Pennsylvania Stormwater Best Management Practices Manual

DRAFT - JANUARY 2005

Appendix D
Stormwater Calculations and Methodology: Case Study

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EXAMPLE 1: Control Guideline 1 for Residential 10-Lot Subdivision

This example describes a 10-lot residential subdivision in Blair County, Pennsylvania for the following situations:

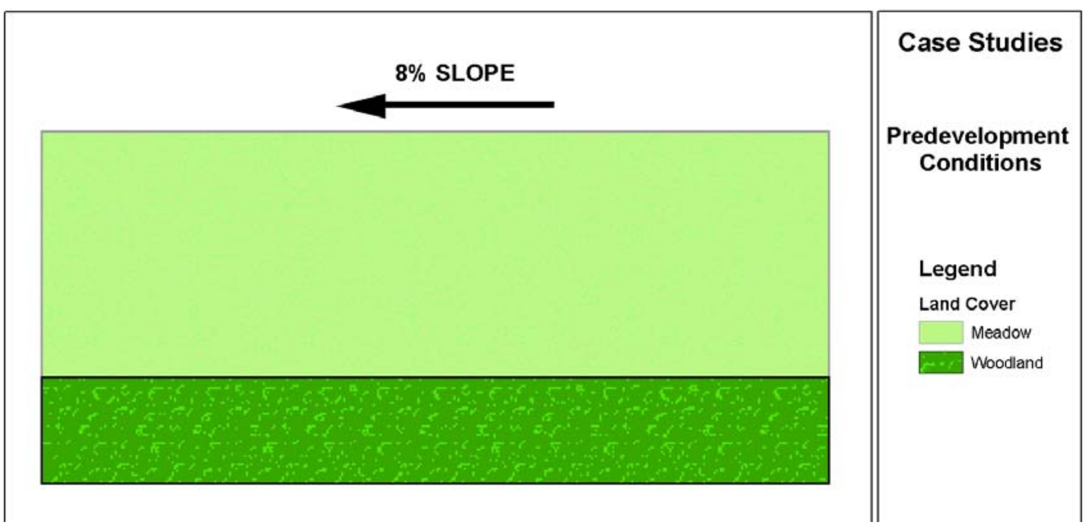
1. A 10-lot subdivision in which on-lot structural BMPs provide volume and infiltration for the net increase in volume for the 2-year, 24-hour storm event. Peak rate calculations are developed by two different techniques. Because of the relatively slow-draining soils and a small total infiltration area, increased storage in the BMPs or downstream detention is required to mitigate the peak rate of the larger storm events.

2. The same design is then revised to incorporate Non-structural BMPs to reduce the requirements of the structural BMPs. Adjusted volume calculations are provided.

3. In addition, the 10-lot subdivision is modeled with a dry detention basin for conventional peak rate control for comparison. Finally, the site is routed with an extended detention (ED) basin for ED of the 1-year storm and peak rate control for the larger storms.

Follow Flow Chart A

- **Step 1**: Provide General Site Information (Worksheet 1)



In this example, the pre-development condition is a 10-acre site with 7 acres of meadow and 3 acres of woods. The underlying soils are classified as hydrologic group "C", and the overall site slope is approximately 8%.

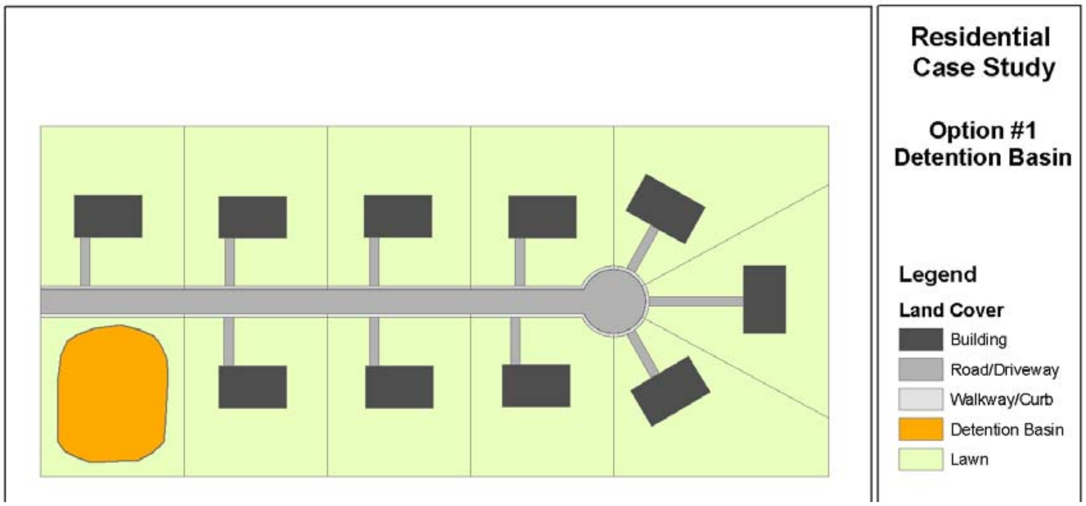
- **Step 2**: Identify sensitive natural resources (if applicable) and what areas will be protected or maintained. (Worksheet 2).

Note: In this example, there are 3 acres of woodlands that are not protected.

- **Step 3**: Estimate the benefits of Non-structural BMPs in the stormwater design (Worksheet 3).

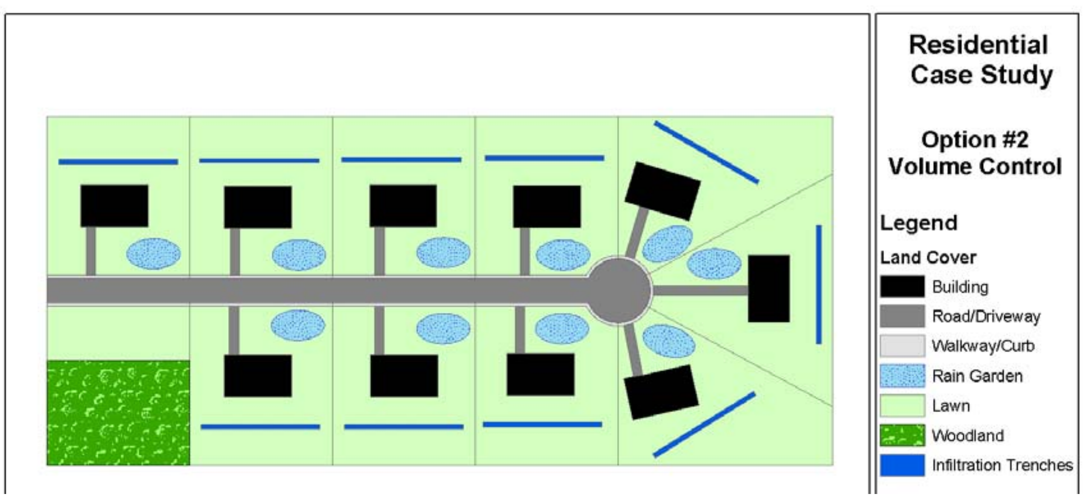
Note: In this example, Non-structural BMPs are not initially applied.

