BMPs 5.4.1 through 5.4.3**.

Restorative Volume Credit Worksheet							
Sub-Drainage ID	Sub-Drainage SOV (ft^3)	Restorative Practice Credit Type	Area (ft^2)	# of Trees	Volume Credit (ft^3)	Total Volume Credit (limit to maximum of 25% of SOV) (ft^3)	Net Drainage Area SOV (ft^3)
1	2,290	Tree Planting - Evergreen		10	100	100	2,190
		None			0		
		None			0		
2	7,740	Tree Planting - Deciduous		15	90	90	7,650
		None			0		
		None			0		
3	595	None			0	0	595
		None			0		
		None			0		
4	5,942	Amend and Restore Disturbed Soils	5,000		104	104	5,838
		None			0		
		None			0		
5	1,254	Change Cover Type to Meadow	2,000		42	42	1,213
		None			0		
		None			0		

Figure K-16. Restorative Credits for Tree Plantings and Cover Type Changes, BMP Excel Workbook, Worksheet 2

Determine the BMP area and storage capacity necessary for each sub-drainage area.

The WQv remaining after restorative credits are applied will be managed by six structural BMPs designed to capture and slow-release the WQv, one in each sub-drainage area. Using the recommended loading ratio of 8:1 for a 2.1-inch rainfall depth, BMPs were located on the site plan. Locations of proposed BMPs with regard to setbacks from structures were considered in accordance with **Appendix A (Protocol 1 Infiltration BMP Setbacks from Structures)**, to avoid potential damage due to water migration. Also, coordination with other utilities, in accordance with **Appendix B (Protocol 2 BMP Coordination with Other Utilities)**, determined that the locations of the proposed BMPs would not conflict with existing or proposed utilities. Even though the proposed BMPs will not be designed for infiltration, the design guidance provided in these appendices should be considered to ensure appropriate safety in design.

A summary of the BMP areas, calculated capture volumes, and impervious to BMP area loading ratios is shown on Figure K-17. The BMPs may be dimensioned using the **BMP Excel Workbook, Worksheet 3**.

The process of sizing and selection of BMPs needs to incorporate site and design knowledge that may not be found in this manual. Site conditions and design requirements need to be considered to determine which BMPs are the most appropriate given specific site conditions and what BMP dimensions will best fit within a site. Dimensioning a BMP can become an iterative process, so utilizing the **BMP Excel Workbook, Worksheet 3** may be helpful.

The **BMP Excel Workbook** provides a designer with the necessary SOV that is required to be captured per sub-drainage area in **BMP Excel Workbook, Worksheet 3** under the column titled, "Net Drainage Area

SOV." This column is the net value of SOV after SOV volume credit has been subtracted for all restorative practices tabulated in **BMP Excel Workbook,Worksheet 2**. In general, a designer will need to know at this point in the design process which areas are available onsite within each sub-drainage area for each BMP and also what volume is needed to be captured in each BMP (**BMP Excel Workbook, Worksheet 3**). Most often this will be indicated by a parking area that may be able to contain an infiltration bed or a landscaped area that could be used for bioretention. These available areas will be the starting point for sizing the necessary BMPs per sub-drainage area.

BMP Excel Workbook, Worksheet 3 can then be used to iteratively adjust which BMPs will be applied to each sub-drainage area and their dimensions. For example, if sub-drainage area 2 has a large parking lot required by City code where an infiltration bed is feasible, a designer might start with the area of the parking lot and adjust the depth of stone storage until the BMP capture Volume is greater than the net drainage area SOV. If it appears the entire area of parking is not needed for use as an infiltration bed, the designer can scale down the footprint of the infiltration bed. These design iterations should consider pipe elevations entering and exiting a BMP, pipe cover requirements, and any other site conditions that could influence BMP dimensions. Additional information specific to BMP selection and sizing can be found in **Chapter 5.** Another example might be a situation where a landscape feature such as a bioretention area is desired by the property owner but a maximum amount of ponding is not appropriate. The designer would then have to minimize surface storage in **BMP Excel Workbook, Worksheet 3** for that particular sub-drainage area and provide additional subsurface storage in the form of soil or stone. Using guidance provided in **Chapter 5,** each chosen BMP can be tailored to site requirements using **BMP Excel Workbook, Worksheet 3** to vary BMP area, storage media, and storage media depths per design requirements.

