2.0 Stormwater Management Criteria and Environmental Site Design

This chapter presents a unified approach for managing stormwater runoff and sizing stormwater BMPs in the State of Maryland to meet pollutant removal goals, maintain groundwater recharge, reduce channel erosion, minimize the risk of overbank flooding, and safely pass extreme floods. To meet these goals, Maryland requires an environmental site design (ESD) to the maximum extent practicable (MEP) standard. For new development, the ESD to the MEP standard is addressed when ESD planning techniques are employed, adequate water quality treatment and adequate groundwater recharge are provided in an ESD practice, and downstream channels are adequately protected. For redevelopment, the ESD to the MEP standard is addressed when water quality treatment for 50% of the redeveloped area is provided in an ESD practice, the existing impervious area is reduced by 50%, or a combination of the two is implemented. Maryland also requires quantity management for all new development to reduce the risks of local flooding.

This chapter describes the ESD planning techniques and the five required stormwater management criteria in detail and explains how to size stormwater management practices to ensure compliance with the required criteria for a development site. The five required stormwater management criteria are summarized in Table 2.1.

Table 2.1 Statewide Stormwater Management Criteria

Criteria	**Summary of Stormwater Management Criteria**
Water Quality Volume (WQ_v)	WQ_v is the post-development runoff from the required rainfall depth (P) that is to be treated with water quality management practices. P for the water quality storm is equal to 1.0 inch in the Western Rainfall Zone and 1.5 inches in the Central/Eastern Rainfall Zone.
Recharge Volume (Re_v)	Re_v is the portion of WQ_v that is captured and stored for seepage into the ground. It is dependent on the pre-development soil hydrologic group.
Channel Protection Volume (Cp_v)	The Cp_v is the volume of runoff from the one-year 24-hour design storm adjusted for climate change. The specified runoff volume, is captured, stored, and slowly released to reduce erosive velocities during bankfull and near-bankfull events in downstream channels.
Overbank Flood Protection (q_p)	Overbank flood protection (q_p) controls the peak discharge rate from the post-development design storm event adjusted for climate change, to the pre-development rate, not adjusted for climate change. Management of the ten-year storm event (q_{p10}) is required.
Extreme Flood Protection (q_f)	Extreme flood protection (q_f) controls the peak discharge rate from the post-development extreme flood event. Extreme flood protection is required for interjurisdictional watersheds and may also be required locally by the appropriate reviewing authority in areas prone to flooding.

2.1 Computing Stormwater Management Requirements

Maryland's requirements for stormwater management and BMP sizing are based on managing the runoff from a prescribed amount of rainfall. Water quality volume and recharge volume requirements are based on capturing and treating 90% of the average annual runoff. An analysis of statewide precipitation data has determined that the average rainfall depth that produces 90% of average annual runoff is 1.0 inch in the Western Rainfall Zone and 1.5 inches in the Central/Eastern Rainfall Zone of Maryland, as shown in Figure 2.1. Design requirements for channel protection volume, overbank flood protection, and extreme flood protection are based on controlling runoff from the one-year, 10-yr, and 100-yr, 24-hour duration storms, respectively. Rainfall depths (P) for these design storms are provided for each Maryland county in Table 2.2.

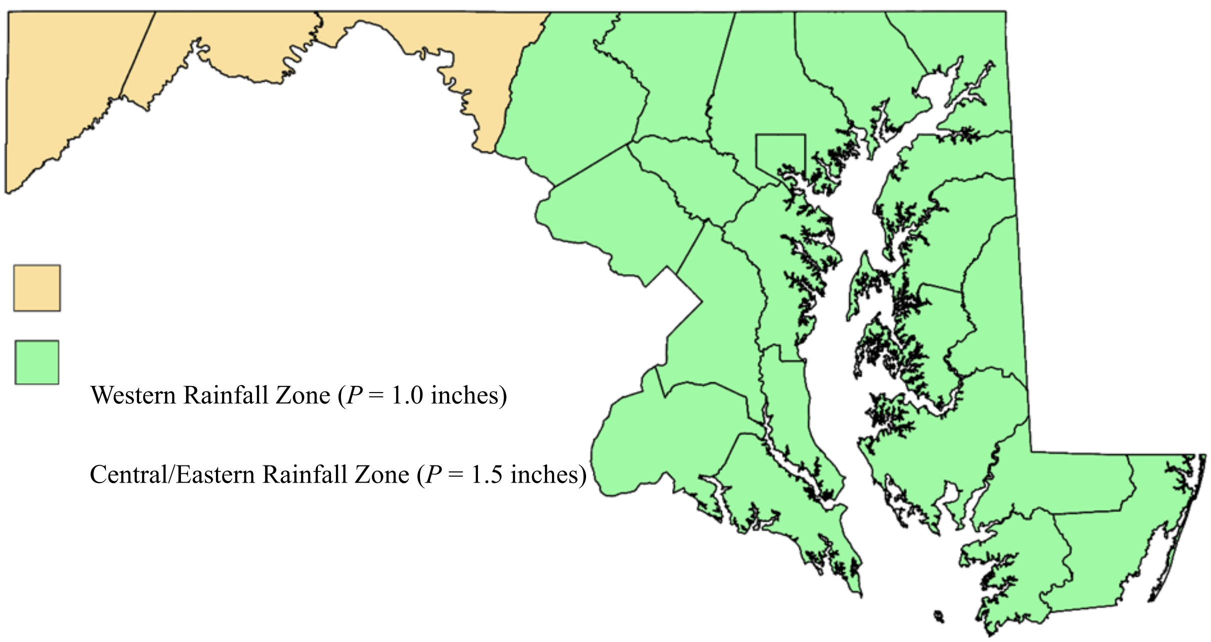

Figure 2.1 Location of the Western and Central/Eastern Rainfall Zones in Maryland for Determining the Water Quality Storm

Table 2.2 Rainfall Depths (P) for Design Storms in Maryland

County		Rainfall Depth (P) (inches)						
		Water Quality Storm	1 yr, 24 hr		10 yr, 24 hr		100 yr, 24 hr	
			Atlas 14	Adjusted[1]	Atlas 14	Adjusted[1]	Atlas 14	Adjusted[1]
			Pre	Post	Pre	Post	Pre	Post
Allegany		1.0	2.07	2.50	3.64	4.38	5.96	7.17
Anne Arundel		1.5	2.64	3.14	4.94	5.73	8.53	9.89
Baltimore[2]		1.5	2.70	3.21	5.01	5.81	8.65	10.03
Calvert		1.5	2.73	3.30	5.17	6.12	8.93	10.57
Caroline		1.5	2.70	3.19	5.13	6.07	8.84	10.46
Carroll		1.5	2.54	3.00	4.69	5.57	8.06	9.56
Cecil		1.5	2.66	3.09	4.87	5.73	8.10	9.53
Charles		1.5	2.67	3.23	5.04	5.96	8.70	10.30
Dorchester		1.5	2.77	3.13	5.27	6.01	9.08	10.35
Frederick	Catoctin	1.5	2.54	2.92	4.51	5.31	7.44	8.75
	Frederick	1.5	2.54	2.92	4.63	5.31	7.94	8.75
Garrett		1.0	2.13	2.41	3.69	4.22	5.99	6.85
Harford		1.5	2.70	3.19	5.00	5.85	8.57	10.03
Howard		1.5	2.64	2.98	4.91	5.65	8.47	9.74
Kent		1.5	2.66	3.01	5.01	5.91	8.63	10.18
Montgomery		1.5	2.57	3.01	4.77	5.52	8.23	9.52
Prince George’s		1.5	2.63	3.02	4.92	5.74	8.49	9.91
Queen Anne’s		1.5	2.67	3.12	5.06	5.97	8.72	10.29
St. Mary’s		1.5	2.77	3.19	5.24	6.13	9.04	10.58
Somerset		1.5	2.65	3.02	5.01	5.81	8.64	10.02
Talbot		1.5	2.74	3.12	5.19	6.00	8.97	10.38
Washington	East	1.0	2.52	2.85	4.41	5.19	7.30	8.59
	West	1.0	2.37	2.68	4.11	4.19	6.40	8.59
Wicomico		1.5	2.13	3.23	5.34	6.14	9.22	10.60
Worcester			2.70	3.32	5.34	6.25	9.23	10.80

1. 1, 10, and 100-year, 24-hour design storms from NOAA Atlas 14 and adjusted to reflect climate change using the MARISA tool county climate change factors for the 100-year median confidence level for the 8.5 Representative Concentration Pathway (RCP) and 2050-2100 time period
2. Includes Baltimore City and Baltimore County

2.1.1 Computing WQ_v, Re_v, and Cp_v

The stormwater management criteria for WQ_v, Re_v, and Cp_v, are functions of direct runoff depth (Q). Direct runoff is the portion of precipitation that flows over the surface of the ground when it rains. The depth of this direct runoff is expressed in inches of rainfall over the drainage area. The drainage area retains some rainfall before runoff begins. This portion of the rainfall that does not contribute to runoff is called the initial abstraction. The initial abstraction includes rainfall that is lost early in the storm due to processes like evaporation, interception by vegetation, infiltration into the soils, and depression storage. The remaining rainfall results in direct runoff.