- **Step 4**: Based on the proposed design, estimate the increased volume of runoff for the 2-year storm event, using the Cover Complex Curve Number method. **The use of a weighted curve number is NOT acceptable**. Runoff volume should be calculated based on major land use types and soil types (Worksheet 4).



The proposed development includes 10 residential lots, each covering 0.91 acres.

- **Step 5**: Design and incorporate Structural and Non-Structural BMPs that provide volume control for the 2-Year volume increase (Worksheet 5).



Note: In this example, Rain Gardens and Infiltration Trenches are placed on each lot.

Calculations are provided to demonstrate that the required volume is provided. The storage volume is calculated for each rain garden and infiltration trench. The total volume is indicated on Worksheet 5 and compared to the volume requirement for CG1 of the net increase in runoff volume for the 2-year storm (Worksheet 4).

For this example, the net increase in runoff volume for the 2-year storm is approximately 25,913 ft^3, and the combined storage provided by the rain garden and infiltration trench BMPs is approximately 26,020 ft^3, so the volume requirement of CG1 has been met.

- **Step 6**: Demonstrate Peak Rate Control for the 2-year through 100-year events.
    - If Conditions for Peak Rate mitigation can be met, detailed Peak Rate Analysis and Flood Routing can be waived (Worksheet 6). This example does not meet those conditions because it has 2 acres of impervious cover. The maximum impervious area for a waiver is 1 acre.
    - If Conditions for Peak Rate mitigation cannot be met, detailed Peak Rate Analysis and Flood routing is required.

One of the challenges designers often face in using many BMPs throughout the site is that traditional engineering models and methods of peak rate calculation do not lend themselves to this type of design. As a result, designers often include BMPs for volume control, infiltration, or water quality, and then add detention measures. These detention measures may be greatly oversized because the volume-reduction and detention benefits of the BMPs and the effects of slowing the movement of runoff from the site are not accounted for. Chapter 9 provides a discussion titled "Guidelines: Volume Credits for Detention Routing" that proposes several options for considering the volume and rate mitigation benefits of multiple volume-reducing BMPs.

In this example, some of those techniques are applied, including: Composite BMP and Travel Time Adjustment with Volume Diversion.

For the Composite BMP example, the volume and discharge of the multiple BMPs (ten rain gardens and ten infiltration trenches) are combined to create a "synthetic" storage reservoir with a composite stage-storage-discharge curve. The post-development runoff hydrograph for the entire site is routed into the composite storage reservoir represented by the combined stage-storage-discharge characteristics of the many BMPs. The routed discharge from this "synthetic reservoir" is then used to size the required detention facility for the site to meet the peak rate attenuation requirements of the 1- to 100- year storm events. This method allows the designer to "take credit" for the storage/detention volume and infiltration occurring in the many BMPs, and to reduce the size of the downstream detention facility that will be built. The method is limited because it does <u>not</u> provide adequate consideration of the effect that many BMPs have on how <u>fast</u> water travels from and across the site. Since the peak of the runoff hydrograph is strongly influenced by how fast water travels across the site (or the Time of Concentration, T_c), this method is somewhat conservative.

For the Travel Time Adjustment example, the post-development Time of Concentration (T_c) is increased to take into consideration the amount of time it takes for runoff to move through the various BMPs. Both structural and non-structural BMPs can significantly slow the movement of water and reduce the peak flow rate. In this approach, the total storage of the volume-reduction BMPs (in cubic feet) is divided by the peak flow rate (calculated without the BMPs in place, in cubic feet per second) for the 100-year storm event to estimate how long it will take for water to move "through" the BMPs. This estimated time where runoff is essentially slowed by the BMP is added to the original post-development T_c in determining the post-development runoff hydrograph. Because the T_c increases, the calculated peak rate of flow for the site will be lower and the required downstream detention facility will be smaller. To account for the actual storage and infiltration of the volume-reducing BMPs (trenches and rain gardens), a diversion is incorporated into the modeling framework.

Residential 10 Lot Subdivision – Part 2

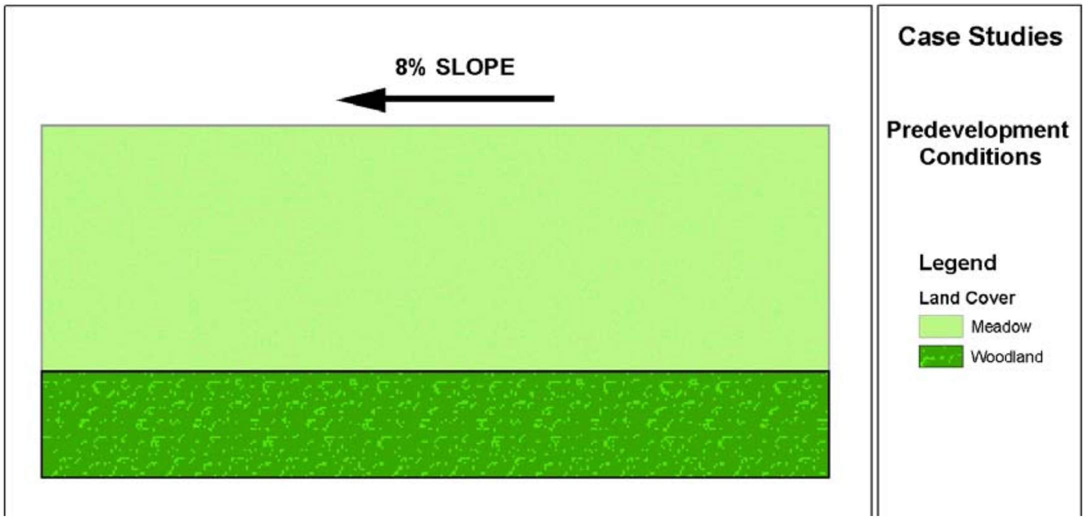
In this example, the same 10-lot residential subdivision is evaluated, but the design has been revised to incorporate Non-structural BMPs. These non-Structural BMPs include:

