A Literature Review of Stormwater Management Design Manuals from US Cities and States

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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY 7
2.1 VA SWM Handbook (1st Edition) 21
2.1.1 Uniform BMP Sizing Criteria 21
2.2 VA SWM Handbook (2nd Edition) 24
2.2.1 Uniform BMP Sizing Criteria 24
2.2.2 Treatment Volume – Water Quality (Runoff Reduction Method) 27
2.2.3 Stream Channel Protection 31
2.2.4 Overbank Flood Protection 32
2.2.5 Extreme Flood Protection 32
2.3 Roanoke, VA 33
2.3.1 Water Quality and Quantity 33
2.3.2 Culvert Design 33
2.4 Boston, MA 35
2.4.1 Performance Standards 35
2.5 Charlottesville, VA 38
2.5.1 Water Quantity and Quality Requirements 38
2.5.2 Culvert Design Standards 38
2.6 Fairfax, VA 39
2.7 Maryland 40
2.7.1 Unified Sizing Criteria 41
2.7.2 Water Quality Volume Requirement 42
2.7.3 Recharge Volume Requirement 42
2.8 North Carolina 44
2.8.1 Minimum Standards 44
2.9 New York City, NY 46
2.10 Philadelphia, PA 49
2.10.1 Water Quality Requirements 49
2.10.2 Channel Protection Requirements 50
2.10.3 Flood Control Requirements 51
2.10.4 Public Health and Safety Release Rate Requirement 54
2.11 Portland/Washington County, OR 55
2.11.1 Water Quantity 55

2.11.2 Water quality 55
2.11.3 Culvert Design 57
2.12 Seattle, WA 60
2.12.1 Minimum Requirements for All Projects 61
2.12.2 Description of Minimum Requirements 62
2.12.3 Minimum Requirements based on Project Type 69
2.13 Washington, DC 77
2.13.1 Minimum Standards (Water Quantity and Quality) 77
2.13.2 Culvert Design 80
BIBLIOGRAPHY 81

LIST OF FIGURES

Figure 1. Summary of land disturbance thresholds for enacting water quantity requirements. 8
Figure 2. Summary of design storms used for channel flood prevention (extreme flood prevention requirements not shown). 9
Figure 3. Summary of design storms used for prevention of channel erosion. 9
Figure 4. Summary of land disturbance thresholds for enacting water quality requirements. 10
Figure 5. Summary of design storms used for water quality requirements. 11
Figure 6. Summary of required total phosphorus (TP) removal efficiencies. 11
Figure 7. Summary of required total suspended sediment (TSS) removal efficiencies. 12
Figure 8. Frequency of storm total rainfall depths measured by all Roanoke gauges for January through November 2018. 13
Figure 9. Spread of storm total rainfall depths measured by all Roanoke gauges for January through November 2018 (mean, median, 90th percentile = 0.99", 0.67", 2.54") 13
Figure 10. Rainfall depth for each component of BMP sizing criteria (copied from VA SWM Handbook 2nd Ed. – Ch. 10) 26
Figure 11. Nested approach for meeting BMP sizing criteria (copied from VA SWM Handbook 2nd Ed. – Ch. 10) 27
Figure 12. Treatment volume equation (copied from VA SWM Handbook 2nd Ed. – Ch. 10) 28
Figure 13. Energy balance equation (copied from VA SWM Handbook 2nd Ed. – Ch. 10) 31
Figure 14. Recharge volume equation (copied from Boston's SBMP:GD) 36
Figure 15. Water quality volume equation (copied from Boston's SBMP:GD) 36
Figure 16. Water quality volume equations (copied from MDE MSDM) 42
Figure 17. Recharge volume equations (copied from MDE MSDM) 43
Figure 18. Runoff coefficients provided by NYC for use in rational method (copied from NYC SG) 46
Figure 19. Storage volume equation for facilities with variable release rates (copied from NYC DEP "Criteria for Detention Facility Design") 47
Figure 20. Storm duration equation for facilities with variable release rates (copied from NYC DEP "Criteria for Detention Facility Design") 47
Figure 21. Storage volume equation for facilities with constant release rates (copied from NYC DEP "Criteria for Detention Facility Design") 48
Figure 22. Storm duration equation for facilities with constant release rates (copied from NYC DEP "Criteria for Detention Facility Design") 48
Figure 23. Allowable flow equations for sites less than 10,000 SF (copied from NYC DEP "Criteria for Detention Facility Design") 48
Figure 24. Exemptions for Channel Protection Requirement (copied from PSGM) 51
Figure 25. Exemptions for Flood Control Requirement (copied from PSGM) 53
Figure 26. General minimum requirements for Roadway Projects flow chart 74
Figure 27. Flow Control minimum requirements for Roadway Projects flow chart 75
Figure 28. Water Quality Treatment minimum requirements for Roadway Projects flow chart . 76

LIST OF TABLES

Table 1. Key summary of stormwater management regulations by municipality 15
Table 2. Water quality BMPs, Phosphorus removal efficiencies, and target percent imperviousness range (copied from VA SWM handbook 1st Ed.) 22
Table 3. Statewide Uniform BMP Sizing Criteria (copied from VA SWM Handbook 2nd Ed. – Ch. 10)..... 25
Table 4. 90th Percentile rainfall event for various locations in Virginia (data from VA SWM Handbook 2nd Ed. – Ch. 10)..... 28
Table 5. Runoff coefficients for calculating treatment volume (copied from VA SWM Handbook 2nd Ed. – Ch. 10) 29
Table 6. Runoff reduction and nutrient removal credits by BMP type (copied from Virginia Stormwater BMP Clearinghouse)..... 30
Table 7. Culvert obstruction allowance factors 33
Table 8. Culvert overflow depth and velocity 34
Table 9. Culvert minimum design criteria based on usage..... 39
Table 10. Stormwater sizing criteria summary (copied from MDE MSDM)..... 41
Table 11. Summary of Philadelphia Water Quality Requirements (copied from PSGM)..... 50
Table 12. Flood Control Requirements for each Flood Management District (copied from PSGM) 52
Table 13. Stormwater management practices (SMP) listed by preference (copied from PSGM) 54
Table 14. Outlet protection criteria based on design discharge velocity (copied from CWS DCS) 58
Table 15. Summary of acceptable treatment approaches (copied from CWS DCS)..... 59
Table 16. Seattle, WA - Summary Table of Project Types 60
Table 17. On-site treatment methods for Single Family Residential projects (copied from Seattle Stormwater Manual) 66
Table 18. On-site treatment methods for Trail and Sidewalk projects (copied from Seattle Stormwater Manual) 67
Table 19. On-site treatment methods for Parcel-based projects (copied from Seattle Stormwater Manual)..... 68
Table 20. On-site treatment methods for Roadway projects (copied from Seattle Stormwater Manual)..... 69
Table 21. Sizing criteria for stormwater management performance requirements (copied from DC Stormwater Management Guidebook) 78

List of Acronyms and Terms (Applicable to Table 1 only*)

Acronym	Term
%IC	Percent impervious cover
ADT	Average Daily Traffic
D	Culvert Diameter
DCIA	Directly Connected Impervious Area
E&SC	Erosion and Sediment Control
GCP	Construction General Permit
HDPE	High Density Polyethylene
LDA	Land Disturbing Activity
MFR	Multifamily Residential
MLDA	Major Land Disturbing Activity
MSIA	Major Substantial Improvement Activity
NPRHS	New Plus Replaced Hard Surface
P	Precipitation depth
PGPS	Pollution Generating Pervious Surface
Q_{post}	Post-development peak flow
Q_{pre}	Pre-development peak flow
RCP	Reinforced Concrete Pipe
SF	Single Family
SWMP	Stormwater Management Plan
TP	Total phosphorus loading
TSS	Total Suspended Sediment
VA SWM	Virginia Stormwater Management
VSMP	Virginia Stormwater Management Program
WQv	Water Quality Volume

*Acronyms in each section are unique based on each municipality's terminology, but a uniform set of acronyms was used in the summary table.

1. EXECUTIVE SUMMARY

In order to better inform the drafting process of a forthcoming, new stormwater management (SWM) design manual, the City of Roanoke (COR) commissioned a literature review of SWM design manuals published by various municipalities and states. The 13 manuals reviewed were primarily requested by COR stormwater staff and originate from cities or states on the east- and west-coast. The manuals were summarized individually in detail, then overall comparisons were made between each manual. The key consideration of the review was design criteria for post-construction stormwater control measures (SCMs) governing water quality, water quantity, and culverts. Generally, parameters compared across manuals included design storm return period required to meet various criteria (e.g. water quality, flood protection, channel erosion, groundwater recharge), flow and contaminant attenuation (e.g. peak flow and/or volume reduction, nutrient removal requirements), spillway sizing, and culvert criteria (e.g. sizing, headwater restrictions, erosion prevention). The regulatory trigger thresholds for quality and quantity requirements were also summarized (e.g. ≥ 1 acre of land disturbance).

Graphical summaries of key regulatory triggers and design criteria are presented in the next few pages, as well as a number of recommendations based on the literature review and 2018 rainfall data for Roanoke. The remainder of this document contains a summary table of all the manuals reviewed (Table 1) and a narrative section with a detailed, individual summary for each manual.

Figure 1, Figure 2, and Figure 3 show summary graphics for the regulatory thresholds that trigger water quantity requirements, channel flood protection, and channel erosion protection, respectively. Generally, a value of 0 indicates that all projects must comply, and no value indicates that another metric was used, or (less commonly) no standard exists. Some manuals have different thresholds or design criteria depending on the project type, amount of disturbance, etc., for those cases the most typical or likely value was shown in the following graphics.

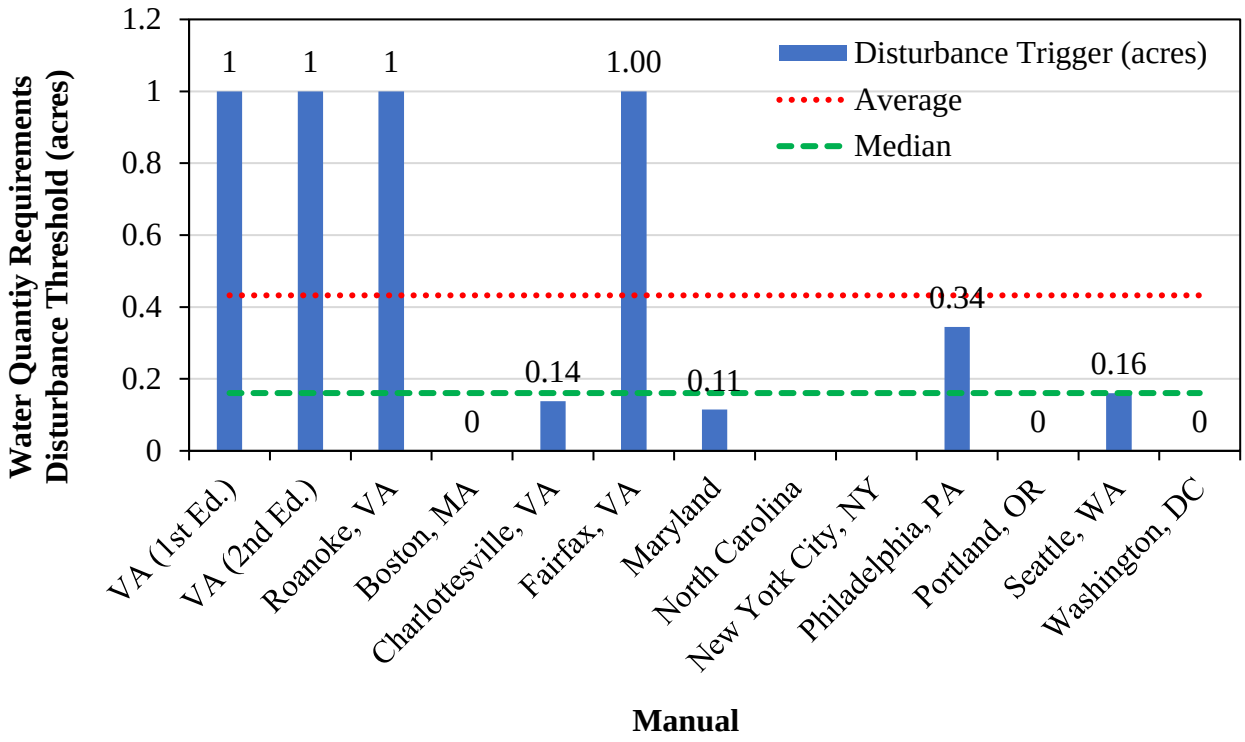

Figure 1. Summary of land disturbance thresholds for enacting water quantity requirements.

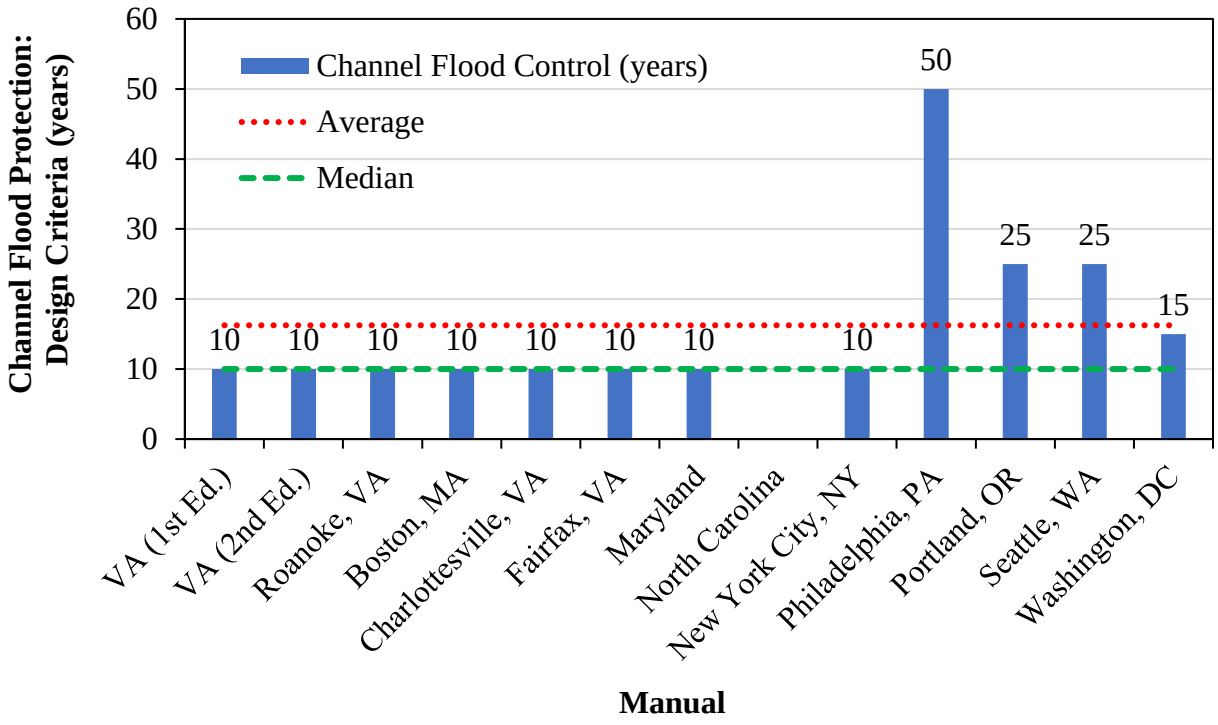

Figure 2. Summary of design storms used for channel flood prevention (extreme flood prevention requirements not shown).

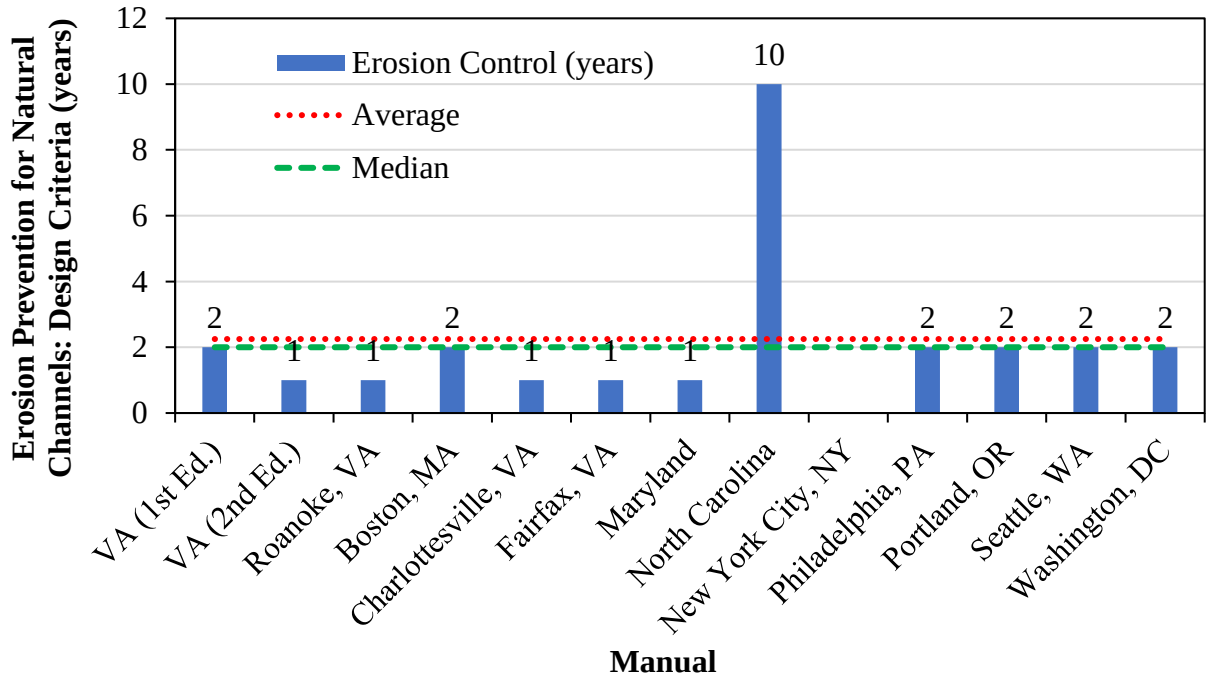

Figure 3. Summary of design storms used for prevention of channel erosion.

Figure 4, Figure 5, Figure 6, and Figure 7 respectively show the summary graphics for the regulatory thresholds that trigger water quality requirements, water quality treatment design depths, required total phosphorus (TP) removal efficiencies, and required total suspended sediment (TSS) removal efficiencies.

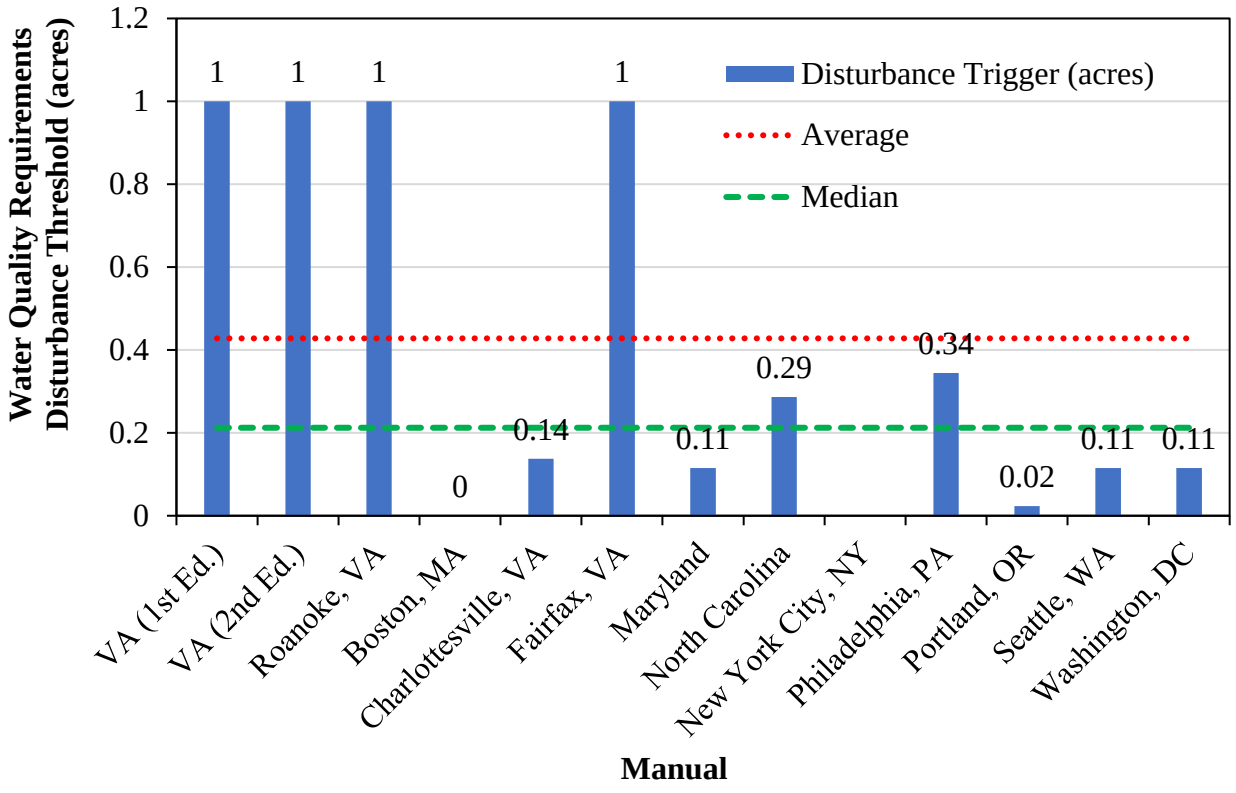

Figure 4. Summary of land disturbance thresholds for enacting water quality requirements.