Direct runoff depth is also affected by the soil type, land cover type, and the hydrologic condition of the drainage area. These factors along with the antecedent runoff condition are used to determine the Curve Number (CN) of the drainage area. The CN is a dimensionless parameter used to estimate the runoff depth. The methodology for calculating direct runoff depth (Q) was developed by the Natural Resources Conservation Service Runoff (NRCS) and is described in detail in the National Engineering Handbook (NEH), Part 630, Chapter 10 – Estimation of Direct Runoff from Storm Rainfall (NRCS, 2021).

- Direct runoff depth (Q) is determined using the equations below:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad \text{(Equation 2.1)}$$

and

$$S = \left(\frac{1000}{CN}\right) - 10 \qquad \text{(Equation 2.2)}$$

Based on $I_a = 0.2S$ and where:

I_a = initial abstraction (inches)
S = the potential maximum retention (inches) related to the CN through soil and cover conditions
Q = depth of runoff (inches)
P = depth of rainfall (inches) provided in Table 2.2 for the county where the project is located and the applicable design storm

CNs shall reflect NRCS land use/impervious cover relationships. [See Tables 9-1 to 9-5, NRCS NEH, Part 630, Chapter 9 - Hydrologic Soil-Cover Complexes (2004).]

Table 2.3 presents the direct runoff depth (Q) for specific CNs and rainfall depths (P). Q for the associated site area or drainage area shall be determined using Table 2.3 for the applicable CNs and rainfall depths (P). For values of P greater than 3.3 inches, use the above equations.

2.1.2 Weighted Direct Runoff Depth for Computing WQ_v and Cp_v

The direct runoff depth from a development site is a combination of direct runoff from impervious area and direct runoff from pervious area. Impervious area is defined as any surface that does not allow stormwater to infiltrate into the ground. Gravel roads, driveways, and parking lots are included as surfaces considered impervious. Pervious areas include vegetated areas, alternative surfaces identified in Chapter 3, and uncompacted gravel, stone, and riprap areas (used as ground cover and not intended to be driven over). For the WQ_v and Cp_v, the Q shall be calculated for the impervious areas using CN of 98, and for pervious areas using the applicable CNs for the pervious areas. Where there is a combination of impervious and pervious areas, a weighted direct runoff depth (Q_w) shall be determined from the impervious runoff depth (Q_i) and the pervious runoff depth (Q_p) as follows:

$$Qw \times A = (Qi \times Ai) + (Qp \times Ap) \qquad \text{(Equation 2.3)}$$

where:

$$A = Ai + Ap \qquad \text{(Equation 2.4)}$$

Substituting Equation 2.4 into Equation 2.3 gives:

$$Qw = \frac{Qi \times Ai}{A} + \frac{Qp \times Ap}{A} \qquad \text{(Equation 2.5)}$$

where:

A_i = impervious area
A_p = pervious area
A = total area
Q_w = weighted runoff depth, in inches
Q_i = runoff depth for the impervious area, in inches
Q_p = runoff depth for the pervious area, in inches

Note that a weighted CN is not used to calculate Q_w and that:

$$Qw \neq Qi + Qp \qquad \text{(Equation 2.6)}$$

Q_i and Q_p shall each be determined using Table 2.3. Q_i and Q_p are then used to determine WQ_v and Cp_v in accordance with Sections 2.2 and 2.4.

Table 2.3 Direct Runoff Depth (Q) for Selected CNs and Rainfall Depth (P)

	Q = Direct Runoff Depth (inches) for Curve Number (CN) of:											
P=Rainfall Depth (inches)	39	48	55	61	67	74	77	80	85	89	91	98
1.0**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.28	0.36	0.79
1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.22	0.35	0.43	0.89
1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.15	0.27	0.41	0.50	0.99
1.3	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.19	0.33	0.48	0.58	1.08
1.4	0.00	0.00	0.00	0.00	0.00	0.12	0.17	0.24	0.39	0.56	0.66	1.18
1.5***	0.00	0.00	0.00	0.00	0.00	0.15	0.21	0.29	0.45	0.63	0.74	1.28
1.6	0.00	0.00	0.00	0.00	0.00	0.18	0.25	0.34	0.52	0.71	0.82	1.38
1.7	0.00	0.00	0.00	0.00	0.00	0.22	0.30	0.39	0.58	0.78	0.91	1.48
1.8	0.00	0.00	0.00	0.00	0.12	0.26	0.35	0.44	0.65	0.86	0.99	1.58
1.9	0.00	0.00	0.00	0.00	0.14	0.30	0.40	0.50	0.72	0.95	1.08	1.68
2.0	0.00	0.00	0.00	0.00	0.17	0.35	0.45	0.56	0.80	1.03	1.16	1.77
2.1	0.00	0.00	0.00	0.00	0.21	0.40	0.50	0.62	0.87	1.11	1.25	1.87
2.2	0.00	0.00	0.00	0.12	0.24	0.45	0.56	0.69	0.94	1.20	1.34	1.97
2.3	0.00	0.00	0.00	0.14	0.28	0.50	0.62	0.75	1.02	1.28	1.43	2.07
2.4	0.00	0.00	0.00	0.17	0.32	0.55	0.68	0.82	1.10	1.37	1.52	2.17
2.5	0.00	0.00	0.00	0.20	0.36	0.61	0.74	0.89	1.18	1.45	1.61	2.27
2.6	0.00	0.00	0.10	0.23	0.40	0.67	0.80	0.96	1.26	1.54	1.70	2.37
2.7	0.00	0.00	0.12	0.26	0.44	0.72	0.87	1.03	1.34	1.63	1.79	2.47
2.8	0.00	0.00	0.14	0.29	0.49	0.78	0.93	1.10	1.42	1.72	1.89	2.57
2.9	0.00	0.00	0.17	0.33	0.54	0.85	1.00	1.18	1.50	1.81	1.98	2.67
3.0	0.00	0.00	0.19	0.37	0.58	0.91	1.07	1.25	1.59	1.90	2.07	2.77
3.1	0.00	0.00	0.22	0.40	0.64	0.97	1.14	1.33	1.67	1.99	2.16	2.87
3.2	0.00	0.00	0.25	0.44	0.69	1.04	1.21	1.40	1.76	2.08	2.26	2.97
3.3	0.00	0.11	0.28	0.49	0.74	1.10	1.28	1.48	1.84	2.17	2.35	3.07

* For rainfall depths and CNs not shown, either interpolate the values from the two closest data points, or use equations to determine depths

** Rainfall depth for the Western Rainfall Zone = 1.0 inch

*** Rainfall depth for the Central/Eastern Rainfall Zone = 1.5 inches

2.2 Water Quality Volume (WQ_v)

To meet Maryland's water quality treatment requirement, all new development impervious areas within the development site shall be treated for the specified runoff depth that corresponds to 90% of the average annual runoff, using one or more ESD practices from Chapter 3. When classified as redevelopment per Section 2.8, 50% of the redevelopment impervious area shall be treated for the same specified runoff depth.

ESD practices are either area-based or volume based and range from vegetative enhancements to small structures. The total impervious area treated by both area and volume-based practices must meet or exceed the total impervious area required to be treated for the development site. ESD area-based practices such as rooftop or non-rooftop disconnections treat the impervious areas draining to them. In the case of alternative surfaces, the surface area of the alternative surface is the treated impervious area. The impervious area treated by area-based practices can be deducted from the total impervious area requiring treatment. ESD volume-based practices, such as micro-bioretention, capture, store, and treat a specified runoff volume, known as the water quality volume (WQ_v). Both area and volume-based ESD practices must be properly sized and designed in accordance with Chapter 3.

Stormwater design engineers and approval authorities must ensure that sufficient treatment is provided for both the required impervious area and the corresponding direct runoff depth. Simply providing the required WQ_v for the development site without ensuring the impervious areas are adequately treated by the individual practices does not ensure that the water quality treatment requirement is satisfied. The stormwater design process requires verification that the direct runoff from the development site impervious area drains to properly sized and designed ESD practices in accordance with this Manual.

The WQ_v equation is used to size volume-based ESD practices to capture and treat the specified runoff for the rainfall zone. The WQ_v is a function of the weighted direct runoff depth (Q_w) and drainage area (A) which are determined using Equations 2.1 through 2.5 as described above. The weighted direct runoff is based on rainfall depths (P) of 1.0 inch in Maryland's Western Rainfall Zone and 1.5 inches in Maryland's Central/Eastern Rainfall Zone. (See Figure 2.1.). A volume-based ESD practice must always be sized for its contributing drainage area using the following equation:

$$WQ_v = \frac{Qw \times A}{12\ in/ft} \qquad \text{(Equation 2.7)}$$

As described in Section 2.1.2, Q_w is based on separate calculations for the impervious areas and pervious areas. Substituting Equation 2.5 into Equation 2.7 gives:

$$WQ_v = \frac{Qi \times Ai}{12\, in/ft} + \frac{Qp \times Ap}{12\, in/ft} \qquad \text{(Equation 2.8)}$$

where:

Q_i = the direct runoff depth from the impervious area calculated based on a CN of 98 and a P of 1.0 inch or 1.5 inches, depending on the rainfall zone. Referring to Table 2.3, Q_i equals 0.79 inches for the Western Rainfall Zone and 1.28 inches for the Central/Eastern Rainfall Zone.