- Maintaining the existing 3 acres of woods (BMP 5.1, Protect Sensitive/Special Value Features and BMP 5.6, Minimize Total Disturbed Area). This has the effect of reducing the volume and rate of runoff that must be managed. ***Because this area remains undisturbed, there is no requirement to manage the volume of runoff. The total area considered in Worksheet 4 is reduced from 10 acres to 7 acres.***
- Reducing the amount of cleared and disturbed area in the construction of the homes (BMP 5.7, Minimize Soil compaction). Rather than clearing and grading the entire site, approximately one-half of the proposed lawn area on the lots will not be graded and stripped of topsoil. This area will be protected from heavy equipment movement during construction, but much of this area will be converted into lawn as part of the development. A portion of the site (approximately ½ an acre) will be planted in meadow mix (BMP 5.8, Re-vegetate Using Native Species). Protecting these areas from grading and compaction during construction maintains their ability to both absorb rainfall and slow the rate of flow across the site. ***To encourage this practice, a "volume credit" is given under BMP 5.7. This reduces the volume of runoff to be managed in structural BMPs.***
- Shortening the house setbacks and driveway lengths reduces the amount of impervious cover (BMP 5.4, Cluster) as does reducing the street width (BMP 5.9 Reduce Street Imperviousness). ***The benefit of BMPs 5.4 and 5.10 is significant – the amount of impervious area is reduced from 2 acres to 1.6 acres, and the total site imperviousness is reduced from 20% to 16%.***

Rooftop leaders will also be disconnected, but because the disconnected roof leaders will discharge into the Rain Gardens and Infiltration Trenches, the 75-foot overland flow requirement will not be met, and so no additional volume reduction credit is given. Existing trees will also be protected, but because this area is addressed under BMP 5.6 (Minimize Total Disturbed Area) additional credit for protecting trees is not given. In other words, credit for a measure (structural or non-structural) can only be taken once.

Following the same Design and Calculation Process for the design with Non-Structural BMPs is as follows:

- **Step 1**: Provide General Site Information (Worksheet 1). The Existing Site conditions are the same.



- **Step 2**: Identify sensitive natural resources (if applicable) and what areas will be protected or maintained. (Worksheet 2).

Note: In this example, there are 3 acres of woodlands that ARE protected. Therefore, the overall site area contributing to runoff volume requirements is reduced from 10 acres to 7 acres.

- **Step 3**: Estimate the benefits of Non-structural BMPs in the stormwater design (Worksheet 3).
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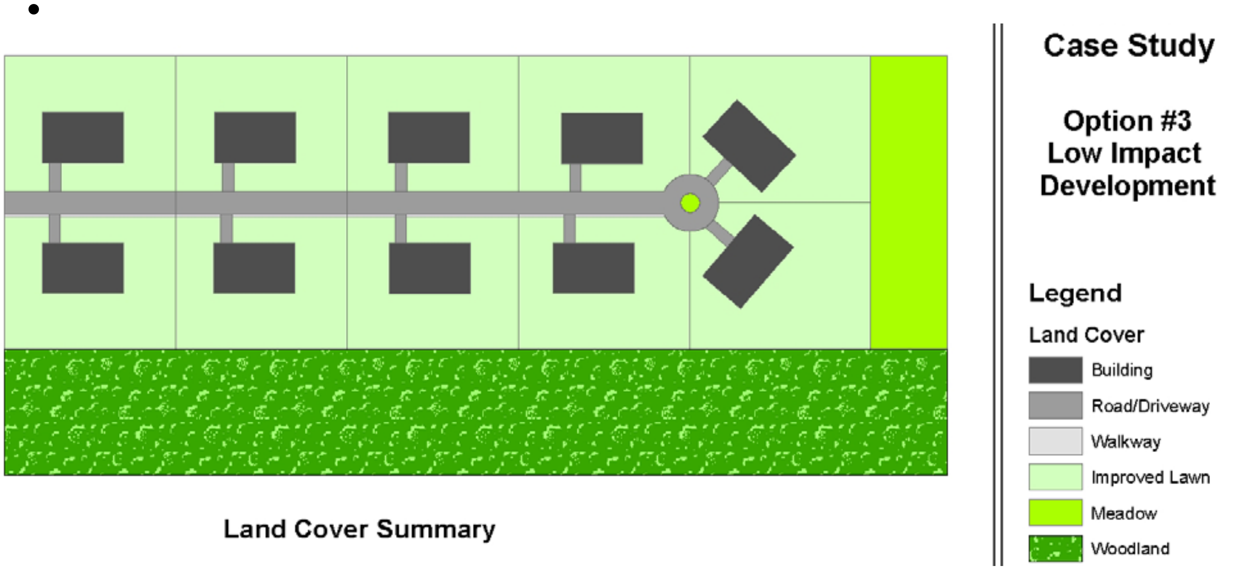

In this example, Woods are maintained, lot setbacks and driveway lengths are reduced, the street width is reduced, and areas of lawn are protected from topsoil removal and compaction. Portions of lawn are replaced with meadow. Rain Gardens and Infiltration Trenches are placed on each lot, however, these BMPs are reduced in size. The proposed development still includes 10 residential lots.

Note: Direct volume credit can be calculated for certain Non-Structural BMPs. In this example, a volume credit of approximately 2,900 ft^3 is provided by creating lawns and meadows in areas that have NOT been cleared of topsoil and have been protected from compaction during construction.

- **Step 4**: Based on the proposed design, estimate the increased volume of runoff for the 2-Year storm event, using the Cover Complex Curve Number method. **The use of a weighted curve number is NOT acceptable**. Runoff volume should be calculated based on major land use types and soil types (Worksheet 4).

Note: Because a number of Non-structural BMPs are applied (as discussed above), the stormwater management volume requirement is reduced from 25,913 ft^3 to 18,088 ft^3. This is a 30% reduction in the volume requirement.

- **Step 5**: Design and incorporate Structural and Non-Structural BMPs that provide volume control for the 2-Year volume increase (Worksheet 5).

Calculations are provided to demonstrate that the required volume is provided. The storage volume is calculated for each rain garden and infiltration trench. The total volume is indicated on Worksheet 5 and compared to the volume requirement for CG1 of the net increase in runoff volume for the 2-year storm (Worksheet 4).

For this example that includes Non-Structural BMPs, the volume requirement has been reduced and so the Structural BMPs are reduced in size. The volume requirement for the original design (without Non-structural BMPs) was 25,913 ft^3. By incorporating the Non-structural BMPs, this volume requirement has been reduced to 15,199 ft^3 (including the non-structural volume credits). Correspondingly, the structural BMPs have been reduced in size: the rain gardens are reduced from 1,820 ft^2 to 1,070 ft^2 each, and the infiltration trenches are reduced from 1,500 ft^2 to 875 ft^2.