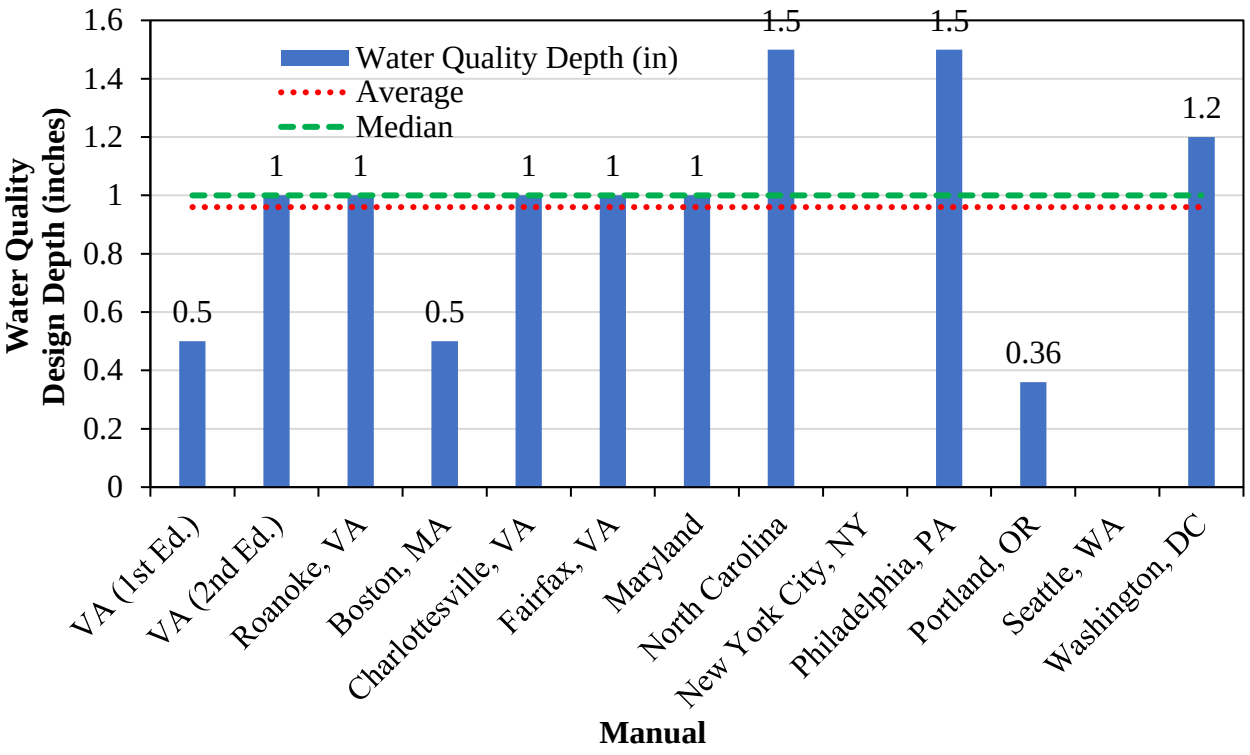

Figure 5. Summary of design storms used for water quality requirements.

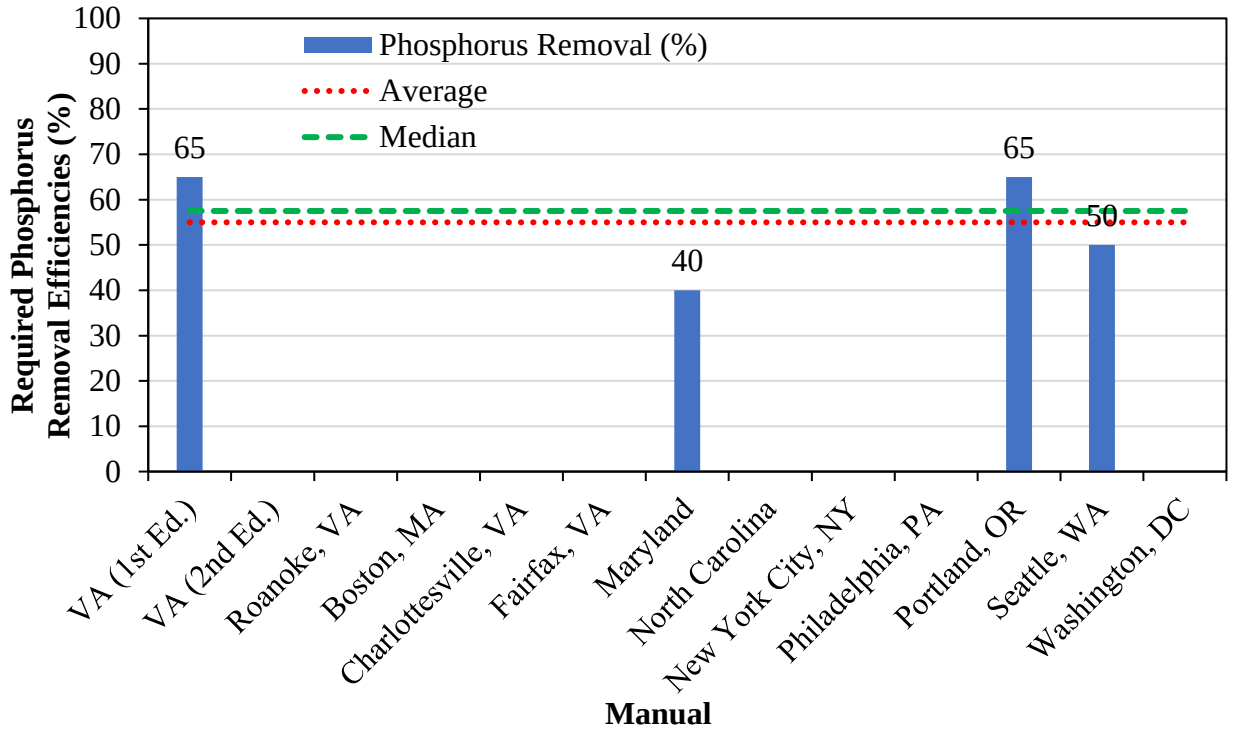

Figure 6. Summary of required total phosphorus (TP) removal efficiencies.

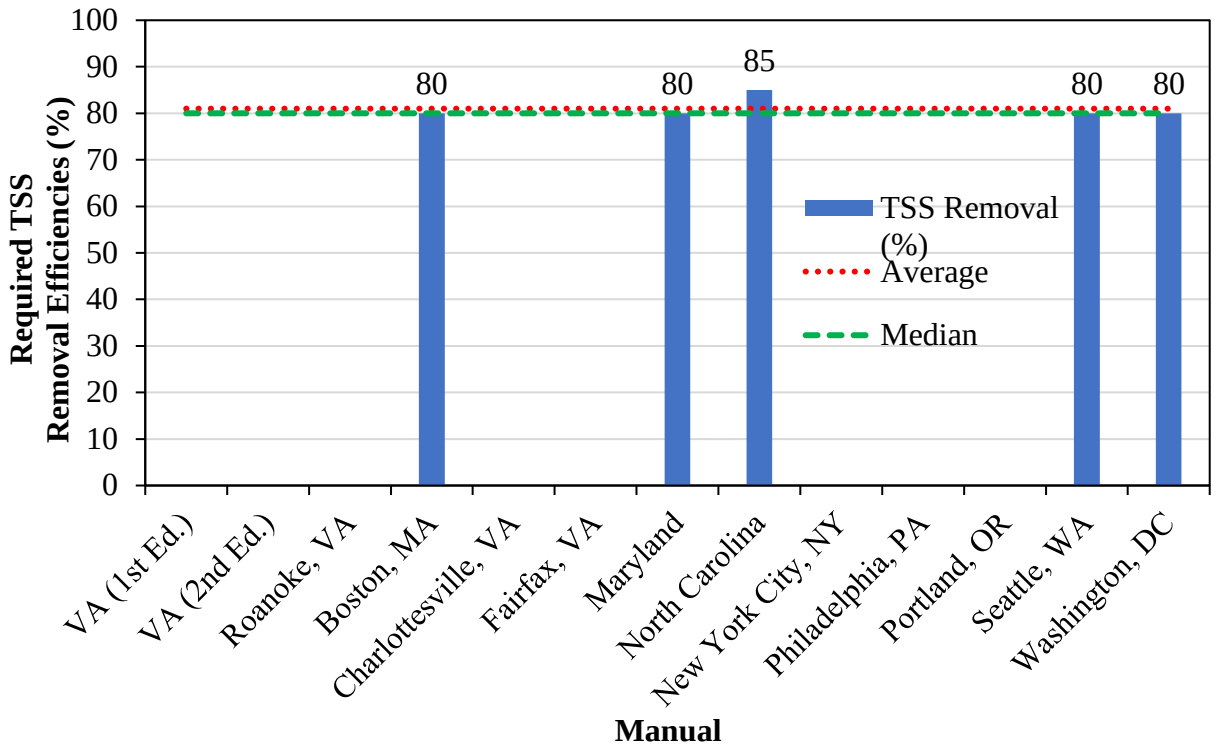

Figure 7. Summary of required total suspended sediment (TSS) removal efficiencies.

Figure 8 and Figure 9 summarize the storm total rainfall depths measured by all Roanoke gauges (USGS and NOAA) for January through November 2018. Although 2018 was a wetter than average year, these two plots may provide support for some of the recommendations. For example, over 25% of the storms had a depth over 1", indicating possible flaws with the 90th percentile – 1" correlation in the Virginia stormwater handbook. From Figure 8 an appropriate water quality depth may be ~1.5". Similarly, using the 90th percentile of this year's rainfall data as the design depth (2.54", slightly less than the upper fence in Figure 9) would provide even more comprehensive treatment for both quality and quantity.

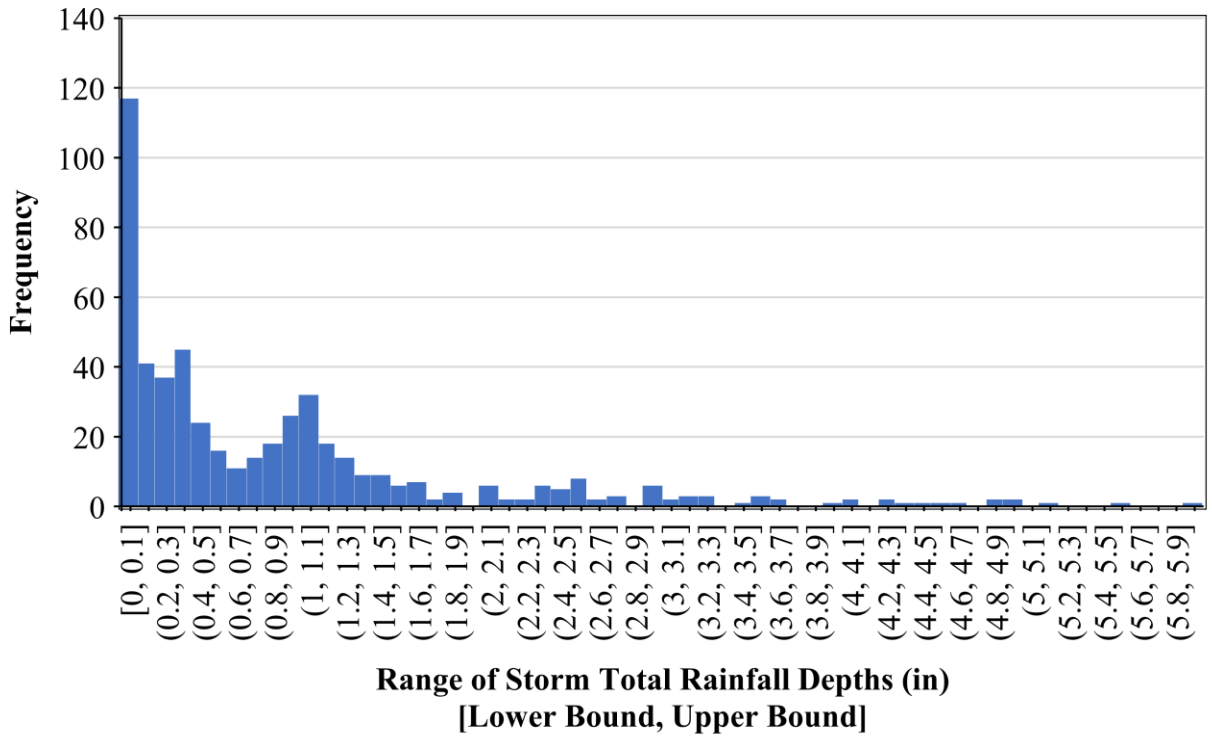

Figure 8. Frequency of storm total rainfall depths measured by all Roanoke gauges for January through November 2018.

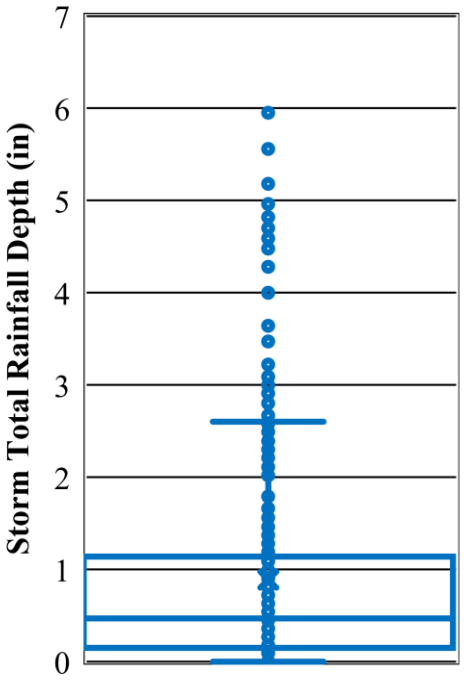

Figure 9. Spread of storm total rainfall depths measured by all Roanoke gauges for January through November 2018 (mean, median, 90th percentile = 0.99", 0.67", 2.54")

Based on the literature review, comparison among design manuals, and the 2018 Roanoke rainfall data, some general recommendations can be made for *consideration* in the drafting of COR's new design manual.

1. Consider reducing the regulatory trigger thresholds (amount of land disturbed) to enact quality and/or quantity requirements, particularly for watersheds where flooding or water quality issues exist. For example, use 0.1 acres, 0.25 acres, or 0.5 acres rather than 1 acre as the threshold.
2. Consider requiring a higher return period for flood control purposes (e.g. 15-, 20-, or 25-year), particularly in flood prone watersheds. For example, recommendations 1. and 2. could be applied in the Lick Run watershed to capture runoff from more sites and delay runoff longer, respectively, thereby attempting to avoid downstream flooding due to coincidence with Trout Run runoff.
3. Consider requiring a higher water quality depth, particularly for pollutant hotspots and watersheds with impairments/TMDLs.
4. Consider enacting total suspended sediment (TSS) reduction requirements if it's determined that the current phosphorus removal requirements are not effective in mitigating sediment related water quality issues and associated legal ramifications (e.g. impairment designations and TMDLs). For example, sediment restrictions may reduce bacterial loading and aid in compliance with Roanoke's 12 bacterial TMDLs.
5. Consider requiring the Energy Balance method in design of all stormwater facilities, in order to better match pre- and post-development volumes. Restrict loopholes, grandfathering, etc. that allow new projects to use peak attenuation only.
6. Consider enacting groundwater recharge requirements (allowed under current VA stormwater laws) in order to mitigate quality and quantity issues. This may not be feasible or effective in areas with karst geology, due to sinkhole issues or rapid transport of contaminants and minimal attenuation, respectively.
7. Consider rooftop and subsurface storage for runoff in highly impervious areas (e.g. Trout Run watershed). Heavily developed cities such as New York and Philadelphia emphasize various methods falling under these two categories.
8. Consider emphasizing, incentivizing implementation of environmental site design, low-impact development, green infrastructure, reductions in impervious area (esp. directly connected), and preservation or re-introduction of green space. LEED-ND and Envision are both good frameworks for this.
9. Consider implementing more stringent post-construction monitoring, maintenance, and enforcement for stormwater control measures pertaining to quality and quantity.

Table 1. Key summary of stormwater management regulations by municipality

Municipality	Water Quantity			Water Quality			Culvert Design	
	Trigger	**Design Criteria**	**Comments**	**Trigger**	**Design Criteria**	**Comments**	**Design Criteria**	**Comments**
VA SWM Handbook (1st Ed.)	Disturbance of ≥ 1 acre, or disturbance of < 1 acre if part of a larger development plan	-All projects: control of Q_{post} to Q_{pre} for the 10-year, 24-hour storm. -Natural channels: no flooding or erosion from the 2-year Q_{post} -Constructed channels: no flooding from the 10-year Q_{post}, no erosion from the 2-year Q_{post} If above criteria are not met, a BMP must be used to control Q_{post} to Q_{pre} for the 2- and 10-year, 24-hour storms		-Disturbance of ≥ 1 acre, or disturbance of < 1 acre if part of a larger development plan -Level of treatment depends on existing and proposed imp. area, and whether performance- or technology-based standards are selected	- Water quality depth of 0.5" from the site's impervious area *-Performance-based:* 1. Existing and prop. Percent imp. (%IC) is less than ALCC, no treatment req. 2. Existing %IC is ≤ ALCC and proposed PI is > ALCC, $TP_{post} \leq TP_{ALLC}$ 3. Existing PI > ALCC, $TP_{post} \leq$ the larger of $0.9TP_{pre}$ or TP_{ALLC} 4. Existing %IC is treated by BMP, $TP_{post} \leq TP_{pre}$ less BMP removal credit *-Technology-based:* A BMP from Table 2 is selected based on the site's proposed %IC and the "Percent Impervious Cover" column in Table 2	ALCC: Average land Cover condition (default 16% but can vary by municipality) Note: Virginia law requires E&SC for regulated land disturbing activities ≥ 10,000 SF (source)	None	
VA SWM Handbook (2nd Ed.)	-Disturbance of ≥ 1 acre, or disturbance of < 1 acre if part of a larger development plan	*-Channel Protection:* 1. Natural channels: no channel erosion from the 1-year, 24-hour storm 2. Constructed channels: no channel erosion from the 2-year, 24-hour Q_{post}, the 10-year, 24-hour Q_{post} must be contained within channel banks *-Overbank Flood Protection (2 options):* 1. Control of 10-year, 24-hour Q_{post} to Q_{pre} (most common) 2. Containment of 10-year, 24-hour Q_{post} within channel banks to a point downstream where the drainage area is 100 times the site area *-Extreme Flood Protection* Control of the 100-year Q_{post} to Q_{pre} is required if development exists downstream in the 100-year floodplain.	The Energy Balance Equation is used for both the channel- and flood-protection requirements	-Statewide: disturbance of ≥ 1 acre, or disturbance of < 1 acre if part of a larger development plan -Localities may set stricter thresholds	-Treatment volume based on 1" depth, site area, and composite runoff coefficient; used to calculate phosphorus loading *-New development:* $TP_{post} \leq 0.41$ lb/ac/yr *-Redevelopment:* 1. For sites ≥ 1 acre, $TP_{post} \leq 0.8TP_{pre}$ 2. For sites < 1 acre, $TP_{post} \leq 0.9TP_{pre}$ 3. For any new impervious area, $TP_{post} \leq$ 0.41 lb/ac/yr 4. For linear projects*, $TP_{post} \leq 0.8TP_{pre}$	*For underground utility projects, if there are no significant shifts from the site's predevelopment hydrology, then the local VSMP authority may not require a SWMP. Similarly, above- or under- ground utility projects may be exempted from a GCP if pre-development hydrology is not significantly altered, less than 1 acre is disturbed on a daily basis, stabilization of completed work areas occurs on a daily basis, E&SC and pollution prevention practices are implemented on site. Note: Virginia law requires E&SC for regulated land disturbing activities ≥ 10,000 SF (source)	None	

Municipality	Water Quantity			Water Quality			Culvert Design	
	Trigger	**Design Criteria**	**Comments**	**Trigger**	**Design Criteria**	**Comments**	**Design Criteria**	**Comments**
Roanoke, VA	-Follows VSMP criteria: disturbance of ≥ 1 acre, or disturbance of < 1 acre if part of a larger development plan -May set stricter criteria and/or requirements	-*VA SWM Handbook 2nd Ed. Criteria apply*		Follows VSMP criteria: disturbance of ≥ 1 acre, or disturbance of < 1 acre if part of a larger development plan -May set stricter criteria and/or requirements	-*VA SWM Handbook 2nd Ed. Criteria apply*		-No damage to upstream property -No increase in 100-year floodplain -Headwater WSE ≤ 18" below road low point -HW depth ≤ 1.5*D -No escaping flow to other channels -Certain criteria for overtopping (see narrative) -Etc. see narrative section	
Boston, MA	-All development projects, except: SF development on four or fewer lots and emergency road/drainage repairs.* -Maximum extent practicable requirements for sites consisting of SF development of 5 to 9 lots or boat yards.*	-Control of 2- and 10-year Q_{post} to Q_{pre} -No increase in off-site flooding from the 100-year storm. -Pre- and post-development groundwater recharge volumes must be approx. equal	*Full regulations apply if development drains to a critical area.	-All development projects, except: single family (SF) development on four or fewer lots and emergency road/drainage repairs.* -Maximum extent practicable requirements for SF development of 5 to 9 lots or boat yards.*	-Removal of 80% of the average annual post construction TSS loading; achievable via pollution prevention, SCMs, and pretreatment. -Water quality treatment volume is based on the site's impervious area and a depth of 0.5" for most areas (1" is used for areas with high pollution potential, high infiltration rates, or sensitive areas).	*Full regulations apply if development drains to a critical area.	-Outfall protection based on max. velocity from the 2-year, 24-hour storm.	
Charlottesville, VA	-Any project which disturbs over 6,000 SF of land and causes an increase in runoff volume, peak flow, or velocity.	-Control of 2-, 10-, and 100-year Q_{post} to Q_{pre}	Disturbance between 6,000 SF and 1 acre must use the ALLC from the 1st Ed. Of the VA SWM handbook (16% impervious) for pre-development. Disturbance over 1 acre must use the ALLC from the 2nd Ed.	-Any project which disturbs over 6,000 SF of land and causes a decrease in water quality.	-*VA SWM Handbook 2nd Ed. Criteria apply*		-Storm sewers in ROW or associated with roadway or sidewalk projects must have a minimum diameter of 15" and be made of RCP or HDPE pipe.	
Fairfax, VA	-Follows VSMP criteria: disturbance of ≥ 1 acre, or disturbance of < 1 acre if part of a larger development plan	-*VA SWM Handbook 2nd Ed. Criteria apply*		Follows VSMP criteria: disturbance of ≥ 1 acre, or disturbance of < 1 acre if part of a larger development plan	-*VA SWM Handbook 2nd Ed. Criteria apply*		-Minimum diameter of 15" for RCP -Maximum diameter of 48" for HDPE pipe -Minimum design criteria for culvert use: a) Normal runoff (10-year) b) Primary roads (25-year) c) Secondary roads (10-year) c) Flooding of buildings/structures (100-year) d) Curb and gutter inlets (2-year)	