Q_p = the direct runoff depth from the pervious area calculated based on the weighted pervious CN and a P of 1.0 inch (Western Rainfall Zone) or 1.5 inches (Central/Eastern Rainfall Zone) as provided in Table 2.3 or calculated using Equations 2.1 and 2.2.

A_i = impervious area within the drainage area to the BMP

A_p = pervious area within the drainage area to the BMP

2.2.1 Determining the Water Quality Treatment and WQ_v

The following represent the minimum standards for calculating the water quality treatment requirement:

- The water quality treatment requirement for the development site is satisfied when the requisite impervious area is treated for the direct runoff depth (Q_i) from a rainfall (P) of 1.0 inch for development located in Maryland's Western Rainfall Zone and 1.5 inches for development located in Maryland's Central/Eastern Rainfall Zone. This corresponds to a runoff depth of 0.79 inch (Western Rainfall Zone) or 1.28 inches (Central/Eastern Rainfall Zone). See Table 2.3. Note that treating more rainfall than required for the rainfall zone does not result in additional water quality treatment. However, depending on the design and the type of BMP, the additional volume may be used to meet Cp_v requirements.

- The water quality treatment requirement shall be expressed in terms of the impervious area treated for a certain depth of rainfall. This provides a way to account for BMPs that provide partial water quality treatment. In addition, this tracking method accommodates both area-based and volume-based BMPs.

- The impervious area requiring water quality treatment shall be calculated for the drainage area to each discharge point from the development site.

- When there are multiple discharge points from a development site, the water quality treatment requirement for the different discharge points shall be provided within the development site. Treatment is not required to be provided within the drainage area to the specific discharge point, unless the project is divided by multiple Maryland 12-Digit

Watersheds. Water quality treatment shall be addressed separately for each 12-Digit Watershed.

- When a discharge point is located in a Tier II watershed, the water quality treatment requirement shall always be provided in that watershed at the Maryland 12-digit watershed scale.

- The area occupied by a volume-based BMP (i.e., footprint) shall be considered pervious when calculating the impervious area requiring water quality treatment, sizing the practice, calculating the treated rainfall, and computing the treated impervious area.

- For new development, the water quality treatment requirement shall be provided by one or more ESD practices.

- For redevelopment, the use of non-structural ESD practices should be maximized (refer to Chapter 3, Section 3.3.1).

- For area-based ESD practices that provide vegetative enhancements without storing runoff, the water quality treatment provided is based on the impervious area that is directed to the practice or the area of the practice (i.e., alternative surfaces). These practices include nonstructural and alternative surfaces. When designed in accordance with Chapter 3, the impervious areas treated by area based nonstructural practices and the areas of the alternative surfaces shall be subtracted from the total impervious area requiring water quality treatment for the development site. The remaining impervious area shall be treated by a volume-based practice(s).

The following represent the minimum standards for volume-based BMPs:

- When sizing a volume-based practice, the WQ_v shall be based on the weighted runoff depth and the drainage area to the BMP and is calculated using Equation 2.8. Note that the required BMP volume for the drainage area is a function of both the impervious and pervious areas, yet the water quality treatment requirement is only a function of impervious area.

- For the purpose of determining CNs for the post-development conditions:
    - The measured area of a development site that does not have vegetative or permeable cover shall be considered as the total impervious cover and shall be represented by a CN of 98. Gravel areas used for vehicular purposes, such as roads, driveways, and parking lots, shall be included as impervious surface.
    - Pervious areas including vegetated areas, alternative surfaces, uncompacted gravel, stone, and riprap areas (used as ground cover and not intended to be driven over) shall be represented by the appropriate CNs for the respective HSG.
    - All vegetated areas within a development site shall be considered as open space in good

  condition for the respective HSG.
  - o Any vegetated areas outside the development site should be modeled based on actual land use.
  - o Alternative surfaces shall use the appropriate CNs as provided in Section 3.1.

- ➢ The WQ_v shall be provided off-line from the primary conveyance system so that storms larger than the WQ_v design storm are directed away from (i.e., bypassed around) the water quality practice. When WQ_v and Cp_v are being managed together in an ESD practice, the 1-year 24-hour storm shall be conveyed to the ESD practice, and storms larger than the 1-year 24-hour storm shall be bypassed around the ESD practice.

- ➢ Runoff from off-site areas shall be diverted away from or bypassed around all ESD practices. Off-site areas should be bypassed around any structural practices that provide water quality treatment using filtration or infiltration. If bypass is not feasible, the structural practice shall be sized to provide water quality treatment for the entire contributing drainage area. Treating impervious area from outside the property on which the development site is located shall not count towards meeting the development site water quality treatment requirement.

- ➢ For volume-based practices, the storage volume provided, and the BMP drainage area will determine the level of water quality treatment provided. Computing the treated rainfall and treated impervious area shall be based on the following steps:

  1. Calculate the required WQ_v. Use Equation 2.8 to determine the volume required to fully treat the impervious area draining to the BMP for the entire water quality design storm. (i.e., for P = 1.0 inch in the Western Rainfall Zone or P = 1.5 inches in the Central/Eastern Rainfall Zone). This is the maximum volume that can be attributed to water quality requirements. Provided volumes greater than this (up to the 1-year storm) may be used to meet channel protection volume requirements in accordance with Section 2.4.1.
  2. Calculate the provided WQ_v. The provided WQ_v is not always the provided water quality storage volume[1]. For certain BMPs, such as micro-bioretention, only 75% of the provided WQ_v needs to be stored in the BMP.

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[1] For reference, comparison, and consistency, these terms related to water quality refer to the following:
- o The "required WQ_v" is based on the drainage area to the BMP and the required rainfall depth to treat the water quality storm (i.e., 1.0 inch or 1.5 inch depending on the rainfall zone). It is also the maximum volume that can be attributed to water quality requirements.
- o The "water quality storage volume" is the actual, physical storage volume provided by the BMP for water quality purposes as specified in Chapter 3.

3. Calculate the treated rainfall depth (P). If the provided WQ_v is equal to or greater than the required WQ_v for the BMP, then the treated P equals 1.0 inch in the Western Rainfall Zone or 1.5 inches in the Central/Eastern Rainfall Zone[2]. If the provided WQ_v is less than the required WQ_v for the BMP, then the P treated by the BMP is calculated based on the following linear relationship:

$$treated\ P\ = \left(\frac{provided\ WQ_v}{required\ \ WQ_v\,for\ the\ BMP}\right) \times required\ P\ for\ Rainfall\ Zone$$

(Equation 2.9)

- The impervious area treated by a volume-based BMP is expressed as the "effective impervious area". The effective imperious area treated equals the product of the impervious drainage area to the BMP and the treated rainfall. Note that treating more rainfall than required does not result in additional water quality treatment.

- The sum of the effective impervious areas treated by volume-based BMPs plus the impervious area treated by area-based BMPs shall equal or exceed the impervious area requiring water quality treatment for the development site.

Table 2.4 Effective Impervious Area Treated

Western Rainfall Zone

When treated P < 1.0 in:	effective impervious area treated = A_i to BMP x treated P/1.0 in
When treated P ≥ 1.0 in:	effective impervious area treated = A_i to BMP

Central/Eastern Rainfall Zone

When treated P < 1.5 in:	effective impervious area treated = A_i to BMP x treated P/1.50 in
When treated P ≥ 1.5 in:	effective impervious area treated = A_i to BMP

- The "provided WQ_v" is the water quality storage volume divided by the requisite percentage of storage for the type of BMP.

[2] For treated P's larger than the WQ storm, if the actual treated P is needed, it is calculated by substituting Equations 2.1 and 2.2 into Equation 2.8. The known values are the WQ_v provided by the BMP, the A_i, the impervious CN, the A_p, and the pervious CN for the drainage area to the BMP. Because P is a repeating variable, the solution requires iterating.

2.3 Recharge Volume (Re_v)

The intent of the recharge criteria is to maintain existing groundwater recharge rates at development sites by introducing runoff into the ground. This helps to preserve existing water table elevations to maintain the hydrology of streams and wetlands. The volume of recharge that occurs on a site depends on slope, soil type, vegetative cover, precipitation, and evapotranspiration. Sites with natural ground cover, such as forest and meadow, have higher recharge rates, less runoff, and greater transpiration under most conditions. Because development increases impervious surfaces, the amount of water that replenishes the groundwater table and aquifers decreases from the natural recharge rate.

