Chapter
2.0

Unified Stormwater Sizing Criteria

2.0 Unified Stormwater Sizing Criteria

This chapter presents a unified approach for sizing stormwater BMPs in the State of Maryland to meet pollutant removal goals, maintain groundwater recharge, reduce channel erosion, prevent overbank flooding, and pass extreme floods. For a summary, please consult Table 2.1 below. The remaining sections describe the five sizing criteria in detail and present guidance on how to properly compute and apply the required storage volumes.

This chapter also presents a list of acceptable BMP options that can be used to comply with the sizing criteria. Lastly, the chapter designates certain land uses as "stormwater hotspots" which restrict the use of certain BMPs and may also require a pollution prevention plan.

Table 2.1 Summary of the Statewide Stormwater Criteria

Sizing Criteria	Description of Stormwater Sizing Criteria
Water Quality Volume (WQ_v) (acre-feet)	$\boldsymbol{WQ_v} = [(\boldsymbol{P})(\boldsymbol{R_v})(\boldsymbol{A})]/12$ P= rainfall depth in inches and is equal to 1.0" in the Eastern Rainfall Zone and 0.9" in the Western Rainfall Zone (Fig. 2.1), R_v = volumetric runoff coefficient, and A = area in acres.
Recharge Volume (Re_v) (acre-feet)	Fraction of WQ_v, depending on pre development soil hydrologic group. $Re_v = [(\boldsymbol{S})(\boldsymbol{R_v})(\boldsymbol{A})]/12$ S = soil specific recharge factor in inches.
Channel Protection Storage Volume (Cp_v)	Cp_v = 24 hour (12 hour in USE III and IV watersheds) extended detention of post-developed one-year, 24 hour storm event. Not required for direct discharges to tidal waters and the Eastern Shore of Maryland. (See Figure 2.4.)
Overbank Flood Protection Volume (Q_p)	Controlling the peak discharge rate from the ten-year storm event to the pre development rate (Q_{p10}) is optional; consult the appropriate review authority. For Eastern Shore: Provide peak discharge control for the two-year storm event (Q_{p2}). Control of the ten-year storm event is not required (Q_{p10}).
Extreme Flood Volume (Q_f)	Consult with the appropriate reviewing authority. Normally, no control is needed if development is excluded from 100-year floodplain and downstream conveyance is adequate.

Section 2.1 Water Quality Volume (WQ_v)

The Water Quality Volume (denoted as the WQ_v) is the storage needed to capture and treat the runoff from 90% of the average annual rainfall. In numerical terms, it is equivalent to an inch of rainfall multiplied by the volumetric runoff coefficient (R_v) and site area. The specific rainfall depth to be used depends on whether the site is located in the Eastern or Western rainfall zone of Maryland (see Figure 2.1).

The following equations are used to determine the storage volume, WQ_v (in acre-feet of storage):

$$WQ_v = \frac{(1.0)\,(R_v)(A)}{12}$$ Eastern Rainfall Zone P = 1.0 inches of rainfall

$$WQ_v = \frac{(0.9)\,(R_v)(A)}{12}$$ Western Rainfall Zone P = 0.9 inches of rainfall

where:

WQ_v = water quality volume (in acre-feet)

R_v = 0.05 + 0.009(I) where I is percent impervious cover

A = area in acres*

Treatment of the WQ_v shall be provided at all developments where stormwater management is required. A minimum WQ_v of 0.2 inches per acre shall be met at sites or in drainage areas that have less than 15% impervious cover.

Drainage areas having no impervious cover and no proposed disturbance during development may be excluded from the WQ_v calculations. Designers are encouraged to use these areas as non-structural practices for WQ_v treatment (see Chapter 5, "Stormwater Credits for Innovative Site Planning").

The WQ_v is directly related to the amount of impervious cover created at a site. The relationship between WQ_v and impervious cover is shown in Figure 2.2.

* The water quality volume (WQ_v) is required to be controlled only for the specific project. WQ_v for offsite areas is not required (see page 2.4 "Offsite Drainage Areas")

Figure 2.1 Location of the Eastern and Western Rainfall Zones in Maryland (For use in selecting the appropriate WQ_v equation.)

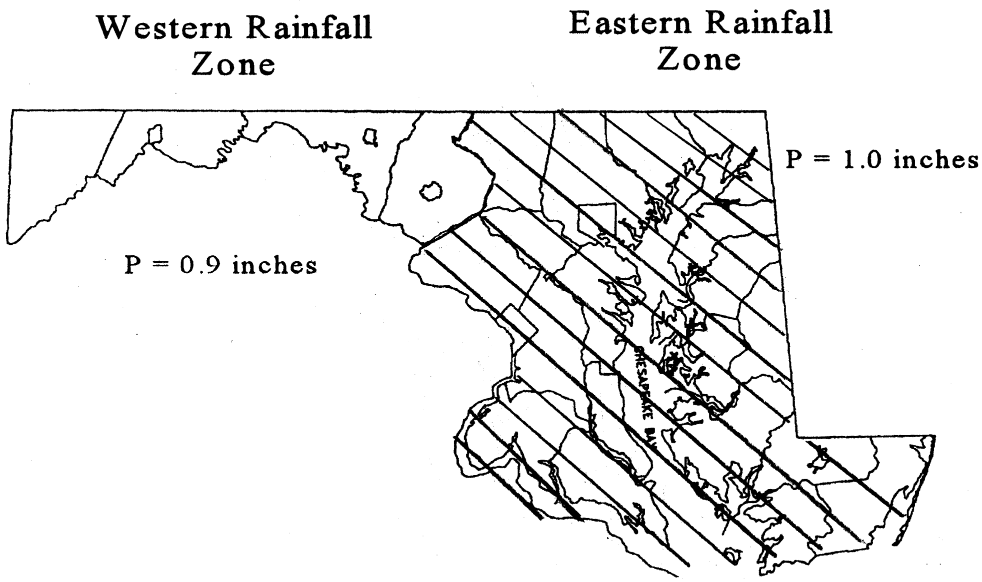
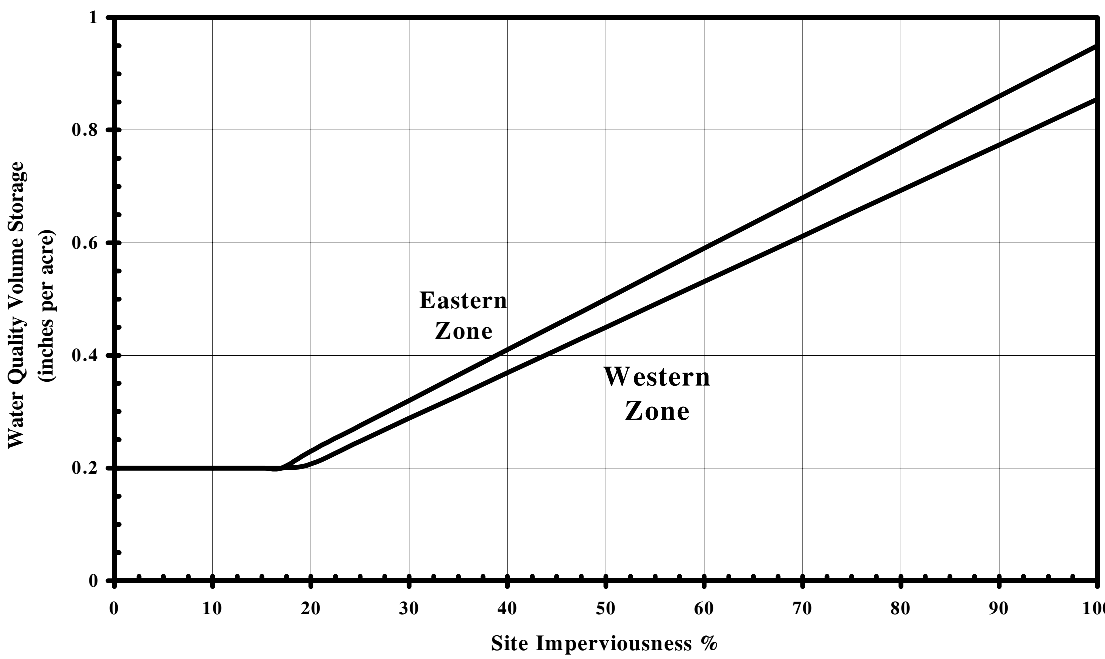


Figure 2.2 Relationship between Impervious Cover and the Water Quality Volume



Basis for Determining Water Quality Treatment Volume

As a basis for design, the following assumptions may be made:

- **Measuring Impervious Cover**: the measured area of a site plan that does not have vegetative or permeable cover shall be considered total impervious cover. Where direct measurement of impervious cover is impractical, NRCS land use/impervious cover relationships can be used to estimate impervious cover (see Table 2.2a in TR-55, NRCS, 1986). Estimates should be based on actual land use and homogeneity.

- **Multiple Drainage Areas**: When a project contains or is divided by multiple drainage areas, the WQ_v volume shall be addressed for each drainage area. See the design examples in Chapter 2, Section 2.6.

- **Offsite Drainage Areas***:* The WQ_v shall be based on the impervious cover of the proposed site. Offsite existing impervious areas may be excluded from the calculation of the water quality volume requirements.

- **Sensitive Streams**: Consult with the appropriate local review authority to determine if a greater WQ_v is warranted to protect sensitive streams.

- **BMP Treatment**: The final WQ_v shall be treated by an acceptable BMP(s) from the list presented in Chapter 2, Section 2.7, or an equivalent practice allowed by the appropriate review authority.

- **Subtraction for Structural Practices***:* Where structural practices for treating the Re_v are employed upstream of a BMP, the Re_v may be subtracted from the WQ_v used for design.

- **Subtraction for Non-structural Practices**: Where non-structural practices are employed in the site design, the WQ_v volume can be reduced in accordance with the conditions outlined in Chapter 5.

- **Determining Peak Discharge for WQ_v Storm**: When designing flow splitters for off-line practices, consult the small storm hydrology method provided in Appendix D.10.

- **Extended Detention for Water Quality Volume**: The water quality requirement can be met by providing a 24 hour drawdown of a portion of the water quality volume (WQ_v) in conjunction with a stormwater pond or wetland system as described in Chapter 3. Referred to as ED, this is different than providing the extended detention of the one-year storm for the channel protection volume (Cp_v). The ED portion of the WQ_v may be included when routing the Cp_v.