Municipality	Water Quantity			Water Quality			Culvert Design	
	Trigger	**Design Criteria**	**Comments**	**Trigger**	**Design Criteria**	**Comments**	**Design Criteria**	**Comments**
Maryland Department of the Environment	≥ 5,000 SF of disturbed earth	-If history of flooding or mandated by local authorities: control of 10-year Q_{post} to Q_{pre} (2-year in Eastern shore) -Channel protection volume: detention of 1-year, 24- Q_{post} to Q_{pre} (12-hour in some areas) -Control of 100-year, 24-hour Q_{post} to Q_{pre} may be required if development exists in 100-year floodplain or the receiving channel is inadequate. -SCMs must be able to pass the 100-year peak flow.		≥5,000 SF of disturbed earth	-Treatment volume based on composite runoff coefficient, site area, and 0.9" or 1" for western or eastern half of state, respectively. -SCM removal of 80% and 40% of the average annual post development TSS and TP load, respectively.		-Minimum diameter of 6" -Certain pipe material requirements/criteria	
North Carolina	Determined by local government	Determined by local government		Depends on watershed classification, various thresholds for land disturbance: 1. > 1 acre 2. > 0.5 acre 3. > 12,500 SF -or- 4. >10,000 SF of imp. area added	-Treat runoff from entire site based on design storm: 1. Non-coastal counties: 1" 2. Coastal counties: 1.5" or the pre- & post-volumetric difference for the 1 year, 24-hour storm -Drawdown times must be between 48 and 120 hours. -All SCMs must remove 85% of average annual TSS (TN and/or TP requirements in certain areas)	-Receiving channel cannot be eroded by the 10-year storm -Spillway must pass the 100-year storm -Possible exemptions for LID and redevelopment if certain conditions are met	Determined by local govt.	
New York City, NY	New developments: if post-development peak flow (5-year, 6-min) is greater than 0.25 cfs or the "allowable flow" to sewer system, then detention is required Redevelopment: If an increase in imp. area occurs, similar criteria to new development apply, with an adjustment (see right)	-Storage facilities based on the 10-year storm and a storm duration based on site characteristics (Rational Method) -*Release rate from the detention facility:* 1. Discharging to CSS: larger of 0.25 cfs or 10% of allowable flow 2. Discharging to MS4, allowable flow Redevelopment: flow from the altered area ≤ total site release rate (as determined above) times the ratio of the altered to total area.		None	None	Since most of NYC is served by a CSS, the stormwater manual is focused on reducing flow into the CSS. Accordingly, there are no formal water quality design criteria.	None	

Municipality	Water Quantity			Water Quality			Culvert Design	
	Trigger	**Design Criteria**	**Comments**	**Trigger**	**Design Criteria**	**Comments**	**Design Criteria**	**Comments**
Philadelphia, PA	-New development: > 15,000 SF of earth disturbance (5,000 SF in certain watersheds) triggers Channel Protection and Flood Control. -Redevelopment: >1 acre of earth disturbance triggers Channel Protection and > 15,000 SF (5,000 SF in certain watersheds) triggers Flood Control. -Projects that discharge to capacity limited sewers must comply with Public Health and Safety Release Rate Requirements	-Channel Protection: detain and discharge post-development at a maximum rate of 0.24 cfs per acre of DCIA within limits of earth disturbance and drain within 72 hours. -Flood Control requires attenuation of Q_{post} to Q_{pre} for a range of return periods from entire site. Standards vary by Flood Control District: • Least strict (post- to pre-peak flow): 2-year → 1-year 5-year → 5-year 10-year → 10-year 25-year → 25-year 50-year → 50-year 100-year → 100-year • Most strict (post- to pre-peak flow): 2-year → 1-year 5-year → 2-year 25-year → 5-year 50-year → 10-year 100-year → 100-year -Public Health and Safety Release Rate Requirements: maximum peak flow rates from all surfaces (pervious and impervious) within the limits of disturbance are set for all storms between the 1- and 10-year events based on the receiving sewer's available capacity.	-Channel Protection exemptions for re-development projects which disturb less than 1 acre or have post-development DCIA 20% less than pre-development IA. -Flood Control exemptions for re-development projects which have post-development DCIA 20% less than pre-development IA or do not use public sewers to drain to certain waterbodies.	15,000 SF of earth disturbance (5,000 SF in certain watersheds)	-Treat a water quality volume (WQv) resulting from a design depth of 1.5" over the site's DCIA • If infiltration is feasible, the entire WQv must be infiltrated. • If infiltration is not feasible, and the project drains to a combined sewer, all non-infiltrated runoff must be treated with an acceptable practice, detained for 72 hours, and released at a max. rate of 0.05 cfs per acre of DCIA. For projects draining to a separate sewer, the same requirements apply except the max. release rate.	ES&C required for all projects during construction regardless of size.	None	
Portland/Washington County, OR	All development projects	-Control of 2-, 10-, 25- year, 24-hour Q_{post} to Q_{pre} -Emergency spillway sized for 100-year storm	Additional control of all storms which cause "downstream deficiency"	≥ 1,000 SF of disturbance	-0.36" depth over 4 hours falling on the site's impervious area -Average 96-hour return period -65% TP removal		-Sized for 25-year flow *-Protection:* D > 18" needs inlet protection D > 12" needs outlet protection *-Headwater restrictions:* a) D ≤ 18" - HW ≤ 2*D or 3*D with seepage collar b) D ≥ 18" - HW ≤ 1.5*D	Additional restrictions for FEMA flood zones or sensitive areas

Municipality	Water Quantity			Water Quality			Culvert Design	
	Trigger	Design Criteria	Comments	Trigger	Design Criteria	Comments	Design Criteria	Comments
Seattle, WA	-All projects must meet certain criteria (see narrative document). -On-site Stormwater Management: NPRHS > 2,000 SF or LDA > 7,000 SF* -Wetland Protection Standard: NPRHS > 5,000 SF, or > 0.75 acres of vegetation converted to lawn, or > 2.5 acres of native vegetation converted to pasture. -Pre-developed Forest Standard: If existing conditions are forested or <35% impervious <u>AND</u> NHS > 5,000 SF, or NPRHS > 10,000 SF, or > 0.75 acres of vegetation converted to lawn, or > 2.5 acres of native vegetation converted to pasture, or 0.1 cfs increase in the 100-year peak flow. -Pre-developed Pasture Standard: roadway projects with NPRHS > 10,000 SF or parcel projects with NPRHS > 2,000 SF -Peak Control Standard: roadway projects with NPRHS > 10,000 SF or parcel projects with NPRHS > 2,000 SF (> 10,000 SF if draining to public combined sewers).	-Large projects, projects with excavation depth > 12', or excavation depths < 12' in shallow groundwater zones must ensure receiving separate sewers can convey the 25-year peak flow and combined sewers can convey the 5-year peak flow. -On-site Stormwater Management: • Case 1: If the existing hard surface coverage is less than 35% and discharges to a listed creek or its watershed, post-development discharge duration must match the duration of pre-developed forested conditions for a range of flows from 8% of the 2-year flow to 50% of the 2-year flow • Case 2: For all other projects, post-development discharge rates must match durations of pre-developed pasture conditions for a range of flow durations from the 10-year storm to the 100-year storm. -Flow Control: • Wetland Protection Standard: post-development flow volume to wetland must be within 20% and 15% (higher <u>or</u> lower) of pre-development volumes on an event- and monthly-basis, respectively. • Pre-developed Forested Standard: post-development flow durations must match the pre-development duration under forested conditions for 50% of the 2-year peak flow up to the 50-year peak flow. • Pre-developed Pasture Standard: post-development flow durations must match the pre-development duration under pasture conditions for 50% of the 2-year peak flow up to the 2-year peak flow. • Peak Control Standard: the 25-year and 2-year post-development peak flows cannot be greater than 0.4 cfs/acre and 0.15 cfs/acre, respectively.		-Minimum Water Quality Standards (Treatment Volume, Treatment Rate, and Infiltration Treatment): sites with NPRHS > 5,000 SF or sites with PGPS > 0.75 acres. -Oil Treatment: Commercial or industrial areas with: ADT > 100 vehicles per 1,000 SF building area, or petroleum storage or transfer > 1,500 gallons per year, or road intersections with ADT > 25,000 vehicles on primary road and > 15,000 vehicles on intersecting road. -Phosphorus Treatment: sites discharging or infiltrating within 0.25 miles of a nutrient-critical waterbody or its tributary. -Enhanced treatment: sites draining or infiltrating within 0.25 miles of a fresh water body with an aquatic life designated use, AND: site is industrial, commercial, or MFR, or limited access highways with ADT > 15,000, or roadways with ADT > 7,000. -Basic Treatment: sites with any of the following characteristics must comply: usage of infiltration, SF residential not requiring TP control, drainage to specific waterbodies, drainage to waterbodies without an aquatic life designated use, parking lots on industrial or commercial sites only used for employee parking.	-Runoff Treatment Volume: The required treatment volume is the daily runoff volume that generates 91% of the entire runoff volume for the period of record. -Runoff Treatment Flow Rate: design flow rates are dependent on the presence of an upstream or downstream detention facility. • Facilities upstream of detention facilities must use a design flow rate that results in treatment of 91% of the total runoff volume for the period of record. • Facilities downstream of detention facilities must use a design flow equal to the full release rate of the 2-year storm. -Infiltration Treatment Requirements: infiltrative facilities used for water quality treatment must infiltrate 91% of the total runoff volume for the period of record. This treatment volume (24-hour volume) must drain within 48-hours. -Oil Treatment: • Grab samples ≤ 15 mg/L • 24-hour average concentrations ≤ 10 mg/L • No persistent or repeated visible oil sheen -Phosphorus Treatment: 50% TP removal for influent concentrations between 0.1 and 0.5 mg/L. -Enhanced Treatment: ≥ 30% dissolved copper removal and ≥ 60% dissolved zinc removal. -Basic Treatment: 80% TSS removal for influent concentrations between 100 and 200 mg/L, higher removal for influent concentrations > 200 mg/L, and 20 mg/L effluent target concentration for influent concentrations < 100 mg/L.			Inspect periodically for scour.

Municipality	Water Quantity			Water Quality			Culvert Design	
	Trigger	**Design Criteria**	**Comments**	**Trigger**	**Design Criteria**	**Comments**	**Design Criteria**	**Comments**
Washington, DC	All development projects	-Control of 2-year and 15-year, 24-hour Q_{post} to Q_{pre} (erosion and flood control, respectively) -Control of 100-year Q_{post} to Q_{pre} under certain conditions -Emergency spillway sized for the 100-year Q_{post}		-MLDA (≥ 5,000 SF of land disturbance) -MSIA (≥ 5,000 SF of improvement activity of existing structures with some or no land disturbance)	-Required retention volume based on impervious, compacted, and natural land covers *-Design storm depth (P) based on type of disturbance:* 1. For MLDA, P = 1.2" (90th percentile event) 2. For MSIA in the Anacostia River watershed, P = 1.0" (85th percentile event) 3. For all other MSIA, P = 0.8" (80th percentile event)	Certain activities in the Anacostia River Watershed must treat runoff from the 95th percentile event (1.7") less the normal required retention volume and 80% TSS removal MLDA: Major land disturbing activity MSIA: Major substantial improvement activity	-Inlet must resist long-term erosion and accommodate future increases in hydraulic loading -Outlet must be built to prevent future channel scour	

2.1 VA SWM Handbook (1st Edition).

The first edition of the Virginia stormwater management (VA SWM) handbook has three main criteria: water quality, channel erosion, and water quantity. These criteria, enacted under the Virginia Stormwater Management Program (VSMP), essentially bundle several separate laws: the Chesapeake Bay Preservation Act (CBPA), the Virginia Pollutant Discharge Elimination System (VPDES), Minimum Standard 19 (MS-19), and local flood requirements.

Two key regulatory tools are used by the VSMP: a construction general permit (CGP) and a general permit (GP). CGPs are required for construction sites disturbing 1 or more acres, or sites that disturb less than 1 acre but are part of a larger development plan and/or larger, contiguous piece of land undergoing disturbance (even at different times). Localities with a municipal separate storm sewer system (MS4) are required to obtain a general permit. These general permits mandate that municipalities reduce and regulate stormwater pollution to protect downstream water quality through six minimum control measures (VDOT, 2012).

1. Stormwater impacts education and outreach
2. Public involvement
3. Illicit discharge detection and elimination (IDDE)
4. Construction stormwater management
5. Post-construction stormwater management for new- and re-development
6. Pollution prevention in municipal operations

2.1.1 Uniform BMP Sizing Criteria

The MS-19 regulations were initially only concerned with control of peak flows and erosive velocities and were enacted in 1990. The original MS-19 regulations state that to prevent channel erosion and flooding downstream, natural channels that receive stormwater from developed sites must be able to convey the peak flow from the 2-year storm within the channel banks and withstand channel erosion from the 2-year event. Constructed channels must convey the peak flow from the 10-year storm within the channel banks and withstand erosion from the 2-year storm. If the receiving channel is found to be inadequate, a BMP must be implemented on site and must be sized to release the peak flow rates from the 2- and 10-year storms to pre-development levels (all storm durations are 24-hours). For natural channels that experience erosion issues from existing conditions or that may be sensitive to any development, 24-hour detention of the 1-year storm may be required by the local authorities rather than the 2-year storm.

In 1999, MS-19 was amended to include water quality requirements for state projects, CBPA jurisdictions, and MS4s. Post-construction stormwater water quality treatment is required for new- and re-development in these jurisdictions. To achieve this, a water quality volume (WQV) of 0.5” was created, and BMPs must be designed to treat one or more WQVs depending on existing and proposed site conditions. There are two options for meeting the water quality criteria: performance based- and technology based-criteria. For the performance-based criteria, the level of treatment depends on post- and pre-development conditions, and the “average land cover

condition" (defined as the impervious area of the watershed, assumed to be a default of 16% but can vary based on locality). There are four categories by which the level of treatment is determined:

1. Category 1: The existing and proposed percent impervious (PI) is less than the average land cover condition (ALCC). No treatment is required for the proposed conditions.
2. Category 2: The existing PI is less than or equal to the ALCC and the proposed PI is greater than the ALCC. Post-development pollutant loading cannot exceed current loading from the ALCC.
3. Category 3: Existing PI is greater than the ALCC. The post-development loading cannot exceed 90% of the existing loading or the loading from the ALCC, whichever value is larger.
4. Category 4: The existing PI is treated by a water quality BMP. The post-development loading cannot exceed the existing loading minus the pollutant removal from the existing BMP. The existing BMP must have been designed properly, maintained, and must function properly.

BMPs can be selected based on the removal efficiencies shown in Table 2. Sizing is based on the required removal (essentially the number of water quality volumes multiplied by the contributing impervious area). Design standards are available in the VA SWM Handbook.

Table 2. Water quality BMPs, Phosphorus removal efficiencies, and target percent imperviousness range (copied from VA SWM handbook 1st Ed.)

Water Quality BMP	Target Phosphorus Removal Efficiency	Percent Impervious Cover
Vegetated filter strip	10%	16-21%
Grassed swale	15%	
Constructed wetlands	30%	
Extended detention (2 x WQ Vol)	35%	22 -37%
Retention basin I (3 x WQ Vol)	40%	
Bioretention basin	50%	
Bioretention filter	50%	
Extended detention-enhanced	50%	38 -66%
Retention basin II (4 x WQ Vol)	50%	
Infiltration (1 x WQ Vol)	50%	
Sand filter	65%	
Infiltration (2 x WQ Vol)	65%	67 -100%
Retention basin III (4 x WQ Vol with aquatic bench)	65%	

For the technology-based treatment criteria, a BMP from Table 2 must be implemented based on the site's proposed PI and the "Percent Impervious Cover" column in Table 2.

Additionally, to meet flood control criteria, all sites must capture and attenuate the post-development 10-year, 24-hour storm peak flow to pre-development levels. Alternate criteria may be required by localities depending on local conditions (e.g. geology, topography, land use, downstream conditions). Linear development projects are not required to meet the flood control criteria, unless required by a regional SWM or watershed plan (Aguilar, 2017).

Generally, the requirements for erosion, water quality, and water quantity may be combined into a single BMP if desired.

In 2004, the CGPs were amended to require water quality treatment for all development sites 1 acre or larger. In 2009, water quality requirements that are stricter than the state threshold could be determined by local municipalities, and in 2014, the VSMP was revised significantly with the release of the 2nd edition of the VA SWM handbook.

2.2 VA SWM Handbook (2nd Edition).

The 2nd Edition of the Virginia Stormwater Management (SWM) Handbook was published in 2013, with the revised regulations (a.k.a. the 3rd CGP cycle) taking effect in 2014. This revision shifted design standards toward low impact development (LID) and infiltrative BMP approaches. Additionally, the Runoff Reduction Method was introduced, which uses a design depth of 1" for water quality. The Virginia Stormwater Management Act (VSMA) now requires all cities, counties, and towns with an MS4 to administer construction general permits (CGP) via an adopted Virginia Stormwater Management Program (VSMP). Large and medium municipalities with an MS4 (Phase I and II, respectively) must comply with general permit (GP) requirements set forth by the Virginia Pollutant Discharge Elimination System (VPDES). The criteria for determining if a CGP or General Permit (GP) is needed remains unchanged.

2.2.1 Uniform BMP Sizing Criteria

Following the widespread adoption of stormwater management based on peak flow reduction, there was a recognition that since such methods did not control increases in runoff volume or address the increased frequency of higher flows, issues with stream channel erosion and water quality persisted. For BMP sizing, the revised regulations shifted from a water quality volume of 0.5" from the site's impervious area to a "treatment volume" (Tv) based on 1" over the entire site. Additionally, the channel protection and overbank flood protection volumes now use an "energy balance method" and are based on the 1-year, 24-hour and 10-year, 24-hour storms, respectively. A groundwater recharge volume is accounted for in the treatment volume, and an extreme flood protection volume is only required if certain conditions apply. The overall goal is to match pre- and post-development hydrology as closely as possible for a wide variety of storms. Table 3 summarizes each component of the uniform BMP sizing criteria:

Table 3. Statewide Uniform BMP Sizing Criteria (copied from VA SWM Handbook 2nd Ed. – Ch. 10)

Sizing Criteria	Description of Stormwater Sizing Criteria
Recharge Volume (Re_v) (acre-feet)	Virginia has no separate recharge requirement. The Virginia Runoff Reduction Methodology serves to address both the recharge and water quality treatment criteria in the regulations. The Method can also potentially meet or help to meet the water quantity control criteria. See Appendix 13-A for an optional approach to assuring reasonable groundwater recharge.
Treatment Volume (T_v) (acre-feet)	$Tv = \frac{P \times (Rvi \times \%i + Rvt \times \%t + Rvf \times \%f) \times SA}{12}$ Where: Tv = Runoff reduction volume in acre feet P = Depth of rainfall (1-inch) for "water quality" event Rvi = runoff coefficient for impervious cover[1] Rvt = runoff coefficient for turf cover or disturbed soils[1] Rvf = runoff coefficient for forest cover[1] %i = percent of site in impervious cover %t = percent of site in turf cover %f = percent of site in forest cover SA = total site area, in acres [1] Obtain Rv values from **Table 10.3** below
Channel Protection Storage Volume (Cp_v)	The required storage volume is situational, based on the type of receiving channel that exists downstream of the drainage outfall (9 VAC 25-870-66 A), with the flow released at a rate that will prevent erosion of the receiving channel; depending upon how much runoff volume reduction is achieved on-site with water quality BMPs, there may be little or no additional Cp_v; detention upstream of natural receiving channels is based on situational energy balance formulas described on page 13 of this chapter and based on the 1-year 24-hour storm.
Overbank Flood Protection Volume (Q_{10})	The required storage volume is situational, based on the type of receiving channel that exists downstream of the drainage outfall (9 VAC 25-870-66 B), with the flow released at a rate that will prevent erosion of the receiving channel; depending upon how much runoff volume reduction is achieved on-site with water quality BMPs, there may be little or no additional Q_{10}; detention upstream of natural receiving channels is based on the energy balance formula described on page 13 of this chapter and based on the 10-year 24-hour storm.
Extreme Flood Protection Volume (Q_f)	Consult the appropriate review authority. Normally, no control is required if development is excluded from the 100-year floodplain and downstream conveyance is adequate for up to the 10-year 24-hour design storm.

The regulations promote a philosophy of "avoid-minimize-mitigate" during the land development process, in other words: avoid impacts if possible, minimize impacts if avoidance is impossible, and mitigate any resulting impacts through BMPs, etc. Environmental site design and effective, efficient BMP design are key aspects of this philosophy.

The purpose of each component of the BMP sizing criteria is relatively self-explanatory. Figure 10 shows an approximate range of rainfall depths for each component. Note that the recharge volume consists of rainfall events which typically do not produce runoff but are important for groundwater recharge.

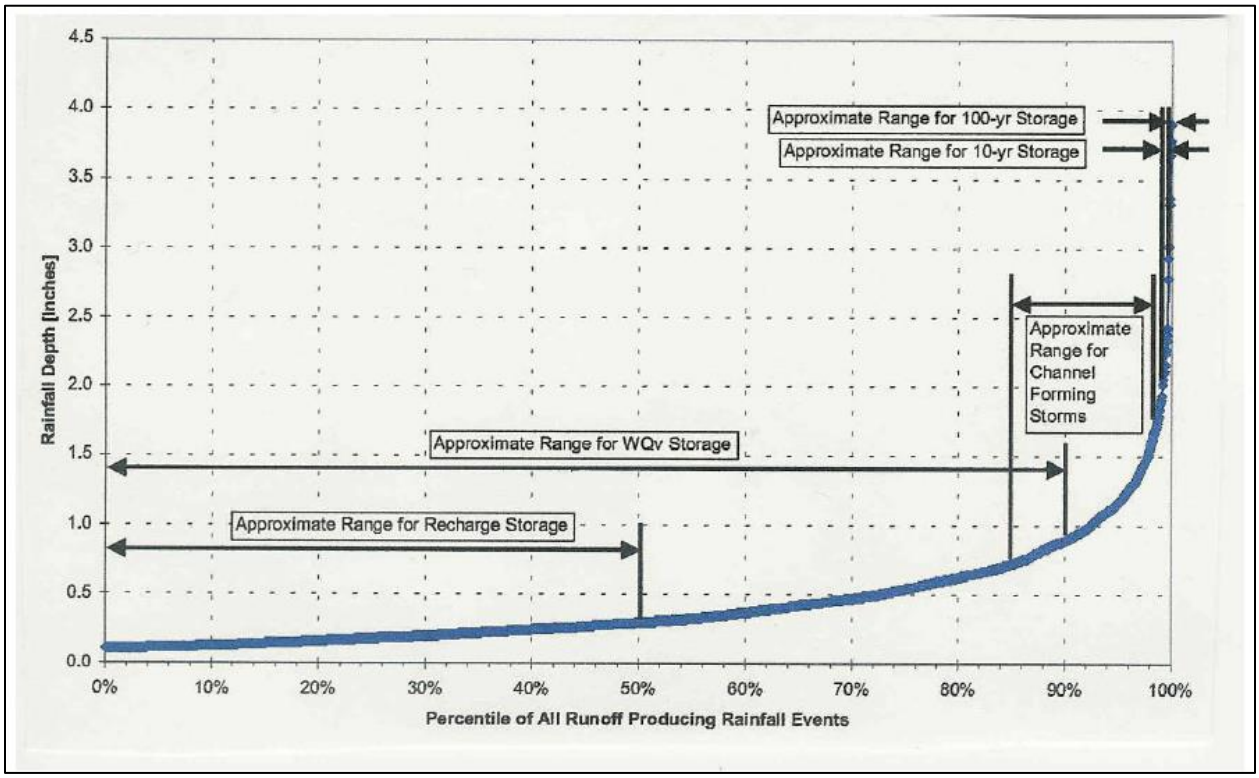

Figure 10. Rainfall depth for each component of BMP sizing criteria (copied from VA SWM Handbook 2nd Ed. – Ch. 10)

The storage volume required for each sizing component increases as the magnitude of the design storm increases (e.g. the channel protection volume is larger than the water quality volume). However, the regulations allow a "nested" design approach, whereby the volume from one sizing criteria can be counted towards the required volume from a "higher" criterion (e.g. the water quality volume can be counted towards the channel protection volume). This nested approach is illustrated in Figure 11.