The criterion for maintaining groundwater recharge is based on the average annual recharge rate of the hydrologic soil groups (HSG) present at a development site as determined from USDA, NRCS Soil Surveys or from data derived from development site soils investigations. The proportion of runoff that can infiltrate into the ground is represented by the soil specific recharge factor (R_f). The listed R_f values were calculated from the USDA average annual recharge volume per soil type divided by the average annual rainfall in Maryland (45 inches per year) (Horsely, 1996). The amount of runoff from a developed area that needs to be captured and infiltrated into the ground to replicate natural recharge is calculated by applying the R_f to the runoff from 90% of the average annual rainfall (i.e., the "water quality storm").

The Re_v requirement is calculated using the following equation:

$$Re_v = R_f \times \frac{Qi \times Ai}{12\ in/ft} \qquad \text{(Equation 2.10)}$$

where:

R_f = soil specific recharge factor
Q_i = direct runoff depth (inches) from the impervious area for the water quality design storm
A_i = impervious area within the development site

The soil specific recharge factors for each HSG are:

Hydrologic Soil Group (HSG)	Soil Specific Recharge Factor (R_f)
A	0.40
B	0.27
C	0.13
D	0.07

2.3.1 Determining Recharge Volume

The following represent the minimum standards for calculating the Re_v requirement:

- Re_v shall be provided for the post-development impervious area within the development site and shall be addressed using an acceptable ESD practice in accordance with Chapter 3. When area-based ESD practices are designed to meet Re_v, the impervious areas treated by these practices shall be subtracted from the total impervious area required to be treated for the development site. The remaining impervious area shall be used in Equation 2.9 to calculate the remaining Re_v requirement.

- When a development site contains multiple points of discharge, the Re_v requirement for the drainage areas may be addressed either separately or cumulatively within the development site.

- The HSG used to determine R_f is based on the soils that are present in the location of the impervious area in the development site. If more than one HSG is present, a composite soil specific recharge factor shall be computed.

- For volume-based ESD practices, only that storage volume that is held in a position to infiltrate into the ground shall contribute to the provided Re_v.

- Storage provided within a BMP may contribute toward both provided WQ_v and provided Re_v if the volume meets the design requirements for both WQ_v and Re_v in accordance with Chapter 3.

- Re_v may be provided separately or upstream of the WQ_v treatment. Re_v may also be in-line with the primary conveyance system. In these situations, the Re_v storage volume shall not contribute to the WQ_v.

- A BMP sized greater than the Re_v requirement for the contributing drainage area does not result in more provided Re_v.

- BMPs that are constructed with impermeable liners, intercept groundwater, or are designed for trapping sediment (e.g., forebays) shall not be used for meeting the Re_v requirement.

- BMPs with underdrain systems shall provide a reservoir for storing volume below the underdrain. The volume of the reservoir shall be equal to or greater than the Re_v requirement so that recharge below the invert of the outlet may occur. Storage above the invert of the underdrain outlet does not contribute to meeting the Re_v requirement.

- The recharge volume provided at the development site should be located in the most permeable soils on-site.

- The recharge volume requirement does not apply to, nor should recharge be located in, any portion of a development site that is:
  - Identified as a stormwater hotspot in Chapter 4; or
  - Situated on unsuitable soils (e.g., marine clays), karst, or other geological features where providing recharge could be problematic.

- The recharge volume requirement does not apply to redevelopment projects or discharge points categorized as redevelopment, unless specified by the approving agency.

2.4 Channel Protection Volume (Cp_v)

To protect receiving channels and streams from erosion, the runoff from the one-year 24-hour storm, adjusted for climate change, shall be captured, stored, and slowly released over an extended period of time. The rationale for this criterion is that runoff stored and released in a gradual manner reduces the occurrence of critical erosive velocities during bankfull and near-bankfull events. The release time shall be either 36 hours or 18 hours depending on the use-class of the watershed.

The Cp_v equation is a function of the weighted direct runoff depth (Q_w) in inches and area (A). Q_w is determined from the rainfall depth (P) in inches and the post-development curve number (CN), using the NRCS method for estimating direct runoff from rainfall presented in Section 2.1.2. This method requires separate calculations for runoff from impervious area and runoff from pervious area. Table 2.2 is used to determine the rainfall depth (P) associated with the one-year 24-hour design storm, adjusted for climate change, for the county where the project is located. Table 2.3 or Equations 2.1 and 2.2 are used to calculate the direct runoff depth from the impervious area (Q_i) and the direct runoff depth from the pervious area (Q_p) for P and the respective CNs for post-development conditions.

The Cp_v requirement is determined using the following equation:

$$Cp_v = \frac{Qw \times A}{12\ in/ft} \qquad \text{(Equation 2.11)}$$

Substituting Equation 2.5 into Equation 2.10 gives:

$$Cp_v = \frac{Qi\ \times Ai}{12\ in/ft} + \frac{Qp\ \times Ap}{12\ in/ft} \qquad \text{(Equation 2.12)}$$

where:

Q_w = weighted direct runoff depth (inches) for one-year storm, 24-hour design, adjusted for climate change

Q_i = direct runoff depth (inches) for impervious CN of 98 for one-year storm, 24-hour design, adjusted for climate change

Q_p = direct runoff depth (inches) for pervious areas for one-year storm, 24-hour design, adjusted for climate change

A = total area

A_i = impervious area in post-development conditions

A_p = pervious area in post-development conditions

2.4.1 Determining Channel Protection Volume

The following represent the minimum standards for calculating the Cp_v requirement:

- The rainfall depth (P) used to calculate Cp_v shall be the one-year, 24-hour design storm, adjusted for climate change, as provided in Table 2.2.

- The Cp_v requirement shall be addressed for all new development.

- The Cp_v requirement shall be addressed when development creates a hydrologic or hydraulic change.

- The Cp_v requirement shall be addressed for each discharge point from the development site containing new development

- When a development site is divided into multiple drainage areas, the Cp_v requirement shall be addressed for each discharge point from the development site, and the required management shall be provided within the respective discharge point.

- The Cp_v requirement does not apply to any portion of the development site that has a direct discharge to tidal waters.

- Equations 2.10 and 2.11 shall be used to calculate the Cp_v requirement for each discharge point. When calculating the Cp_v requirement for the discharge point, A is the area of the development site within the drainage area to the discharge point, and Q_w is the weighted runoff depth for A.

- When calculating the Cp_v requirement, the area (i.e., footprint) occupied by stormwater BMPs shall be considered pervious. However, when sizing or modeling a BMP, the surface area of the BMP shall be considered impervious.

- The Cp_v requirement is satisfied when the sum of the Cp_v provided by BMPs within the discharge point equals or exceeds the required Cp_v for the discharge point. The Cp_v provided is the runoff volume that reaches the BMP, not the requisite storage volume for the practice (e.g., 75% for micro-bioretention).

The following represent the minimum standards for meeting the channel protection requirement and sizing a BMP using the Equation 2.11.

- The Cp_v requirement shall be provided by either an ESD practice or a structural practice, based on the following:

- For discharge points located in all class watersheds except Use Class III/IV:
  - Where the Cp_v requirement for the discharge point from the development site is less than or equal to 8,000 cubic feet, the Cp_v shall be managed exclusively in ESD practices.
  - Where the Cp_v requirement for the discharge point is greater than 8,000 cubic feet, the Cp_v for the discharge point shall be managed exclusively in one or more structural practices. If in-situ soils allow for more than 0.52 inches per hour (soil testing required), the rate of infiltration may be used in determining the Cp_v sizing. Where underdrains are utilized, the rate of discharge from the underdrain must be controlled to slowly release the Cp_v volume over 36 hours. A removable cap with a small hole may be utilized to accomplish the slow-release rate.

- For discharge points located in Use Class III/IV watersheds:
  - Where the Cp_v requirement for the discharge point is less than or equal to 4,000 cubic feet, the Cp_v shall be managed exclusively in ESD practices. ESD practices slowly release the Cp_v through filtration and infiltration.
  - Where the Cp_v requirement for the discharge point is greater than 4,000 cubic feet, the Cp_v for the discharge point shall be managed exclusively in one or more structural practices. If in-situ soils allow for more than 0.52 inches per hour (soil testing required), the rate of infiltration may be used in determining the Cp_v sizing. Where underdrains are utilized, the rate of discharge from the underdrain must be controlled to slowly release the Cp_v volume over 18 hours. A removable cap with a small hole may be utilized to accomplish the slow-release rate.

➢ Equations 2.10 and 2.11 shall be used to size a BMP for providing Cp_v. When sizing the BMP to provide Cp_v, A is the drainage area to the practice, and Q_w is the weighted runoff depth for the drainage area.

➢ For the purpose of determining CNs for the post-development conditions:

- The measured area of a development site that does not have vegetative or permeable cover shall be considered the total impervious area and shall be represented by a CN of 98 for determining direct runoff depth, Q_p. Gravel roads, driveways, and parking lots are included as surfaces considered as impervious Pervious areas include vegetated areas, alternative surfaces, and uncompacted gravel, stone, and riprap areas (used as ground cover and not intended to be driven over), shall be represented by the appropriate CNs for the respective HSG.
- All vegetated areas within a development site shall be considered as open space in good condition for the respective HSG.
- Any vegetated areas outside the development site should be modeled based on actual land use.
- Alternative surfaces shall use the appropriate CNs as shown in Section 3.1.