Sub-Drainage ID	BMP Type	Infiltration Rate (in./hr)	Runoff Storage Type	Mid-height Area (ft^2)	Depth of Storage (ft)	Storage Capacity (%)	Storage Volume (ft^3)	BMP Surface Area (ft^2)	BMP Capture Volume (ft^3)	Net Drainage Area SOV (ft^3)	Drawdown Time (hrs)	Loading Ratio
1	**Bioretention**		Surface	1,200	1	100%	1,200	1,200	2,280	2190	-	8
			Soil	1,200	3	20%	720					
			Stone	1,200	0.75	40%	360					
2	**Infiltration Bed**		Surface			0%	0	10,000	8,000	7650	-	5
			Soil			0%	0					
			Stone	10,000	2	40%	8,000					
3	**NONE**		Surface			0%	0	0	0	595	-	N/A
			Soil			0%	0					
			Stone			0%	0					
4	**Infiltration Bed**		Surface			0%	0	10,000	7,000	5838	-	4
			Soil			0%	0					
			Stone	10,000	1.75	40%	7,000					
5	**Bioretention**		Surface	800	1	100%	800	800	1,600	1510	-	5
			Soil	800	3	20%	480					
			Stone	800	1	40%	320					

Figure K-17. Summary of BMP Sizing, BMP Workbook, Worksheet 3

Calculate the total volume managed and confirm that WQv is met.

After sizing the BMPs, the spreadsheet can compute the total WQv managed (using both structural BMPs and restorative practices) and compare the BMP capture volume (WQv) to the required sub-drainage area WQv. As shown on Figure K-18, the structural BMPs combined with the restorative credits have achieved slightly more than 100% of the WQv for the entire project area, even though the impervious sidewalk in sub-drainage area 3 is not managed. The BMPs across the rest of the project area have been sized to capture 18,800 feet^3, which is slightly more than the 17,783 feet^3 required after subtracting the restorative credits. Figure K-18 was generated from the **BMP Excel Workbook, Summary Table**.

Project Summary								
Sub-Drainage ID	Total Disturbed Area (ft^2)	Total Disturbed Impervious Area (ft^2)	Sub-Drainage Area SOV (ft^3)	Volume Credit (ft^3)	Net Sub-Drainage Area SOV (ft^3)	Loading Ratio	BMP Capture Volume (ft^3)	Capture > SOV?
1	27,710	10,000	2,290	100	2,190	8	2,280	YES
2	62,194	46,394	7,740	90	7,650	5	8,000	YES
3	4,000	4,000	595	0	595	N/A	0	NO
4	44,280	35,200	5,942	104	5,838	4	7,000	YES
5	31,700	4,250	1,552	42	1,510	5	1,600	YES
Totals	169,884	99,844	18,119	336	17,784		18,880	YES

Figure K-18. Calculate required total volume managed onsite. If the total volume managed (BMP capture volume) is equal to or greater than the net sub-drainage area SOV (WQv), 100% of the WQv has been achieved. BMP Excel Workbook, Summary Table

Step 7 Prepare a Preliminary Stormwater Management Plan

Develop preliminary slow-release system design.

Proposed BMP design for water quality volume includes engineering design and calculation of a slow-release structure (i.e., weir plate, orifice, etc.) to ensure the BMP drains down within 48 and 72 hours in accordance with **Chapter 7, Section 7.4**.

Adjust Curve Number for the project site and evaluate peak rate.