Part 1 – Structural BMP Design

Worksheet 1. General Site Information

INSTRUCTIONS: Fill out Worksheet 1 for each watershed

Date: ____________________

Project Name: 10 Lot Residential Subdivision

Municipality: Smith Township

County: Blair County

Total Area (acres): 10

Major River Basin: ____________________

http://www.dep.state.pa.us/dep/deputate/watermgt/wc/default.htm#newtopics

Watershed: Purdy Creek

Sub-Basin: ____________________

Nearest Surface Water(s) to Receive Runoff: Tributary to Purdy Creek

Chapter 93 - Designated Water Use: HQ

http://www.pacode.com/secure/data/025/chapter93/chap93toc.html

Impaired according to Chapter 303(d) List?	Yes	
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/303d-Report.htm	No	X

List Causes of Impairment:

Is project subject to, or part of:

Municipal Separate Storm Sewer System (MS4) Requirements?	Yes	
http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/GeneralPermits/default.htm	No	X
Existing or planned drinking water supply?	Yes	
	No	X

If yes, distance from proposed discharge (miles): ____________

Approved Act 167 Plan?	Yes	
http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/Approved_1.html	No	X
Existing River Conservation Plan?	Yes	
http://www.dcnr.state.pa.us/brc/rivers/riversconservation/planningprojects/	No	X

Worksheet 2. Sensitive Natural Resources

INSTRUCTIONS:

1. Provide Sensitive Resources Map according to non-structural BMP 1.1 in Section 5.0 Non-Structural BMPs. This map should identify waterbodies, floodplains, riparian areas, wetlands, woodlands, natural drainage ways, steep slopes, and other sensitive natural features.

2. Summarize the existing extent of each sensitive resource in the Existing Sensitive Resources Table (below, using Acres).

3. Summarize Total Protected Area as defined under BMPs in Section 5.0.

4. Do not count any area twice. For example, an area that is both a floodplain and a wetland may only be considered once.

EXISTING NATURAL SENSITIVE RESOURCE	MAPPED? yes/no/n/a	TOTAL AREA (Ac.)	PROTECTED AREA (Ac.)
Waterbodies			
Floodplains			
Riparian Areas			
Wetlands			
Woodlands	YES	3	0
Natural Drainage Ways			
Steep Slopes, 15% - 25%			
Steep Slopes, over 25%			
Other:			
Other:			
TOTAL EXISTING:		3	0

Worksheet 3. Nonstructural BMP Credits

PROTECTED AREA

5.1 Area of Protected Sensitive/Special Value Features (see WS 2)	**0**	**Ac.**
5.2 Area of Riparian Forest Buffer Protection	**0**	**Ac.**
5.6 Area of Minimum Disturbance/Reduced Grading	**0**	**Ac.**
TOTAL	**0**	**Ac.**

Site Area	*minus*	Protected Area	=	Stormwater Management Area
10	-	**0**	=	**10**

This is the area that requires stormwater management

VOLUME CREDITS

5.3 Protect/Utilize Natural Flow Paths

Flow Path/Depression ______ ft^2 x 1/4" x 1/12 = ______ **ft^3**

5.7 Minimum Soil Compaction

Lawn ______ ft^2 x 1/4" x 1/12 = ______ **ft^3**

Meadow ______ ft^2 x 1/3" x 1/12 = ______ **ft^3**

3.3 Protect Existing Trees

For Trees within 100 feet of impervious area:

Tree Canopy ______ ft^2 x 1/2" x 1/12 = ______ **ft^3**

For Trees within 20 feet of impervious area:

Tree Canopy ______ ft^2 x 1" x 1/12 = ______ **ft^3**

5.1 Disconnect Roof Leaders to Vegetated Areas

For Runoff directed to areas protected under 3.1 and 3.2

Roof Area ______ ft^2 x 1/3" x 1/12 = ______ **ft^3**

For all other disconnected roof areas

Roof Area ______ ft^2 x 1/4" x 1/12 = ______ **ft^3**

5.2 Disconnect Non-Roof impervious to Vegetated Areas

For Runoff directed to areas protected under 3.1 and 3.2

Impervious Area ______ ft^2 x 1/3" x 1/12 = ______ **ft^3**

For all other disconnected roof areas

Impervious Area ______ ft^2 x 1/4" x 1/12 = ______ **ft^3**

TOTAL NON-STRUCTURAL VOLUME CREDIT* 0 **ft^3**

** For use on Worksheet 5*

WORKSHEET 4 . CHANGE IN RUNOFF VOLUME FOR 2-YR STORM EVENT

PROJECT: **10 Lot Subdivision**
Drainage Area: **1** (acres)
2-Year Rainfall: **2.8 in**

Total Site Area: 10 **acres**
Protected Site Area: 0 **acres**
Stormwater Management Area: 10 **acres** (From Worksheet 3)

Existing Conditions:

Cover Type	Soil Type	Area (sf)	Area (ac)	CN	S	Q Runoff[1] (in)	Runoff Volume[2] (ft^3)
Woodland	C	130,680	3.0	70	4.29	0.61	6,600
Meadow	C	304,920	7.0	71	4.08	0.65	16,469
Impervious	C	-	0.0				
TOTAL:			**10**				**23,069**

Developed Conditions:

Cover Type	Soil Type	Area (sf)	Area (ac)	CN	S	Q Runoff[1] (in)	Runoff Volume[2] (ft^3)
Buildings	C	45050	1.0	98	0.20	2.57	9,645
Roads, Driveways, walks	C	42070	1.0	98	0.20	2.57	9,007
Lawn	C	333480	7.7	79	2.66	1.04	29,024
Detention Basin	C	15,000	0.3	79	2.66	1.04	1,306
TOTAL:			**10**				**48,982**

2-Year Volume Increase (ft3):	**25,913**

2-Year Volume Increase = Developed Conditions Runoff Volume - Existing Conditions Runoff Volume
= 48,982 - 23,069 = 25, 913 ft3

1. Runoff (in) = Q = $(P - 0.2S)^2 / (P + 0.8S)$ where

P = 2-Year Rainfall (in)

S = 1000/ CN

2. Runoff Volume (CF) = Q x Area x 1/12 x 43,560 ft^2/acre

Q = Runoff (in)

Area = Stormwater Management Area (ac) *from Worksheet 3*

Note: Runoff Volume must be calculated for EACH land use type and soil.
The use of a weighted CN value for volume calculations is not acceptable.