Section 2.2 Recharge Volume Requirements (Re_v)

The criteria for maintaining recharge is based on the average annual recharge rate of the hydrologic soil group(s) (HSG) present at a site as determined from USDA, NRCS Soil Surveys or from detailed site investigations. More specifically, each specific recharge factor is based on the USDA average annual recharge volume per soil type divided by the annual rainfall in Maryland (42 inches per year) and multiplied by 90%. This keeps the recharge calculation consistent with the WQ_v methodology. Thus, an annual recharge volume requirement is specified for a site as follows:

Site Recharge Volume Requirement

$Re_v = [(\boldsymbol{S})(\boldsymbol{R_v})(\boldsymbol{A})]/12$ (percent volume method)

where: R_v = 0.05 + 0.009(I) where I is percent impervious cover

A = site area in acres

$Re_v = (\boldsymbol{S})(\boldsymbol{A_i})$ (percent area method)

where: A_i = the measured impervious cover

Hydrologic Soil Group	Soil Specific Recharge Factor (S)
A	0.38
B	0.26
C	0.13
D	0.07

The recharge volume is considered part of the total WQ_v that must be provided at a site and can be achieved either by a structural practice (e.g., infiltration, bioretention), a non-structural practice (e.g., buffers, disconnection of rooftops), or a combination of both.

Drainage areas having no impervious cover and no proposed disturbance during development may be excluded from the Re_v calculations. Designers are encouraged to use these areas as non-structural practices for Re_v treatment (see Chapter 5, "Stormwater Credits for Innovative Site Planning").

Note: Re_v and WQ_v are inclusive. When treated separately, the Re_v may be subtracted from the WQ_v when sizing the water quality BMP (see page 2.4, 'Subtraction for Structural Practices).

The intent of the recharge criteria is to maintain existing groundwater recharge rates at development sites. This helps to preserve existing water table elevations thereby maintaining the hydrology of streams and wetlands during dry weather. The volume of recharge that occurs on a site depends on slope, soil type, vegetative cover, precipitation and evapo-transpiration. Sites with natural ground cover, such as forest and meadow, have higher recharge rates, less runoff, and greater transpiration losses under most conditions. Because development increases impervious surfaces, a net decrease in recharge rates is inevitable.

The relationship between Re_v and site imperviousness is shown in graphical form in Figure 2.3.

Figure 2.3 Relationship between Re_v and Site Impervious Cover

Basis for Determining Recharge Volume

- If more than one HSG is present at a site, a composite soil specific recharge factor shall be computed based on the proportion of total site area within each HSG. The recharge volume provided at the site shall be directed to the most permeable HSG available.

- The "percent volume" method is used to determine the Re_v treatment requirement when structural practices are used to provide recharge. These practices must provide seepage into the ground and may include infiltration and exfiltration structures (e.g., infiltration, bioretention, dry swales or sand filters with storage below the underdrain). Structures that require impermeable liners, intercept groundwater, or are designed for trapping sediment (e.g., forebays) may not be used. In this method, the volume of runoff treated by structural practices shall meet or exceed the computed recharge volume.

- The "percent area" method is used to determine the Re_v treatment requirements when non-structural practices are used. Under this method, the recharge requirement is evaluated by mapping the percent of impervious area that is effectively treated by an acceptable non-structural practice and comparing it to the minimum recharge requirements.

- Acceptable non-structural practices include filter strips that treat rooftop or parking lot runoff, sheet flow discharge to stream buffers, and grass channels that treat roadway runoff (see Chapter 5.)

- The recharge volume criterion does not apply to any portion of a site designated as a stormwater hotspot nor any project considered as redevelopment. In addition, the appropriate local review authority may alter or eliminate the recharge volume requirement if the site is situated on unsuitable soils (e.g., marine clays), karst or in an urban redevelopment area. In this situation, non-structural practices (percent area method) should be implemented to the maximum extent practicable and the remaining or untreated Re_v included in the WQ_v treatment.

- If Re_v is treated by structural or non-structural practices separate and upstream of the WQ_v treatment, the WQ_v is adjusted accordingly.

Section 2.3 Channel Protection Storage Volume Requirements (Cp_v)

To protect channels from erosion, **24 hour extended detention of the one-year, 24 hour storm event** (MDE, 1987) shall be provided. In Use III and IV watersheds, only 12 hours of extended detention shall be provided. The rationale for this criterion is that runoff will be stored and released in such a gradual manner that critical erosive velocities during bankfull and near-bankfull events will seldom be exceeded in downstream channels.

The Cp_v requirement does not apply to direct discharges to tidal water or Maryland's Eastern Shore (as defined in Figure 2.4) unless specified by an appropriate review authority on a case by case basis. Local governments may wish to use alternative methods to provide equivalent stream channel protection such as the Distributed Runoff Control method or bankfull capacity/duration criteria (MacRae, 1993).

The method for determining the Cp_v requirement is detailed in Appendix D.11. A detention pond or underground vault is normally needed to meet the Cp_v requirement (and subsequent Q_{p10} and Q_f criteria). Schematics of a typical design are shown in Figures 2.5.

Figure 2.4 Regions of Maryland Not Subject to the Channel Protection Requirement (Cp_v)

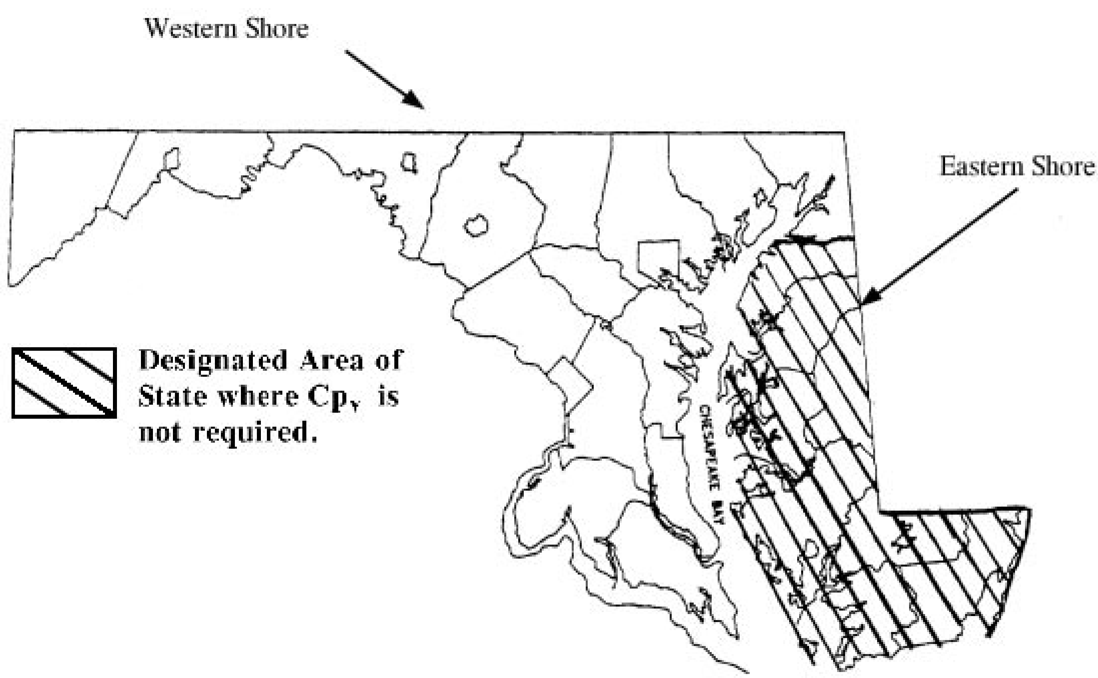
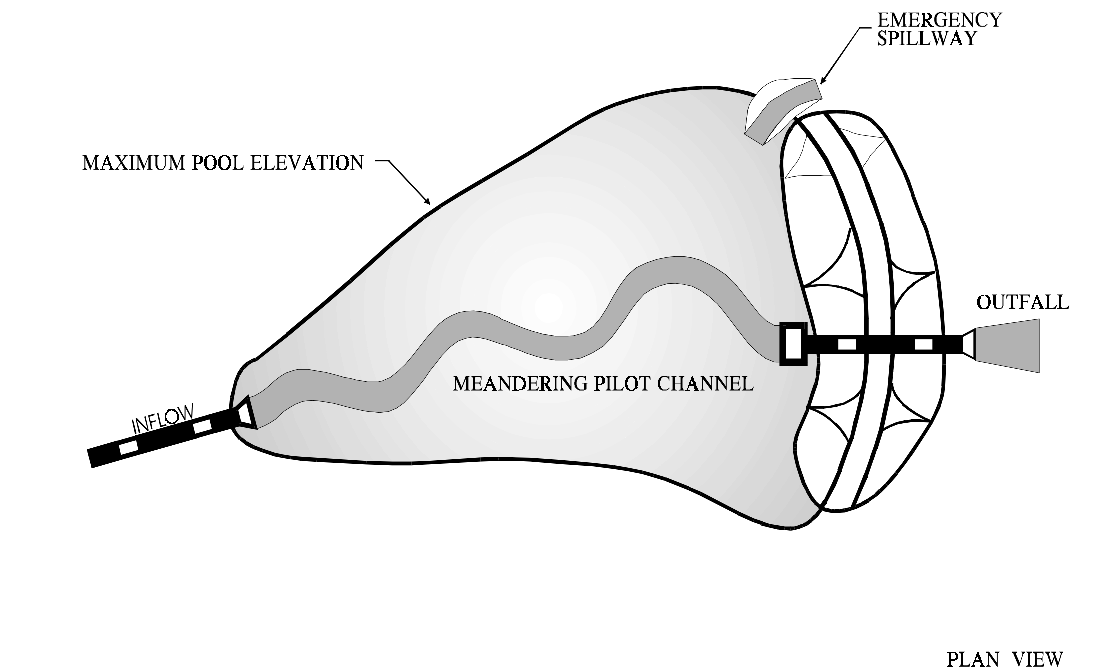
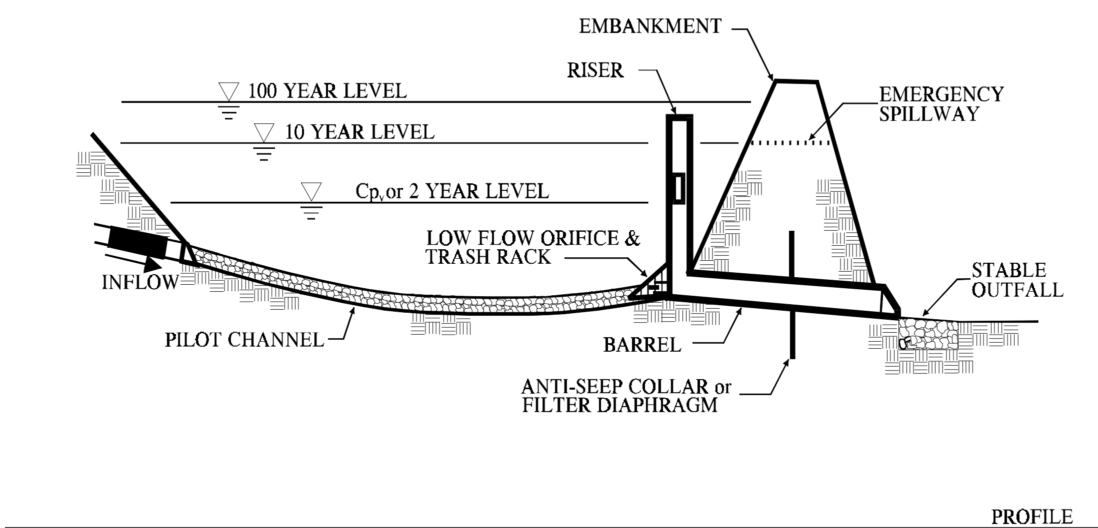


Figure 2.5 Example of Conventional Stormwater Detention Pond





A typical detention facility provides channel protection control (Cp_v) and overbank flood control (Q_p) but not water quality control (WQ_v).