After completing preliminary slow-release system design to manage 100% of WQv, the design professional is required to evaluate the project for peak rates of runoff. To account for the impacts on peak rate reduction through the application of LID measures on a project site, an adjustment may be made to the CN values assigned to disturbed areas managed by an LID BMP. The method for adjusting CN values is provided in **Chapter 7, Section 7.6**. The modified CN value gives the design professional credit for the volume stored in and slow-released from the BMPs.

The first step in CN adjustment is to determine a weighted CN for both the pre-development and post-development conditions. Because the CN adjustment for this section of the example requires only the post-development conditions to be considered, the figures and text only address the post-development weighted CN. The method is the same for determining the pre-development CN. A weighted CN value will be necessary to determine peak rates from both the pre-development and post-development conditions, but only the post-development weighted CN will be adjusted since volume capture will only take place because of the post-development BMPs. The CN weighting procedure is equivalent to dividing the total sum of each land use area multiplied by its corresponding CN value by the total area. A summary of area, land cover descriptions, and associated CNs is shown on Figure K-19. See **Chapter 7, Section 7.6, Table 7-5** for recommended CN values.

Land Cover Description	Area (ft.^{2})	CN
Lawn	70,040	74
Buildings and Driveways	67,844	98
Pervious Parking, Patio, and Sidewalk	22,000	75
Impervious Parking	10,000	98
Total Area =	169,884	ft.^{2}

Figure K-19. Summary of Area, Land Cover, and Corresponding CN for Use in Weighted CN Calculation

$$Weighted\ CN = \frac{\sum(Land\ cover\ area\ x\ CN)}{Total\ land\ cover\ area} = \frac{14{,}369{,}672}{169{,}884} = 85.12\ (rounded\ to\ 85)$$

After determining the weighted CN, calculate the potential retention, *S*, for the project site using the weighted CN value and TR-55 Eqn. 2-4 from **Chapter 7, Section 7.6**.

$$S = \frac{1000}{CN} - 10 = \frac{1000}{85} - 10 = 1.76\ inches$$

Once the potential retention is determined, use that value to calculate the runoff volume, *Q*, for the 2-, 5-, 10-, 25-, and 100-year storms using equation TR-55 2-3 from **Chapter 7, Section 7.6** and the design rainfall depths, P, for each storm shown in **Chapter 7, Section 7.5, Table 7-4.**

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$For\ the\ 10-year\ storm, Q_{10} = \frac{(5.1-0.2\times1.76)^2}{(5.1+0.8\times1.76)} = 3.46\ inches$$

Using the same equation, Q_2 = 2.19 inches, Q_5 = 2.91 inches, Q_{25} = 4.30 inches, and Q_{100} = 5.64 inches.

The reduction volume, *R*, is the sum of all volumes stored (WQv) and slow-released by the BMPs on the project site. WQv volumes for each BMP are summarized on Figure K-20.

Drainage Area / BMP	SOV (ft.^{3})	Infiltration Volume (ft.^{3})
1 - Bioretention	2,280	0
2 - Infiltration Bed	8,000	0
3 - Self-Managing Pervious Pavement	0	0
4 - Infiltration Bed	7,000	0
5 - Bioretention	1,600	0
Total =	18,880	0

Figure K-20. Summary of WQv Volumes Provided by Each BMP

$$R = \frac{\sum_{n=1}^{i}\left[(SOV + Infiltration\ Volume)_n\ (in\ cubic\ feet)\right]}{Total\ land\ cover\ area\ (in\ square\ feet)} \times \frac{12 inches}{1 foot}$$

$$R = \left(\frac{18{,}880ft^3 + 0ft^3}{169{,}884ft^2}\right) \times \frac{12inches}{1foot} = 1.33\ inch$$

Using the runoff volume, *Q*, minus the reduction, *R*, recalculate the potential retention, *S*, for each storm (2-, 5-, 10-, 25-, and 100-year), using modified equation 2-3 from **Chapter 7, Section 7.6**.