WORKSHEET 5 . STRUCTURAL BMP VOLUME CREDITS

PROJECT: **10 Lot Subdivision**
SUB-BASIN: **1**

Required Control Volume (ft^3) - *from Worksheet 4*: 25,913
Non-structural Volume Credit (ft^3) - *from Worksheet 3*: - 0

Structural Volume Reqmt (ft^3) 25,913
(Required Control Volume minus Non-structural Credit)

	Proposed BMP*	Number of BMPs	Storage Volume (ft^3)
6.1	Porous Pavement		
6.2	Infiltration Basin		
6.3	Infiltration Bed		
	Infiltration Trench	10	6,000
6.4	Rain Garden/Bioretention	10	20,020
6.5	Dry Well / Seepage Pit		
6.6	Constructed Filter		
6.7	Vegetated Swale		
6.8	Vegetated Filter Strip		
6.9	Berm		
6.10	Vegetated Roof		
6.11	Capture and Re-use		
6.12	Constructed Wetlands		
6.13	Wet Pond / Retention Basin		
6.14	Dry Extended Detention Basin		
6.15	Water Quality Filters		
6.16	Riparian Buffer Restoration		
6.17	Landscape Restoration / Reforestation		
6.18	Soil Amendment		
6.19	Level Spreader		
6.20	Special Storage Areas		
Other			26,020

Total Structural Volume (ft^3): 26,020
Structural Volume Requirement (ft^3): 25,913

DIFFERENCE 107

* Complete BMP Design Checklist each measure proposed
NOTE: Provide supporting Volume Calculations for each Structural BMP

Supporting Calculations for Worksheet 5: Part 1 Structural BMPs

Design Volume Calculations for Structural, Volume-Reduction BMPs

1. **Infiltration Trenches**:

Storage Volume = Area x Depth to overflow x Void Space in Stone
= 1,500 ft^2 x 1.0 ft x 40%
= 600 ft^3

Infiltration Volume for "Volume Abstraction" in Routing Process:
= Infiltration Rate x Infiltration Area x Infiltration Period (assume 6 hours)
= 1/2 in/hour x 1,500 ft^2 x 6 hr x (1/12) ft/in
= 375 ft^3

Total "Volume Abstraction" = Storage Volume + Infiltration Volume
= 600 ft^3 + 375 ft^3 = **975 ft^3**

2. **Rain Gardens**

Storage Volume = Surface Storage + Soil Storage*
= (Area x Depth) + (Area x Soil Depth x 10%)
= (1,820 ft^2 x 1.0 ft) + (1,820 ft^2 x 1 ft x 10%)
= 2,002 ft^3

Infiltration Volume for "Volume Abstraction" in Routing Process:
= Infiltration Rate x Infiltration Area x Infiltration Period (assume 6 hours)
= 1/2 in/hour x 1,820 ft^2 x 6 hr x (1/12) ft/in
= 455 ft^3

Total "Volume Abstraction" = Storage Volume + Infiltration Volume
= 2,002 ft^3 + 455 ft^3 = **2,457 ft^3**

Structural Volume Storage per Lot = Infiltration Trench + Rain Garden = 2,602 ft^3

** Assume 1 ft depth modified soil with 10% void space for water retention.*

WORKSHEET 6 . SMALL SITE / SMALL IMPERVIOUS AREA EXCEPTION FOR PEAK RATE MITIGATION CALCULATIONS

The following conditions must be met for exemption from peak rate analysis for small sites under CG-1:

Yes — The 2-Year Runoff Volume increase must be met in BMPs designed in accordance with Manual Standards

No — Total Site Impervious Area may not exceed **1 acre.**

Yes — Maximum Development Area is **10 acres**.

Yes — Maximum site impervious cover cannot be greater than 50%.

Yes — No more than 25% Volume Control can be in Non-structural BMPs

Yes — Infiltration BMPs must have an infiltration rate of 0.5 in/hr.

Site Area	Percent Impervious	Total Impervious
10 acre	10%	1 acre
5 acre	20%	1 acre
2 acre	50%	1 acre
1 acre	50%	0.5 acre
0.5 acre	50%	0.25 acre

Peak Rate Calculations for Structural BMP Case

As discussed previously, the residential subdivision was modeled for peak rate mitigation using two techniques: Composite BMP and Travel Time Adjustment with Volume Diversion. As a comparison, dry detention basins were also simulated for conventional peak rate control as well as for extended detention. The properties of the infiltration trenches and rain gardens as shown in tables D-1 and D-2.

Table D-1. Properties of Infiltration Trenches

Stage (ft)	Area (SF)	Individual Storage (AF)	Total Storage (AF)	Individual Discharge (cfs)	Total Discharge (cfs)	Individual Infiltration (cfs)	Total Infiltration (cfs)
0.00	1,500	0.000	0.000	0.00	0.00	0.00	0.00
0.01	1,500	0.000	0.001	0.02	0.17	0.02	0.17
0.1	1,500	0.001	0.014	0.02	0.17	0.02	0.17
0.2	1,500	0.003	0.028	0.02	0.17	0.02	0.17
0.3	1,500	0.004	0.041	0.02	0.17	0.02	0.17
0.4	1,500	0.006	0.055	0.02	0.17	0.02	0.17
0.5	1,500	0.007	0.069	0.02	0.17	0.02	0.17
0.6	1,500	0.008	0.083	0.02	0.17	0.02	0.17
0.7	1,500	0.010	0.096	0.02	0.17	0.02	0.17
0.8	1,500	0.011	0.110	0.25	2.54	0.02	0.17
0.9	1,500	0.012	0.124	0.69	6.88	0.02	0.17
1	1,500	0.014	0.138	1.25	12.49	0.02	0.17

Table D-2. Properties of Rain Gardens

Stage (ft)	Area (SF)	Individual Storage (AF)	Total Storage (AF)	Individual Discharge (cfs)	Total Discharge (cfs)	Individual Infiltration (cfs)	Total Infiltration (cfs)
0.00	1,820	0.000	0.000	0.00	0.00	0.00	0.00
0.01	1,820	0.005	0.046	0.02	0.21	0.02	0.21
0.1	1,820	0.008	0.084	0.02	0.21	0.02	0.21
0.2	1,820	0.013	0.125	0.02	0.21	0.02	0.21
0.3	1,820	0.017	0.167	0.02	0.21	0.02	0.21
0.4	1,820	0.021	0.209	0.02	0.21	0.02	0.21
0.5	1,820	0.025	0.251	0.02	0.21	0.02	0.21
0.6	1,820	0.029	0.292	0.38	3.81	0.02	0.21
0.7	1,820	0.033	0.334	1.02	10.21	0.02	0.21
0.8	1,820	0.038	0.376	1.78	17.81	0.02	0.21
0.9	1,820	0.042	0.418	2.74	27.41	0.02	0.21
1	1,820	0.046	0.460	3.06	30.61	0.02	0.21

For the Composite BMP method, the infiltration trenches and rain gardens are summed into a single combined storage reservoir for modeling purposes. The properties of the "Composite BMP" are given in Table D-3.