- Reduced CNs such as presented in "Change in Runoff Curve Number Method" (McCuen, R., 1983) cannot be used.

- Runoff from off-site areas shall be diverted away from or bypassed around all ESD practices. Off-site areas that drain to the site should be bypassed around any structural practices that provide water quality treatment using filtration or infiltration. If bypass is not feasible for structural practices, the BMP shall be sized to safely pass runoff from the entire contributing drainage area. The Cp_v requirement does not include the off-site areas.

- When computing peak discharge rates related to the Cp_v design, the models TR-55 and WinTR-20 (or an equivalent model based on TR-20 methodology, as approved by the approving agency) shall be used. Peak discharges for the 1-year storm may be calculated using a weighted curve number for the drainage area rather than the weighted direct runoff depth used to calculate the Cp_v. Any adjustments for unique land features, such as karst topography, shall be determined by the local approval authority with MDE's concurrence. The Eastern Shore Dimensionless Hydrograph shall be used for sites located in the Delmarva peninsula. Refer to Appendix F.

- Successful channel protection is dependent on slowly releasing the stored runoff volume over a specified time. In all watersheds except Use Class III/IV, the Cp_v requirement shall be discharged over 36 hours. If the development is located in watersheds that are identified on the Maryland Department of Natural Resources Cold Water Resources Mapping Tool as cold-water resources watersheds, Maryland Trout Watersheds, Put and Take Trout Watersheds, Benthic Cold-Water Macroinvertebrates, or Use Class III or Use Class IV watersheds, the Cp_v requirement shall be discharged over 18 hours.

- ESD practices depend on a combination of filter media and infiltration to slowly release the Cp_v and do not have outflow control orifices for Cp_v. It is not necessary to calculate the Cp_v release rate when using ESD practices to manage Cp_v. Refer to Section 2.4.2.

- Structural practices depend on an outflow orifice control to slowly release the Cp_v, unless the Cp_v is being managed through infiltration in accordance with Chapter 3. Refer to Section 2.4.3.

2.4.2 Designing ESD practices to Manage Cp_v

- ESD practice performance for meeting Cp_v is dependent on flow passing slowly through a media layer or infiltrating into the ground. An outflow control device is not required or allowed because the Cp_v managed by an ESD practice is too small to control with an orifice. Cp_v management in an ESD practice is provided solely through filtration or infiltration.

- ESD practices used to manage Cp_v shall be designed and constructed in accordance with Chapter 3. ESD practices that do not store runoff cannot be used to manage Cp_v.

- When Cp_v is being managed in an ESD practice, the 1-year storm shall be conveyed to the ESD practice, and storms larger than the 1-year storm shall be bypassed around the ESD practice.

- When an ESD practice is used to manage both WQ_v and Cp_v, the design volume shall be the larger volume. For new development, where Cp_v is managed in an ESD practice, the WQ_v treatment is also met (i.e., the Cp_v includes the WQ_v).

2.4.3 Designing Structural BMPs to Manage Cp_v

- Structural BMPs used to manage the Cp_v shall be designed to capture and store a specified volume, referred to as the extended detention storage, for slow release over 36 hours (or 18 hours for cold water resources). The extended detention storage volume provided in the BMP shall be at least 62% of the required Cp_v for BMPs located in all watersheds except Use Class III/IV, and at least 56% of the required Cp_v for BMPs located in Use Class III/IV watersheds.

- The Cp_v design release rate shall be calculated by dividing the Cp_v (i.e., runoff volume) by the required release time for the watershed (i.e., 36 hours or 18 hours). This is the average discharge rate for the Cp_v control opening. The required outflow control opening size for the extended detention design shall be computed using the orifice or weir flow equation, an appropriate orifice or weir flow coefficient for the storage volume, and the maximum Cp_v storage volume depth divided by two. The required control opening is the maximum allowable size. Because of the potential for clogging, outflow control openings less than 3.0 inches in diameter shall include protection with an internal control. Control openings less than 1.0 inch in diameter, even with protection, shall not be used.

2.5 Overbank Flood Protection (q_p)

The primary purpose of the Overbank Flood Protection (q_p) requirement is to reduce the risk of an increase in the frequency and magnitude of localized flooding due to development and conveyance capacity limitations. The q_p management shall be based on controlling the 10-year 24-hour design storm by providing sufficient storage to attenuate the post-development peak discharge rates to pre-development rates as follows:

- Pre-development peak discharge rates (q_p pre) shall be based on the q_p design storm as determined using current rainfall from NOAA Atlas 14 (see Table 2.2, "pre").

- Post-development peak discharge rates (q_p post) shall be based on the q_p design storm, adjusted for climate change as shown (see Table 2.2, "post").

The rainfall depths used for determining pre-development and post-development peak discharge rates are shown in Table 2.2.

Adoption of the NOAA Atlas 14 precipitation data requires the use of NOAA rainfall distribution curves developed from the improved Atlas 14 data. The NRCS Type II rainfall distribution curve previously used in Maryland is not consistent with NOAA Atlas 14. The NOAA rainfall distributions range from the most intense (NOAA A) to the least intense (NOAA D). Most of Maryland is represented by NOAA C (see Figure 2.2). Western Maryland is represented by NOAA B. Portions of Wicomico and Worcester counties are represented by NOAA D; however, the Eastern Shore Dimensionless Hydrograph may be used for sites where appropriate.

2.5.1 Standards for Determining Overbank Flood Protection

The following represent the minimum standards for determining the q_p requirement:

- q_p shall be managed for all new development projects.

- q_p shall be managed when development creates a hydrologic or hydraulic change.

- q_p shall be managed for each discharge point from the development site containing new development or having a hydraulic/hydrologic change.

- When a development site is divided into multiple drainage areas, q_p shall be addressed for each discharge point, and the required management shall be provided within the respective discharge point.

- The q_p requirement does not apply to any portion of the development site that has a direct discharge to tidal waters.

- Delineation of the drainage area to the discharge point shall consider stormwater conveyance systems and reflect runoff patterns for the respective design storm. For example, if a storm drain system is designed to convey the 10-year storm, the delineated drainage divides and drainage area for the 10-year storm could differ from the 100-year storm. The discharge point from the development site shall be evaluated for the entire contributing drainage area. Off-site areas that drain to the discharge point should be modeled as present land use in actual hydrologic condition.

- When sizing or modeling a BMP, the surface area of the BMP (i.e., wet footprint) shall be considered impervious.

- The USDA WinTR-20 (or an equivalent model based on TR-20 methodology as accepted by the approving agency) shall be used to determine peak discharge rates.

- Any adjustments for unique land features such as karst topography shall be determined by the approving agency with MDE’s concurrence.

- The standard for characterizing pre-development hydrologic land use for non-forested vegetated areas (including agriculture) within the development site shall be meadow, and the standard for forested areas shall be woods in good condition. Vegetated areas outside the development site should be modeled based on actual land use.

- For the purpose of determining CNs for the post-development conditions:

  - Impervious areas (including gravel roads, driveways, and parking lots) shall be considered impervious surfaces and represented by a CN of 98.
  - All vegetated areas within a development site shall be considered as open space in good condition for the respective HSG.
  - Any vegetated areas outside the development site should be modeled based on actual land use and shall be the same for pre-development and post-development conditions; and
  - Alternative surfaces shall use the appropriate CNs as shown in Section 3.1.
  - Green roofs shall be represented by a CN of 98.

- The length of overland flow used in time of concentration calculations is limited to no more than 150 feet for pre-development conditions and 100 feet for post-development conditions; On the Eastern Shore, this maximum distance is extended to 250 feet for pre-development conditions and 150 feet for post-development conditions.

- q_p shall be provided in a structural practice. q_p could also be provided in an appropriately designed rainwater harvesting system (see Chapter 3).

- Reduced CNs ["Change in Runoff Curve Number Method" (McCuen, R., 1983)] cannot be used.

- The q_p design storm shall be diverted away from or bypassed around all ESD practices. Therefore, routing the q_p storm through ESD practices is not permissible.

- Off-site areas that drain to the site should be bypassed around structural BMPs. If bypass is not feasible for structural practices, the BMP shall be sized for runoff from the entire contributing drainage area. A BMP shall always be sized for its contributing drainage area.

- The design storm for the conveyance systems carrying runoff to a BMP shall be equal or greater than the storm for which the BMP is designed.