$$Q - R = \frac{(P-0.2S_{mod})^2}{(P+0.8S_{mod})}$$

$$For\ the\ 10-year\ storm, Q_{10} -\ R = (3.46-1.33) = 2.13\ inches = \frac{(5.1-0.2S_{mod})^2}{(5.1+0.8S_{mod})}$$

Solve for S to obtain $S_{10,mod}$ = 4.24 (BMP Excel Workbook, Worksheet 4)

Similarly, using the same equation, $S_{2,mod}$ = 5.39, $S_{5,mod}$ = 4.57, $S_{25,mod}$ = 3.94 inches, and $S_{100,mod}$ = 3.66 inches.

Once the potential retention is determined for each storm, these values are used in rearranged equation 2-4 to calculate the adjusted CN for each storm.

$$CN_{adj} = \frac{1000}{S_{mod} + 10}$$

$$For\ the\ 10 - year\ Storm, CN_{10,adj} = \frac{1000}{S_{10,mod} + 10} = \frac{1000}{(4.24 + 10)} = 70$$

Using the same equation, $CN_{2,adj}$ = 65, $CN_{5,adj}$ = 69, $CN_{25,adj}$ = 72, and $CN_{100,adj}$ = 73.

The adjusted CNs were used in WinTR-55, along with the calculated time of concentration (Tc), to evaluate the peak rate of runoff from the developed site with the designed BMPs and compared to the peak rate of runoff from the pre-developed site. The adjusted CNs for the 2-, 5-, 10-, 25- ,and 100-year design storms are shown on Figure K-21. The peak rates of runoff for the 2-, 5-, 10-, 25-, and 100-year design storm in the pre-developed, developed/unmanaged, and developed/managed conditions are shown on Figure K-22.

Weighted CN	Storm Frequency	Rainfall (in)	S	Q (in)	BMP Capture Volume (ft^3)	Infiltration Volume (12 hrs) (ft^3)	Total BMP Volume Reduction (ft^3)	Q minus Total Volume Reduction (in)	Adjusted CN
85	2	3.70		2.19				0.86	65
	5	4.50		2.91				1.58	69
	10	5.10	1.76	3.46	18,880		18,880	2.13	70
	25	6.00		4.30				2.97	72
	100	7.40		5.64				4.30	73

Figure K-21. Adjusted Curve Numbers for the 2-, 5-, 10-, 25-, and 100-Year Design Rainfall Events, BMP Excel Workbook, Worksheet 4

Condition	CN	Tc (hr)	2-Yr Peak Rate (cfs)	5-Yr Peak Rate (cfs)	10-Yr Peak Rate (cfs)	25-Yr Peak Rate (cfs)	100-Yr Peak Rate (cfs)
Predeveloped	78	0.32	7.27	10.52	12.38	15.86	21.27
Developed/Unmanaged (No BMPs)	85	0.3	10.12	13.76	15.8	19.49	25.24
Developed/Managed	73	0.3	5.93	9.06	10.9	14.29	19.8

Figure K-22. Peak rates of Runoff in the Pre-developed, Developed/Unmanaged, and Developed/Managed Conditions. Implementation of appropriate volume management BMPs (structural and restorative) may result in a design that does not require additional detention measures.

Depending on conditions and the extent of LID, the adjusted post-development CN may be lower than the pre-development CN, negating the requirement for additional peak rate attenuation structures. This case can be seen in the example. Peak rates for all storms in the Developed/Managed condition with LID BMPs are lower than the pre-development peak rates. The WQv abstracted from the runoff by these BMPs is accounted for so that additional peak rate mitigation is not necessary. This limits the construction and maintenance of stormwater facilities that are oversized by ignoring the value of WQv capture and slow-release.