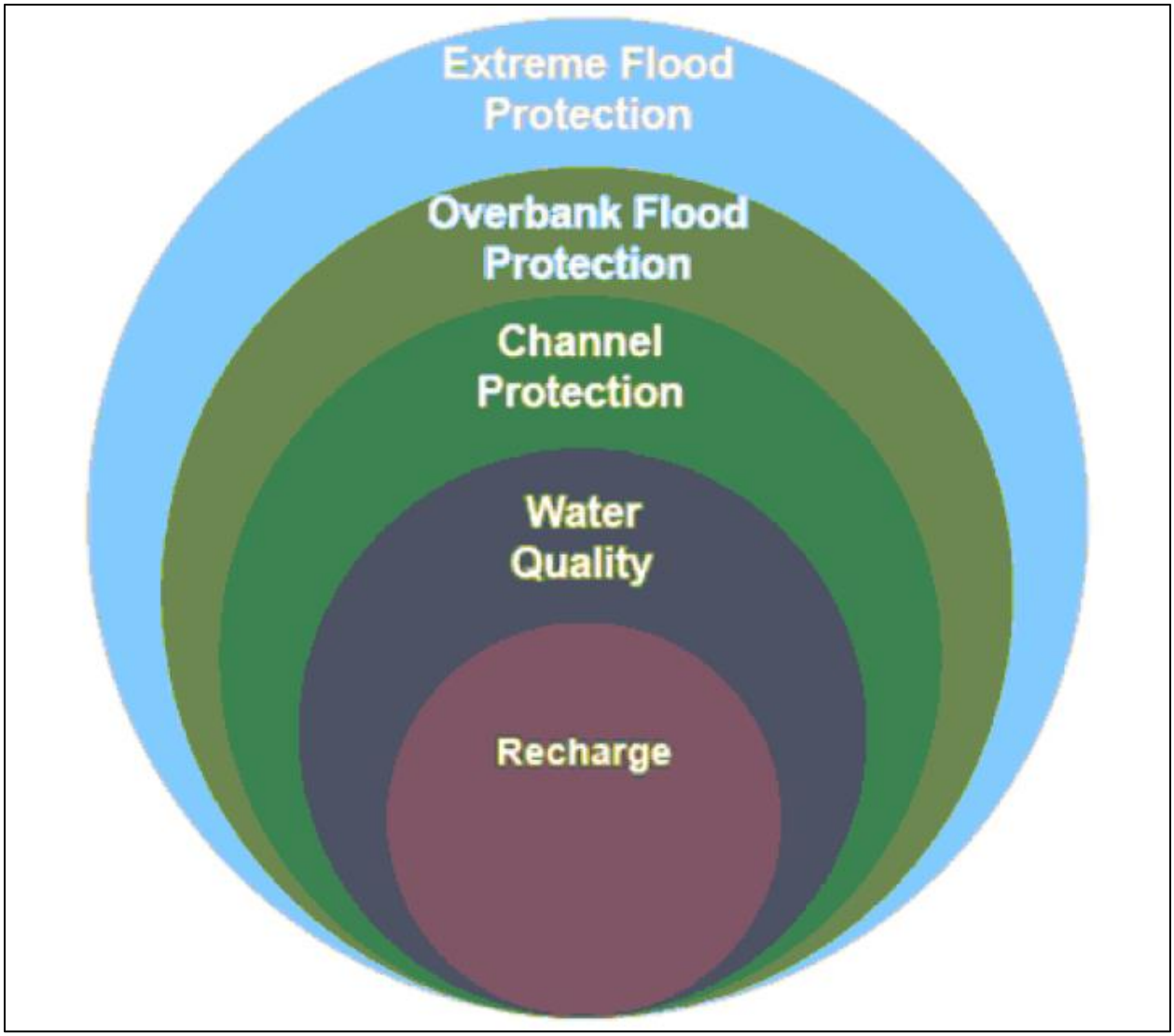

Figure 11. Nested approach for meeting BMP sizing criteria (copied from VA SWM Handbook 2nd Ed. – Ch. 10)

The Virginia Runoff Reduction Method (RRM), which essentially comprises the criteria of recharge, water quality, and channel protection, has goals of reducing the pollutant carrying runoff volume, reducing the total volume to receiving streams, and achieving recharge rates which maintain pre-development water tables and baseflow. Localities may set more stringent sizing criteria under certain conditions. Although the treatment volume should theoretically include the recharge volume, the handbook offers a method for calculating a separate recharge volume if a locality desires to do so (explained later).

2.2.2 Treatment Volume – Water Quality (Runoff Reduction Method)

Previously, many water quality design standards used a "first flush" criteria of 0.5", however since pollutant mobilization and transport is also dependent on rainfall intensity and duration, the first flush approach has fallen out of favor. Instead, design criteria have shifted to a

"percentile" approach. Typically, the 90th percentile of all storms for a given area is used as the water quality design depth, this ensures that, annually, all but the largest storms are treated for water quality (essentially everything except for the exponential segment in Figure 10). For Virginia, the water quality depth is 1", and while the 90th percentile rainfall depth varies somewhat across Virginia (Table 4), an assumed 1 in. rainfall is more straightforward for statewide use.

Table 4. 90th Percentile rainfall event for various locations in Virginia (data from VA SWM Handbook 2nd Ed. – Ch. 10)

Location	90th Percentile Rainfall Depth (in)
Abingdon	0.97
Harrisonburg	1.05
Lynchburg	1.23
Richmond	1.29
Northern Virginia	1.14

The treatment volume is based on the product of the 1" water quality depth, a composite runoff coefficient, and the site area (Figure 12).

$$Tv = \frac{P \times (Rvi \times \%i + Rvt \times \%t + Rvf \times \%f) \times SA}{12}$$

Where:

Tv = Runoff treatment volume in acre feet
P = Depth of rainfall (1-inch) for "water quality" event
Rvi = runoff coefficient for impervious cover [1]
Rvt = runoff coefficient for turf cover or disturbed soils [1]
Rvf = runoff coefficient for forest cover1
%i = percent of site in impervious cover (fraction)
%t = percent of site in turf cover (fraction)
%f = percent of site in forest cover (fraction)
SA = total site area, in acres

[1] Obtain Rv values from Table 5 below

Figure 12. Treatment volume equation (copied from VA SWM Handbook 2nd Ed. – Ch. 10)

Use of runoff coefficients means that sites with very high impervious and/or disturbed areas will be closer to 1" for the treatment volume. This is an incentive to reduce disturbed and impervious areas (and preserve forested areas), thereby reducing the required treatment volume and associated costs for construction, land, maintenance, etc. Overall, the treatment volume should

capture about 90% of annual runoff, while partially treating larger storms – an approach consistent with several other Chesapeake Bay watershed states. It also provides a measure (treatment volume) for evaluating the efficacy of various management approaches (e.g. ESD, runoff reduction, infiltrative approaches, and traditional BMPs).

Another revision to the stormwater handbook was inclusion of land covers other than impervious area in water quality treatment calculations (Table 5). Research has found that disturbed soils and managed turfgrass significantly contribute to runoff volume and pollutant loading due to factors such as compaction and fertilizer, pesticide applications, respectively. Although similar to the runoff coefficients used in the NRCS or Rational Methods, the coefficients in Table 5 should only be used when calculating the treatment volume.

Table 5. Runoff coefficients for calculating treatment volume (copied from VA SWM Handbook 2nd Ed. – Ch. 10)

Soil Cover Condition	Runoff Coefficients			
	HSG-A	HSG-B	HSG-C	HSG-D
Forest	0.02	0.03	0.04	0.05
Disturbed Soil or Managed Turf	0.15	0.20	0.22	0.25
Impervious Cover	0.95			

The RRM also includes phosphorus removal criteria which varies based on the type of development, as summarized below:

- New Development
  - Post-development phosphorus loading (P_{post}) cannot exceed 0.41 lbs/ac/year from the entire site.
- Redevelopment
  - Post-development impervious area ≤ pre-development impervious area:
    - For sites ≥ 1 acre, $P_{post} \leq 0.8P_{pre}$
    - For sites < 1 acre, $P_{post} \leq 0.9P_{pre}$
  - Post-development impervious area > pre-development impervious area:
    - For sites ≥ 1 acre, 0.41 lbs/ac/yr from new imp. and $P_{post} \leq 0.8P_{pre}$ for remaining area
    - For sites < 1 acre, 0.41 lbs/ac/yr from new imp. and $P_{post} \leq 0.9P_{pre}$ for remaining area
  - Linear projects:
    - $P_{post} \leq 0.8P_{pre}$

The annual phosphorus loading from the site is calculated using the Simple Method, which is based on the site's treatment volume, Virginia's average annual rainfall depth (43"), an event mean concentration (EMC) of total phosphorus (TP) of 0.26 mg/L, and a dimensionless correction factor of 0.9. Based on the development type and removal criteria listed above, one or more BMPs are selected to achieve TP loading compliance. The runoff reduction and TP removal credits for each BMP category is listed in Table 6. The RRM spreadsheet performs the required calculations and determines which BMPs can achieve compliance based on the site characteristics.

Table 6. Runoff reduction and nutrient removal credits by BMP type (copied from [Virginia Stormwater BMP Clearinghouse])

Practice	Design Level	Runoff Reduction	TN EMC Removal[3]	TN Load Removal	TP EMC Removal	TP Load Removal [6]
Rooftop Disconnect	1 [2]	25 to 50 [1]	0	25 to 50 [1]	0	25 to 50 [1]
	No Level 2 Design					
Sheet Flow to Veg. Filter or Conserv. Open Space	1	25 to 50 [1]	0	25 to 50 [1]	0	25 to 50 [1]
	2 [5]	50 to 75 [1]	0	50 to 75 [1]	0	50 to 75 [1]
Grass Channels	1	10 to 20 [1]	20		15	23
	No Level 2 Design					
Soil Compost Amendment	Can be used to Decrease Runoff Coefficient for Turf Cover at Site. See the design specs for Rooftop Disconnection, Sheet Flow to Vegetated Filter or Conserved Open Space, and Grass Channel					
Vegetated Roof	1	45	0	45	0	45
	2	60	0	60	0	60
Rainwater Harvesting	1	Up to 90 [3, 5]	0	Up to 90 [3, 5]	0	Up to 90 [3, 5]
	No Level 2 Design					
Permeable Pavement	1	45	25	59	25	59
	2	75	25	81	25	81
Infiltration Practices	1	50	15	57	25	63
	2	90	15	92	25	93
Bioretention Practices	1	40	40	64	25	55
	2	80	60	90	50	90
Urban Bioretention	1	40	40	64	25	55
	No Level 2 Design					
Dry Swales	1	40	25	55	20	52
	2	60	35	74	40	76
Wet Swales	1	0	25	25	20	20
	2	0	35	35	40	40
Filtering Practices	1	0	30	30	60	60
	2	0	45	45	65	65
Constructed Wetlands	1	0	25	25	50	50
	2	0	55	55	75	75
Wet Ponds	1	0	30 (20) [4]	30 (20) [4]	50 (45) [4]	50 (45) [4]
	2	0	40 (30) [4]	40 (30) [4]	75 (65) [4]	75 (65) [4]
Ext. Det. Ponds	1	0	10	10	15	15
	2	15	10	24	15	31

Notes [1] Lower rate is for HSG soils C and D, Higher rate is for HSG soils A and B.
[2] The removal can be increased to 50% for C and D soils by adding soil compost amendments, and may be higher yet if combined with secondary runoff reduction practices.
[3] Credit up to 90% is possible if all water from storms of 1-inch or less is used through demand, and the tank is sized such that no overflow occurs. The total credit may not exceed 90%.
[4] Lower nutrient removal in parentheses apply to wet ponds in coastal plain terrain.
[5] See BMP design specification for an explanation of how additional pollutant removal can be achieved.
[6] Total mass load removed is the product of annual runoff reduction rate and change in nutrient EMC.

2.2.3 Stream Channel Protection

Historically, there has been a recognition that the increase in peak flow, runoff volume and enhanced hydraulic efficiency of urbanization causes stream channel erosion, resulting in channel enlargement by a factor of 2 to 10. Channel erosion causes significant increases in downstream sediment and nutrient loading, due to erosion of nutrient rich alluvium. As with many other states, the 1st edition of the stormwater handbook stipulated that the 2-year, 24-hour storm must be controlled to pre-development levels for channel erosion control. This was based on the idea that the "bankfull" discharge, also known as the "channel forming" discharge, occurred in most channels from storms with a return period of 1-2 years, with ~1.5 years as the most common. However, research has shown that detaining the 2-year storm may increase channel erosion: since only the peak flow is attenuated and not the increase in volume, the channel is potentially exposed to an erosive velocity (i.e. bankfull or even smaller flows) for a longer period of time.

The revised regulations mandate that "*Properties, state waters, and stormwater conveyances within or downstream of a land disturbing activity shall be protected from sediment deposition, erosion and flood damage due to unmanaged quantity of stormwater and changes in runoff characteristics.*" Runoff characteristics are defined as: *"Runoff characteristics include, but are not limited to velocity, peak flow rate, volume, time of concentration, and flow duration, and their influence on channel morphology including sinuosity, channel cross-sectional area, and channel slope."*

As with a number of other states, Virginia now requires that the 1-year, 24-hour storm be detained for 24-hours and released at pre-development rates. Man-made channels must also convey the 2-year peak flow at non-erosive velocities and the 10-year peak flow within the channel banks.

Another key revision to the channel protection criteria is the use of the "energy balance method". Research suggests that channels forming flows are better represented by an "energy" basis rather than a peak flow basis alone. Essentially, this means that both flow volume and velocity determine channel morphology. Therefore, the maximum allowable 1-year, 24-hour flow peak flow rate is determined via the equation in Figure 13:

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

Where:

$Q_{Developed}$ = The allowable peak flow rate of runoff from the developed site
$I.F.$ = Improvement factor, equal to 0.8 for sites > 1 acre or 0.9 for sites ≤ 1 acre
$Q_{Pre\text{-}Developed}$ = The peak flow rate of runoff from the site in the pre-developed condition
$RV_{Pre\text{-}Developed}$ = The volume of runoff from the site in the pre-developed condition
$RV_{Developed}$ = The volume of runoff from the site in the developed site

Figure 13. Energy balance equation (copied from VA SWM Handbook 2nd Ed. – Ch. 10)

If the site discharges to a natural, stable stream, the pre-development land cover is used to calculate the pre-development peak flow and runoff volume. If discharging to a natural stream that is was already experiencing "excessive erosion", then a good forested condition must be used for the pre-development calculations. Theoretically, the energy balance equation should result in non-erosive discharges for the 1-year and lower storms.

2.2.4 Overbank Flood Protection

The overbank flood protection criterion is designed to prevent damage to structures and property resulting from overbank flows. If downstream flooding is an existing problem, the flood protection criterion requires that the post-development peak flow from the 10-year, 24-hour storm either be contained within the receiving channel or be attenuated to the pre-development peak flow via storage. For the first option, the channel must contain the flow until the point downstream where the drainage area is 100 times the site drainage area. Control of the 10-year event is the most commonly used option and provides significant attenuation of higher return period events (e.g. 70-80% reduction of the 25-year storm peak flow). If existing downstream flooding does not exist, then no action may be needed, however detention or channel improvements may be required by the local VSMP authority regardless.

2.2.5 Extreme Flood Protection

The goals of the extreme flood protection criterion are to maintain 100-year FEMA floodplains (i.e. prevent an increase in the 100-year floodplain extent) and prevent loss of life and property damage; there are two options to achieve this:

1. Detain and release the post-development 100-year, 24-hour peak flow to pre-development levels (the most expensive option). The structural BMP used must be able to convey the 100-year 24-hour flow (typically via an emergency spillway), to prevent damage to the embankment or riser.

2. If development is not allowed within the 100-year floodplain, no action is needed. However, if development exists within the ultimate 100-year floodplain or the "review authority" does not have full jurisdiction over the floodplain, then this option may not be allowed.

2.3 Roanoke, VA

2.3.1 Water Quality and Quantity

Generally, Roanoke defers to Virginia Stormwater Management Program (VSMP) requirements for water quality, which focus on phosphorus removal. However, the City reserves the right to impose stricter removal requirements and/or removal criteria for a wider variety of contaminants (e.g. hydrocarbons, sediment, heavy metals, thermal pollution), particularly for pollution hotspots. Similarly, the City defers to VSMP and VDOT requirements for water quantity but has the right to apply stricter criteria. The city encourages use of low-impact development (LID) practices in order to reduce water quantity and quality issues.

2.3.2 Culvert Design

The design criteria for culverts depends on the type of roadway that the culvert services: for primary and arterial roads a 25-year design frequency is required and for secondary and other roads a 10-year design frequency is required. NFIP compliance is required for projects which intersect with a 100-year floodplain, and stricter design requirements may be required for projects which pose a significant hazard to life or property. Design calculations must route the 100-year peak flow through the culvert without flooding nearby structures and only minimal flooding on nearby property and roadways. In the 100-year calculation no obstruction allowance is permitted but overtopping of the culvert's roadway is allowed for certain types of roadways. In some cases, particularly for culverts serving critical areas, the local authority may require that an obstruction allowance is added onto the peak design flow, in order to account for blockages that can occur during the lifespan of a culvert. The obstruction allowance depends on the culvert size and is detailed in Table 7.

Table 7. Culvert obstruction allowance factors

Culvert Size (inches)	Obstruction Allowance Factor
≤18	25%
21-24	20%
30	15%
≥36	10%

A number of headwater restrictions apply to culvert projects:

1. No damage to upstream property occurs.
2. No increases in the 100-year floodplain according to National Flood Insurance Program delineations.
3. For design storms, the headwater WSE must be at least 18" below the point where the culvert crosses the roadway or the low point of the road.
4. The headwater depth must be less than or equal to 1.5 times the culvert diameter/height.
5. The headwater depth cannot be high enough to let water escape to other stormwater channels or other diversions which circumvent the culvert.

6. Overtopping of certain roadways is allowed for the 100-year storm, as shown in Table 8. Roadway overtopping can be modeled as a broad crested weir.

Table 8. Culvert overflow depth and velocity

Road Classification	Maximum Depth Over Crown (ft)	Maximum Velocity (fps)
Local	1	6
Collector	1	6
Arterial	No overflow	No overflow
Highway	No overflow	No overflow

*No overflow is allowed on any type of roadway that is the only access route for 40 or more residences, unless the applicant shows that the surrounding roads experience significant overtopping thereby making this requirement futile.

In some cases, design tailwater elevations may be set by the headwater elevation of a nearby, downstream culvert or by the maximum WSE of a receiving stream, lake, or other waterbody that occurs for the design storm. Scour and erosion issues must be prevented in accordance with the Virginia Erosion and Sediment Control Handbook. Similarly, deposition due to low velocities must be prevented through a minimum design velocity of 3 fps during the 2 year storm. The minimum allowable culvert size is 18”; a 15” minimum diameter is allowed for private roads and driveways if all other criteria are met. The maximum length of a culvert is 300’, culverts longer than 300’ must have manholes or junction boxes and must met requirements set forth in Chapter 8. A number of other criteria

2.4 Boston, MA

As with many stormwater management plans, Boston's "Stormwater Best Management Practices: Guidance Document" (SBMP:GD) emphasizes low impact development (LID) and green infrastructure (GI). Specific non-structural examples include preservation of existing vegetation, maintaining natural buffers and drainage paths, use of cluster and concentrated development, minimizing disturbance, disconnected and distributed practices, source control, street sweeping, as well as reduction and disconnection of impervious areas. Structural examples include: location of structural BMPs near easy access points to reduce site disturbance, usage of erosion and sediment control practices (ESC) during construction, as well as selection of structural BMPs that have high infiltration, filtration rates, can be integrated into the natural terrain, and have a minimal site disturbance. Infiltration refers to the process of water on the surface of the ground entering the subsurface via soil pores, whereas filtration refers to removal of contaminants in water due to processes such as sorption, vegetative stripping, deposition, uptake, etc.

Boston's Stormwater Management Standards (SMS) regulates water quality and quantity of all development types during construction and afterwards if point source stormwater discharges are created. The SMS do not apply to single family homes, new or redevelopment of single-family homes or multi-family homes on four or less lots (the site must not affect critical areas), or emergency repairs to roads and related drainage systems. The SMS apply to a maximum extent practicable to: new and redevelopment of single family or multi-family housing on four or less lots that may affect a critical area, single family or multi-family housing of five to nine lots that do not affect critical areas, boat yards and marinas (the service and painting areas must be protected from rain, snow, and runoff, as well as bike paths and foot paths. For any projects not subject to the above criteria, the SMS apply.

2.4.1 Performance Standards

The SMS are comprised of 10 standards. Standard 1 stipulates that outfalls may not discharge untreated stormwater directly to- or cause erosion in- receiving waters or wetlands. Treatment entails meeting specific contaminant and sediment removal rates. In addition to treating stormwater, the developer must calculate and size outfall protection based on the 2-year, 24-hour maximum velocity at each outfall. Standard 2 regulates water quantity, post-development peak flow rates must be controlled to pre-development rates or lower for the 2- and 10-year storms. Additionally, the 100-year storm cannot increase off-site flooding. Standard 3 regulates groundwater recharge. The post- and pre-development annual recharge volumes must be approximately the same; this can be achieved with infiltrative BMPs and can be calculated with the equation in Figure 14:

Rv = F * ImpArea

where Rv is the recharge volume; F is the target depth factor (as defined in the MA Stormwater Handbook) and ImpArea is the impervious area in the associated soil hydrologic group (examples are presented in the MA Stormwater Handbook).

Figure 14. Recharge volume equation (copied from Boston's SBMP:GD)

Standard 4 regulates water quality, specifically total suspended solids (TSS). Stormwater systems must remove 80% of the average annual post construction TSS loading. The load reduction can be achieved by: implementation and adherence to a long-term pollution prevention plan for source control, structural SCMs which capture and treat a specified water quality volume, and pretreatment using guidelines from the Massachusetts Stormwater Handbook.

The water quality volume is based on a rainfall depth and the site's impervious area, and is calculated via Figure 15:

WQv = D * ImpArea

where D is the water quality depth in inches (use 1.0 for land uses with a higher pollutant load potential, within an area of rapid infiltration (> 2.4 in/hour), within Zone II or the interim wellhead protection area or discharging to a critical area or 0.50 for all other land uses) and ImpArea is the post construction impervious area.