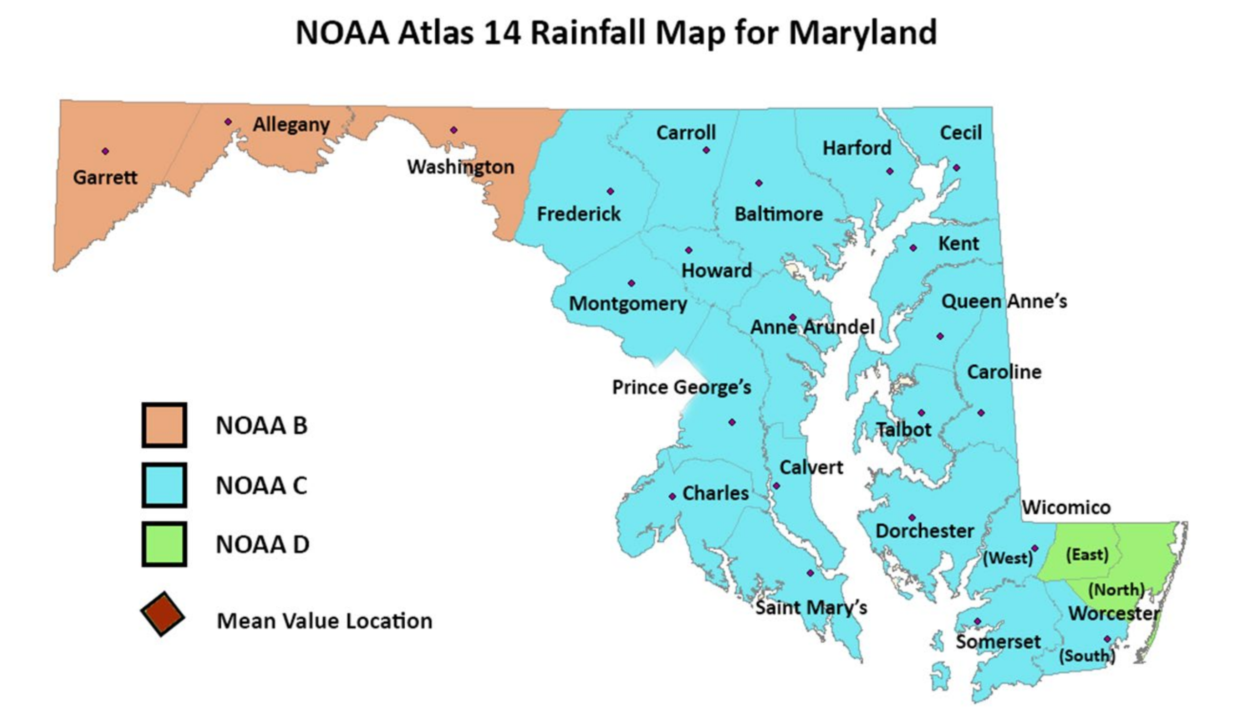

Figure 2.2 NOAA Atlas 14 Rainfall Distribution Map for Maryland

2.6 Extreme Flood Protection (q_f)

The purpose of the Extreme Flood Protection criteria is to (a) minimize the risk of flood damage from large storm events, particularly in interjurisdictional watersheds; (b) minimize changes to the boundaries of the pre-development 100-year Federal Emergency Management Agency (FEMA) and/or locally designated 100-year floodplain; and, (c) protect the physical integrity of small ponds and dams. There are two requirements related to extreme flood volume:

- **Control of discharges** from storms larger than the 10-year, 24-hour design storm used for Overbank Flood Protection.
  - For interjurisdictional watersheds control of the 100-year, 24-hour peak discharge rate (qf) shall be provided. Pre-development peak discharge rates (qf pre) shall be based on the qf design storm as determined using current rainfall from NOAA Atlas 14 (see Table 2.2, "pre"). The post-development peak discharge rates (qf post) shall be based on the qf design storm, adjusted for climate change (see Table 2.2, "Adjusted").
  - For all other watersheds, consult with the appropriate review authority to determine the required analysis and whether 100-year control or other local q_f is required.

- **Safe conveyance** of the 100-year peak discharge through stormwater management structures means safely passing the 100-year storm event through or around a BMP. Small ponds and dams shall be designed to safely pass the 100-year storm for ultimate conditions in accordance with MDE dam safety policies and criteria.

- The design storm for the conveyance systems carrying runoff to a BMP shall be equal or greater than the storm for which the BMP is designed.

2.6.1 Standards for Determining Extreme Flood Protection Criteria

The following represents the minimum standards for determining the q_f design requirement for interjurisdictional watersheds:

- Development shall not increase the downstream peak discharge for the 100-year frequency storm event and shall comply with the approved flood management plans. The following watersheds and their tributaries are interjurisdictional flood hazard watersheds:
  - Carroll Creek in the City of Frederick and Frederick County;
  - Gwynns Falls in Baltimore City and Baltimore County;
  - Jones Falls in Baltimore City and Baltimore County; and
  - Herring Run in Baltimore City and Baltimore County.

- Control of the 100-year discharge rate requires providing storage in a BMP to attenuate the post-development 100-year, 24-hour peak discharge rate (q_f) to pre-development conditions.

- Pre-development peak discharge rates (qf pre) shall be based on the qf design storm as determined using current rainfall from NOAA Atlas 14 (see Table 2.2, "Pre").

- Post-development peak discharge rates (qf post) shall be based on the qf design storm as determined using current rainfall from NOAA Atlas 14 adjusted for climate change (see Table 2.2, "Post").

- The same hydrologic and hydraulic methodologies used for overbank flood control shall be used to analyze q_f.

- 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.

- q_f shall be managed in a structural practice. q_f could also be managed in an appropriately designed rainwater harvesting system (see Chapter 3).

- Reduced CNs ["Change in Runoff Curve Number Method" (McCuen, R., 1983)] cannot be used.

- The q_f design storm shall be diverted away from or bypassed around all ESD practices.

- Off-site areas that drain to the site should be bypassed around structural BMPs. If bypass is not feasible for structural practices, the BMP shall be sized for runoff from the entire contributing drainage area. A BMP shall always be sized for its contributing drainage area.

2.7 Environmental Site Design

Maryland law (Environment Article §4-203(b), Annotated Code of Maryland) requires the implementation of environmental site design to the maximum extent practicable. Maryland's Environment Article §4-201.1(B) defines environmental site design as "…using small-scale stormwater management practices, nonstructural techniques, and better site planning to mimic natural hydrologic runoff characteristics and minimize the impact of land development on water resources." Environmental site design includes:

- Optimizing conservation of natural features (e.g., drainage patterns, soil, vegetation),
- Minimizing impervious surfaces (e.g., pavement, concrete channels, roofs),
- Slowing down runoff to maintain pre-development discharge timing and to increase infiltration and evapotranspiration,
- Using nonstructural practices or small-scale practices distributed across a development site for water quality treatment, and
- Providing channel protection management in either ESD practices or structural practices.

In addition to the implementation of these principles, ESD includes a three-phased approach to site planning. This process promotes the incorporation of the principles of stormwater management into site planning and design to maximize natural resource protection, minimize soil compaction, minimize impervious surfaces, and enhance stormwater BMP effectiveness. The three phases of the stormwater management design and approval process are:

1. Concept Plan
2. Site Development Plan
3. Final Plan

The concept plan shall include site resource mapping as well as protection and conservation strategies to demonstrate the relationship between proposed impervious surfaces and the protected natural resources. The concept plan shall establish the preliminary footprint of the proposed project, determination of stormwater management requirements, general stormwater management practice selection, preliminary location of proposed ESD practices and structural practices, and preliminary stormwater management calculations. Approval of the concept plan ensures that all important resources have been mapped and protected and that all opportunities to enhance natural areas have been explored early in the design process. The stormwater approving authorities and sediment control approving authorities will collaborate to provide coordinated feedback to the designer before a project proceeds to the more detailed site development phase.

Included in this second phase is the preparation of more detailed designs, computations, and grading plans. The site development plan shall include a detailed design for stormwater management as well as the design of an erosion and sediment control plan. The site footprint shall be finalized with respect to the layout of buildings, roadways, parking areas, and other structures, while continuing to protect natural resources and buffers and incorporating small scale ESD practices throughout the site. Larger structural BMPs for quantity management shall be sited, and hydrologic, hydraulic, and stormwater management computations shall be prepared.

After site development plan approval, the developer shall prepare final designs by incorporating comments from the appropriate review agencies. Final plans incorporate final sizing and design of all stormwater BMPs to meet minimum stormwater management requirements. The design process described above is intended to be iterative, as comments from all review agencies are incorporated during each phase of project design. This will help local jurisdictions coordinate with other programs requiring environmental review and ensure that development plans fit priorities for resource protection, enhancement, and restoration.

2.7.1 ESD to the Maximum Extent Practicable Standard

- ESD planning techniques shall be utilized to protect natural resources, identify sensitive areas, minimize impervious areas, use natural conveyances, and plan for ESD implementation in the early phase of project design.

- A three-phase, joint review process between the local stormwater review agency and the sediment control review agency shall be employed to integrate stormwater and erosion and sediment control strategies into site plans.