Basis for Determining Channel Protection Storage Volume

The following represent the minimum basis for design:

- The models TR-55 and TR-20 (or approved equivalent) shall be used for determining peak discharge rates.

- Rainfall depths for the one-year, 24 hour storm event are provided in Table 2.2.

- Off-site areas should be modeled as present land use in good condition for the one-year storm event.

- The length of overland flow used in time of concentration (t_c) calculations is limited to no more than 100 feet for post development conditions. On the Eastern Shore, the maximum distance for t_c calculations is 150 feet for the post development conditions.

- The Cp_v storage volume shall be computed using the detention lag time between hydrograph centroids developed in "Design Procedures for Stormwater Management Extended Detention Structures" (MDE, 1987) and outlined in Appendix D.11. The detention lag time (T) for the one-year storm is defined as the interval between the center of mass of the inflow hydrograph and the center of mass of the outflow hydrograph. Examples of this technique are shown in Appendix C.1 and in the design example under Section 2.6.

- Cp_v is not required at sites where the one-year post development peak discharge (q_i) is less than or equal to 2.0 cfs. A Cp_v orifice diameter (d_o) of less than 3.0" is subject to approval by the appropriate review authority and is not recommended unless an internal control for orifice protection is used (see Appendix D.8).

- Cp_v shall be addressed for the entire site. If a site consists of multiple drainage areas, Cp_v may be distributed proportionately to each drainage area.

- Extended detention storage provided for the Cp_v does not meet the WQ_v requirement (that is Cp_v and WQ_v should be treated separately).

- The stormwater storage needed for Cp_v may be provided above the WQ_v storage in stormwater ponds and wetlands; thereby meeting all storage criteria except Re_v in a single facility with appropriate hydraulic control structures for each storage requirement.

- Infiltration is not recommended for Cp_v control because of large storage requirements.

Table 2.2 Rainfall Depths Associated with the 1,2,10 and 100-year, 24-hour Storm Events

County	Rainfall Depth			
	1 yr - 24 hr	2 yr-24 hr	10 yr-24 hr	100 yr-24 hr
Allegany	2.4 inches	2.9 inches	4.5 inches	6.2 inches
Anne Arundel	2.7	3.3	5.2	7.4
Baltimore	2.6	3.2	5.1	7.1
Calvert	2.8	3.4	5.3	7.6
Caroline	2.8	3.4	5.3	7.6
Carroll	2.5	3.1	5.0	7.1
Cecil	2.7	3.3	5.1	7.3
Charles	2.7	3.3	5.3	7.5
Dorchester	2.8	3.4	5.4	7.8
Frederick	2.5	3.1	5.0	7.0
Garrett	2.4	2.8	4.3	5.9
Harford	2.6	3.2	5.1	7.2
Howard	2.6	3.2	5.1	7.2
Kent	2.7	3.3	5.2	7.4
Montgomery	2.6	3.2	5.1	7.2
Prince George’s	2.7	3.3	5.3	7.4
Queen Anne’s	2.7	3.3	5.3	7.5
St. Mary’s	2.8	3.4	5.4	7.7
Somerset	2.9	3.5	5.6	8.1
Talbot	2.8	3.4	5.3	7.6
Washington	2.5	3.0	4.8	6.7
Wicomico	2.9	3.5	5.6	7.9
Worcester	3.0	3.6	5.6	8.1

Section 2.4 Overbank Flood Protection Volume Requirements (Q_p)

The primary purpose of the overbank flood protection volume sizing criteria is to prevent an increase in the frequency and magnitude of out-of-bank flooding generated by development (e.g., flow events that exceed the bankfull capacity of the channel and therefore must spill over into the floodplain). Overbank flood protection for the ten-year storm shall only be required if local approval authorities have no control of floodplain development, no control over infrastructure and conveyance system capacity design, or determine that downstream flooding will occur as a result of the proposed development.

For most regions of the State, the overbank flood control criteria translates to preventing the post development ten-year, 24 hour storm peak discharge rate (Q_{p10}) from exceeding the pre development peak discharge rate.

On the Eastern Shore of Maryland, the overbank flood control criteria is defined as preventing the post development two-year, 24 hour storm peak discharge rate (Q_{p2}) from exceeding the pre development peak discharge rate. The rainfall depths associated with the two and ten-year, 24 hour storm events are shown in Table 2.2.

Basis for Determining Overbank Flood Protection Volume

When addressing the overbank flooding design criteria, the following represent the minimum basis for design:

- The models TR-55 and TR-20 (or an equivalent approved by the appropriate local authority) will be used for determining peak discharge rates. The Eastern Shore Dimensionless Hydrograph may be used for sites where appropriate (see Appendix D.14). Any adjustments for unique land features such as Karst topography shall be determined by the local approving authority.

- The standard for characterizing pre development hydrologic land use for non-forested vegetated areas (including agriculture) shall be meadow in good hydrologic condition.

- Off-site areas should be modeled as "present land use condition" in good hydrologic condition for both the 2 and 10-year storm events.

- The length of overland flow used in t_c calculations is limited to no more than 150 feet for pre development conditions and 100 feet for post development conditions. On the Eastern Shore (see Figure 2.4) this maximum distance is extended to 250 feet for pre development conditions and 150 feet for post development conditions.

- Overbank flood protection does not apply to direct discharges to tidal water.

Section 2.5 Extreme Flood Volume (Q_f)

The intent of the extreme flood criteria is to (a) prevent flood damage from large storm events, (b) maintain the boundaries of the pre development 100-year Federal Emergency Management Agency (FEMA) and/or locally designated floodplain, and (c) protect the physical integrity of BMP control structures. This is typically done in two ways:

100-Year Control: requires storage to attenuate the post development 100-year, 24 hour peak discharge (Q_f) to pre development rates. The Q_f is the most stringent and expensive level of flood control and is generally not needed if the downstream development is located out of the 100-year floodplain. In many cases, the conveyance system leading to a stormwater structure is designed based on the discharge rate for the ten-year storm (Qp_{10}). In these situations, the conveyance systems may be the limiting hydrologic control.

Reserve Ultimate 100-Year Floodplain: 100-year storm control may be required by an appropriate review authority if:

- buildings or development are located within the ultimate 100-year floodplain, or
- the reviewing authority does not completely control the 100-year floodplain.

Hydraulic/hydrologic investigations may be required to demonstrate that downstream roads, bridges and public utilities are adequately protected from the Q_f storm. These investigations typically extend to the first downstream tributary of equal or greater drainage area or to any downstream dam, highway, or natural point of restricted stream flow

Basis for Determining Extreme Flood Criteria

- Consult with the appropriate review authority to determine the analyses required for the Q_f storm.
- The same hydrologic and hydraulic methods used for overbank flood control shall be used to analyze Q_f.
- In addition, off-site areas should be modeled as "ultimate condition" when the 100-year design storm event is analyzed. Table 2.2 indicates the depth of rainfall (24 hour) associated with the 100-year storm event for all counties in the State of Maryland

Section 2.6 Design Examples: Computing Stormwater Storage Volumes

Design examples are provided only to illustrate how the five stormwater management sizing criteria are computed for hypothetical development projects. These design examples are also utilized elsewhere in the manual to illustrate structural and non-structural BMP design.

Design Example No. 1: Residential Development - Reker Meadows

Site data and the layout of the Reker Meadows subdivision are shown in Figure 2.6.

Step 1. Compute WQ_v Volume

$$WQ_v = \frac{(P)(R_v)(A)}{12}$$

Step 1a. Compute Volumetric Runoff Coefficient (R_v)

R_v = 0.05 + (0.009) (I); I = 13.8 acres/38.0 acres = 36.3%
= 0.05 + (0.009) (36.3) = 0.38

Step 1b. Determine Rainfall Zone for WQ_v Formula

Location	**Rainfall (*P*)**
Eastern Rainfall Zone	1.0 inches
Western Rainfall Zone	0.9 inches
Minimum WQv (I ≤ 15%)	0.2 inches

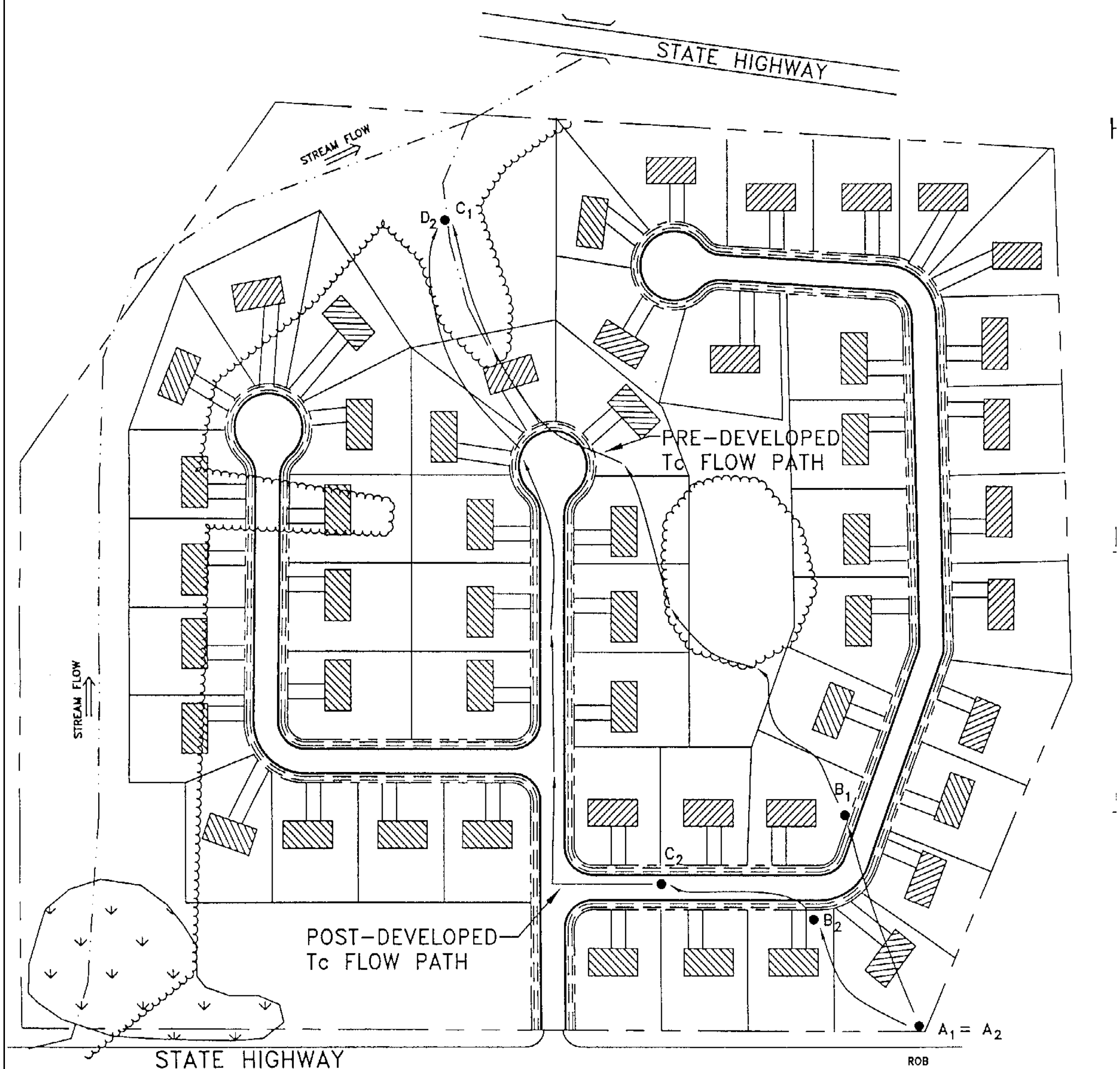
Because this site is located in the Western Rainfall Zone, use 0.9″ of rainfall to determine WQ_v.