Table D-3. Properties of Composite Infiltration Trench/Rain Garden

Stage (ft)	Total Storage (AF)	Total Discharge (cfs)	Total Infiltration (cfs)
0.00	0.000	0.00	0.00
0.01	0.047	0.38	0.38
0.1	0.097	0.38	0.38
0.2	0.153	0.38	0.38
0.3	0.208	0.38	0.38
0.4	0.264	0.38	0.38
0.5	0.320	0.38	0.38
0.6	0.375	3.98	0.38
0.7	0.431	10.38	0.38
0.8	0.486	20.35	0.38
0.9	0.542	34.29	0.38
1	0.597	43.10	0.38

All scenarios were modeled using the U.S. Army Corp of Engineers' Hydrologic Modeling System (HEC-HMS) Version 2.2.2 (May 28, 2003). The model schematic for the Composite BMP method is shown in Figure D-1. Notice that the impervious and pervious areas are routed separately to the Composite Storage Reservoir ("Comp. RG&Trench") and then the runoff being infiltrated is removed through a Composite Infiltration Rate ("Compos. Infilt") based on the design infiltration rate of the BMPs.

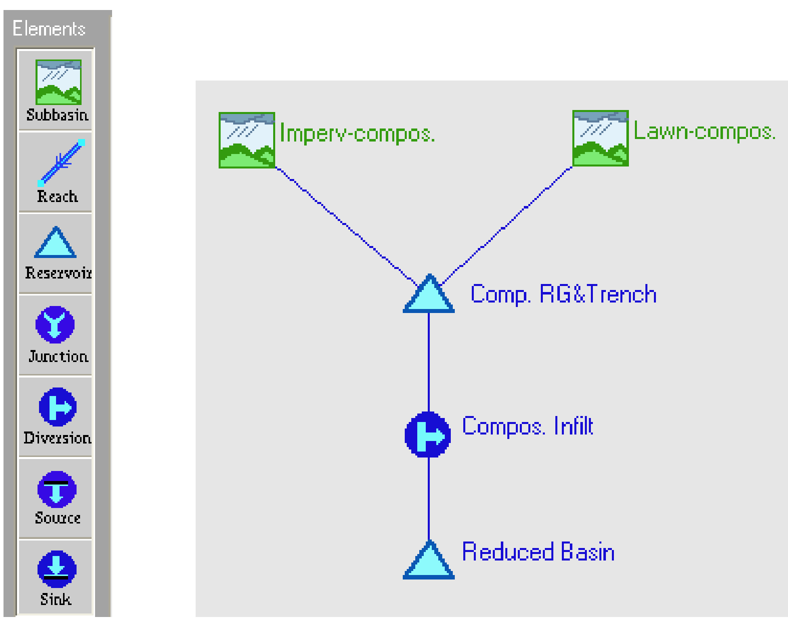

Figure D-1. Model Schematic for Composite BMP

The model schematic for 'Travel Time Adjustment with Volume Diversion' method is shown in Figure D-2. Figures D-3 and D-4 shown the model setups for conventional peak rate control and extended detention respectively.

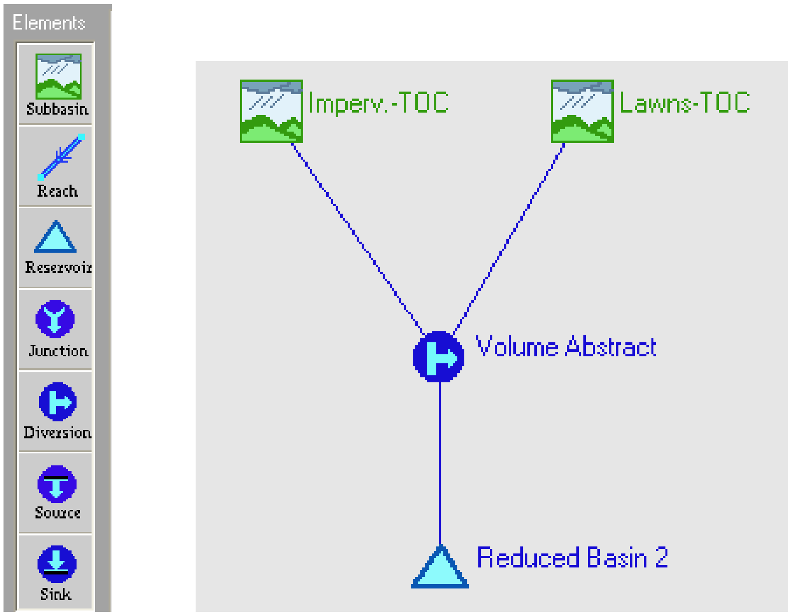

Figure D-2. Model Schematic for 'Travel Time Adjustment with Volume Diversion' method

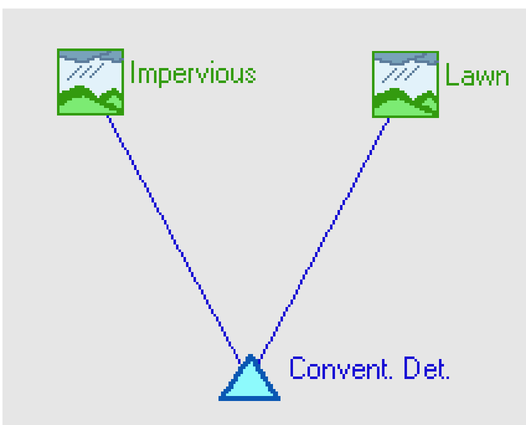

Figure D-3. Model Schematic for conventional peak rate control

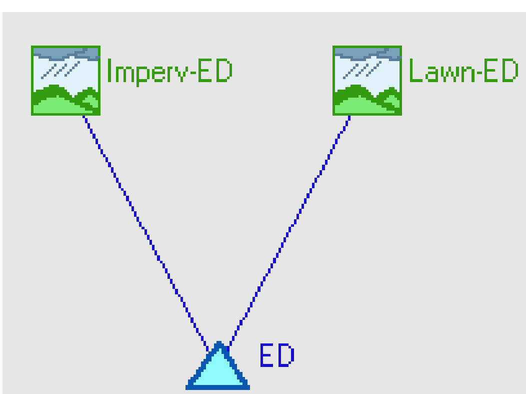

Figure D-4. Model Schematic for extended detention

In the 'Travel Time Adjustment with Volume Diversion' method the Time of Concentration was increased by the average residence time of the volume-reducing BMPs that were not be routed. The residence time for the 100-year storm was used to be conservative. The residence time is simply calculated by dividing the storage volume of the BMPs by the unmitigated post-development 100-year peak flow. As shown in Table D-4, this results in a average residence time of 9.1 minutes. The post-development time of concentration was increased by this amount in the model to account for the slowing effect of the volume-reduction BMPs.