- ESD practices shall be used to satisfy the water quality treatment requirement and the Re_v requirement in accordance with Sections 2.2 and 2.3. Depending on the type of ESD practice used, the water quality treatment provided may incorporate the Re_v requirement or the Re_v requirement may need to be provided separately.

- The Cp_v requirement shall be addressed by either managing the entire Cp_v in an ESD practice ($\leq$ 8,000 ft^3 or 4,000 ft^3 in cold water resource watersheds); or by managing the entire Cp_v (> 8000 ft^3 or 4, 000 ft^3 in cold water resource watersheds) in a structural practice that slowly releases the volume over 36 hours (or 18 hours for cold water resources) in accordance with Section 2.4.

- When the Cp_v is provided in an ESD practice, the Cp_v incorporates the water quality treatment in accordance with Section 2.4.2.

- When the Cp_v is provided in a structural practice, the practice shall be designed in accordance with Section 2.4.3.

2.7.2 Elements for ESD Planning Techniques

Site and Resource Mapping

The site and resource mapping component should be used as a basis for all subsequent decisions during project design. During this step, the designer shall identify significant natural resources and demonstrate that these areas shall be protected and preserved. Additionally, options shall be evaluated to enhance important hydrologic functions. This map shall be field verified by the project designer. Specific areas that shall be mapped include:

Wetlands and buffers	Steep slopes
Perennial and intermittent streams, and buffers	Highly erodible soils
Floodplains	Bedrock outcrops and karst geology
Springs, seeps, and groundwater	Forests and forest buffers
Critical Area of the Coastal Bays	Other vegetated areas

The mapping process shall identify important natural resources as well as areas that are highly susceptible to erosion caused by construction activities or stormwater runoff. When steep slopes and highly erodible soils are found, measures need to be taken to limit disturbance and minimize impacts. For the purpose of project planning, steep slopes are considered to be any mapping unit with a slope of 15 percent or greater.

While it may not be practicable to eliminate earth disturbing activities exclusively on the basis of soil erodibility or slope alone, constraints are warranted when both steep slopes and highly erodible soils occupy the same area within the development footprint. Areas with highly erodible soils and slopes equal to or greater than 25 percent should be incorporated into adjacent buffers, remain undisturbed, be protected during the construction process, and/or be preserved as open space.

Protecting other existing natural resources up front in the planning process will allow their many functions to be utilized for infiltration, flow attenuation, groundwater recharge, flood storage, runoff reduction, nutrient cycling, air and water pollution reduction, habitat diversity, and thermal impact reduction.

Natural resource protection and enhancement strategies include:

- Protecting large tracts of contiguous open space, forested areas, and other important resources through conservation easements
- Identifying afforestation opportunities in open space areas and setting aside land for natural regeneration
- Identifying important resource areas that may be expanded such as stream buffers and floodplains
- Minimizing disturbance of highly erodible soils

Site Fingerprinting and Development Layout

The next step in the planning process involves determining the approximate location of buildings, roadways, parking lots, and other impervious areas. These site improvements should be placed at a sufficient buffer distance to protect the resource conservation areas. Minimum buffer widths may be expanded based on receiving stream characteristics, stream order, adjacent land slopes, 100-year floodplain, wetlands, mature forests, vegetative cover, depth of the groundwater table, the presence of spring seeps, and other sensitive areas. Several studies have suggested that minimum buffer widths could be based on site specific functions (Palone and Todd, 1998) including: bank stability and water temperature moderation (50 feet), nitrogen removal (100 feet), sediment removal (150 feet), or flood mitigation (200 feet).

After the development footprint has been established, consideration should be given to natural drainage areas and how runoff will travel over and through the site. Sheetflow and existing drainage patterns should be maintained and discharges from the site should occur at the pre-development location. New drainage patterns could result in concentrated flow leaving the site at an inappropriate or unstable location, as well as creating erosion, sediment transport, stream channel stability problems, and increasing flood risk. The use of storm drains and impervious conveyance systems should be minimized. Planning for on-site and off-site drainage patterns shall be done early in the design process to establish a stable and adequate outfall for downstream discharges. In some cases, these strategies can also be used to establish area-based ESD practices such as sheetflow to conservation area. Strategies for site layout and connecting landscape features include:

- Plan the building footprint and layout to protect conservation areas
- Evaluate opportunities to enhance/expand forested, wetland, and stream buffers
- Grade the site so that runoff will flow from impervious areas directly to pervious areas or other natural conveyance systems
- Maintain natural flow paths between the site and upstream and downstream systems
- Maintain sheetflow and natural overland flow processes wherever feasible
- Provide adequate and stable outfall conveyance systems

Commercial and industrial developments offer other opportunities to reduce impervious cover. Because parking lots are the dominant land cover for most commercial and industrial projects, designers can minimize impervious surface area dedicated to parking, use non-structural ESD practices such as alternative surfaces, and use ESD practices in landscaped areas for stormwater treatment.

Locating Stormwater Management Practices

Reducing the impervious area in residential, commercial, and industrial development may also create additional opportunities for landscaped features (e.g., parking lot islands, medians, plazas). Many of the micro-scale practices discussed in Chapter 3 are tailored to blend in with these smaller landscaped areas. When strategies for reducing imperviousness and protecting natural resources are combined with design options that distribute ESD practices throughout a site, the resulting plans will provide an effective means to address storm water quality requirements at the source.

After the site footprint has been established and potential management areas identified, preliminary calculations for determining stormwater requirements can be completed, and ESD and structural practices can be located.

Stormwater Management Plans

When the development layout is finalized, the proposed topography shall be determined and final drainage areas established. Natural features and conservation areas can be utilized to serve stormwater quantity and quality management requirements, as well as stormwater outfalls. Individual ESD locations shall be determined and all alternative surfaces, nonstructural, and micro-scale practices shall be finalized. When locating and sizing ESD practices, the primary objective is to manage runoff as close to its source as possible by using vegetated buffers, natural flow paths, sheetflow to natural areas, and landscape features. ESD practices and structural practices are then designed according to sizing requirements and discharge computations. Calculations and details shall be submitted to the review agencies to support the design.

Erosion and Sediment Control Plans

After concept plan approval, the proposed grading plan should be designed and the drainage areas during construction established. These will form the basis of the erosion and sediment control plan. The following are critical to developing an effective erosion and sediment control plan:

- Identification of areas to be preserved or protected
- Phasing and construction sequencing
- Implementation of properly designed sediment controls and effective stabilization strategies for each phase of construction
- Integration of stormwater management and sediment control plans

Preservation

Strategies to preserve sensitive resources, ensure soil stability, and prevent erosion begin with protecting those areas during project construction. Erosion and sediment control plans should identify areas to be protected by marking the limit of disturbance, sensitive areas, buffers, and forested areas that are to be preserved or protected. In addition, infiltration and recharge areas that need to be protected from fine sediments and compaction should be identified. Plans should also note that all protected areas be marked in the field prior to any land disturbing activity.

Phasing and Sequences of Construction during Each Stage of Development

The erosion and sediment control plan shall provide adequate sediment controls for each phase or stage of development as well as a sequence of construction for the contractor. These include initial clearing and grubbing, rough grading, site development, site construction, and final grading. Because initial and final flow patterns do not apply to all interim phases, the sediment control measures and sequences shall consider flow pattern changes, drainage areas, and discharge points at transitional phases of the construction process. Phased plans need to ensure that erosion and sediment controls adequately address the changing runoff patterns.

Design of Sediment Controls

Properly designed sediment control measures and effective stabilization strategies shall be implemented for each phase of construction in accordance with the latest version of the Maryland Standards and Specifications for Soil Erosion and Sediment Control.

Integration of Permanent Stormwater Management and Sediment Control Measures

The erosion and sediment control plan shall be designed to take the location and function of the proposed stormwater BMPs into consideration. In addition to the sediment control plan preventing erosion and keeping sediment laden runoff from leaving the site for all phases of construction, a successful sediment control plan shall avoid compaction and contamination of all areas earmarked for infiltration or groundwater recharge and prevent fully constructed stormwater BMPs from being contaminated with sediment.

Likewise, the stormwater management design and plans shall also take the sediment control plan into consideration. For example, when the BMP location is used for sediment control, the invert of the BMP may need to be raised, or the design may need to incorporate additional excavation and/or ground preparation to restore the soils to their natural state.

Areas that are to be used for infiltration dependent BMPs, recharge, or area-based BMPs such as disconnections, grass swales, and alternative surfaces, will ultimately perform better when protected from fine sediments and soil compaction caused by heavy construction equipment. The sediment control plan should include provisions to prevent runoff from unstabilized areas from entering these locations during construction. These areas should be identified on erosion and sediment control plans as protected areas and marked in the field prior to earth disturbance commencing.

Ideally, BMP construction will begin only after the entire contributing drainage area to the BMP has been stabilized. However, this is often not practicable, and in some instances, the BMP location may need to be used for a sediment trap or basin. Regardless, the principles presented above shall always apply and can be achieved by constructing the BMP in stages and implementing the appropriate sediment control measures for each stage. The construction of a BMP can be broken down into the following fundamental operations: (1) grading of the BMP; (2) installation of major piping (e.g., inflow and outflow pipes); (3) installation of internal piping (e.g., underdrains and low flow devices); (4) placement of media; and (5) seeding and/or planting of vegetation.