Step 1c. Compute WQ_v

WQ_v = [(0.9″) (R_v) (A)]/12
= [(0.9″)(0.38)(38.0 ac)]/12
= 1.08 ac-ft

Check Minimum: [(0.2″)(38.0 ac)]/12 = 0.63 ac-ft < 1.08 ac-ft
∴ Use WQ_v = 1.08 ac-ft

Figure 2.6 Reker Meadows



<table>
<tr><td rowspan="4"><u>Base Data</u>
Location: Frederick, MD
Site Area = Total Drainage Area (A) = 38.0 ac
Measured Impervious Area = 13.8 ac; I=13.8/38 = 36.3%
Soils Types: 60% “B”, 40% “C”
Stream Use Designation – I
Zoning: Residential (½ acre lots)</td><td colspan="3"><u>Hydrologic Data</u></td></tr>
<tr><td></td><td>Pre</td><td>Post</td></tr>
<tr><td>CN</td><td>63</td><td>78</td></tr>
<tr><td>tc</td><td>0.35 hr</td><td>0.19 hr</td></tr>
</table>

Step 2. Compute Recharge Volume (Re_v)

$$Re_v = \frac{(S)(R_v)(A)}{12}$$ (percent volume method)

or

$$Re_v = (S)(A_i)$$ (percent area method)

Step 2a. Determine Soil Specific Recharge Factor (*S*) Based on Hydrologic Soil Group

HSG	Soil Specific Recharge Factor (*S*)
A	0.38
B	0.26
C	0.13
D	0.06

Assume imperviousness is located proportionally (60/40) in B and C soils and compute a composite S:

S = (0.26)(0.60) + (0.13)(0.40) = 0.208; Use 0.208 or 20.8% of site imperviousness

Step 2b. Compute Recharge Using Percent Volume Method

Re_v = [(S)(R_v)(A)]/12
= [(0.208)(0.38)(38 ac)]/12
= 0.25 ac-ft

or

For "B" soils = [(0.26)(.38)(38 ac)]/12 × 60% = 0.19 ac-ft
For "C" soils = [(0.13)(.38)(38 ac)]/12 × 40% = .06 ac-ft

Add recharge requirement for both soils for a total volume of 0.25 ac-ft

Step 2c. Compute Recharge Using Percent Area Method

Re_v = (S)(A_i)
= (0.208)(13.8 ac)
= 2.87 acres

or

For "B" soils = (0.26)(13.8 ac)(60%) = 2.15 acres
For "C" soils = (0.13)(13.8 ac)(40%) = 0.72 acres
Added together = 2.87 acres of the total site impervious area needs to be treated by non-structural practices.

The Re_v requirement may be met by: a) treating 0.25 ac-ft using structural methods, b) treating 2.87 acres using non-structural methods, or c) a combination of both (e.g., 0.12 ac-ft structurally and 1.44 acres non-structurally).

Step 3. Compute Channel Protection Volume (Cp_v): (See Appendix D.11)

Step 3a. Select Cp_v Sizing Rule

For channel protection, provide 12 or 24 hours of extended detention time (*T*) for the one-year design storm event.

Use Classification	Maximum Hours Allowable
Use I (general)	24
Use II (tidal)	N/A (if direct discharge)
Use III (reproducing trout)	12
Use IV (recreational trout)	12

Given that our stream is Use I, we will use a *T* of 24 hours for the one-year design storm event.

Step 3b. Develop site hydrologic and TR-55 Input Parameters

Per attached TR-55 calculations (see Figures 2.7 and 2.8).

Condition	**CN**	t_c	**Runoff (Q_a)** **1 yr storm**	**Q** **1-year**	**Q** **2-year**	**Q** **10-year**	**Q** **100 year**
		hours	*inches*	*cfs*	*cfs*	*cfs*	*cfs*
pre-developed	63	0.35	0.2	4.62	13.58	50.38	102.6
developed	78	0.19	0.8	35.0	54.94	129.96	216.30

Step 3c. Utilize MDE Method to Compute Storage Volume (Appendix D.11)

Initial abstraction (I_a) for CN of 78 is 0.564: (TR-55) [I_a = (200/CN) - 2]

I_a/P = (0.564)/2.5" = 0.226
t_c = 0.19 hours

Figure D.11.1 (App. D.11), q_u = 740 csm/in
Knowing q_u and T (extended detention time) find q_o/q_i from Figure D.11.2, “Detention Time Versus Discharge Ratios.”

Peak outflow discharge/peak inflow discharge (q_o/q_i) = 0.024

With q_o/q_i, compute V_s/V_r for a Type II rainfall distribution,

$V_s/V_r = 0.683 - 1.43(q_o/q_i)+1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$ (App. D.11)
$V_s/V_r = 0.65$

Therefore, V_s = 0.65(0.8″)(1/12)(38 ac) = 1.65 ac-ft

Step 3d. Define the Cp_v Release Rate

q_i is known (35.0 cfs), therefore,
$q_o = (q_o/q_i)\ q_i$ = .024 (35.0) = .84 cfs

Step 4. Compute Overbank Flood Protection Volume (Q_p):

Step 4a. Determine Appropriate Q_p Requirement

Location	**Type of Peak Control**
Eastern Shore	2 year/2 year
Western Shore	10 year/10 year

Because this site is located on the Western Shore, ten-year quantity peak control may be required. Assume ten-year control is needed.

Step 4b. Model Site Using TR-55 for 10 year storm

Per TR-55, Figure 6-1 (Page 6-2 of TR-55) for a Q_{in} of 130.0 cfs, and an allowable Q_{out} of 50.4 cfs, the V_s necessary for control is 2.83 ac-ft, with a developed CN of 78. (See TR-55 Worksheet 6a, Page 6-5 of TR-55). Note that there is 5.0 inches of rainfall during this event, with 2.7 inches of runoff.

Step 5. Extreme Flood Volume (Q_f)

For this example, management of Q_f is not required. However, at final design the 100-year event must be conveyed safely through the stormwater management practice. Based on field observation, downstream conveyance may require analysis for passing the 100-year event through an existing culvert.

Table 2.3 Summary of General Storage Requirements for Reker Meadows

Step	Requirement	Volume Required (ac- ft)	Notes
1.	Water Quality Volume (WQ_v)	1.08	
2.	Recharge Volume (Re_v)	.25 (or 2.87 acres)	this volume is included within the WQ_v storage
3.	Channel Protection Volume (Cp_v)	1.65	Cp_v release rate is .84 cfs
4.	Overbank Flood Protection Volume (Q_p)	2.83	10-year, in this case
5.	Extreme Flood Volume (Q_f)	N/A	provide safe passage for the 100-year event in final design

Figure 2.7: Reker Meadows – Pre Developed Conditions
(Source: TR-55 computer printouts)

```
                    RUNOFF CURVE NUMBER COMPUTATION          Version 2.00
Project : REKER MEADOWS                          User: SRC      Date: 08-01-97
County  : FREDERICK          State: MD      Checked: ____     Date: ________
Subtitle: PRE-DEVELOPED CONDITIONS
-------------------------------------------------------------------------------
                                                   Hydrologic Soil Group
         COVER DESCRIPTION                     A        B        C        D
                                                       Acres (CN)
-------------------------------------------------------------------------------
OTHER AGRICULTURAL LANDS
Meadow -cont. grass (non grazed) ----          -  22.8(58)  9.2(71)       -

Woods                          good            -        -   6.0(70)       -

Total Area (by Hydrologic Soil Group)            22.8     15.2
                                                 ====     ====
                TOTAL DRAINAGE AREA: 38 Acres       WEIGHTED CURVE NUMBER: 63*

                      TIME OF CONCENTRATION AND TRAVEL TIME       Version 2.00
-------------------------------------------------------------------------------
Flow Type   2 year   Length   Slope  Surface   n   Area    Wp   Velocity  Time
             rain     (ft)   (ft/ft)  code        (sq/ft) (ft)  (ft/sec)  (hr)
-------------------------------------------------------------------------------
Sheet        3.1      150     .025     F                                  0.306
Shallow Concent'd     500     0.04     U                                  0.043
                                                 Time of Concentration = 0.35*
                                                                         =====
        --- Sheet Flow Surface Codes ---
    A Smooth Surface           F Grass, Dense     --- Shallow Concentrated ---
    B Fallow (No Res.)         G Grass, Burmuda   ---     Surface Codes    ---
    C Cultivated < 20 % Res.   H Woods, Light              P Paved
    D Cultivated > 20 % Res.   I Woods, Dense              U Unpaved
    E Grass-Range, Short       J Range, Natural
* - Generated for use by GRAPHIC method

                        GRAPHICAL PEAK DISCHARGE METHOD           Version 2.00
 Data: Drainage Area        :  38 * Acres
        Runoff Curve Number  :  63 *
        Time of Concentration:  0.35 * Hours
        Rainfall Type        :  II
        Pond and Swamp Area  :  NONE
```

Storm Number	1	2	3	4	5	6	7
Frequency (yrs)	1	2	5	10	25	50	100
24-Hr Rainfall (in)	2.5	3.1	4	5	5.4	6.1	7
Ia/P Ratio	0.47	0.38	0.29	0.23	0.22	0.19	0.17
Runoff (in)	0.24	0.48	0.92	1.51	1.77	2.25	2.90
Unit Peak Discharge (cfs/acre/in)	0.504	0.698	0.834	0.880	0.894	0.913	0.932
Pond and Swamp Factor 0.0% Ponds Used	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Peak Discharge (cfs)	5	13	29	50	60	78	103