If peak rate mitigation was not achieved during the initial BMP design, this would be the point to modify BMP dimensions or add additional facilities to the system for peak rate control. Note that from previous sections of this example, some BMPs have a lower loading ratio than the 8:1 guideline, meaning that these BMPs may have capacity for additional stormwater management. At this point, the design professional may elect to use the BMPs for peak rate control as well as WQv, eliminating other detention BMP requirements if peak rate requirements are not met with the initial BMP sizing. This decision will depend on proposed BMP dimensions, site conditions, and BMP guidance found in **Chapter 5** of this manual. If current BMP dimensions are optimized for site conditions and can only be used for WQv slow-release, other facilities may be needed to manage peak rates if calculations show peak rate mitigation is necessary. An alternative to separate facilities would be to increase the dimensions of the BMP to accommodate peak rate control within the system as long as WQv slow-release is maintained along with BMP design guidance found in **Chapter 5**. Porous parking lots are an example of a BMP well-suited to providing both volume and rate management.

<u>Complete a stormwater management plan narrative.</u>

A stormwater plan narrative must be prepared and submitted with preliminary stormwater management plans for approval by the City. The stormwater management plan narrative must include documentation of the calculations performed above, as well as construction specifications of materials to be used in the proposed stormwater management measures.

<u>Prepare an Operations and Maintenance Plan.</u>

An Operations and Maintenance Plan must be prepared in accordance with **Chapter 8, Section 8.2**.

<u>Submit preliminary stormwater management plan.</u>

In accordance with **Chapter 4, Section 4.2.2**, the owner will provide the City with one hard copy and one electronic copy of preliminary stormwater management plan drawings, as well as of all applicable supporting data, plans, and calculations (i.e., soil testing reports, stormwater calculations, etc.) for the City’s review and comment.

The Preliminary Stormwater Management Plan Checklist in **Appendix H (Concept, Preliminary, and Final Stormwater Management Plan Checklist)** provides additional details on the required components of a preliminary stormwater management plan submission, including both stormwater management plan narrative and drawings.

FINAL PLAN DEVELOPMENT, SUBMISSION, AND REVIEW (Steps 8 and 9)

Step 8 Submit Final Plan Documents and Obtain Permits

Following approval of preliminary stormwater management plans, final plans may be submitted to the City. In accordance with **Chapter 4, Section 4.2.3**, the owner will provide the City with three hard copies of the final stormwater management plan drawings, as well as one copy of all applicable supporting data, plans, and calculations (i.e., soil testing reports, stormwater calculations, etc.) for review and approval. An electronic submission of all materials is also required.

Inspection and Maintenance Agreements, prepared in accordance with **Chapter 8, Section 8.3**, must also be filed for each project, as directed by the City and submitted to the Land Development Office, with the final plan submission.

No final plan will be approved by the City until all applicable state and federal permits have been obtained and all applicable bonds have been posted.

Step 9 Construct and Inspect

Construction Oversight

During construction, the licensed professional responsible for the design of stormwater management BMPs must oversee the construction of subsurface stormwater management BMPs. The Construction Oversight Certification for Stormwater Management BMPs in **Appendix I (Construction Oversight Certification for Stormwater Management BMPs)** must be completed and submitted to the City prior to building occupancy.

Inspection and Certification

The City of Chattanooga will conduct a Final Inspection of the stormwater management practices associated with this project. The Final Inspection will include inspection of all surface BMPs to ensure consistency with the City approved plans and details. The Post-Construction Inspection and Certification for Stormwater Management BMPs, outlined in **Appendix J (Post-Construction Inspection and Certification for Stormwater Management BMPS),** must be included with as-built drawings, as required.

As-Built Drawings

As stated in **Chapter 4, Section 4.2.3.4**, the City's current procedures, requirements, and content regarding as-built drawings are applicable as identified on the City's webpage at http://www.chattanooga.gov/public-works/land-developmentoffice/forms-and-permits.

Annual Reporting

The inspection checklists provided in **Chapter 8, Section 8.4** will be submitted to the City's Water Quality Department annually.

END OF EXAMPLE 2