Table D-4. Time of Concentration Adjustment

Storm Event	Peak Flow without BMPs (cfs)	Volume Control BMP Storage (CF)	Ave. Residence Time/ Time of Conc. Increase (min.)
100	47.5	26,020	9.1

In addition to increasing the time of concentration, the volume-reduction BMPs will also significantly reduce the amount of runoff being discharged by the site. In order to account for this in the 'Travel Time Adjustment with Volume Diversion' method and "volume abstraction" is incorporated into the model. The runoff simulated in the model is abstracted or "diverted" until the storage and infiltration volume of the BMPs is full. After that point, the diversion has no effect on the runoff rate or volume. The total volume abstracted in the model is calculated in Table D-5.

Table D-5. Total Volume Abstraction from Infiltration Trenches and Rain Gardens

BMP Type	Total Bottom Area (SF)	Design Infiltration Rate (in./hr)	Applied Infiltration Period Prior to Peak Runoff (hr)	Infiltration Volume (CF)	Storage Volume (CF)	Total Volume Abstraction (CF)
Infilt. Trench	15,000	0.5	6	3,750	6,000	9,750
Rain Garden	18,200	0.5	6	4,550	20,020	24,570
TOTAL	33,200	---	---	8,300	26,020	**34,320**

The results for the various scenarios are shown in Table D-6. Important results to note include:

- **The drastic increase in runoff for both cases without volume-reduction BMPs**
- **The volume control provided by infiltration BMPs, even for the 10- and 100-year storms**
- **The reduced downstream extended detention requirements when using infiltration BMPs:**
    - **Reduced from 45,000 to 25,000 for the "Composite BMP" method**
    - **Reduced from 45,000 to 16,000 for the "Travel Time Adjustment with Volume Diversion" method**
- **The improved peak rate control with volume-reduction BMPs**

Table D-6. Modeling Results for all scenarios

Runoff Volume Results

		Conv. Basin (40,000 CF)		Infilt. BMPs (26,000 CF)	
Storm Event	Pre-Dev. Runoff (in.)	Post-Dev. Runoff (in.)	Change (%)	Post-Dev. Runoff (in.)	Change (%)
1	0.43	1.09	153%	0.23	-47%
2	0.64	1.39	117%	0.47	-27%
10	1.57	2.62	67%	1.58	1%
100	2.71	3.96	46%	2.86	6%

Peak Rate for Detention - 40,000 CF Convential Basin & 45,000 CF E.D. Basin*

			Conventional Basin		Extended Det. Basin	
Storm Event	Pre-Dev. Peak (cfs)	Post-Dev. Peak (cfs)	Post-Dev. Peak w/ Basin (cfs)	Change (%)	Post-Dev. Peak w/ ED (cfs)	Change (%)
1	3.9	12.2	3.0	-23.1%	1.14	-62.0%
2	6.3	16.0	5.0	-20.6%	2.6	-48.0%
10	17.6	31.2	15.4	-12.6%	14.2	-7.8%
100	30.9	47.5	29.9	-3.2%	29.2	-2.3%

** Extended detention flow target for 1-year storm is 1.15 cfs from WS 9*

Peak Rate for Volume Control Approaches (Trenches/RGs & Reduced Detention)

			Composite Volume BMPs & 25,000 Det.		TOC Adj./ Vol. Abstract. & 16,000 CF Det.	
Storm Event	Pre-Dev. Peak (cfs)	Post-Dev. Peak (cfs)	Post-Dev. Peak w/ Volume Control (cfs)	Change (%)	Post-Dev. Peak w/ Volume Control (cfs)	Change (%)
1	3.9	12.2	1.2	-69.2%	0.22	-81.7%
2	6.3	16.0	3.0	-52.4%	0.7	-78.3%
10	17.6	31.2	14.9	-15.5%	11.8	-20.8%
100	30.9	47.5	30.8	-0.3%	30.4	-1.3%

Part 2 – Structural and Non-structural BMP Design

Worksheet 1. General Site Information

INSTRUCTIONS: Fill out Worksheet 1 for each watershed

Date: ______________________

Project Name: 10 Lot Residential Subdivision

Municipality: Smith Township

County: Blair County

Total Area (acres): 10

Major River Basin: ______________________

http://www.dep.state.pa.us/dep/deputate/watermgt/wc/default.htm#newtopics

Watershed: Purdy Creek

Sub-Basin: ______________________

Nearest Surface Water(s) to Receive Runoff: Tributary to Purdy Creek

Chapter 93 - Designated Water Use: HQ

http://www.pacode.com/secure/data/025/chapter93/chap93toc.html

Impaired according to Chapter 303(d) List?	Yes	
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/303d-Report.htm	No	X

List Causes of Impairment:

Is project subject to, or part of:

Municipal Separate Storm Sewer System (MS4) Requirements?	Yes	
http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/GeneralPermits/default.htm	No	X
Existing or planned drinking water supply?	Yes	
	No	X
If yes, distance from proposed discharge (miles): ____________		
Approved Act 167 Plan?	Yes	
http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/Approved_1.html	No	X
Existing River Conservation Plan?	Yes	
http://www.dcnr.state.pa.us/brc/rivers/riversconservation/planningprojects/	No	X

Worksheet 2. Sensitive Natural Resources

INSTRUCTIONS:

1. Provide Sensitive Resources Map according to non-structural BMP 1.1 in Section 5.0 Non-Structural BMPs. This map should identify waterbodies, floodplains, riparian areas, wetlands, woodlands, natural drainage ways, steep slopes, and other sensitive natural features.

2. Summarize the existing extent of each sensitive resource in the Existing Sensitive Resources Table (below, using Acres).

3. Summarize Total Protected Area as defined under BMPs in Section 5.0.

4. Do not count any area twice. For example, an area that is both a floodplain and a wetland may only be considered once.

EXISTING NATURAL SENSITIVE RESOURCE	MAPPED? yes/no/n/a	TOTAL AREA (Ac.)	PROTECTED AREA (Ac.)
Waterbodies			
Floodplains			
Riparian Areas			
Wetlands			
Woodlands	YES	3	3
Natural Drainage Ways			
Steep Slopes, 15% - 25%			
Steep Slopes, over 25%			
Other:			
Other:			
TOTAL EXISTING:		3	3

Worksheet 3. Nonstructural BMP Credits

PROTECTED AREA

5.1 Area of Protected Sensitive/Special Value Features (see WS 2)	**0**	**Ac.**
5.2 Area of Riparian Forest Buffer Protection	**0**	**Ac.**
5.6 Area of Minimum Disturbance/Reduced Grading	**3**	**Ac.**
TOTAL	**3**	**Ac.**

Site Area	*minus*	Protected Area	=	Stormwater Management Area
10	-	**3**	=	**7**

This is the area that requires stormwater management

VOLUME CREDITS

5.3 Protect/Utilize Natural Flow Paths

Flow Path/Depression	NA	ft^2	x 1/4"	x 1/12	=	**0**	ft^3

5.7 Minimum Soil Compaction

Lawn	105,006	ft^2	x 1/4"	x 1/12	=	**2,188**	ft^3
Meadow	25,240	ft^2	x 1/3"	x 1/12	=	**701**	ft^3