* - Value(s) provided from TR-55 system routines

Figure 2.8: Reker Meadows –Developed Conditions
(Source: TR-55 Computer Printouts)

```
                       RUNOFF CURVE NUMBER COMPUTATION           Version 2.00
Project : REKER MEADOWS                          User: SRC      Date: 08-01-97
County  : FREDERICK           State: MD      Checked: ____     Date: ________
Subtitle: DEVELOPED CONDITIONS
```

COVER DESCRIPTION	A	B	C	D
		Hydrologic Soil Group — Acres (CN)		
FULLY DEVELOPED URBAN AREAS (Veg Estab.)				
Open space (Lawns,parks etc.)				
Good condition; grass cover > 75%	-	13.0(61)	5.2(74)	-
Impervious Areas				
Paved parking lots, roofs, driveways	-	7.9(98)	5.9(98)	-
OTHER AGRICULTURAL LANDS				
Woods good	-	-	6.0(70)	-
Total Area (by Hydrologic Soil Group)		20.9	17.1	

```
             TOTAL DRAINAGE AREA: 38 Acres       WEIGHTED CURVE NUMBER: 78*
```

```
                     TIME OF CONCENTRATION AND TRAVEL TIME       Version 2.00
```

Flow Type	2 year rain	Length (ft)	Slope (ft/ft)	Surface code	n	Area (sq/ft)	Wp (ft)	Velocity (ft/sec)	Time (hr)
Sheet	3.1	100	.025	E					0.152
Shallow Concent'd		300	0.02	P					0.029
Open Channel		600						16.2	0.010

```
                                                  Time of Concentration = 0.19*
                                                                          =====
        --- Sheet Flow Surface Codes ---
    A Smooth Surface           F Grass, Dense     --- Shallow Concentrated ---
    B Fallow (No Res.)         G Grass, Burmuda   ---     Surface Codes    ---
    C Cultivated < 20 % Res.   H Woods, Light             P Paved
    D Cultivated > 20 % Res.   I Woods, Dense             U Unpaved
    E Grass-Range, Short       J Range, Natural
* - Generated for use by GRAPHIC method
```

```
                       GRAPHICAL PEAK DISCHARGE METHOD           Version 2.00
Data: Drainage Area        :  38 * Acres
        Runoff Curve Number  :  78 *
        Time of Concentration:  0.19 * Hours
        Rainfall Type        :  II
        Pond and Swamp Area  :  NONE
```

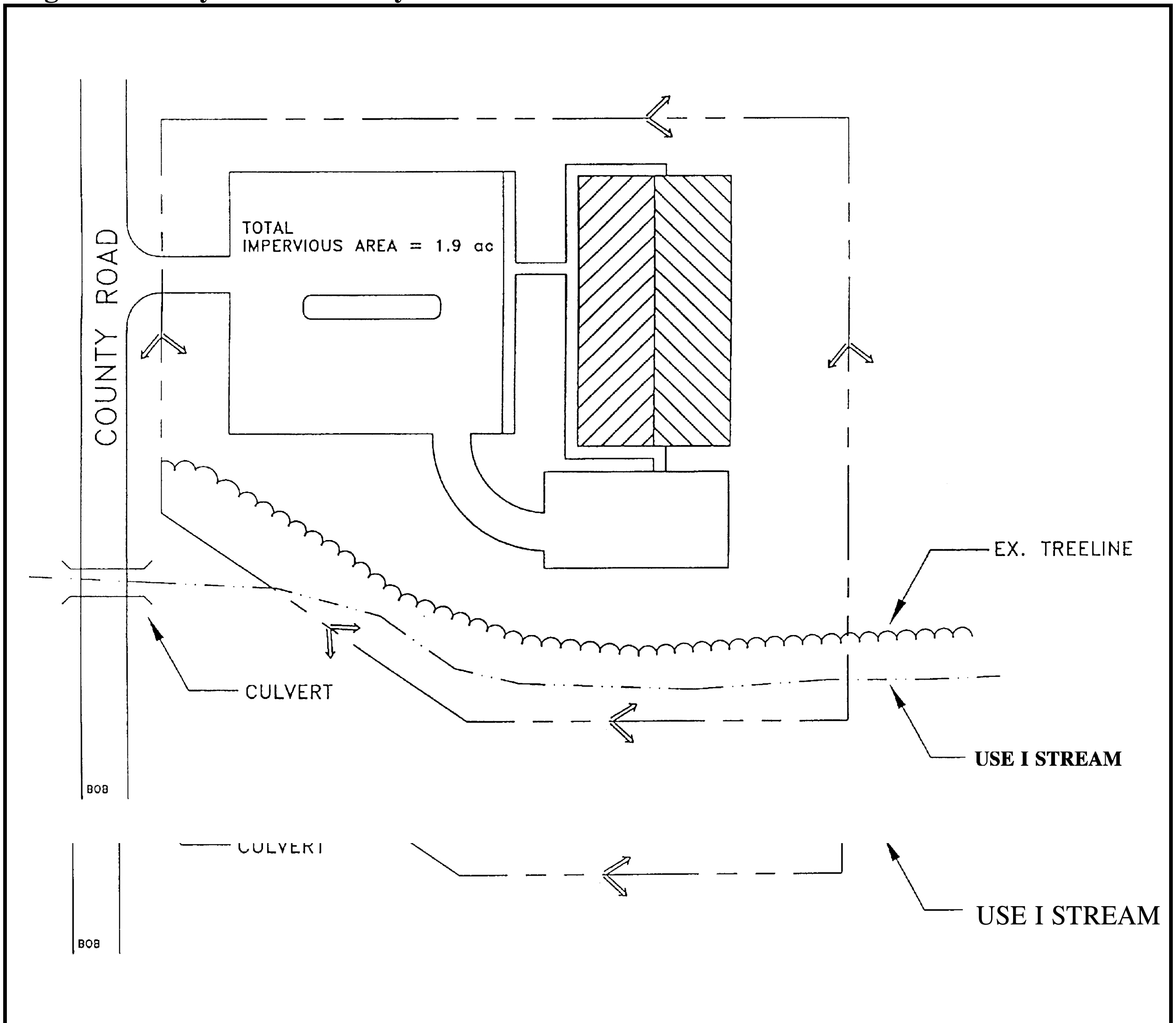
Storm Number	1	2	3	4	5	6	7
Frequency (yrs)	1	2	5	10	25	50	100
24-Hr Rainfall (in)	2.5	3.1	4	5	5.4	6.1	7
Ia/P Ratio	0.23	0.18	0.14	0.11	0.10	0.09	0.08
Used	0.23	0.18	0.14	0.11	0.10	0.10	0.10
Runoff (in)	0.79	1.20	1.89	2.71	3.05	3.67	4.47
Unit Peak Discharge (cfs/acre/in)	1.175	1.209	1.242	1.264	1.271	1.275	1.275
Pond and Swamp Factor 0.0% Ponds Used	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Peak Discharge (cfs)	35	55	89	130	148	178	217

```
* - Value(s) provided from TR-55 system routines
```

Design Example No. 2: Commercial Development - Claytor Community Center

Site data and the layout of the Claytor Community Center are shown in Figure 2.9.

Figure 2.9 Claytor Community Center



Base Data
Location: Easton, MD
Site Area = Total Drainage Area (A) = 3.0 ac
Impervious Area = 1.9 ac; I= 1.9/3.0 = 63.3%
R_v = 0.05 + (63.3)(0.009) = 0.62
Soils Type "B"
Stream Use Designation I

Hydrologic Data		
	Pre	Post
CN	57	83
t_c	0.42 hr	0.16 hr

Step 1. Compute Water Quality Volume WQ_v

$$WQ_v = \frac{(P)(R_v)(A)}{12}$$

Step 1a. Compute Volumetric Runoff Coefficient (R_v)

$R_v = 0.05 + (0.009)\ (I);\ I = 1.9\ \text{acres}/3.0\ \text{acres} = 63.3\%$
$= 0.05 + (0.009)\ (63.3) = 0.62$

Step 1b. Determine Rainfall Zone for WQ_v Formula

Location	**Rainfall (*P*)**
Eastern Rainfall Zone	1.0 inches
Western Rainfall Zone	0.9 inches
Minimum WQ_v ($I \leq 15\%$)	0.2 inches

Because this site is located in the Eastern Rainfall Zone, use the 1″ of rainfall to determine WQ_v.

Step 1c. Compute WQ_v

$WQ_v = [(1.0'')(R_v)(A)]/12$
$= [(1.0'')(0.62)(3.0\text{ac})]/12 \times (43560\text{ft}^2/\text{acre})$
$= \underline{6752\ \text{ft}^3}$

Check Minimum: $[(0.2'')(3.0\ \text{ac})]/12 \times (43560\text{ft}^2/\text{acre}) = 2178\ \text{ft}^3 < 6752\ \text{ft}^3$
$\therefore$ Use $WQ_v = 6752\ \text{ft}^3$

Step 2. Compute Recharge Volume (Re_v)

$$Re_v = \frac{(S)(R_v)(A)}{12}$$ (percent volume method)

or

$$Re_v = (S)(A_i)$$ (percent area method)

Step 2a. Determine Soil Specific Recharge Factor (*S*) Based on Hydrologic Soil Group

HSG	Soil Specific Recharge Factor (*S*)
A	0.38
B	0.26
C	0.13
D	0.06

Site is located within B soils, $\therefore S = 0.26$; Use 0.26 or 26%

Step 2b. Compute Recharge Using Percent Volume Method

$$
\begin{aligned}
Re_v &= [(S)(R_v)(A)]/12 \\
&= [(0.26)(0.62)(3.0\text{ ac})]/12 \times (43560\text{ft}^2/\text{acre}) \\
&= \underline{1{,}755.5\text{ ft}^3}
\end{aligned}
$$

Step 2c. Compute Recharge Using Percent Area Method

$$
\begin{aligned}
Re_v &= (S)(A_i) \\
&= (0.26)(1.9\text{ ac}) \times (43560\text{ft}^2/\text{acre}) \\
&= 21{,}518.6\text{ ft}^2
\end{aligned}
$$

The Re_v requirement may be met by: a) treating 1,755 ft^3 using structural methods, b) treating 21,518.6 ft^2 using non-structural methods, or c) a combination of both (e.g., 580 ft^3 structurally and 14,200 ft^2 non-structurally).

<u>Step 3. Compute Channel Protection Volume (Cp_v):</u>

Because this site is located on the Eastern Shore (see Fig. 2.4), Cp_v is not required.