Figure 15. Water quality volume equation (copied from Boston's SBMP:GD)

From , the water quality depth is either 1 in or 0.5 in, depending on site and watershed characteristics. Massachusetts Department of Environmental Protection (MDEP) provides a spreadsheet for calculating TSS removal, all stormwater outlets must be shown to have at least 44% TSS removal before they can discharge to infiltration BMPs. Long term pollution prevention plans (LTPPP) generally involve proper storage and/or management practices for vehicles, chemicals (e.g. fertilizers, pesticides, herbicides), pet waste, deicing chemicals, waste products, as well as BMP inspections and maintenance, maintenance of landscaped areas, and O&M for septic systems, waste etc.

Standard 5 involves regulation of Land Uses with Higher Potential Pollutant Loads (LUHPPLs). In areas with a high potential for pollutant loading, stormwater discharge must be eliminated or reduced to the maximum extent practicable through the use of source control and pollution prevention as outlined in a LTPPP. Additionally, if source control cannot completely prevent exposure of pollutants to stormwater, then certain structural BMPs identified in the Massachusetts Stormwater Handbook must be used with a water quality depth of 1 in. Additionally, 44% TSS removal must be achieved with pre-treatment before stormwater can be discharged to an infiltrative BMP. Oil and grease pre-treatment may be required for areas with a potential for high

concentrations in runoff. Essentially the same requirements apply for areas that serve as recharge zones for public water supplies. The only differences are that different source control methods and structural BMPs might be used (again defined in the Massachusetts Stormwater Handbook), and that a recharge depth of 1 in. is called for, rather than a water quality depth of 1 in.

Standard 7 pertains to redevelopment. Redevelopment projects must fully meet Standards 2 and 3 and must meet the structural BMP and pre-treatment requirements from Standards 4, 5, and 6. Existing outfalls must meet Standard 1 to the maximum extent practicable. The maximum extent practicable means that the developer must make reasonable efforts to meet the Standards, evaluates all possible BMPs, including LID, structural BMPs, and minimization of disturbance, and if compliance is not meet, then the highest level possible for implementation must be met.

Standard 8 requires that the developer submit a Construction Erosion and Sediment Control Plan (CESCP) which shows the erosion controls to be used during construction, their locations, and supporting calculations with respect to sizing. If the construction site or common development plan exceeds 1 acre, then a Stormwater Pollution Prevention Plan and NPDES requirements must be met.

Standard 9 pertains to long term operation and maintenance (O&M) of stormwater systems. An O&M plan must be made which must include: stormwater management owners, responsible parties for O&M, a list and schedule for routine and non-routine maintenance, locations of all BMPs and outfalls, descriptions and delineations of public safety features, and an O&M budget.

Standard 10 stipulates that illicit discharges are not allowed into the stormwater system, and the developer must agree to this in writing.

2.5 Charlottesville, VA

2.5.1 Water Quantity and Quality Requirements

Charlottesville primarily defers to the Virginia Stormwater Handbook for design requirements. However, the amount of land disturbance to trigger post-construction stormwater measures is much lower than the state standard of 1 acre. Charlottesville requires that all projects, new development or redevelopment, (including single family lots, subdivisions, roadways, building permits) which disturb over 6,000 SF of land must implement post-construction measures to mitigate increases in water quantity or decreases in water quality. Projects which disturb more than 1 acre must comply with the Virginia Stormwater Management Act and create a Stormwater Pollution Prevention Plan. For disturbances over 1 acre, the average land cover condition stipulated in the most recent edition (2nd Ed.) of the Virginia Stormwater Management Handbook (VSWMH) must be used for pre-development analysis. For projects disturbing between 6,000 SF and 1 acre, the average land cover condition (16% impervious area) in the first edition of the VSWMH must be used for pre-development analysis.

If the pre- and post-development hydrologic analysis shows an increase in runoff rate, volume, or velocity, then a stormwater management plan and post-construction stormwater facilities are required. Similarly, if the analysis shows a decrease in water quality, then a Stormwater Quality Plan and water quality facilities are required. Sites that must implement water quantity facilities must first consider the use of methods which address both quantity and quality (e.g. low impact development, infiltrative practices). Water quantity structural control measures (SCMs) must be designed based on the following criteria:

- SCMs must attenuate the 2-year peak flow from post- to pre-development levels in order to prevent erosion in the receiving channel.
- SCMs must attenuate the 10-year peak flow from post- to pre-development levels in order to maintain predevelopment velocities in receiving pipes; receiving pipes must not surcharge under the 10-year peak flow.
- SCMs (detention, bioretention, and spillways) must be sized to attenuate the 100-year peak flow from post- to pre-development levels to prevent downstream flooding.

The water quality requirements from the most recent edition of the VSWMH apply to regulated projects, with phosphorus as the target contaminant.

2.5.2 Culvert Design Standards

Storm sewers constructed in a right of way or related to construction of roads and sidewalks must have a minimum diameter of 15” and be made of reinforced concrete or high-density polyethylene. Various separation requirements from other utilities also exist.

2.6 Fairfax, VA

Fairfax uses the 2nd Edition of the Virginia Stormwater Management Handbook (VSWMH) for both water quantity and water quality requirements. New development projects over 1 acre trigger the phosphorus loading limitation of 0.41 lbs per acre per year. Redevelopment projects over 1 acre are subject to varying phosphorus reduction requirements depending on pre- and post-development conditions and project type.

Water quantity facilities must be sized based on VSWMH requirements, however Fairfax has additional design criteria for certain types of on-site conveyances:

- Streets, gutters, and inlets must be sized for the 10-year storm
- Culverts and storm sewers must be sized for the 100-year storm (if no potential for damage to public or private property, then the 25-year storm can be used).
- Natural and constructed channels must have a capacity sized based on the 10-year storm and must use the 2-year storm as a "linear requirement" (erosion threshold?).

Fairfax requires conformance with VDOT Road and Bridge specifications, which means that projects can use either reinforced concrete pipe or high-density polyethylene pipe, with a minimum diameter of 15" and maximum diameter of 48", respectively. Additional design requirements apply to culverts depending on the culvert's purpose, as summarized in Table 9:

Table 9. Culvert minimum design criteria based on usage

Minimum Design Frequency for Storm Drainage Culverts	
Condition	**Minimum Design Frequency***
Normal Runoff	10-year
Primary road crossings	25-year
Secondary roads and other locations	10-year
Flooding of building structures	100-year
Curb and gutters, curb and gutter inlets	2-year

*Culverts should be checked for the effects of the 100-year storm. No flooding of building structures shall result from the 100-year design flow.

2.7 Maryland

The Maryland Stormwater Design Manual (MSDM) originally published by the Maryland Department of the Environment (MDE) in 2000, was revised in 2009. Any project in the state which disturbs 5,000 SF or more of earth must implement 14 performance standards. Exceptions include:

1. "Additions or modifications to existing single family structures;
2. Developments that do not disturb more than 5000 square feet of land; or
3. Agricultural land management activities"

The 14 performance standards are described below:

1. Designs must maximize pervious area and minimize stormwater generation.
2. Any stormwater discharged to waters of the state of Maryland or jurisdictional wetlands must be adequately treated.
3. Post development annual groundwater recharge rates must mimic pre-development rates, achieved through use of non-structural and structural SCMs.
4. Water quality management must be achieved through environmental site design.
5. Structural SCMs must remove 80% and 40% of the average annual post development TSS and TP load, respectively. These removal standards are met if: the SCM is sized for the water quality volume (described later), designed using MSDM standards, is constructed correctly, and is subject to regular maintenance.
6. Control of the 2- and 10-year storms for flood control may be required by the local authorities if there is a history of flooding issues and downstream development and conveyances are not able to be controlled. SCMs must be able to safely pass the 100-year storm.
7. A channel protection storage volume, which is based on a 1-year storm, must be met primarily through environmental site design (to the maximum extent practicable). The remainder of this volume can be stored in a variety of structural SCMs.
8. Any projects draining to water quality sensitive areas (e.g. recharge zones, water supply reservoirs, swimming areas, cold water fisheries, shellfish beds, or the Chesapeake and Atlantic Coastal Bays Critical Area), may have additional performance requirements and/or restrictions on- or requirement of certain SCMs.
9. All SCMs must have "an enforceable operation and maintenance agreement to ensure the system functions as designed."
10. All SCMs must have an approved water quality pre-treatment measure.
11. Redevelopment on sites with impervious cover greater than 40% is subject to special stormwater sizing criteria dependent on the increase or decrease of impervious area.
12. Certain industrial sites (new and existing) must prepare and implement a pollution prevention plan and file a notice of intent, under the regulations of Maryland's Stormwater Industrial NPDES general permit.
13. Areas designated as pollution hotspots may be required to use specific SCMs and pollution prevention measures and may not use infiltrative measures.

14. Local authorities perform reviews on stormwater management plans and applications, and local regulations may be more stringent than state regulations. Some earth disturbing activities could require a NPDES construction general permit.

2.7.1 Unified Sizing Criteria

Maryland uses unified sizing criteria for all approved SCMs, Table 10 summarizes the various components which comprise the total design volume. Generally, structural SCMs must be sized based on a variety of components, including: a water quality volume, a recharge volume, a channel protection storage volume, an overbank flood protection volume, and an extreme flood volume.

Table 10. Stormwater sizing criteria summary (copied from MDE MSDM)

Sizing Criteria	Description of Stormwater Sizing Criteria
Water Quality Volume (WQ_v) (acre-feet)	$WQ_v = [(P)(R_v)(A)]/12$ 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. $Re_v = [(S)(R_v)(A)]/12$ 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.

2.7.2 Water Quality Volume Requirement

The water quality volume (WQ_v) is based on capturing and storing 90% of average annual rainfall as well as a runoff coefficient and the site area. In the eastern and western halves of Maryland, the water quality rainfall depth is 1" and 0.9", respectively. Figure 16 shows the equations for water quality and the runoff coefficient.

$$WQ_v = \frac{(1.0)\,(R_v)(A)}{12}$$ 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*

Figure 16. Water quality volume equations (copied from MDE MSDM)

The WQ_v requirements apply to all sites where stormwater management is required, but sites with no impervious cover and no planned disturbance can be exempted from these requirements. For sites with less than 15% impervious cover, the minimum WQ_v is 0.2 inches per acre. Impervious cover is defined as areas without vegetative or permeable cover. Separate WQ_v must be met for sites with multiple drainage areas, however offsite existing impervious cover may be excluded. Local authorities may impose stricter requirements for catchments draining to sensitive streams. The required WQ_v may be reduced by subtracting the volume treated by upstream structural SCMs used for recharge volume requirements or through use of non-structural practices.

2.7.3 Recharge Volume Requirement

The recharge volume requirement (RE_v) is based on the average annual recharge rate of the site's hydrologic soil groups divided by Maryland's average annual rainfall (42 inches) then multiplied by 90%. The relevant equations and recharge rates are summarized in Figure 17:

$Re_v = [(S)(R_v)(A)]/12$ (percent volume method)

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

A = site area in acres

$Re_v = (S)(A_i)$ (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

Figure 17. Recharge volume equations (copied from MDE MSDM)

The RE_v may be counted towards, and subtracted from, the WQ_v if the Rev is treated separately. Catchments with no impervious cover and no proposed disturbance can be exempted from the RE_v requirements. The goal of the RE_v is to maintain pre-development groundwater recharge rates and thereby ensure stream and wetland hydrology is not altered during dry weather periods.

2.8 North Carolina

The North Carolina (NC) Department of Environmental Quality (DEQ) recently revised its Minimum Design Criteria (MDC) and associated stormwater management manual. NC DEQ now offers two options for treating runoff from high density projects with respect to water quality. The first option is a traditional runoff treatment approach, achieved through use of a primary stormwater control measure (SCM) and possible secondary SCMs. The second, new option is runoff volume match, which is analogous to low impact development (LID) and seeks to match pre-development hydrology as much as possible. For volume matching, the post-development annual runoff volume can be at most 10% higher than the pre-development annual runoff volume. For certain sensitive areas, the allowable increase is 5%. The volume reduction will generally be achieved through infiltration and evapotranspiration.

No statewide regulations exist with respect to flood control; local municipalities may set flood control regulations if they wish.

2.8.1 Minimum Standards

The entire state is not subject to the stormwater regulations. Only certain areas are required to implement SCMs, and the regulatory trigger varies depending on the area. Phase I and II MS4s, coastal counties, watersheds with nutrient sensitive waterbodies, water supply watersheds, and "Outstanding National Resource Waters" are the areas where regulations apply (encompassing about 65% of the state's total area). For the regulated areas, any project which disturbs more than 1 acre, or disturbs over 0.5 acres but is part of a larger development site, require stormwater permits. Depending on the water quality/supply watershed, single family and duplex projects that disturb over 0.5-1 acres and "commercial, industrial, institutional, multifamily residential, or local government property" that disturb over 12,000 SF-0.5 acres require stormwater permits (US EPA). In coastal counties, the following categories require permits:

- Residential projects that disturb over 1 acre
- Non-residential projects that disturb less than 1 acre but add 10,000 SF of impervious area
- Residential projects that drain to, and are within 0.5 miles of shell fishing waters, and disturb less than 1 acre but add over 10,000 SF resulting in a site impervious area of 12% or greater.

Exceptions are made for re-development and low-density projects. For re-development, treatment is not required if there is no increase in impervious area, and the developer provides SCMs that are equal to or better than those of the prior development.

SCMs must be designed based on treatment of all runoff generating surfaces at build out on the site. Off-site drainage can be bypassed. The design depth may be met through a combination of SCMs. Infiltrative measures cannot be located in contaminated soils. Outlets must be protected such that the channel immediately downstream will not be eroded by a 10-year storm. SCMs must

have a spillway or bypass for overflow events, the specific criteria of which (e.g. 100-year event) is determined by the local authorities.

Two methods are available for calculating runoff volume: the Simple Method and the NRCS Curve Number Method. The design storms to be used are 1" for non-coastal counties and for coastal counties, 1.5" or the difference in volume from the 1 year, 24-hour storm between pre- and post-development. Drawdown times must be between 48 and 120 hours. All SCMs must remove 85% of average annual TSS, but certain watersheds have TN and/or TP reduction requirements.

2.9 New York City, NY

The New York City (NYC) Stormwater Guidelines (SG) use the Rational Method for determining run-off rates. If post-development flow rates exceed a specified "release rate" (Q_{RR}), then on-site detention and compliance with Department of Environmental Protection (DEP) regulations is required. If the post-development flow is less than the release rate, then the developer must examine the site's allowable flow to the sewer system. The allowable flow is the flow that is permitted to be released to an existing separate or combined sewer based on existing conditions. For calculating post-development flows with the rational method, NYC requires a 5-year design storm with a time of concentration of 6-minutes (5.95 in/hr). Figure 18 shows the coefficients provided by NYC for determining a weighted runoff coefficient. The coefficients are representative of average annual runoff rates, and variances can be accepted if supporting site data (e.g. bore logs, conductivity tests) is provided.

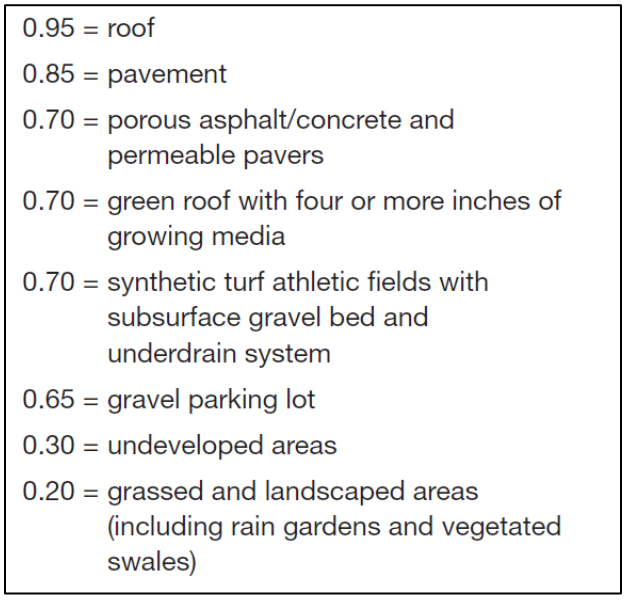

Figure 18. Runoff coefficients provided by NYC for use in rational method (copied from NYC SG)

For new development, sizing of detention measures is based on the previously mentioned stormwater release rate (Q_{RR}), the storage volume (V_R), and the maximum storage depth (S_D). According to NYC DEP's summary of the guidelines, for sites draining to a combined sewer, the release rate is either 0.25 cfs or 10% of the allowable flow, whichever is larger. If the allowable flow is lower than 0.25 cfs, then the release rate will be the allowable flow. For sites draining to a separate storm sewer, the release rate must be the allowable flow.

For redevelopment that causes an increase in impervious area, the same process used for new development applies, but the release rate is multiplied by the ratio of the altered to total site area. No new discharge points are allowed.

The storage volume is based on a 10-year design storm. For detention facilities with variable outflows (e.g. orifice-controlled outflow with variability due to stage and head), the required storage volume can be determined via the equation in Figure 19. Generally, $Q_{RR} = Q_{DRR}$ unless infiltration credit is granted or detention facilities in series are used.

$$V_V = [0.19 C_{WT} A_t / (t_V + 15) - 40 Q_{DRR}] \, t_V$$

where:

- V_V = the maximum required detention volume in ft^3 with a variable outflow
- C_{WT} = the weighted runoff coefficient for the area tributary to the detention facility
- A_t = the area tributary to the detention facility in ft^2
- t_V = the duration of the storm in min., with a 10 yr. return frequency, requiring the maximum detention volume with a variable outflow
- Q_{DRR} = the detention facility maximum release rate in cfs

Figure 19. Storage volume equation for facilities with variable release rates (copied from NYC DEP "Criteria for Detention Facility Design")

The storm duration in Figure 19 can be determined by the equation in Figure 20:

$$t_V = 0.27 (C_{WT} A_t / Q_{DRR})^{0.5} - 15$$

where:

- t_V = the duration of the storm in min. with a 10 yr. return frequency requiring the maximum detention volume with a variable outflow
- C_{WT} = the weighted runoff coefficient for the area tributary to the detention facility
- A_t = the area tributary to the detention facility in ft^2
- Q_{DRR} = the detention facility maximum release rate in cfs

Figure 20. Storm duration equation for facilities with variable release rates (copied from NYC DEP "Criteria for Detention Facility Design")

For detention facilities with a constant outflow rate (e.g. pump-controlled discharges), the detention volume is calculated from:

$$V_C = [0.19 C_{WT} A_t / (t_C + 15) - 57 Q_{DRR}] \, t_C$$

where:

- V_C = the maximum required detention volume with an approximately constant outflow
- C_{WT} = the weighted runoff coefficient for the area tributary to the detention facility
- A_t = the area tributary to the detention facility in ft^2
- t_C = the duration of the storm in min., with a 10 yr. return frequency, requiring the maximum detention volume with an approximately constant outflow
- Q_{DRR} = the detention facility maximum release rate in cfs

Figure 21. Storage volume equation for facilities with constant release rates (copied from NYC DEP "Criteria for Detention Facility Design")

Again, the storm duration in Figure 21 can be computed with the equation in Figure 22.

$$t_C = 0.23 (C_{WT} A_t / Q_{DRR})^{0.5} - 15$$

where:

- t_C = the duration of the storm in min., with a 10 yr. return frequency, requiring the maximum detention volume with an approximately constant outflow
- C_{WT} = the weighted runoff coefficient for the area tributary to the detention facility
- A_t = the area tributary to the detention facility in ft^2
- Q_{DRR} = the detention facility maximum release rate in cfs

Figure 22. Storm duration equation for facilities with constant release rates (copied from NYC DEP "Criteria for Detention Facility Design")

Much of the NYC design manual is focused heavily towards subsurface storage and blue/green roofs (non-vegetated or vegetated rooftop storage, respectively). This is due to the heavily developed nature of the city, low availability and high cost of land. For sites less than 10,000 SF, the allowable flow can be calculated from the equations in Figure 23; otherwise, the allowable flow is specified in the site's existing building/drainage plans.

Bronx-pre 1964	$Q_{ALL} = A_S / 24{,}800$
Bronx-post 1964	$Q_{ALL} = A_S / 14{,}500$
Brooklyn	$Q_{ALL} = A_S / 17{,}400$
Manhattan	$Q_{ALL} = A_S / 12{,}200$
Queens	$Q_{ALL} = A_S / 18{,}200$
Staten Island Combined	$Q_{ALL} = A_S / 24{,}400$
Staten Island Storm	$Q_{ALL} = C_Z * A_S / 7{,}320$

Figure 23. Allowable flow equations for sites less than 10,000 SF (copied from NYC DEP "Criteria for Detention Facility Design")

2.10 Philadelphia, PA

Philadelphia's Stormwater Management Guidance Manual (SMGM) triggers regulatory action based on three criteria: development type, watershed, and earth disturbance. The post-construction stormwater management requirements include standards for: Water Quality, Channel Protection, Flood Control, and a Public Health and Safety Release Rate. Projects that disturb more than 5,000 SF of earth must submit an application to the city which will determine if the project is regulated and what regulations apply. This is determined by the project's watershed, specific amount of earth disturbance, and the development type. Development types include new development, redevelopment, demolition, and stormwater retrofit.

All projects which disturb 15,000 SF or more of earth are required to comply with the Stormwater Regulations. However, for projects in certain watersheds with state regulated Flood Management Districts, the Stormwater Regulations may be triggered at an earth disturbance threshold of 5,000 SF. Similarly, projects in some watersheds must comply with additional stormwater management requirements and limitations are set for a project's impervious area. If a project is found to have disturbed more than 15,000 SF but did not apply for a permit, the Stormwater Regulations will be put into effect and enforcement actions will be taken. If a project disturbs over 1 acre, then a NPDES permit is required. Erosion and Sediment Control requirements apply during the construction phase to all projects regardless of size and can be found in the *PA DEP Erosion and Sediment Pollution Control Program Manual*.

The following sections describe each of the Stormwater Regulations:

2.10.1 Water Quality Requirements

The overall goals of the water quality requirements are to reduce pollutant loading from runoff, maintain the site's natural hydrology, increase groundwater recharge to increase stream baseflow, and reduce the number of combined sewer overflows (CSO). The primary requirement is "infiltration of the first 1.5" of runoff from all directly connected impervious area (DCIA) within the limits of earth disturbance," also known as the Water Quality Volume (WQv). If infiltration is feasible, the entire WQv must be infiltrated. This is made easier through reductions in the amount of DCIA, particularly through the use of disconnections, green space, permeable pavement, and green roofs. Projects with over 95% DCIA may be eligible for an expedited permit review. If infiltration is not feasible, treatment requirements depend on whether the project drains to a combined or separated sewer:

- If the project drains to a *combined sewer*, all the non-infiltrated runoff must be treated with an acceptable practice for pollutant reduction, detained for 72 hours or less, and released at a maximum rate of 0.05 cfs per acre of DCIA.
- If the project drains to a *separate sewer*, all the non-infiltrated runoff must be treated with an acceptable practice for pollutant reduction and detained for 72 hours or less.