It is common for the storm drain system to be constructed during preliminary grading. Partial grading of a BMP could also be part of the preliminary grading plan. Where this occurs, runoff could potentially collect in the BMP location. Consideration needs to be given to whether the runoff is clear from an undisturbed area or sediment laden from a disturbed area, and appropriate diversion or protection measures would need to be implemented. Runoff can be diverted around the BMPs using water conveyance practices, such as diversion fence, earth dikes, and pipe slope drains. Curb openings, inlets, or other points of inflow can be blocked to prevent runoff from entering the BMP during construction or when otherwise necessary. Special protection measures such as erosion control matting may be needed to protect vulnerable side slopes from erosion during the construction process. While it could be acceptable to grade the BMP prior to stabilizing the contributing drainage area, subject to proper sediment control measures being employed, the installation of the internal piping, placement of media, and landscaping shall not occur prior to stabilizing the entire contributing drainage area to the BMP.

The sequence of construction shall address both the installation of temporary sediment controls and construction of stormwater management. This includes the staging of the BMP construction, the implementation of the sediment control measures needed for each of these stages, permanent and temporary stabilization and re-stabilization, and, when applicable, the conversion of the BMP from sediment control mode to permanent stormwater management mode.

Stormwater BMPs and Sediment Control Measures that Share Location

Because construction tends to clog soils and reduce their capacity to infiltrate, when a temporary sediment control device, such as a trap, basin, or stone outlet structure, is located in the footprint of a proposed infiltration dependent BMP, the bottom elevation of the sediment control device shall be at least two feet higher than the finish grade bottom elevation of the infiltration dependent BMP. Additionally in these areas, excavators or backhoes should work from the sides to excavate the BMP area to its appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the BMP area.

When a proposed BMP includes a permanent pretreatment forebay, the forebay should be constructed and used in conjunction with the temporary sediment control practices to help prevent clogging of soils within the footprint of the BMP.

When a stormwater BMP location is used for both temporary sediment control and permanent stormwater management, the plans and sequence of construction shall clearly establish which components are to be constructed with the installation of the erosion and sediment control practice, which components are to be removed and added upon conversion from sediment control to permanent stormwater management. When converting a sediment control practice to a stormwater BMP, all accumulated sediment shall be removed and disposed of prior to final grading of the stormwater BMP.

2.8 Redevelopment

Redevelopment is defined as any construction, alteration, or improvement performed on development sites where the existing land use is commercial, industrial, institutional, or multifamily residential and the existing development site impervious area exceeds 40%. The "development site" is defined in the Code of Maryland Regulations as "the land area where development is proposed or occurring and includes the full extents of the proposed disturbance." This corresponds to the project's limit of disturbance. The goal of the redevelopment criteria is to achieve water quality treatment and groundwater recharge. Because redevelopment often occurs in existing urban areas, there can be unique challenges to providing on-site stormwater management. Designs shall consider local goals, available resources, and limited space for implementing stormwater practices.

To determine whether a project falls under the new development or the redevelopment criteria, the impervious area within the development site shall be calculated. For redevelopment sites, existing impervious areas that are reconstructed are subject to the redevelopment requirements. For development sites with multiple discharge points, the approving agency may require that each discharge point be evaluated separately for qualification as redevelopment.

2.8.1 Redevelopment Policy

- Stormwater management shall be addressed for redevelopment sites according to the following criteria:
    - Reduce existing impervious area within the development site by at least 50%;
    - Provide water quality treatment for at least 50% of the existing impervious area within the development site; or
    - Use a combination of impervious area reduction and water quality treatment for at least 50% of existing impervious area.

- Stormwater management for any net increases in impervious area and for any hydrologic or hydraulic changes shall be addressed according to new development requirements. This includes water quality treatment, Re_v, Cp_v, and q_{p10}, and includes q_f for interjurisdictional watersheds.

- The water quality treatment requirement shall be provided for an impervious area equal to 50% of the existing impervious area and 100% of the net increase in impervious area for the development site. The impervious areas treated by management practices shall equal or exceed the impervious area required to be treated for the development site. The method presented in Section 2.2 shall be used to determine the amount of treatment provided by a BMP.

- When there is an increase in impervious area to a discharge point, the Cp_v requirement shall be computed based on the direct runoff depth for the net increase in impervious area only in accordance with Section 2.4. The provided Cp_v shall be based on Equation 2.11 and shall be computed for the drainage area to the BMP.

- The use of on-site ESD practices shall be maximized to meet the above water quality treatment requirements. Alternative stormwater management practices may be used to meet the requirements provided that it is satisfactorily demonstrated to the approving authority that impervious area reduction has been maximized and that a maximum level of WQ_v has been addressed using ESD practices. Alternative stormwater management measures include but are not limited to:

  - An on-site structural BMP to provide water quality treatment for at least 50% of existing impervious area and 100% of net increase in impervious area;
  - An off-site ESD practice or structural BMP to provide water quality treatment for an area equal to or greater than 50% of existing impervious areas and 100% of the net increase in impervious area; or
  - A combination of impervious area reduction, use of on-site ESD practices and on-site structural BMPs, and off-site ESD practices or structural BMPs to provide water quality treatment for an area equal to or greater than 50% of existing impervious areas and 100% of the net increase in impervious area.

2.9 Summary

Table 2.5 offers a quick reference to the stormwater management criteria presented in this chapter and a comparison of management requirements for new development and redevelopment. Table 2.6 summarizes the types of BMPs required to meet the stormwater management criteria, the equations used to size the BMPs, and the methods for calculating provided management

Table 2.5 Stormwater Management Requirements for New Development and Redevelopment

STORMWATER MANAGEMENT CRITERIA[3,4,5]				
Development Site Type	**WQ[1]**	**Re_v**	**Cp_v**	**q_p and q_f[2]**
New Development (development site existing Ai ≤ 40% impervious)	Impervious Area Requiring Treatment = post-development A_i	$Re_v = R_f \times Q_i \times A_i$	$Cp_v = Q_i \times A_i + Q_p \times A_p$	Manage post-development q_p and q_f to a flow rate ≤ pre-development flow rate.
Redevelopment (development site existing Ai > 40% impervious)	Impervious Area Requiring Treatment = pre-development $A_i + \Delta A_i$	N/A unless $\Delta A_i > 0$, then $Re_v = R_f \times Q_i \times \Delta A_i$	N/A unless $\Delta A_i > 0$, then $Cp_v = Q_i \times \Delta A_i$	N/A unless there is an increase in the post-development flow rate from the discharge point resulting from an increase in impervious area or a change to drainage area divides within the development site. Then, manage post-development q_p and q_f to a flow rate ≤ pre-development flow rate.

[1]ΔA_i is the net increase in impervious area from pre-development to post-development.
[2]qf is required for development sites located within interjurisdictional watersheds.
[3]SWM requirements are calculated based on discharge point.
[4]Quality management (i.e., WQ and Re_v) is provided within the development site.
[5]Quantity management (i.e., Cp_v, q_p, q_f) is provided within the discharge point from the development site.

Table 2.6 BMP Type, BMP Sizing, and Provided Management Calculations

STORMWATER MANAGEMENT CRITERIA[1]				
	WQ	**Re_v**	**Cp_v**	**q_p and q_f**
Type of BMP	ESD practices are mandatory for new development and ΔAi related to redevelopment. ESD practices are to be maximized for redevelopment.	ESD practices are mandatory for new development and ΔAi related to redevelopment.	ESD practices are mandatory for discharge points where required $Cp_v \leq 8{,}000\ ft^3$ ($\leq 4{,}000\ ft^3$ for Use III/IV). Otherwise, structural practices are mandatory.	Structural.
BMP Sizing	$WQ_v = Q_i \times A_i + Q_p \times A_p$	$Re_v = R_f \times Q_i \times A_i$	$Cp_v = Q_i \times A_i + Q_p \times A_p$	Develop a TR-20 model to determine the storage necessary to attenuate the post-development q_p and q_f to a flow rate ≤ pre-development flow rate.
Provided Management	The treated Ai is the impervious area that drains to an adequately sized BMP. Ai treated by an area-based ESD practice is subtracted from the impervious area requiring treatment. The level of treatment provided by a volume-based BMP is dependent on the P treated. Use Equations 2.1 and 2.2 into above WQ_v equation and solve for P. Effective Ai treated = treated Ai × treated P.	Ai treated by an area-based ESD practice is subtracted from the impervious area requiring treatment. Provided Re_v is the storage provided by the BMP in a location where it will recharge groundwater.	The provided Cp_v is a straight volume calculation of the storage provided by the BMP divided by the applicable requisite storage ratio for the type of BMP.	Management is provided when post-development q_p and q_f ≤ pre-development q_p and q_f.

[1]BMP sizing and provided management are computed the same way for new development and redevelopment.