<u>Step 4. Compute Overbank Flood Protection Volume (Q_p):</u>

Step 4a. Determine Appropriate Q_p Requirement

Location	Type of Peak Control
Eastern Shore	2-year/2-year
Western Shore	10-year/10-year

Per attached TR-55 calculations (Figure 2.10 and 2.11)

Condition	CN	t_c	Q 1-year	Q 2-year	Q 10-year	Q 100-year
		hours	*cfs*	*cfs*	*cfs*	*cfs*
pre-developed	57	0.42	0.22	0.58	2.91	6.75
developed	83	0.16	5.08	7.11	13.97	22.69

Because this site is located on the Eastern Shore, two-year quantity peak control is required (Q_{p2}). Per TR-55, Figure 6-1 (Page 6-2 in TR-55), for a Q_{in} of 7.11 cfs, and an allowable Q_{out} of 0.58 cfs, the Vs necessary for 2-year control is 0.24 ac-ft or 10,630 ft^3, under a developed CN of 83. (See TR-55 Worksheet 6a, Page 6-5 of TR-55.) Note that there is 3.4 inches of rainfall during this event, with 1.8 inches of runoff.

Step 5. Extreme Flood Volume (Q_f):

For this example, management of Q_f is not required. However, at final design the 100-year event must be conveyed safely through the stormwater management practice and to receiving waters.

Table 2.4 Summary of General Design Information for Claytor Community Center

Step	Category	Volume Required (cubic feet)	Notes
1	Water Quality Volume (WQ_v)	6,752	
2	Recharge Volume (Re_v)	1,688	this volume can be included within the WQ_v storage
3	Channel Protection Volume (Cp_v)	N/A	not required on the Eastern Shore
4	Overbank Flood Protection Volume (Q_p)	10,630	2-year, in this case
5	Extreme Flood Volume (Q_f)	N/A	provide safe passage for the 100-year event in final design

Figure 2.10: Claytor Community Center – Pre Developed Conditions

```
                       RUNOFF CURVE NUMBER COMPUTATION          Version 2.00
Project : CLAYTOR COMMUNITY CENTER              User: SRC      Date: 07-31-97
County  : DORCHESTER          State: MD      Checked: ____     Date: ________
Subtitle: PRE-DEVELOPED
```

COVER DESCRIPTION	Hydrologic Soil Group A	B	C	D
	Acres (CN)			
OTHER AGRICULTURAL LANDS				
Meadow -cont. grass (non grazed) ----	-	2.4(58)	-	-
Woods good	-	0.6(55)	-	-
Total Area (by Hydrologic Soil Group)		3		
		====		

```
               TOTAL DRAINAGE AREA: 3 Acres        WEIGHTED CURVE NUMBER: 57*
```

```
             TIME OF CONCENTRATION AND TRAVEL TIME        Version 2.00
```

Flow Type	2 year rain	Length (ft)	Slope (ft/ft)	Surface code	n	Area (sq/ft)	Wp (ft)	Velocity (ft/sec)	Time (hr)
Sheet	3.4	150	0.015	F					0.358
Shallow Concent'd		500	0.02	U					0.061
								Time of Concentration =	0.42*
									=====

```
        --- Sheet Flow Surface Codes ---
    A Smooth Surface           F Grass, Dense     --- Shallow Concentrated ---
    B Fallow (No Res.)         G Grass, Burmuda   ---     Surface Codes    ---
    C Cultivated < 20 % Res.   H Woods, Light            P Paved
    D Cultivated > 20 % Res.   I Woods, Dense            U Unpaved
    E Grass-Range, Short       J Range, Natural
```

```
                       GRAPHICAL PEAK DISCHARGE METHOD           Version 2.00
Data: Drainage Area        :  3 * Acres
        Runoff Curve Number  :  57 *
        Time of Concentration:  0.42 * Hours
        Rainfall Type        :  II
        Pond and Swamp Area  :  NONE
```

Storm Number	1	2	3	4	5	6	7
Frequency (yrs)	1	2	5	10	25	50	100
24-Hr Rainfall (in)	2.8	3.4	4.6	5.4	6.2	6.9	7.8
Ia/P Ratio	0.54	0.44	0.33	0.28	0.24	0.22	0.19
Used	0.50	0.44	0.33	0.28	0.24	0.22	0.19
Runoff (in)	0.19	0.38	0.90	1.32	1.80	2.25	2.86
Unit Peak Discharge (cfs/acre/in)	0.392	0.511	0.712	0.769	0.796	0.814	0.833
Pond and Swamp Factor 0.0% Ponds Used	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Peak Discharge (cfs)	0	1	2	3	4	5	7

```
* - Value(s) provided from TR-55 system routines
```

Figure 2.11: Claytor Community Center - Developed Conditions

```
                       RUNOFF CURVE NUMBER COMPUTATION           Version 2.00
Project : CLAYTOR COMMUNITY CENTER               User: SRC      Date: 07-31-97
County  : DORCHESTER          State: MD      Checked: ____      Date: ________
Subtitle: POST-DEVELOPED
-------------------------------------------------------------------------------
                                                    Hydrologic Soil Group
         COVER DESCRIPTION                     A        B        C        D
                                                        Acres (CN)
-------------------------------------------------------------------------------
FULLY DEVELOPED URBAN AREAS (Veg Estab.)
Open space (Lawns,parks etc.)
  Good condition; grass cover > 75%            -    0.5(61)      -        -
Impervious Areas
  Paved parking lots, roofs, driveways         -    1.9(98)      -        -
OTHER AGRICULTURAL LANDS
Woods                            good          -    0.6(55)      -        -

Total Area (by Hydrologic Soil Group)                 3
                                                    ====
                TOTAL DRAINAGE AREA: 3 Acres        WEIGHTED CURVE NUMBER: 83*

                     TIME OF CONCENTRATION AND TRAVEL TIME       Version 2.00
-------------------------------------------------------------------------------
Flow Type    2 year   Length   Slope  Surface   n   Area     Wp  Velocity  Time
             rain     (ft)   (ft/ft)   code       (sq/ft)  (ft)  (ft/sec)  (hr)
-------------------------------------------------------------------------------
Sheet        3.4      50       0.015    E                                 0.102
Shallow Concent'd     600      0.02     P                                 0.058
Open Channel          50                                          7.25    0.002
                                                 Time of Concentration = 0.16*
                                                                         =====
        --- Sheet Flow Surface Codes ---
    A Smooth Surface          F Grass, Dense     --- Shallow Concentrated ---
    B Fallow (No Res.)        G Grass, Burmuda   ---     Surface Codes    ---
    C Cultivated < 20 % Res.  H Woods, Light            P Paved
    D Cultivated > 20 % Res.  I Woods, Dense            U Unpaved
    E Grass-Range, Short      J Range, Natural
* - Generated for use by GRAPHIC method

                       GRAPHICAL PEAK DISCHARGE METHOD           Version 2.00
  Data: Drainage Area        :  3 * Acres
        Runoff Curve Number  :  83 *
        Time of Concentration:  0.16 * Hours
        Rainfall Type        :  II
        Pond and Swamp Area  :  NONE
```

Storm Number	1	2	3	4	5	6	7
Frequency (yrs)	1	2	5	10	25	50	100
24-Hr Rainfall (in)	2.8	3.4	4.6	5.4	6.2	6.9	7.8
Ia/P Ratio	0.15	0.12	0.09	0.08	0.07	0.06	0.05
Used	0.15	0.12	0.10	0.10	0.10	0.10	0.10
Runoff (in)	1.29	1.77	2.81	3.54	4.28	4.93	5.79
Unit Peak Discharge (cfs/acre/in)	1.322	1.342	1.357	1.357	1.357	1.357	1.357
Pond and Swamp Factor 0.0% Ponds Used	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Peak Discharge (cfs)	5	7	11	14	17	20	24

* - Value(s) provided from TR-55 system routines

Design Example No. 3: Multiple Drainage Areas – Pensyl Pointe

Site data and the layout of the Pensyl Pointe subdivision are shown in Fig. 2-12.

Step 1. Compute WQ_v Volume

$$WQ_v = \frac{(P)(R_v)(A)}{12}$$

Step 1a. Compute Runoff Coefficient

Drainage Area 1
$R_v = 0.05 + (0.009)(I)$; $I = 2.25 \text{ acres} / 7.6 \text{ acres} = 29.6\%$
$= 0.05 + (0.009)(29.6) = 0.32$

Drainage Area 2
$R_v = 0.05 + (0.009)(I)$; $I = 11.55 \text{ acres} / 30.4 \text{ acres} = 38.0\%$
$= 0.05 + (0.009)(38.0) = 0.39$
or

Total Site
$R_v = 0.05 + (0.009)(I)$; $I = 13.8 \text{ acres} / 38.0 \text{ acres} = 36.3\%$
$= 0.05 + (0.009)(36.3) = 0.38$

Step 1b. Determine Rainfall Zone for WQ_v Formula

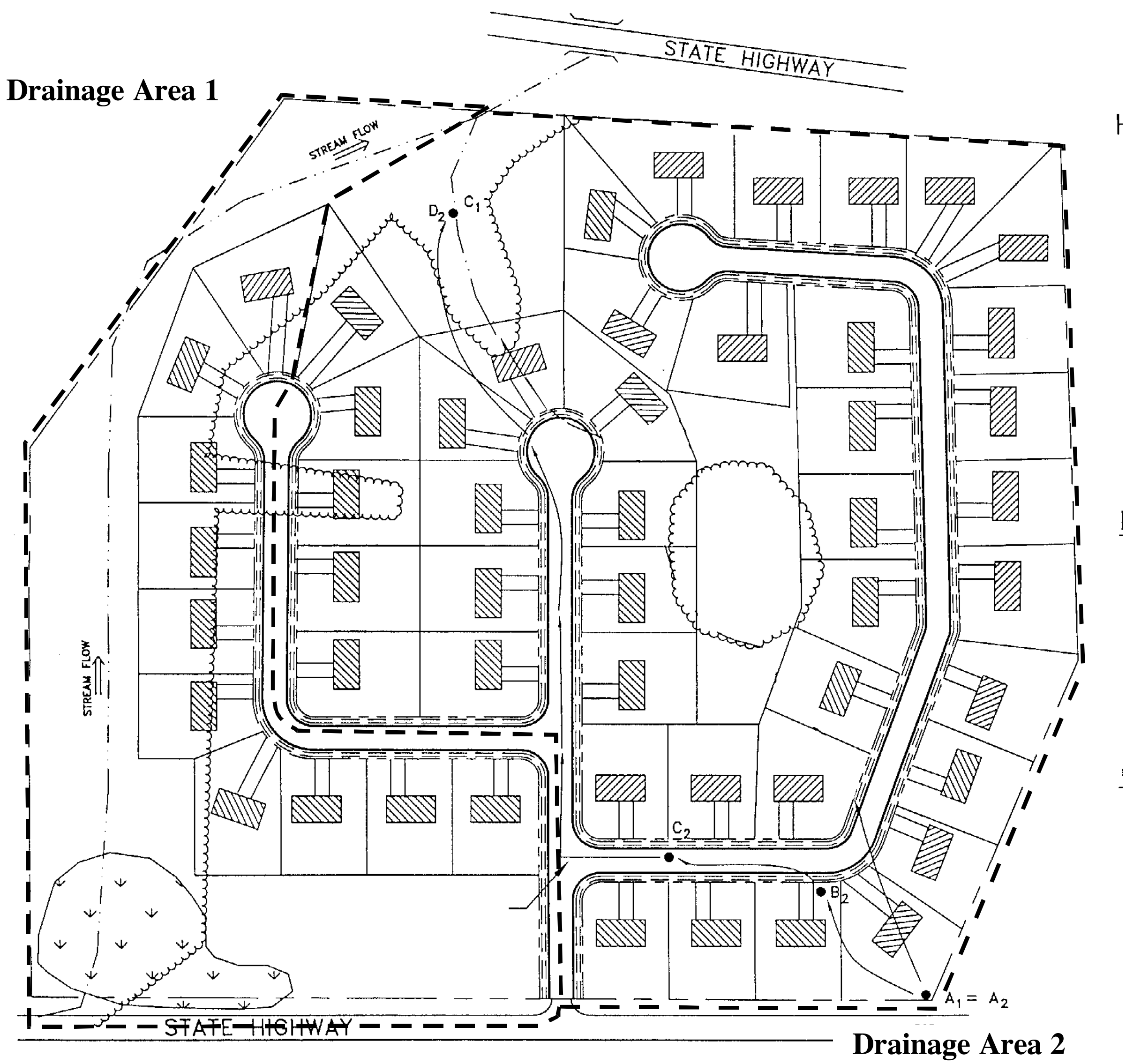
Location	Formula
Eastern Rainfall Zone	1.0 inches
Western Rainfall Zone	0.9 inches
Minimum WQ_v ($I \leq 15\%$)	0.2 inches