The water quality requirements are summarized in Table 11:

Table 11. Summary of Philadelphia Water Quality Requirements (copied from PSGM)

Infiltration Feasible	
PROJECT LOCATION	REQUIREMENTS
All	Infiltrate 100% of the WQv

Infiltration NOT Feasible	
PROJECT LOCATION	REQUIREMENTS
In Combined Sewer Area	100% of the WQv that is not infiltrated must be: • Routed through an acceptable pollutant-reducing practice *AND* • Detained in each SMP for no more than 72 hours *AND* • Released from the site at a maximum rate of 0.05 cfs per acre of associated DCIA
Not In Combined Sewer Area	100% of the WQv that is not infiltrated must be: • Routed through an acceptable pollutant-reducing practice *AND* • Detained in each SMP for no more than 72 hours

2.10.2 Channel Protection Requirements

The channel protection requirements are meant to reduce damage to downstream structures, banks and channels, and fish habitat due to erosion and sedimentation in addition to reducing the frequency, duration, and quantity of CSOs. The Channel Protection Requirements stipulate that all projects, regardless of downstream conveyance type (river, stream, channel, ditch, sewer, etc.), must detain and discharge the 1-year, 24-hour (NRCS Type II, 2.83" in Philadelphia) storm at a maximum rate of 0.24 cfs per acre of DCIA within the limits of earth disturbance. The runoff must be drained from the facility within 72 hours. Exemptions to this requirement include: redevelopment sites with under 1 acre of disturbance, redevelopment projects which reduce impervious area by 20% (based on proposed DCIA and existing impervious area), or redevelopment projects in two specific watersheds. Figure 24 shows a flow chart of the exemption criteria.

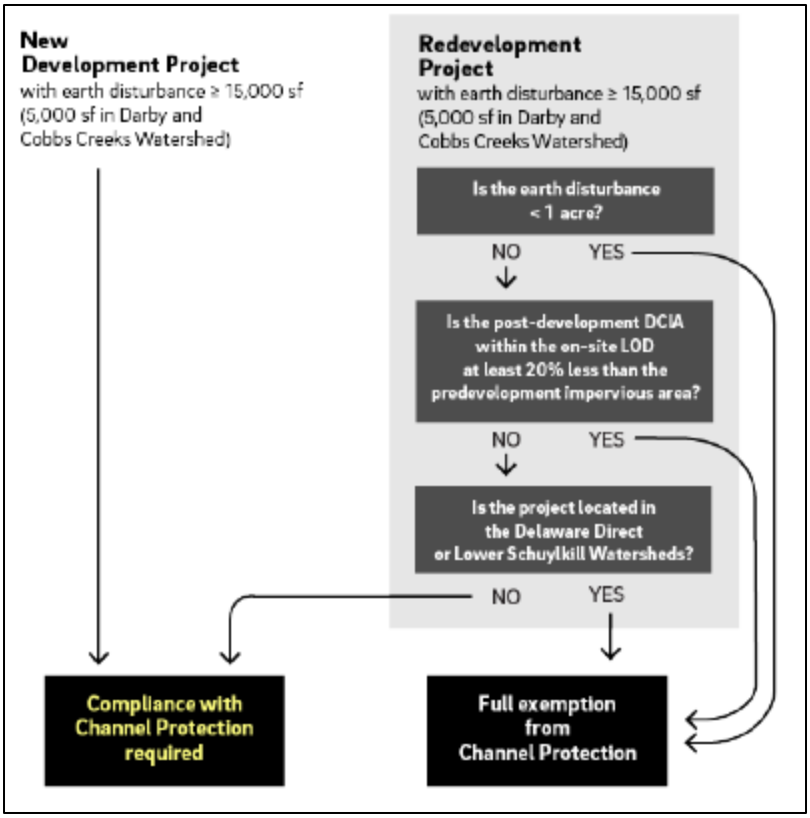

Figure 24. Exemptions for Channel Protection Requirement (copied from PSGM)

2.10.3 Flood Control Requirements

The flood control goals are to prevent or reduce flooding downstream of the site due to sewer overflows or overbank flooding, in addition to reducing the quantity, duration, and frequency of CSOs. Flood control standards are set by the Pennsylvania Stormwater Management Act, and the standards vary based on which Flood Management District the project is within. Table 12 shows the peak flow attenuation requirements for each flood district, which vary significantly by district. In Table 12, the peak flow for each return period in the proposed conditions (left column) cannot exceed the peak flow for the return period under pre-development conditions (right column). Attenuation of all return periods can be meet concurrently, and the volumes from the water quality and channel protection requirements can be counted towards the flood control volume. Peak flows are calculated based on the entire site using the NRCS Method, rather than from DCIA alone as with the water quality and channel protection requirements. The threshold for enacting flood control requirements is 15,000 SF of disturbance, except for two watersheds where the threshold is 5,000 SF.

A full exemption from the flood control requirements may be granted if a project reduces its post-development DCIA by 20% compared to the pre-development impervious area or if the project is in specific watersheds and does not use public infrastructure to drain to specific rivers. In certain watersheds, if the second criterion applies to a project, then the project must comply with flood control requirements for the 2-year and 5-year post-development storms. Figure 25

shows a flow chart for determining exemptions from the flood control requirements. The manual suggests that many developers install green roofs in order to meet the exemption for a 20% reduction in DCIA.

Table 12. Flood Control Requirements for each Flood Management District (copied from PSGM)

District	NRCS Type II 24-Hour Design Storm Applied to Proposed Condition	NRCS Type II 24-Hour Design Storm Applied to Predevelopment Condition
A	2-year	1-year
A	5-year	5-year
A	10-year	10-year
A	25-year	25-year
A	50-year	50-year
A	100-year	100-year
B	2-year	1-year
B	5-year	2-year
B	10-year	5-year
B	25-year	10-year
B	50-year	25-year
B	100-year	50-year
B-1	2-year	1-year
B-1	5-year	2-year
B-1	10-year	5-year
B-1	25-year	10-year
B-1	50-year	25-year
B-1	100-year	100-year
B-2	2-year	1-year
B-2	5-year	2-year
B-2	25-year	5-year
B-2	50-year	10-year
B-2	100-year	100-year
C	Conditional Direct Discharge District	
C-1	Conditional Direct Discharge District	

For Conditional Direct Discharge Districts, the proposed conditions peak rate of runoff for a Development Site that discharges to City infrastructure must be controlled to the Predevelopment Conditions peak rate as required in District A provisions for the specified Design Storms. The Predevelopment Condition shall be defined according to the procedures found within this Manual.

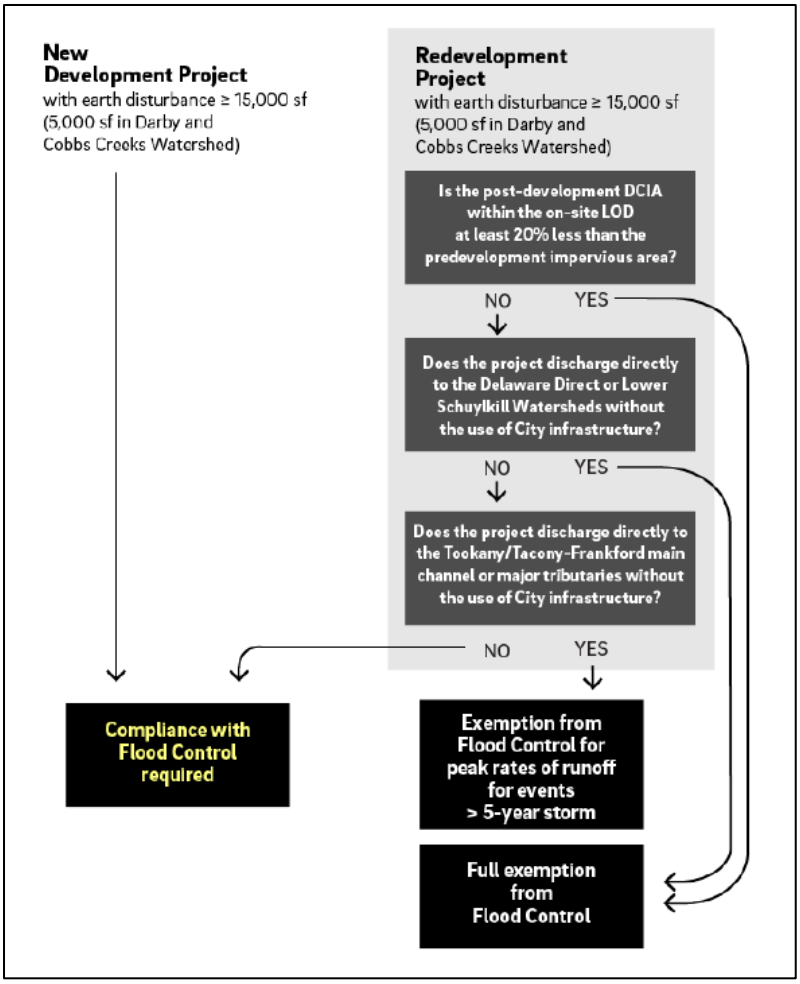

Figure 25. Exemptions for Flood Control Requirement (copied from PSGM)

Table 13 lists various stormwater management practices by preference of Philadelphia stormwater managers.

Table 13. Stormwater management practices (SMP) listed by preference (copied from PSGM)

SMP / SMPs in Series	Section
HIGHEST PREFERENCE	
Bioinfiltration	4.1
Bioretention	4.1
Porous Pavement	4.2
Green Roofs	4.3
MEDIUM PREFERENCE	
Subsurface Infiltration	4.4
Cisterns	4.5
Blue Roofs	4.6
Ponds and Wet Basins	4.7
LOWEST PREFERENCE	
Subsurface Detention with Vegetated Media Filters	4.8 / 4.9
Subsurface Detention with Roof Runoff Isolation	4.8 / 3.2.4
Subsurface Detention with Media Filters	4.8 / 4.9
Vegetated Media Filters	4.9
Media Filters	4.9

2.10.4 Public Health and Safety Release Rate Requirement

Projects that discharge to capacity limited sewers may be subject to the Public Health and Safety Release Rate Requirement which stipulates a maximum discharge rate based on the amount of available capacity in the receiving sewer for all storms between the 1- and 10-year events. For this requirement, site discharge is calculated based on the amount of previous and impervious area within the limits of earth disturbance.

2.11 Portland/Washington County, OR

The City of Portland (CP) and Washington County (WC) regulate development in the Tualatin River Basin (TRB) through the Clean Water Services (CWS) Design and Construction Standards (DCS) manual to mitigate water quality and quantity issues.

2.11.1 Water Quantity

All development projects are required to implement on-site treatment, downstream conveyance enlargement, and/or payment of a stormwater fee, as determined by the local jurisdiction (LJ). On-site detention yields a credit towards the stormwater fee, and is required for quantity control if any of the following apply:

1. If a downstream deficiency exists, and the LJ determines on site detention is more effective than downstream enlargement.
2. An identified regional detention site exists within the development boundary.
3. Watershed or sub-watershed management plans (WMP) adopted by the LJ require a water quantity facility.

Specific hydraulic design criteria for water quantity detention facilities (DF) includes:

- Control of to the 24-hour, 2-, 10-, and 25-year post development peak runoff rates to pre-development rates, unless a LJ WMP requires other criteria.
- Pond overflow system for controlled release of the design storm(s) without embankment overtopping or exceedance of spillway capacity.
- Emergency spillway sized for the 100-year storm, armored with rip rap to the embankment toe, and located in existing soils if feasible.

Other requirements for water quantity detention facilities includes:

- If a DF is required due to downstream channel deficiencies, the DF must control peak runoff flow rates to pre-development levels for the entire range of storms which cause the downstream deficiency.
- On-site DF will not be allowed if they create a negative impact on receiving waters within the (sub) watershed, or if they worsen or increase the likelihood of flooding downstream of the site.
- Low impact development (LID) which follows the DCS can be used to meet some or all of a site's detention requirements.

2.11.2 Water quality

Water quality treatment is required when a project creates or alters 1,000 square feet or more of impervious area, or if the amount of stormwater runoff or pollution from the site increases. Site owners must implement or fund permanent measures to reduce contaminant loading to surface and storm water systems. Requirements may be met using the same DF used to met quantity requirements.

On-site water quality treatment is not required if site topography, soils, etc. cause implementation to be ineffective, impractical, or results in an inefficient use of LJ resources for long-term O&M. Similarly, on-site treatment is not required if the sub basin contains a more effective and efficient regional approach design to accommodate the site, or if the sub basin contains an approach with a demonstrated capacity for treatment of the site. If on-site treatment is not required, the development owner must pay a "Fee-In-Lieu of construction or implementation" of the water quality treatment approach determined by LJ rates.

Water quality treatment approaches must be designed to remove 65% of the total phosphorus from impervious areas that contribute to the facility, however this is not a performance requirement. Three separate categories exist for meeting water quality design standards:

1. Pretreatment followed by any one or more of the following LID practices:
    a. "Vegetated swales
    b. Extended dry basins
    c. Constructed water quality wetland
    d. Structural infiltration planter
    e. Non-structural infiltration planter (rain garden)
    f. Flow-through planter
    g. LID swale
    h. Street-side planter
    i. Landscape filter strip
    j. Vegetated corridor as a filter strip"

    Pretreatment can be achieved through use of a water quality manhole, or as specified in the design standards for the LID approaches above. With permission of the LJ, proprietary devices, filter strips, and trapped catch basins may be used for pre-treatment.

2. Proprietary devices which meet the design standards and meet any one of the below criteria:

    a. "Treatment of runoff from a single parcel.
    b. Treatment of runoff from an adjoining commercial, industrial, or multi-family, or condominium parcels which share a common parking lot.
    c. Treatment of runoff from new and expanded collector and arterial roadways where no other opportunities exist for treatment without necessitating the removal of homes or businesses.
    d. Treatment of runoff from new developments in transit-oriented or similar high-density zoning classifications where the development is primarily single-family residential, and the average lot size is less than 2,500 square feet.
    e. Treatment of runoff as part of a master planned regional facility approved by the District."

3. Alternative methods which meet the water quality removal efficiency requirements and are approved by the LJ.

If an on-site approach for treatment of a project's impervious area is not feasible, then treatment of an existing, currently untreated impervious area (on- or off-site) may used to satisfy the project's treatment requirements (subject to LJ approval). Development runoff must be treated off line from the storm sewer system, then reconnected to upstream flows following treatment – if this is not feasible, extra capacity may be required in the treatment approach for upstream flows. If discharging to a sensitive area, the pre-development hydroperiod and flow regime must be maintained such that the area's "characteristic functions", or ecological characteristics, are protected. Flows that are critical for downstream water quality cannot be redirected to other catchments, except with special permission.

The design storm used for water quality treatment is a dry weather storm with a depth of 0.36 inches over 4 hours and an average return period of 96 hours. The calculation of impervious area used in treatment design depends on the development type. For new single family and duplex construction, the water quality treatment approach will be sized based on 2,640 SF per dwelling unit, or the actual impervious area may be used if either the lot size is less than 2,000 SF or project modifies or creates impervious area "not associated with new home construction, up to a maximum of 2,640 SF". For all projects that are not single family and duplexes, the treatment area is equal to all new impervious area plus 3 times all modified impervious area. If the project results in permanent removal of 1,000 SF or more of impervious area, the removed impervious area may be subtracted from the treatment area. The required water quality volume is given by:

$$WQTv\ (CF) = \frac{0.36\ (in) * Treatment\ Area\ (SF)}{12\ in/ft}$$

Using the 4-hour detention time yields the water quality flow rate:

$$WQF\ (cfs) = \frac{WQTv\ (CF)}{14{,}400\ seconds}$$

The non-propriety LID practices mentioned in category 1 (items d. through i.) shall have surface area equal to 6% of the required treatment area; this assumes site infiltration is less than 2 in/hr. If another surface area sizing factor is used, or the contributing impervious area is over 15,000 SF, or the treatment facility is also used for quantity control, then a site-specific treatment facility surface area shall be determined.

2.11.3 Culvert Design

Culverts 3 ft (36 in) and greater in size are regulated by the LJ and shall conform to all applicable design standards. If a culvert is located within a FEMA floodplain, it must be approved "the local FEMA designated authority." If a culvert passes water "from or through water quality sensitive areas", Oregon Department of Fish and Wildlife will "determine if fish passage is required and any site-specific design criteria."

Culverts shall safely convey a 25-year flow. For new culverts with a diameter 18 inches or less, the maximum allowable headwater elevation (relative to the inlet invert) is two times the pipe diameter or three times the pipe diameter if a seepage collar is used. The maximum headwater

elevation (relative to the inlet invert) for new culverts with a diameter greater than 18 inches shall be no more than 1.5 times the pipe diameter. For any new culvert, the maximum headwater elevation of the design storm must be at least 1 foot lower than the subgrade of the road or parking lot.

Culverts with a diameter of 18 inches or larger must have inlet protection (rock or other material) extending at least five feet from the inlet and up to the design storm headwater elevation. Culverts with a diameter of 12 inches or larger must have outlet protection in the receiving channel consisting of "rock lining, bio-engineering, or other ... approved energy dissipater…(e.g. stilling basins, drop pools, hydraulic jump basins, baffled aprons, and bucket aprons". Table 14 summarized the outlet protection criteria for various design discharge velocities. Table 15 summarizes the various criteria that each treatment approach satisfies.

Table 14. Outlet protection criteria based on design discharge velocity (copied from CWS DCS)

Discharge Velocity at Design Flow (fps)		Minimum Required Protection Dimensions				
Greater than	Less than or Equal	Type	Thickness (ft)	Width	Length (use greater of)	Height Over Crown
0	5	ODOT Class 50 Riprap*	1.5	Diam. + 6 ft	8 ft. or 4 x diam.	1 ft
5	10	ODOT Class 200 Riprap	2.5	Greater of: Diam. + 6 ft	12 ft. or 4 x diam.	1 ft
10		Engineered Energy Dissipater Required				

* - The District or City may require ODOT Class 100 Riprap in areas with a likelihood of vandalism.

Table 15. Summary of acceptable treatment approaches (copied from CWS DCS)

Approach	Public System	Water Quantity Control Approach	Water Quality Treatment Approach	Low Impact Development Approach
Infiltration Planter/Rain Garden	Yes	Yes	Yes	Yes
Flow-through Planter	Yes	No	Yes	Yes
LIDA Swale	Yes	No	Yes	Yes
Landscape Filter Strip	Yes	No	Yes	Yes
Vegetated Swale	Yes	No	Yes	Yes
Extended Dry Basin	Yes	Yes	Yes	Yes
Constructed Water Quality Wetland	Yes	Yes	Yes	Yes
Vegetated Corridor as a Filter Strip	Yes	No	Yes	Yes
Proprietary Treatment System	Per 4.05.8	Yes	Yes	No
Vegetated Corridor Preservation	No	No	No	Yes
Green Roof	No	Yes	No	Yes
Porous Pavement	No	Yes	No	Yes
Tree Preservation	No	No	No	Yes
Rainwater Harvesting	No	Yes	No	Yes
Boardwalk	No	No	No	Yes

2.12 Seattle, WA

In determining the minimum requirements for post-construction stormwater quantity and quality that a project must achieve, a number of steps are required:

1. Identify the project boundary and delineate key components, including discharge points, land disturbing activities, and new plus replaced hard surface (NPRHS).
2. Identify the project type, based on the classifications in Table 16:

Table 16. Seattle, WA - Summary Table of Project Types

Project Type	Criteria	Notes
Single Family Residential (SFR)	• One dwelling unit on single family-zoned land between 5,000- and 9,600 SF • New plus replaced hard surface (NPRHS) is < 10,000 SF • New plus replaced pollution generating hard surface (PGHS) is < 5,000 SF	Projects with >10,000 SF NPRHS or >5,000 SF of PGHS are classified as parcel based projects.
Sidewalk	• New or replaced sidewalk, including associated planting, curb, gutter, roadway repairs, etc.	If NPRHS in the roadway is >10,000 SF then entire project is classified as a roadway project.
Trail	• New or replaced trail with no PGHS	
Roadway	• New or replaced road or alley in public ROW	
Parcel-based	• Any project that is not a SFR-, sidewalk-, trail-, or roadway-project. • Multi-family and commercial development are common examples.	
Utility	• Installation, repair, or maintenance of below ground or overhead utilities such as vaults, conduits, and pipes. • Involves replacing any disturbed ground with the same material or material with similar hydrologic characteristics.	
Pavement maintenance	• Involves activities such as repaving (without expanding existing hard surfaces), patching potholes, grading shoulders and drainage ditches, sealing cracks, and vegetative maintenance.	
WSDOT project	• Washington State Department of Transport (WSDOT) roadway projects within state ROWs.	
Special Circumstances	• Projects which do not fit one of the above categories.	

3. Identify the type of receiving water and downstream conveyance. Minimum requirements are influenced by the type of receiving water, which includes: wetlands, creek basins,

public combined sewer, small lake basins, and designated receiving waters (water bodies that have been designated as having a capacity for accepting discharges).

4. Assess the site and plan for special considerations related to stormwater management (e.g. groundwater, contamination, steep slopes, floodplains, infiltrative capacity, site boundary and existing structures).
5. The trigger threshold for flow control minimum requirements is based on the amount of land disturbing activity. Quantifying the amount of land disturbing activity involves calculating the site's new and replaced hard surfaces, removal or conversion of native and non-native vegetation to lawn, pasture, or landscaping, and land disturbance. Hard surfaces include impervious area, permeable pavement, permeable areas with underdrains (e.g. rail yards, athletic fields), or green roofs.
6. The water quality treatment trigger thresholds are based on the amount of new and replaced pollution generating hard surface (PGHS) and pollution generating pervious surface (PGPS). Pollution generating surfaces include areas that typically generate high pollutant loading. Examples of PGHS include industrial areas, vehicular use areas, storage areas of chemicals, wastes, and erodible or leachable materials. Examples of PGPS include lawns, landscaping, parks, sports fields, and golf courses.
7. Based on the information in steps 1-6, minimum requirements for each project type must be determined for the categories of soil amendment, on-site stormwater management, peak control, and water quality treatment. Additionally, all projects must meet certain minimum requirements.