3.3 Protect Existing Trees

For Trees within 100 feet of impervious area:

Tree Canopy	NA	ft^2	x 1/2"	x 1/12	=	**0**	ft^3

For Trees within 20 feet of impervious area:

Tree Canopy	NA	ft^2	x 1"	x 1/12	=	**0**	ft^3

5.1 Disconnect Roof Leaders to Vegetated Areas

For Runoff directed to areas protected under 3.1 and 3.2

Roof Area	NA	ft^2	x 1/3"	x 1/12	=	**0**	ft^3

For all other disconnected roof areas

Roof Area	NA	ft^2	x 1/4"	x 1/12	=	**0**	ft^3

5.2 Disconnect Non-Roof impervious to Vegetated Areas

For Runoff directed to areas protected under 3.1 and 3.2

Impervious Area	NA	ft^2	x 1/3"	x 1/12	=	**0**	ft^3

For all other disconnected roof areas

Impervious Area	NA	ft^2	x 1/4"	x 1/12	=	**0**	ft^3

TOTAL NON-STRUCTURAL VOLUME CREDIT* 2,889 ft^3

** For use on Worksheet 5*

WORKSHEET 4 . CHANGE IN RUNOFF VOLUME FOR 2-YR STORM EVENT

PROJECT: **10 Lot Subdivision**
Drainage Area: **1** (acres)
2-Year Rainfall: **2.8 in**

Total Site Area: 10 **acres**
Protected Site Area: 3 **acres**
Stormwater Management Area: 7 **acres** (From Worksheet 3)

Existing Conditions:

Cover Type	Soil Type	Area (sf)	Area (ac)	CN	S	Q Runoff[1] (in)	Runoff Volume[2] (ft^3)
Woodland Not Included							
Meadow	C	304,920	7.0	71	4.08	0.65	16,469
Impervious	C	-	0.0				
TOTAL:			**7**				**16,469**

Developed Conditions:

Cover Type	Soil Type	Area (sf)	Area (ac)	CN	S	Q Runoff[1] (in)	Runoff Volume[2] (ft^3)
Buildings	C	45050	1.0	98	0.20	2.57	9,645
Roads, Driveways, walks	C	24619	0.6	98	0.20	2.57	5,271
Lawn	C	90006	2.1	79	2.66	1.04	7,834
Detention Basin	C	15,000	0.3	79	2.66	1.04	1,306
Lawn with Minimal Comp	C	105,005	2.4	79	2.66	1.04	9,139
Meadow	C	25,240	0.6	71	4.08	0.65	1,363
Woods Not Included	C						
TOTAL:			**7**				**34,557**

2-Year Volume Increase (ft3):	**18,088**

2-Year Volume Increase = Developed Conditions Runoff Volume - Existing Conditions Runoff Volume
= 34,5577 - 16,469 = 18,088 ft3

1. Runoff (in) = Q = $(P - 0.2S)^2 / (P+ 0.8S)$ where

P = 2-Year Rainfall (in)

S = 1000/ CN

2. Runoff Volume (CF) = Q x Area x 1/12 x 43,560 ft^2/acre

Q = Runoff (in)

Area = Stormwater Management Area (ac) *from Worksheet 3*

Note: Runoff Volume must be calculated for EACH land use type and soil.
The use of a weighted CN value for volume calculations is not acceptable.

WORKSHEET 5 . STRUCTURAL BMP VOLUME CREDITS

PROJECT: 10 Lot Subdivision
SUB-BASIN: 1

Required Control Volume (ft^3) - *from Worksheet 4*:		18,088
Non-structural Volume Credit (ft^3) - *from Worksheet 3*:	-	2,889
Structural Volume Reqmt (ft^3)		15,199
(Required Control Volume minus Non-structural Credit)		

	Proposed BMP*	Number of BMPs	Storage Volume (ft^3)
6.1	Porous Pavement		
6.2	Infiltration Basin		
6.3	Infiltration Bed		
	Infiltration Trench	10	3,500
6.4	Rain Garden/Bioretention	10	11,770
6.5	Dry Well / Seepage Pit		
6.6	Constructed Filter		
6.7	Vegetated Swale		
6.8	Vegetated Filter Strip		
6.9	Berm		
6.10	Vegetated Roof		
6.11	Capture and Re-use		
6.12	Constructed Wetlands		
6.13	Wet Pond / Retention Basin		
6.14	Dry Extended Detention Basin		
6.15	Water Quality Filters		
6.16	Riparian Buffer Restoration		
6.17	Landscape Restoration / Reforestation		
6.18	Soil Amendment		
6.19	Level Spreader		
6.20	Special Storage Areas		
Other			15,270

Total Structural Volume (ft^3):	15,270
Structural Volume Requirement (ft^3):	15,199
DIFFERENCE	71

* Complete BMP Design Checklist each measure proposed
NOTE: Provide supporting Volume Calculations for each Structural BMP

Supporting Calculations for Worksheet 5: Part 2 – Structural and Non-Structural BMP Design

Volume Credits for Structural BMPs

1. **Infiltration Trench:**

Storage Volume = Area x Depth to overflow x Void Space in Stone
= 875 ft^2 x 1.0 ft x 40%
= 350 ft^3

Infiltration Volume for "Volume Abstraction" in Routing Process:
= Infiltration Rate x Infiltration Area x Infiltration Period (assume 6 hours)
= 1/2 in/hour x 875 ft^2 x 6 hr x (1/12) ft/in
= 219 ft^3

Total "Volume Abstraction" = Storage Volume + Infiltration Volume
= 350 ft^3 + 219 ft^3 = **569 ft^3**

2. **Rain Garden:**

Storage Volume = Surface Storage + Soil Storage*
= (Area x Depth to Overflow) + (Area x Soil Depth x 10%)
= (1,070 ft^2 x 1.0 ft) + (1,070 x 1 ft x 10%)
= 1,177 ft^3

Infiltration Volume for "Volume Abstraction" in Routing Process:
= Infiltration Rate x Infiltration Area x Infiltration Period (assume 6 hours)
= 1/2 in/hour x 1,070 ft^2 x 6 hr x (1/12) ft/in
= 268 ft^3

Total "Volume Abstraction = Storage Volume + Infiltration Volume
= 1,177 ft^3 + 268 ft^3 = **1,445 ft^3**

Structural Volume Storage per Lot = Infiltration Trench + Rain Garden = 1,527 ft^3

** Assume 1 ft depth modified soil with 10% void space for water retention.*