Because this site is located in the Eastern Rainfall Zone and imperviousness exceeds 15%, use 1.0” of rainfall to determine WQ_v.

Step 1c. Compute WQ_v

Drainage Area 1
$WQ_v = [(1.0”)(R_v)(A)]/12$
$= [(1.0”)(0.32)(7.6 \text{ ac})]/12$
$= \underline{0.20 \text{ac-ft}}$

Figure 2.12 Pensyl Pointe



Base Data
Location: Olney, MD
Site Area = 38.0 ac
Measured Site Impervious Area = 13.8 ac; I = 13.8/38 = 36.3%
Soils Types: 60% “B”, 40% C
Stream Use Designation – III, Zoning: Residential (½ acre lots)

Drainage Area (DA) 1
Area = 7.6 ac.
Measured Impervious Area = 2.25 ac; I = 2.25/7.6 = 30.0%

Drainage Area (DA) 2
Area = 30.4 ac.
Measured Impervious Area = 11.55 ac; I = 11.55/30.4 = 38.0%

Hydrologic Data
(Post-developed)

	DA 1	DA 2
CN	76	78
t_c	0.15	0.19

Drainage Area 2
WQ_v = [(1.0")(R_v)(A)]/12
= [(1.0")(0.39)(30.4 ac)]/12
= 0.99 ac-ft

or

Total Site
WQ_v = [(1.0")(R_v)(A)]/12
= [(1.0")(0.38)(38.0)]/12
= 1.20 ac-ft

Step 2. Compute Recharge Volume

Step 2a. Determine Recharge Equation Based on Hydrologic Soil Group

HSG	Soil Specific Recharge Factor (*S*)
A	0.38
B	0.26
C	0.13
D	0.06

Assume imperviousness is located proportionally (60/40) in B and C soils and compute a composite *S*:

$$S = \frac{(0.26 \times 22.8 \ acres)(0.13 \times 15.2 \ acres)}{38.0 \, acres} = 0.208 \ or \ 20.8\,\%$$

Step 2b. Compute Recharge Using Percent Volume Method

Drainage Area 1
Re_v = [(S)(R_v)(A)]/12
= [(0.208)(0.32)(7.6 ac)]/12
= 0.04 ac-ft

Drainage Area 2
Re_v = [(S)(R_v)(A)]/12
= [(0.208)(0.39)(30.4 ac)]/12
= 0.21 ac-ft

or

Total Site
$Re_v = [(S)(R_v)(A)]/12$
$= [(0.208)(0.38)(38.0 \text{ ac})]/12$
$= \underline{0.25 \text{ ac-ft}}$

Step 2c. Compute Recharge Using Percent Area Method

Drainage Area 1
$Re_v = (S)(A_i)$
$= (0.208)(2.25 \text{ ac})$
$= 0.47 \text{ acres}$

Drainage Area 2
$Re_v = (S)(A_i)$
$= (0.208)(11.55 \text{ ac})$
$= 2.40 \text{ acres}$

or

Total Site
$Re_v = (S)(A_i)$
$= (0.208)(13.8 \text{ ac})$
$= 2.87 \text{ acres}$

The Re_v requirement may be met by: a) treating 0.25 ac-ft using structural methods, b) treating 2.87 acres using non-structural methods, or c) a combination of both (e.g., 0.19 ac-ft structurally and 0.72 acres non-structurally).

Step 3. Compute Channel Protection Volume (Cp_v):

Step 3a. Select Cp_v Sizing Rule

For channel protection, provide 12 or 24 hours of extended detention time (*T*) for the one-year design storm event.

Stream Use Designation	Maximum Hours Allowable (*T*)
Use I (general)	24
Use II (tidal)	N/A
Use III (reproducing trout)	12
Use IV (recreational trout)	12

Given that our stream is Use III, we will use a T of 12 hours for the one-year design storm event.

Step 3b. Develop site hydrologic and TR-55 Input Parameters.

Per attached TR-55 calculations (see Figures 2.13 and 2.14)

.

Drainage Area	**CN**	t_c	**Runoff (Q_a),** **1 yr storm**	**Discharge (Q)** **1 yr storm**
		hrs	*inches*	*cfs*
1	76	0.15	0.76	7.40
2	78	0.19	0.85	30.5

Step 3c. Utilize MDE Method to Compute Storage Volume (Appendix D.11)

Drainage Area 1

Initial abstraction (I_a) for CN of 76 is 0.63: (TR-55) [I_a = (200/CN) – 2]

I_a/P = (0.63)/2.6" = 0.24
t_c = 0.15 hours

From Figure D.11.1, q_u = 840 csm/in
Knowing q_u and T, find q_o/q_i from Figure D.11.2, "Detention Time Versus Discharge Ratios"

Peak outflow discharge/peak inflow discharge (q_o/q_i) = 0.040

With q_o/q_i , compute V_s/V_r ; for a Type II rainfall distribution,

$V_s/V_r = 0.683-1.43(q_o/q_i)+1.64(q_o/q_i)^2-0.804(q_o/q_i)^3$ (App.D.11)
$V_s/V_r = 0.62$

Therefore V_s = 0.62(0.76")(1'/12")(7.6 ac) = 0.30 ac-ft

Drainage Area 2

Initial abstraction (I_a) for CN of 78 is 0.564: (TR-55) [I_a = (200/CN) – 2]

I_a/P = (0.63)/2.6" = 0.22
t_c = 0.19 hours

From Figure D.11.1, q_u = 740 csm/in

Knowing q_u and T, find q_o/q_i from Figure D.11.2, "Detention Time Versus Discharge Ratios"
Peak outflow discharge/peak inflow discharge (q_o/q_i) = 0.050

With q_o/q_i, compute V_s/V_r ; for a Type II rainfall distribution,

$V_s/V_r = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$ (App. D.11)
$V_s/V_r = 0.61$

Therefore V_s = 0.61(0.85")(1'/12")(30.4 ac) = 1.31 ac-ft

Step 3d. Define the Cp_v Release Rate

Drainage Area 1

q_i is known (7.4 cfs), therefore,
$q_o = (q_o/q_i)\ q_i$ = .040 (7.4 cfs) = 0.30 cfs

Drainage Area 2

q_i is known (30.5 cfs), therefore,
$q_o = (q_o/q_i)\ q_i$ = .050 (30.5 cfs) = 1.53 cfs

Step 4. Compute Overbank Flood Protection Volume (Q_p):

Step 4a. Determine Appropriate Q_p Requirement

Location	Type of Peak Control
Eastern Shore	2-year/2-year
All Other Areas	10-year/10-year *

*Varies according to local approval authority.

Because the site is located on the Western Shore, ten-year peak management for quantity control may be required. For the purpose of this example, the local approval authority has not required the ten-year peak management requirement.

Step 5. Extreme Flood Volume (Q_f)

For this example, management of Q_f is not required. However, at final design the 100-year event must be conveyed safely through any stormwater management practices. Based on field observation, downstream conveyance may require analysis for passing the 100-year event through existing infrastructure.

Table 2.5 Summary of General Storage Requirements for Pensyl Pointe

No.	Category	Volume Required		Notes
		Drainage Area 1	Drainage Area 2	
1	Water Quality Volume (WQ_v)	0.20 ac-ft	0.99 ac-ft	
2	Recharge Volume (Re_v)	0.04 ac-ft	0.21 ac-ft	this volume is included within the WQ_v storage
3	Channel Protection Volume (Cp_v)	0.30 ac-ft	1.31 ac-ft	release rates are 0.30 and 1.53 cfs, respectively.
4	Overbank Flood Protection Storage Volume (Q_p)	N/A	N/A	10-year peak management has been waived.
5	Extreme Flood Volume (Q_f)	N/A	N/A	provide safe passage for the 100-year event in final design.

Figure 2.13: Pensyl Pointe, Drainage Area 1 – Post Developed Conditions

RUNOFF CURVE NUMBER COMPUTATION Version 2.00

Project : Pensyl Pointe User: SRC Date: 08-31-98
County : Montgomery State: MD Checked: ____ Date: ________
Subtitle: Design Example 3
Subarea : DRAINAGE AREA 1

COVER DESCRIPTION	Hydrologic Soil Group A	B	C	D
		Acres (CN)		
FULLY DEVELOPED URBAN AREAS (Veg Estab.)				
Open space (Lawns,parks etc.)				
Good condition; grass cover > 75%	-	2.60(61)	1.04(74)	-
Impervious Areas				
Paved parking lots, roofs, driveways	-	1.35(98)	0.90(98)	-
OTHER AGRICULTURAL LANDS				
Woods good	-	-	1.71(70)	-
Total Area (by Hydrologic Soil Group)		3.95	3.65	
		====	====	

SUBAREA: DA 1 TOTAL DRAINAGE AREA: 7.6 Acres WEIGHTED CURVE NUMBER: 76

GRAPHICAL PEAK DISCHARGE METHOD Version 2.00

Project : Comstock Pointe User: SRC Date: 08-31-98
County : Montgomery State: MD Checked: ____ Date: ________
Subtitle: Design Example 3

Data: Drainage Area : 7.6 * Acres
Runoff Curve Number : 76 *
Time of Concentration: 0.15 Hours
Rainfall Type : II
Pond and Swamp Area : NONE