2.12.1 Minimum Requirements for All Projects

All projects must meet certain minimum requirements, including:

- Natural drainage patterns must be maintained
- Discharge points must be selected to maintain natural drainage patterns and drain to a conveyance with sufficient capacity for flow volume and peak rate.
- In floodprone areas, flood control measures must be implemented to minimize flooding on the site or on nearby properties.
- Specific erosion and sediment control measures must be implemented on site during the construction phase.
- Sites discharging to wetlands must prevent any net loss to the wetlands' function and/or value.
- Sites discharging to streams must prevent any decrease in water quality through temporary and permanent control measures.
- Sites discharging to shorelines (either directly or through drainage networks) must prevent net decreases in ecological function of shorelines through water quality and quantity control measures.
- Large projects, projects with an excavation depth greater than 12', or projects with an excavation depth less than 12' in areas with shallow groundwater must ensure that the drainage network (either separate or combined sewer) has sufficient capacity up to 0.25

miles downstream of the discharge point to convey the peak flow from a 25-year storm (separate sewer) or 5-year storm (combined sewer).

- Pollution generating activities must be mitigated through source control and good housekeeping practices.
- No obstruction of watercourses shall occur.
- Permits are required for alterations, repairs, or replacements to the sewer system (public or private). Permits and possibly treatment is also required for discharge of contaminants or "process water" to the sewer system.
- Inspection and maintenance must be performed by the site owner at regular intervals to ensure that quality and quantity design capacities are continually met. The owner must inform subsequent owners of the existence, elements, condition, limitations, and inspection requirements of all stormwater control measures (SCMs) on the property. The city may also perform routine or random inspections of SCMs on public or private property and has the authority to enforce compliance if necessary. Inspections may also be performed based on complaints or the SCM's presence in a pollutant hotspot.

2.12.2 Description of Minimum Requirements

Additional minimum requirements apply depending on the project type. The minimum requirements include:

- Soil Amendment
- On-site Stormwater Management
- Flow Control
    - Wetland Protection Standard
    - Pre-developed Forested Standard
    - Pre-developed Pasture Standard
    - Peak Control Standard
- Water Quality Treatment
    - Basic Treatment
    - Oil Treatment
    - Phosphorus Treatment
    - Enhanced Treatment

The requirements are based on a number of factors:

- "The receiving water and/or type of downstream conveyance
- The amount of new plus replaced hard surface (Note: permeable pavement, vegetated roof systems, and areas with underdrains count toward determining this threshold.)
- The amount of converted native vegetation
- The amount of new plus replaced pollution-generating hard surface (PGHS)
- The amount of new plus replaced pollution-generating pervious surface (PGPS)"

The trigger criteria and standards of each minimum requirement are described below:

- Soil Amendment:
    - In areas of a site that are not being developed, preserve existing undisturbed soil. All disturbed, new, or replaced topsoil must be amended with organic matter prior to project completion.

- On-Site Stormwater Management:
    - On-site Performance Standards
        - If the existing hard surface coverage is less than 35% and discharges to a listed creek or its watershed, then the post-development discharge duration* must match the discharge duration of pre-developed forested conditions for a range of flows from 8% of the 2-year flow to 50% of the 2-year flow.
          *Discharge duration is defined as "the aggregate time that peak flows are at or above a particular flow rate of interest."
        - For all other projects, post-development discharge rates must match durations of pre-developed pasture conditions for a range of flow durations from the 10 year storm to the 100 year storm.
    - List of On-site treatment methods by project type:
      Table 17 through Table 20 shows approved on-site treatment methods for each project type. Each surface from a project must be treated with one treatment method from the appropriate table.

- Flow Control:
    - Wetland Protection Standard: For sites discharging directly or indirectly to wetlands, deleterious impacts to the wetlands' hydrology-, vegetation-, or substrate- shall be prevented, and issues related to changes in water quantity and pollutant loading shall be mitigated through use of temporary and permanent SCMs. During a single storm, the total volume of stormwater draining to the wetland after development must not be 20% higher or lower than the pre-development volume. Monthly stormwater volumes draining to the wetland cannot be 15% higher or lower than pre-development volumes. Before being permitted to discharge to wetlands, infiltrative and other discharge points must be considered as measures to meet the volumetric requirements.
    - Pre-developed Forested Standard: post-development flow durations must match the pre-development flow duration under forested conditions for 50% of the 2-year peak flow up to the 50-year peak flow.
    - Pre-developed Pasture Standard: post-development flow durations must match the pre-development flow duration under pasture conditions for 50% of the 2-year peak flow up to the 2-year peak flow.
    - Peak Control Standard: the 25-year and 2-year post-development peak flows cannot be greater than 0.4 cfs/acre and 0.15 cfs/acre, respectively.

- Water Quality Treatment:
    - Runoff Treatment Volume: The required treatment volume is the daily runoff volume that generates 91% of the entire runoff volume* of the simulation period of an "approved, continuous model."
    - Runoff Treatment Flow Rate: design flow rates are dependent on the presence of an upstream or downstream detention facility.
        - Facilities upstream of detention facilities must use a design flow rate that results in treatment of 91% of the total runoff volume for the entire simulation period.
        - Facilities downstream of detention facilities must use a design flow equal to the full release rate of the 2-year storm.
    - Infiltration Treatment Requirements: infiltrative facilities used for "water quality treatment must infiltrate 91% of the total runoff volume as determined using an approved continuous runoff model." This treatment volume (24-hour volume) must drain within 48-hours.

      *Note: for the above design criteria, the 91% figure represents the upper range of daily (24-hour) rainfall depths that account for 91% of total runoff for the multi-decadal period of record.
    - Oil Treatment Standard: certain "high use sites" and projects with a NPDES permit requiring oil control must implement oil control treatment. Linear sand filters, oil separators, or certain proprietary devices may be used.
        - The treatment requirements include:
            1. A 24-hour average concentration of total petroleum hydrocarbons (TPH) less than or equal to 10 mg/L.
            2. A maximum TPH concentration of 15 mg/L for grab samples.
            3. No repeated or constant observable oil sheen.
        - High-use sites include:
            1. Commercial or industrial areas sites average daily traffic (ADT) over 100 vehicles per 1,000 SF of gross building area.
            2. Commercial or industrial sites with petroleum storage and transfer of over 1,500 gallons per year (not including heating oil delivered to any on-site buildings).
            3. Commercial or industrial sites that accommodate parking, maintenance, and/or storage of over 25 vehicles that weigh more than 10 tons.
            4. Road intersections with an ADT of over 25,000 vehicles on the primary roadway or over 15,000 vehicles on the intersecting roadway.
    - Phosphorus Treatment Standard: sites that discharge or infiltrate within 0.25 miles of a nutrient-critical waterbody, or tributary to that waterbody, must implement phosphorus treatment measures.
        - Phosphorus treatment must remove 50% of total phosphorus (TP) for influent concentrations between 0.1 and 0.5 mg/L.

- Sand filters, large wet ponds, infiltrative measures, infiltrating bioretention, filter drains, treatment trains, etc. may be used to achieve compliance.

- Enhanced Treatment: enhanced treatment to reduce dissolved metal concentrations is required for sites that either drain, directly or indirectly, to fresh waters with an aquatic life designated use or for sites that only use infiltrative measures for flow control (not quality treatment) and discharge within 0.25 miles of a fresh water with an aquatic life designated use. Additionally, one of the following criteria must apply:
  - Industrial, commercial, or multi-family sites on a parcel-based project.
  - A roadway project that is either:
    1. "A fully or partially controlled limited access highway with Annual ADT counts of 15,000 or more; or
    2. Any other road with an Annual ADT count of 7,500 or greater."
  - Enhanced treatment facilities must remove at least 30% of dissolved copper and at least 60% of dissolved zinc from the influent (these values assume typical influent ranges of copper and zinc of 5-20 µg/l and 20-300 µg/l, respectively).
  - Sand filters, large wet ponds, infiltrative measures, infiltrating bioretention, filter drains, treatment trains, etc. may be used to achieve compliance.
- Basic Treatment: basic treatment for water quality involves 80% TSS removal for influent concentrations between 100 and 200 mg/L, higher removal performance for influent concentrations above 200 mg/L, and a target effluent concentration of 20 mg/L for influent concentrations less than 100 mg/L. Basic Treatment is required for the following cases:
  - Projects that infiltrate stormwater (unless certain criteria apply)
  - SFR projects that are not required to implement phosphorus control
  - Sites that drain to certain key waterbodies
  - Projects that drain to waterbodies or their tributaries that do not have an aquatic life designated use.
  - Landscaping on MFR, commercial, or industrial sites.
  - Parking lots on commercial or industrial sites, which are only used for employee parking (i.e. no storage, industrial activity, or customer parking).

Table 17. On-site treatment methods for Single Family Residential projects (copied from Seattle Stormwater Manual)

Category	BMPs	All Discharge Locations
1	Full Dispersion	R, S
	Infiltration Trenches	R, S
	Dry Wells	R, S
2	Rain Gardens[a]	R, S
	Infiltrating Bioretention	R, S
	Rainwater Harvesting	X
	Permeable Pavement Facilities	R, S
	Permeable Pavement Surfaces	S
3	Sheet Flow Dispersion	R, S
	Concentrated Flow Dispersion	S
	Splashblock Downspout Dispersion	R
	Trench Downspout Dispersion	R
	Non-infiltrating Bioretention	R, S
	Vegetated Roofs	X
4	Single-family Residential Cisterns	R
	Perforated Stub-out Connections	R
	Newly Planted Trees	S

Note that subsection 22.805.070.D.1 requires consideration of all on-site BMPs in a category for feasibility before moving on to each successive category as necessary. Within a category, BMPs may be considered in any order.

BMPs – Best Management Practices

R = Evaluation is required for all roof runoff from Single-family residential projects.

S = Evaluation is required for all surfaces of Single-family residential projects.

X = Evaluation is not required but is allowed.

[a] Installation is only allowed for projects with less than 5,000 square feet of hard surface infiltrating on the project site.

Table 18. On-site treatment methods for Trail and Sidewalk projects (copied from Seattle Stormwater Manual)

Category	BMPs	Projects Discharging to a Receiving Water Not Designated by Section 22.801.050,[d] or its Basin	Projects Discharging to a Public Combined Sewer or Capacity Constrained System,[c] or its Basin	Projects Discharging to a Designated Receiving Water, or its Basin
1	Full Dispersion	S	S	S
2	Rain Gardens	S	S	X
	Permeable Pavement Surfaces	X	X[a]	X[a, b]
	Permeable Pavement Facilities	S	S[a]	X[a, b]
3	Sheet Flow Dispersion	S	S	S
	Concentrated Flow Dispersion	S	S	S

Note that subsection 22.805.070.D.1 requires consideration of all on-site BMPs in a category for feasibility before moving on to each successive category as necessary. Within a category, BMPs may be considered in any order.

BMPs – Best Management Practices

S = Evaluation is required for all surfaces of trail or sidewalk projects.

X = Evaluation is not required for trail or sidewalk projects.

[a] Minimum permeable pavement area allowed in right-of-way is 2,000 square feet of pavement within the project site.

[b] Installation is not allowed in the right-of-way if new plus replaced pollution-generating hard surface area is less than 2,000 square feet of pavement within the project site.

[c] Does not include any project discharging to a receiving water not designated by Section 22.801.050 (e.g., wetlands, creeks, and small lakes), or its basin, even if the project discharges to a capacity-constrained system or its basin.

[d] Includes wetlands, creeks, and small lakes.

Table 19. On-site treatment methods for Parcel-based projects (copied from Seattle Stormwater Manual)

Category	BMPs	Projects Discharging to a Receiving Water Not Designated by Section 22.801.050,[d] a Public Combined Sewer or Capacity Constrained System, or its Basin	Projects Discharging to a Designated Receiving Water or its Basin
1	Full Dispersion	R, S	R, S
	Infiltration Trenches	R, S	R, S
	Dry Wells	R, S	R, S
2	Rain Gardens	R[a], S[a]	R[a], S[a]
	Infiltrating Bioretention	R, S	R, S
	Rainwater Harvesting	R[b]	X
	Permeable Pavement Facilities	R, S	R, S
	Permeable Pavement Surfaces	S	S
3	Sheet Flow Dispersion	R, S	R, S
	Concentrated Flow Dispersion	S	S
	Splashblock Downspout Dispersion	R	R
	Trench Downspout Dispersion	R	R
	Non-infiltrating Bioretention	R, S	R, S
	Vegetated Roofs	R[c]	X
4	Perforated Stub-out Connections	R	R
	Newly Planted Trees	S	S

Note that subsection 22.805.070.D.1 requires consideration of all on-site BMPs in a category for feasibility before moving on to each successive category as necessary. Within a category, BMPs may be considered in any order.

BMPs – Best Management Practices

R = Evaluation is required for roof runoff from parcel-based projects, unless otherwise noted below.

S = Evaluation is required for all surfaces of parcel-based projects, unless otherwise noted below.

X = Evaluation is not required but is allowed.

[a] Installation is only allowed for projects not required to meet Section 22.805.080 (Minimum Requirements for Flow Control) or Section 22.805.090 (Minimum Requirements for Treatment) and with less than 5,000 square feet of hard surface infiltrating on the project site.

[b] Evaluation is not required for projects with less than 10,000 square feet of new plus replaced rooftop surface.

[c] Evaluation is not required for projects with less than 5,000 square feet of new plus replaced rooftop surface.

[d] Includes wetlands, creeks, and small lakes.

Table 20. On-site treatment methods for Roadway projects (copied from Seattle Stormwater Manual)

Category	BMPs	Projects Discharging to a Receiving Water Not Designated by Section 22.801.050,[h] or its Basin	Projects Discharging to a Public Combined Sewer or Capacity Constrained System,[g] or its Basin	Projects Discharging to a Designated Receiving Water Basin
1	Full Dispersion	S	S	S
2	Rain Gardens	S[a]	S[a]	S[a]
	Infiltrating Bioretention	S	S[b]	S[b, c]
	Permeable Pavement Facilities	X[d]	X[e, f]	X[c, e, f]
	Permeable Pavement Surfaces	S[d]	S[e, f]	S[c, e, f]
3	Sheet Flow Dispersion	S	S	S
	Concentrated Flow Dispersion	S	S	S

Note that subsection 22.805.070.D.1 requires consideration of all on-site BMPs in a category for feasibility before moving on to each successive category as necessary. Within a category, BMPs may be considered in any order.

BMPs – Best Management Practices

PGIS – Pollution generating impervious surface

S = Evaluation is required for all surfaces of Roadway Projects.

X = Evaluation is not required for Roadway Projects, but is allowed.

[a] Installation is only allowed for projects not required to meet Section 22.805.080 (Minimum Requirements for Flow Control) or Section 22.805.090 (Minimum Requirements for Treatment) and with less than 5,000 square feet of hard surface infiltrating on the project site.

[b] Minimum bioretention cell size top area in right-of-way is 500 square feet (including pre-settling area). Evaluation is only required and installation only allowed when contributing area is sufficient to warrant minimum bioretention cell size in right-of-way.

[c] Evaluation is not required, and installation is not allowed, if new plus replaced pollution-generating hard surface is less than 2,000 square feet.

[d] Evaluation of roadway surfaces is not required, and installation is not allowed, if roadway is an arterial street/collector.

[e] Evaluation of roadway surfaces, including alleys, is not required and installation is not allowed.

[f] Minimum permeable pavement area allowed in right-of-way is 2,000 sf of pavement within the project site.

[g] Does not include any project discharging to a receiving water not designated by Section 22.801.050 (e.g., wetlands, creeks, and small lakes), or its basin, even if the project discharges to a capacity-constrained system or its basin.

[h] Includes wetlands, creeks, and small lakes.

2.12.3 Minimum Requirements based on Project Type

The following section will list the previously described minimum requirements that apply to each project type. Additional, possibly stricter requirements exist for some of the projects types if they meet certain criteria (e.g. drains to specific waterbodies, waterbodies with designated uses, impairments, etc.):

- Single-Family Residential Projects
    - Soil amendment
    - On-site stormwater management is required for single family houses that meet one of the two following criteria:

        - Developed or altered after 2016 and the total new plus replaced hard surface (NPRHS) is over 750 SF or the land disturbing activity (LDA) is over 7,000 SF.
        - All other projects: the NPRHS is over 1,500 SF or the LDA is over 7,000 SF.
- Trail and Sidewalk Projects:
    - Soil amendment
    - On-site stormwater management
        - Projects with over 2,000 SF of NPRHS or over 7,000 SF of LDA.
- Roadway Projects:
    - Soil amendment
    - Onsite Stormwater management
        - Roadway projects with over 2,000 SF of NPRHS or over 7,000 SF of LDA.
    - Flow control
        - Roadway projects draining to wetlands must comply with the Wetland Protection Standard if:
            1. NPRHS is over 5,000 SF, or
            2. Over 0.75 acres of vegetation is converted to landscaping or lawn, and there is surface flow from the site into a natural or man-made conveyance that drains off-site, or
            3. Over 2.5 acres of native vegetation is converted to pasture and there is surface flow from the site into a natural or man-made conveyance that drains off-site
        - Roadway projects that drain to listed (specific) creek basins:
            1. Must comply with the Pre-developed Forest Standard if the existing hard surface is less than 35% and one or more of the below criteria apply:
                a. Project adds over 5,000 SF of new hard surface (NHS) and NPRHS is over 10,000 SF, or
                b. Over 0.75 acres of vegetation is converted to landscaping or lawn, and there is surface flow from the site into a natural or man-made conveyance that drains off-site, or
                c. Over 2.5 acres of native vegetation is converted to pasture and there is surface flow from the site into a natural or man-made conveyance that drains off-site, or
                d. Over 5,000 SF of NHS added and causes a 0.1 CFS increase in the 100-year peak flow as evidenced by an approved continuous model.
            2. Must comply with the Pre-Developed Pasture Standard if the above criteria do not apply and the total NPRHS is over 10,000 SF.
        - Roadway projects that drain to non-listed (non-specific) creek basins:
            1. Must comply with the Pre-developed Forest Standard if the existing land cover is forested and one or more of the below criteria apply:

a. Project adds over 5,000 SF of NHS and NPRHS is over 10,000 SF, or
b. Over 0.75 acres of vegetation is converted to landscaping or lawn, and there is surface flow from the site into a natural or man-made conveyance that drains off-site, or
c. Over 2.5 acres of native vegetation is converted to pasture and there is surface flow from the site into a natural or man-made conveyance that drains off-site, or
d. Over 5,000 SF of NHS is added and causes a 0.1 CFS increase in the 100-year peak flow as evidenced by an approved continuous model.

2. Must comply with the Pre-Developed Pasture Standard if the above criteria do not apply and the total NPRHS is over 10,000 SF.

- Roadway projects that drain to small lake basins:
  1. Must comply with the Peak Control Standard if NPRHS is over 10,000 SF.
- Roadway projects that drain to public combined sewers:
  1. Must comply with the Peak Control Standard if NPRHS is over 10,000 SF.
- Roadway projects that drain to capacity constrained systems:
  1. Projects with over 10,000 SF of NPRHS that drain to separated or combined sewers that have existing or predicted inadequate capacity must meet the Peak Control Standard.
- Roadway projects that discharge groundwater to a public separated- or combined- sewer:
  1. Must comply with the Peak Control Standard if NPRHS is over 10,000 SF.

- Water Quality Treatment
  - Roadway projects that have less than 35% existing hard surface cover and a total NPRHS over 5,000 SF must meet the minimum water quality treatment standards.
  - Roadway projects with over 35% existing impervious area and new PGHS over 5,000 SF, must treat the runoff from the total new PGHS and new pollution generating pervious surfaces.
  - Roadway projects with a total new pollution generating pervious surface area greater than 0.75 acres.

Figure 26, Figure 27, and Figure 28 respectively show the flow chart for determining which general-, flow control-, and water quality- minimum requirements apply to roadway projects.

- Parcel-based Projects:
    - Flow Control
        - Parcel-based projects draining to wetlands must comply with the Wetland Protection Standard if:
            1. NPRHS is over 5,000 SF, or
            2. Over 0.75 acres of vegetation is converted to landscaping or lawn, and there is surface flow from the site into a natural or man-made conveyance that drains off-site, or
            3. Over 2.5 acres of native vegetation is converted to pasture and there is surface flow from the site into a natural or man-made conveyance that drains off-site
        - Parcel-based projects that drain to listed (specific) creek basins:
            1. Must comply with the Pre-developed Forest Standard if the existing hard surface is less than 35% and one or more of the below criteria apply:
                a. Project adds over 5,000 SF of new hard surface (NHS) and NPRHS is over 10,000 SF, or
                b. Over 0.75 acres of vegetation is converted to landscaping or lawn, and there is surface flow from the site into a natural or man-made conveyance that drains off-site, or
                c. Over 2.5 acres of native vegetation is converted to pasture and there is surface flow from the site into a natural or man-made conveyance that drains off-site, or
                d. Over 5,000 SF of NHS added and causes a 0.1 CFS increase in the 100-year peak flow as evidenced by an approved continuous model.
            2. Must comply with the Pre-Developed Pasture Standard if the above criteria do not apply and the total NPRHS is over 2,000 SF.
        - Parcel-based projects that drain to non-listed (non-specific) creek basins:
            1. Must comply with the Pre-developed Forest Standard if the existing land cover is forested and one or more of the below criteria apply:
                a. Project adds over 5,000 SF of NHS and NPRHS is over 10,000 SF, or
                b. Over 0.75 acres of vegetation is converted to landscaping or lawn, and there is surface flow from the site into a natural or man-made conveyance that drains off-site, or
                c. Over 2.5 acres of native vegetation is converted to pasture and there is surface flow from the site into a natural or man-made conveyance that drains off-site, or
                d. Over 5,000 SF of NHS added and causes a 0.1 CFS increase in the 100-year peak flow as evidenced by an approved continuous model.

2. Must comply with the Pre-Developed Pasture Standard if the above criteria do not apply and the total NPRHS is over 2,000 SF.

- Parcel-based projects that drain to small lake basins:
  1. Must comply with the Peak Control Standard if NPRHS is over 2,000 SF.
- Parcel-based projects that drain to public combined sewers:
  1. Must comply with the Peak Control Standard if NPRHS is over 10,000 SF.
- Parcel-based projects that drain to capacity constrained systems:
  1. Projects with over 2,000 SF of NPRHS that drain to separated or combined sewers that have existing or predicted inadequate capacity must meet the Peak Control Standard.
- Parcel-based projects that discharge groundwater to a public separated- or combined- sewer:
  1. Must comply with the Peak Control Standard if NPRHS is over 2,000 SF.

- Water Quality Treatment
  - Parcel-based projects that do not discharge to a public combined sewer and have a total NPRHS over 5,000 SF must meet the minimum water quality treatment standards.
  - Parcel-based projects with a total new pollution generating pervious surface area greater than 0.75 acres that discharge into a natural or constructed conveyance system.