Storm Number	1	2	3	4	5	6	7
Frequency (yrs)	1	2	5	10	25	50	100
24-Hr Rainfall (in)	2.6	3.2	4.2	5.1	5.6	6.3	7.2
Ia/P Ratio	0.24	0.20	0.15	0.12	0.11	0.10	0.09
Used	0.24	0.20	0.15	0.12	0.11	0.10	0.10
Runoff (in)	0.76	1.15	1.89	2.62	3.04	3.64	4.44
Unit Peak Discharge (cfs/acre/in)	1.281	1.315	1.351	1.371	1.379	1.388	1.388
Pond and Swamp Factor 0.0% Ponds Used	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Peak Discharge (cfs)	7	12	19	27	32	38	47

Figure 2.14: Pensyl Pointe, Drainage Area 2 – Post Developed Conditions

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                RUNOFF CURVE NUMBER COMPUTATION          Version 2.00

Project : Pensyl Pointe                         User: SRC      Date: 08-31-98
County  : Montgomery          State: MD       Checked: ____     Date: ________
Subtitle: Design Example 3
Subarea : DRAINAGE AREA 2
-------------------------------------------------------------------------------
                                                    Hydrologic Soil Group
         COVER DESCRIPTION                       A        B        C        D
                                                        Acres (CN)
-------------------------------------------------------------------------------
FULLY DEVELOPED URBAN AREAS (Veg Estab.)
Open space (Lawns,parks etc.)
  Good condition; grass cover > 75%              -     10.4(61) 4.16(74)    -

Impervious Areas
  Paved parking lots, roofs, driveways           -     6.63(98) 4.92(98)    -


OTHER AGRICULTURAL LANDS
Woods                        good                -            - 4.29(70)    -



Total Area (by Hydrologic Soil Group)                  17.0     13.3
                                                       ====     ====
-------------------------------------------------------------------------------
SUBAREA: DA 2   TOTAL DRAINAGE AREA: 30.4 Acres      WEIGHTED CURVE NUMBER: 78

GRAPHICAL PEAK DISCHARGE METHOD            Version 2.00

  Data: Drainage Area        :  30.4   Acres
        Runoff Curve Number  :  78
        Time of Concentration:  0.19   Hours
        Rainfall Type        :  II
        Pond and Swamp Area  :  NONE
=========================================================================
| Storm Number           |   1   |   2   |   3   |   4   |   5   |   6   |   7   |
|------------------------|-------|-------|-------|-------|-------|-------|-------|
| Frequency  (yrs)       |   1   |   2   |   5   |  10   |  25   |  50   |  100  |
| 24-Hr Rainfall (in)    |  2.6  |  3.2  |  4.2  |  5.1  |  5.6  |  6.3  |  7.2  |
| Ia/P Ratio             | 0.22  | 0.18  | 0.13  | 0.11  | 0.10  | 0.09  | 0.08  |
|            Used        | 0.22  | 0.18  | 0.13  | 0.11  | 0.10  | 0.10  | 0.10  |
| Runoff (in)            | 0.85  | 1.27  | 2.05  | 2.80  | 3.23  | 3.85  | 4.66  |
| Unit Peak Discharge    |1.182  |1.214  |1.247  |1.266  |1.274  |1.275  |1.275  |
|    (cfs/acre/in)       |       |       |       |       |       |       |       |
| Pond and Swamp Factor  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  | 1.00  |
|    0.0% Ponds Used     |       |       |       |       |       |       |       |
|------------------------|-------|-------|-------|-------|-------|-------|-------|
| Peak Discharge (cfs)   |   31  |   47  |   78  |  108  |  125  |  149  |  180  |
=========================================================================
```

Section 2.7 Acceptable Urban BMP Options

This section sets forth six acceptable groups of BMPs that can be used to meet the water quality and/or groundwater recharge volume criteria.

2.7.1 Urban BMP Groups

The dozens of different BMP designs currently used in the State of Maryland are assigned into six general categories for stormwater quality control (WQ_v and/or Re_v):

BMP Group 1 stormwater ponds
BMP Group 2 stormwater wetlands
BMP Group 3 infiltration practices
BMP Group 4 filtering practices
BMP Group 5 open channel practices
BMP Group 6 non-structural practices

Within each BMP group, detailed performance criteria are presented that govern feasibility, conveyance, pretreatment, treatment, environmental/landscaping and maintenance requirements (see Chapter 3).

To be considered an effective BMP for stand-alone treatment of WQ_v, a design shall be capable of:

1. capturing and treating the required water quality volume (WQ_v),
2. removing 80% of the TSS,
3. removing 40% of the TP, and
4. having an acceptable longevity rate in the field.

A combination of structural and/or non-structural BMPs are normally required at most development sites to meet all five stormwater sizing criteria. Documentation of the capability of the BMPs to remove TSS is provided in Appendix D.5. Guidance on selecting the most appropriate combination of BMPs is provided in Chapter 4.

BMP Group 1. Stormwater Ponds

Practices that have a combination of a permanent pool, extended detention or shallow wetland equivalent to the entire WQ_v include:

P-1 micropool extended detention pond
P-2 wet pond
P-3 wet extended detention pond

P-4 multiple pond system
P-5 pocket pond

BMP Group 2. Stormwater Wetlands

Practices that include significant shallow wetland areas to treat urban stormwater but often may also incorporate small permanent pools and/or extended detention storage to achieve the full WQ_v include:

W-1 shallow wetland
W-2 ED shallow wetland
W-3 pond/wetland system
W-4 pocket wetland

BMP Group 3. Infiltration Practices

Practices that capture and temporarily store the WQ_v before allowing it to infiltrate into the soil over a two day period include:

I-1 infiltration trench
I-2 infiltration basin

BMP Group 4. Filtering Practices

Practices that capture and temporarily store the WQ_v and pass it through a filter bed of sand, organic matter, soil or other media are considered to be filtering practices. Filtered runoff may be collected and returned to the conveyance system. Design variants include:

F-1 surface sand filter
F-2 underground sand filter
F-3 perimeter sand filter
F-4 organic filter
F-5 pocket sand filter
F-6 bioretention*

* may also be used for infiltration.

BMP Group 5. Open Channel Practices

Vegetated open channels that are explicitly designed to capture and treat the full WQ_v within dry or wet cells formed by checkdams or other means include:

O-1 dry swale
O-2 wet swale

BMP Group 6. Non-structural BMPs

Non-structural BMPs are increasingly recognized as a critical feature of stormwater BMP plans, particularly with respect to site design. In most cases, non-structural BMPs shall be combined with structural BMPs to meet all stormwater requirements. The key benefit of non-structural BMPs is that they can reduce the generation of stormwater from the site; thereby reducing the size and cost of structural BMPs. In addition, they can provide partial removal of many pollutants. The non-structural BMPs have been classified into seven broad categories. To promote greater use of non-structural BMPs, a series of credits and incentives are provided for developments that use these progressive site planning techniques in Chapter 5.

- natural area conservation
- disconnection of rooftop runoff
- disconnection of non-rooftop impervious area
- sheet flow to buffers
- open channel use
- environmentally sensitive development
- impervious cover reduction

2.7.2 Structural BMPs that do not fully meet the WQ_v Requirement

Many current and future stormwater management structures may not meet the performance criteria specified in Section 1.2 above to qualify to be used as "stand-alone" practices for full WQ_v treatment. Reasons for this include poor longevity, poor performance, inability to decrease TSS by 80% and TP by 40%, or inadequate testing. Some of these practices include:

- catch basin inserts
- dry extended detention ponds
- water quality inlets and oil/grit separators
- hydro-dynamic structures
- filter strips
- grass channels
- street sweeping

- deep sump catch basins
- dry wells
- on-line storage in the storm drain network

In some cases, these practices are appropriately used for pretreatment, to meet recharge volume (Re_v) requirements, as part of an overall BMP system, or may be applied in redevelopment situations on a case-by-case basis where other practices are not feasible.

New structural BMP designs are continually being developed, including many proprietary designs. All current and future structural practice design variants should fit in one of the six BMP groups referenced above if the intent is to use them independently to treat the full WQ_v. Current or new BMP design variants cannot be accepted for inclusion on the list until independent pollutant removal performance and monitoring data determine that they can meet the 80% TSS and 40% TP removal targets and that the new BMPs conform with local and/or State criteria for treatment, maintenance, and environmental impact.

Section 2.8 Designation of Stormwater Hotspots

A stormwater hotspot is defined as a land use or activity that generates higher concentrations of hydrocarbons, trace metals or toxicants than are found in typical stormwater runoff, based on monitoring studies. Table 2.6 provides a list of designated hotspots for the State of Maryland. If a site is designated as a hotspot, it has important implications for how stormwater is managed. First and foremost, untreated stormwater runoff from hotspots cannot be allowed to infiltrate into groundwater where it may contaminate water supplies. Therefore, the Re_v requirement is NOT applied to development sites that fit into the hotspot category (the entire WQ_v must still be treated). Second, a greater level of stormwater treatment is needed at hotspot sites to prevent pollutant washoff after construction. This typically involves preparing and implementing a ***stormwater pollution prevention plan*** that involves a series of operational practices at the site that reduces the generation of pollutants by preventing contact with rainfall.

Under EPA's NPDES stormwater program, some industrial sites are required to prepare and implement a stormwater pollution prevention plan. A list of industrial categories that are subject to the pollution prevention requirement can be found in Appendix D.6. In addition, Maryland's requirements for preparing and implementing a stormwater pollution prevention plan are also described in the general discharge permit provided in the same Appendix. The stormwater pollution prevention plan requirement applies to both existing and new industrial sites.

In addition, if a site falls into a "hotspot" category outlined in Table 2.6, a pollution prevention plan may also be required by the appropriate reviewing authority. Golf courses and commercial nurseries may also be required to implement a plan by the appropriate approval authority.

Table 2.6 Classification of Stormwater Hotspots

The following land uses and activities are deemed ***stormwater hotspots:***
➤ vehicle salvage yards and recycling facilities* ➤ vehicle service and maintenance facilities ➤ vehicle and equipment cleaning facilities* ➤ fleet storage areas (bus, truck, etc.)* ➤ industrial sites (for SIC codes outlined in Appendix D.6) ➤ marinas (service and maintenance)* ➤ outdoor liquid container storage ➤ outdoor loading/unloading facilities ➤ public works storage areas ➤ facilities that generate or store hazardous materials* ➤ commercial container nursery ➤ other land uses and activities as designated by an appropriate review authority
* stormwater pollution prevention plan implementation is required for these land uses or activities under the EPA NPDES stormwater program (see Appendix D.6).

The following land uses and activities are not normally considered hotspots:

- residential streets and rural highways
- residential development
- institutional development
- commercial and office developments
- non-industrial rooftops
- pervious areas, except golf courses and nurseries [which may need an Integrated Pest Management Plan (IPM)].

While large highways [average daily traffic volume (ADT) greater than 30,000] and retail gasoline outlet facilities are not designated as stormwater hotspots, it is important to ensure that highway and retail gasoline outlet stormwater management plans adequately protect groundwater.