- Utility Projects:
  - Utility projects which involve installation or work on overhead or underground utilities are not required to comply with minimum requirements for on-site stormwater management, flow control, or water quality treatment, unless:
    - The project involves installation or replacement of public combined or separated sewer in the public ROW and is a "publicly bid capital improvement project funded by Seattle Public Utilities", or
    - Installation of overhead or underground utility facility that is "integral with and contiguous to a road-related project."
- Pavement Maintenance Projects:
  - Only the following pavement maintenance activities are not required to comply with the minimum requirements for roadway projects, on-site stormwater management, flow control, or water quality treatment:
    - "Pothole and square cut patching;
    - Overlaying existing asphalt or concrete or brick pavement with asphalt or concrete without expanding the area of coverage;
    - Shoulder grading;
    - Reshaping or regrading drainage ditches;
    - Crack sealing; and
    - Vegetation maintenance."

- WSDOT Projects:
    - State highway ROW projects under WSDOT management that occur in the City of Seattle must use the Highway Runoff Manual unless stricter local-, state, or federal-regulations apply to project area.

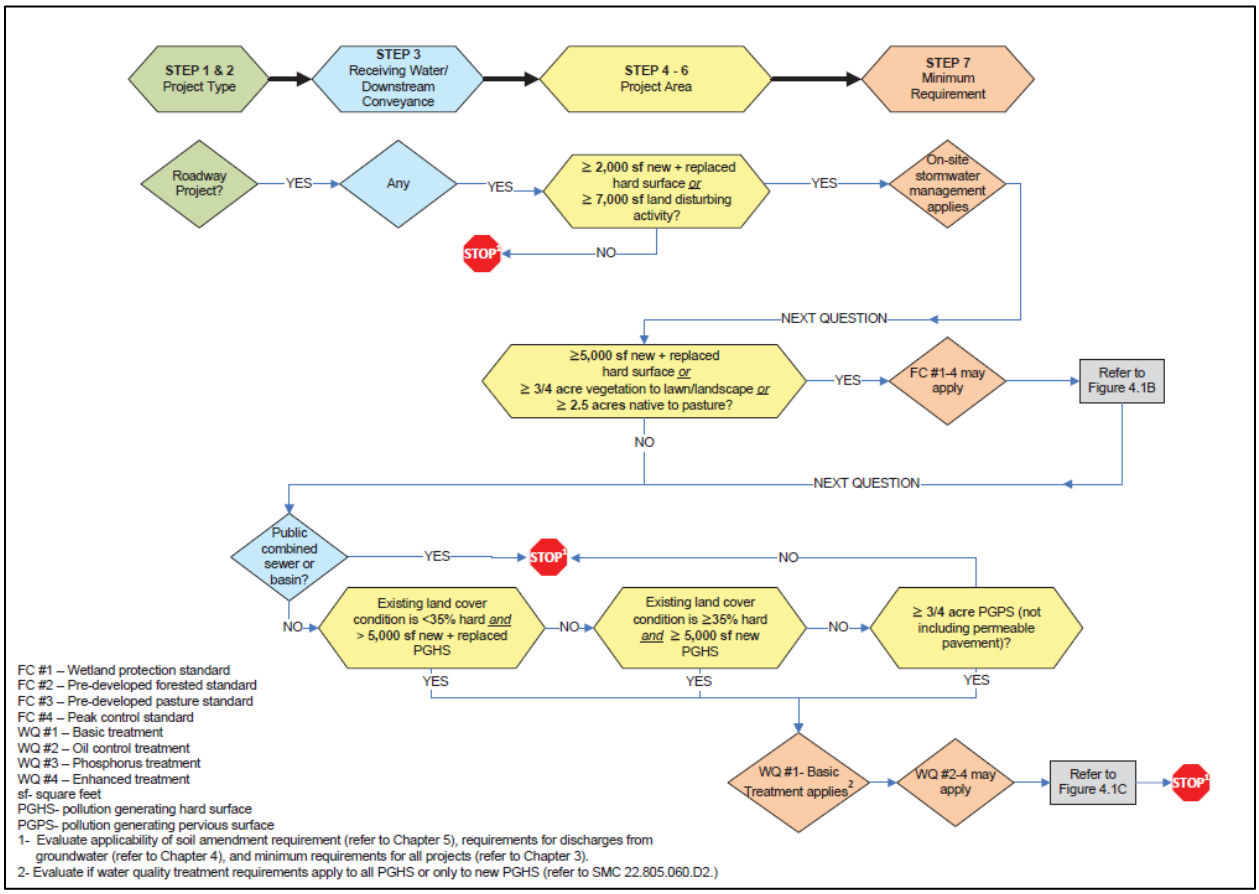

Figure 26. General minimum requirements for Roadway Projects flow chart

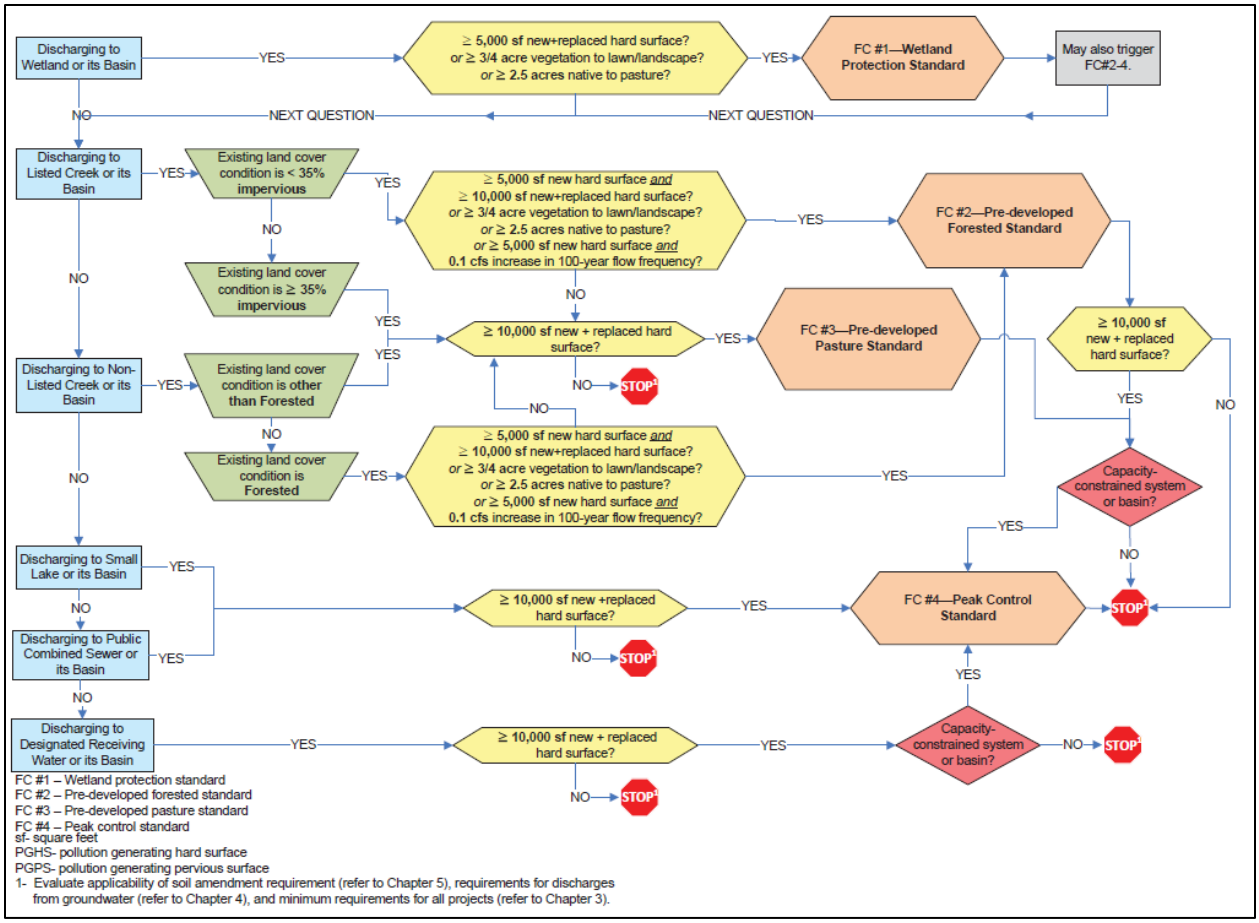

Figure 27. Flow Control minimum requirements for Roadway Projects flow chart

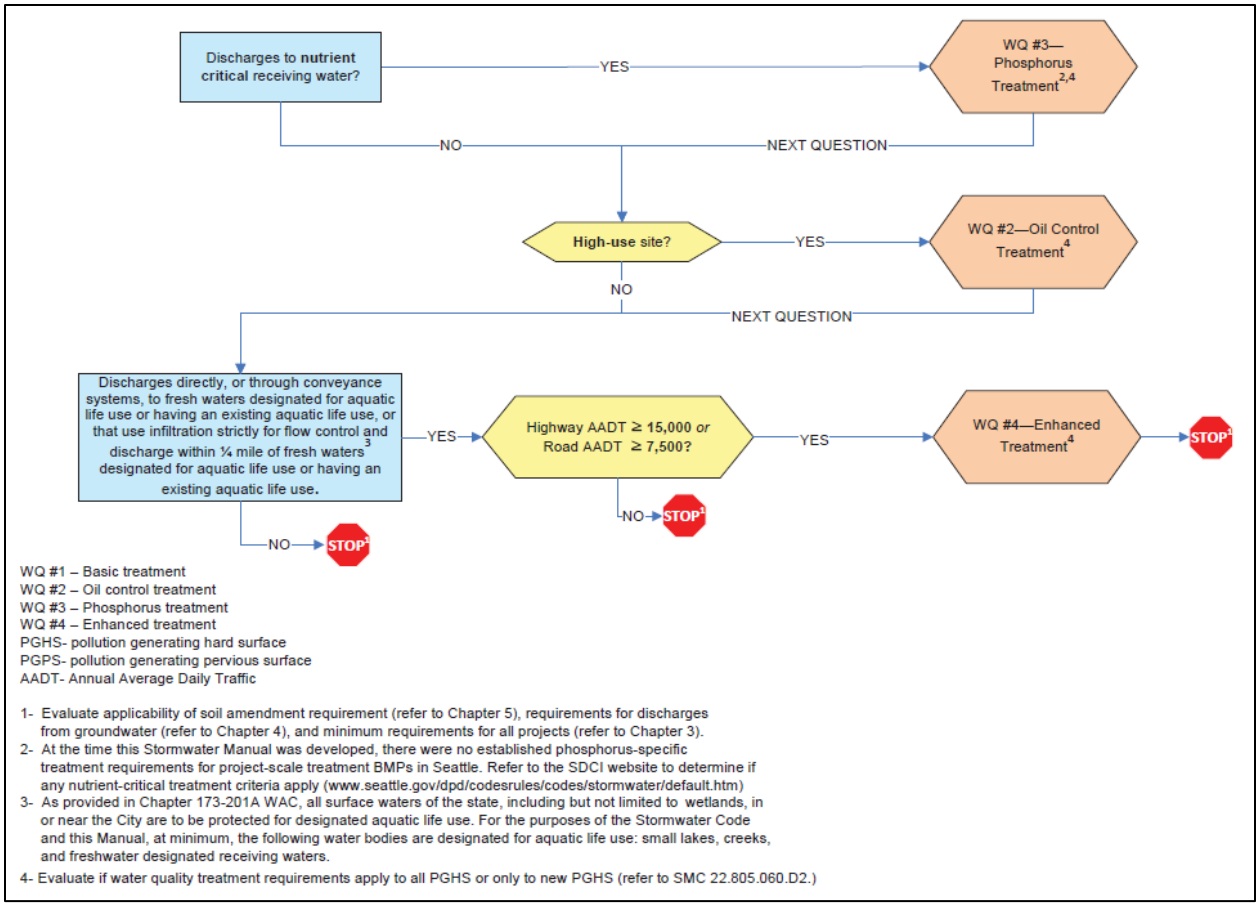

Figure 28. Water Quality Treatment minimum requirements for Roadway Projects flow chart

2.13 Washington, DC

2.13.1 Minimum Standards (Water Quantity and Quality)

Washington DC's (DC) District Department of the Environment (DDE) Stormwater Management Guidebook focuses on both quantity and quality of stormwater runoff. Quantity control requires detention and release at pre-development peak discharge rates of the 2-year, 24 hour and 15-year, 24-hour storms for prevention of channel erosion and flooding, respectively. The flood prevention criteria are based on the typical design capacity of DC's sewer system. Design storms are assumed to have a 72-hour antecedent dry period. Water quality requirements stipulate that "major land disturbing activities" (MLDA) and "major substantial improvement activities" (MSIA) must respectively retain the 1.2-inch (90^{th} percentile) and 0.8-inch (80^{th} percentile) storm events on site. Also known as a Stormwater Retention Volume (SWRv), the water quality requirements may be achieved through prevention-, reduction-, and/or treatment- of stormwater.

MLDA is defined as an "activity that disturbs, or is part of a common plan of development that disturbs, five thousand square feet (5,000 ft^2) or greater of land area, except that multiple distinct projects that each disturb less than 5,000 ft^2 of land and that are in separate, non-adjacent sites do not constitute a major land-disturbing activity."

MSIA is defined as "substantial improvement activity and associated land-disturbing activity, including such activities that are part of a common plan of development, for which the combined footprint of improved building and land-disturbing activity is 5,000 square feet or greater. A major substantial improvement activity may include a substantial improvement activity that is not associated with land disturbance."

Substantial improvement activity is defined as "a repair, alteration, addition, or improvement of a building or structure, the cost of which equals or exceeds fifty percent (50%) of the market value of the structure before the improvement or repair is started."

Special rules apply to projects within the "Anacostia Waterfront Development Zone" (AWDZ). Specifically, MSIA within the AWDZ must retain the 1-inch (85^{th} percentile) storm, rather than the standard 0.8-inch storm. Certain activities in the AWDZ must retain or treat the runoff generated by the 1.7-inch storm (95^{th} percentile) less the SWRv for an additional water quality treatment volume (WQTv). "Maximum extent practicable" guidelines apply for projects which involve reconstruction of public right of ways. Further, control of 2-year post development peak flow is not required if three conditions are met:

(1) "Site discharges flow directly to, or through the separate sewer system, into the main stem of the tidal Potomac or Anacostia Rivers, the Washington Channel, or the Chesapeake and Ohio Canal."

(2) "Site discharges do not flow into or through a tributary to those waterbodies that runs above ground or that the District Department of the Environment (DDOE) expects to be daylighted to run above ground."

(3) “Site discharges will not cause erosion of land or transport of sediment.”

Table 21 summarizes stormwater and water quality volume requirements and calculation equations. The volume equations are based on the design storm depth in conjunction with runoff coefficients and site percentages for impervious-, compacted-, and natural- areas.

Table 21. Sizing criteria for stormwater management performance requirements (copied from DC Stormwater Management Guidebook)

Sizing Criteria	Description of Stormwater Sizing Criteria
Stormwater Retention Volume (*SWRv*) (gal)	$SWRv = [P \times [(Rv_I \times \%I) + (Rv_C \times \%C) + (Rv_N \times \%N)] \times SA] \times 7.48/12$ where: *SWRv* = volume required to be retained on site (gal) *P* = variable percentile rainfall event for the District dependent on regulatory trigger (see next criterion) Rv_I = 0.95 (runoff coefficient for impervious cover) Rv_C = 0.25 (runoff coefficient for compacted cover) Rv_N = 0.00 (runoff coefficient for natural cover) *%I* = percent of site in impervious cover (decimal) *%C* = percent of site in compacted cover (decimal) *%N* = percent of site in natural cover (decimal) *SA* = surface area (ft^2) 7.48 = conversion factor, converting cubic feet to gallons 12 = conversion factor, converting inches to feet
Precipitation value selected based on Regulatory Trigger (*P*)	Major Land-Disturbing Activity (AWDZ and District-wide): 90th percentile event (1.2 inches) Major Substantial Improvement Activity (AWDZ): 85th percentile event (1.0 inches) Major Substantial Improvement Activity (District-wide): 80th percentile event (0.8 inches)
Reconstruction of public right-of-way	Consult Appendix B Maximum Extent Practicable Process for Existing Public Right-of-Way
Water Quality Treatment Volume (*WQTv*) (gal) (applies only to regulated activity in the AWDZ area governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012)	$WQTv = (P \times [(Rv_I \times \%I) + (Rv_C \times \%C) + (Rv_N \times \%N) \times SA] \times 7.48/12) - SWRv$ where: *WQTv* = volume required to be retained or treated, above and beyond the SWRv (gal) *SWRv* = volume required to be retained on site (gal) *P* = 95th percentile rain event for the District (1.7 inches) Rv_I = 0.95 (runoff coefficient for impervious cover) Rv_C = 0.25 (runoff coefficient for compacted cover) Rv_N = 0.00 (runoff coefficient for natural cover) *%I* = percent of site in impervious cover (decimal) *%C* = percent of site in compacted cover (decimal) *%N* = percent of site in natural cover (decimal) *SA* = surface area (ft^2) 7.48 = conversion factor, converting cubic feet to gallons 12 = conversion factor, converting inches to feet
2-Year Storm Control (Qp_2)	The peak discharge rate from the 2-year, 24-hour storm event controlled to the predevelopment peak discharge rate.
15-Year Storm Control (Qp_{15})	The peak discharge rate from the 15-year, 24-hour storm event controlled to the preproject peak discharge rate.
Extreme Flood Requirements (Q_f)	The peak discharge rate from the 100-year storm event controlled to the preproject peak discharge rate if the site: 1) Increases the size of a Special Flood Hazard Area (SFHA) as delineated on the effective Flood Insurance Rate Maps (FIRM) or 2) Meets the following two conditions: (a) Does not discharge to the sewer system and (b) Has a post-development peak discharge rate for a 100-year frequency storm event that will cause flooding to a building.

The area covered by a BMP is considered impervious and included in the calculations for treatment volume. A site must retain at least 50% of the SWRv, unless an exemption is granted by DDOE (exceptionally difficult site conditions must apply). On site retention may be accomplished by conveyance from the site to a shared BMP with available capacity which meets the retention requirements.

Individual drainage areas (IDAs) are areas within a site that discharge to a single outlet from the site. A site can comply with on-site retention requirements by storing more than the SWRv requirements for single (IDAs) under the following conditions:

- At least 50% of the stormwater from each IDA (including vehicular access areas) must be treated within the IDA with a practice that removes 80% of total suspended solids (TSS), unless the IDA drains to a CSS.
- Excess retention for one IDA may be applied to the required volume for another IDA.
- Any retention above the volume generated from a 1.7-inch event (using P = 1.7 inch in the SWRv equation) will not apply towards on-site retention.

Accepted practices for 80% TSS removal include:

- Permeable pavement systems
- Bioretention
- Stormwater filtering systems
- Stormwater ponds
- Wetlands
- Dry Swales
- Wet Swales
- Certain proprietary practices

For WQTv requirements, on site treatment (rather than off-site treatment or use of credits) is achieved via on-site retention, on-site treatment practices with 80% TSS removal, and/or direct conveyance to a shared BMP with sufficient treatment capacity.

Control of the post-development peak flow rate from the 100-year storm to the pre-development discharge rate is required if either of the two conditions are met:

1. The site increases the size of a "Special Flood Hazard Area (SFHA)" a.k.a. the 100-year FEMA floodplain, or
2. Both conditions below are met:
    a. Site does not discharge to the sewer system, and
    b. Post development peak flow rates for the 100-year storm flood a building.

The goals of this "Extreme Flood Criteria" are to prevent building damage and to not increase the size of 100-year FEMA floodplains.

All site discharges must be released to existing, adequate channels (natural or man-made) which meet certain criteria (no erosion or sedimentation, no flooding or excessive ponding, and sufficiently steep slopes). Any BMP receiving oil and grease contamination in excess of 10 mg/L

shall include “a baffle, skimmer, oil separator, grease trap, or other mechanism” to maintain effluent oil and grease concentrations below 10 mg/L. Any areas with confined animals may be required to discharge to the sanitary sewer system.

2.13.2 Culvert Design

Culverts shall be located at the lowest point in order to pass all water across an embankment or road. The inlet must be built to resist long-term erosion and accommodate future increases in hydraulic loading. Similarly, the outlet must be built to prevent future channel scour.

Bibliography

Aguilar, M. (2017). Virginia Stormwater Regulations and Intro to BMP Design. In *Urban Hydrology*. Blacksburg.

Center for Watershed Protection. (2009). *2000 Maryland Stormwater Design Manual Volumes I & II*. Maryland. Retrieved from https://mde.maryland.gov/programs/water/stormwatermanagementprogram/pages/stormwater_design.aspx.

Center for Watershed Protection. (2013). *Stormwater Management Guidebook*. Washington D.C. Retrieved from https://doee.dc.gov/swguidebook.

City of Charlottesvile. (n.d.). *CITY OF CHARLOTTESVILLE CITY STANDARDS AND DESIGN MANUAL*. Charlottesville. Retrieved from http://www.charlottesville.org/home/showdocument?id=10377.

City of Seattle Stormwater Manual. (2016). Seattle. Retrieved from http://www.seattle.gov/sdci/codes/codes-we-enforce-(a-z)/stormwater-code.

Clean Water Services' Design and Construction Standards. (2017). Portland. Retrieved from http://cleanwaterservices.org/permits-development/design-construction-standards/.

CRITERIA FOR DETENTION FACILITY DESIGN. (2012). New York City. Retrieved from http://www.nyc.gov/html/dep/pdf/water_sewer/30_criteria_for_detention_facility_design_06062012.pdf.

Fairfax County. (2017). *Storm Drainage Design*. Fairfax County. Retrieved from https://www.fairfaxva.gov/home/showdocument?id=338.

Geosyntec Consultants. (2013). *Stormwater Best Management Practices: Guidance Document*. Boston. Retrieved from http://www.bwsc.org/ABOUT_BWSC/systems/stormwater_mgt/Stormwater BMP Guidance_2013.pdf.

Guidelines for the Design and Construction of Stormwater Management Systems. (2012). New York City. Retrieved from http://www.nyc.gov/html/dep/html/stormwater/stormwater_management_construction.shtml.

NCDEQ Stormwater Design Manual. (2017). North Carolina. Retrieved from https://deq.nc.gov/sw-bmp-manual.

Philadelphia Water. (2015). *Stormwater Management Guidance Manual*. Philadelphia. Retrieved from https://www.pwdplanreview.org/manual-info/guidance-manual.

STORMWATER MANAGEMENT DESIGN MANUAL. (2007). Roanoke. Retrieved from https://www.roanokeva.gov/1065/Stormwater-Management-Code.

VDOT. (2012). Municipal Separate Storm Sewer System (MS4) Program. Retrieved from http://www.virginiadot.org/programs/stormwater_ms4.asp.

Virginia Stormwater Management Handbook, First Edition. (1999). Virginia. Retrieved from

https://www.deq.virginia.gov/Programs/Water/StormwaterManagement/Publications.aspx.

Virginia Stormwater Management Handbook, Second Edition. (2013). Virginia. Retrieved from https://www.swbmp.vwrrc.vt.edu/references-tools/2013-draft-handbook/.