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6-0000 STORM DRAINAGE

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6-0203 Analysis of Downstream Drainage System (91-06-PFM)

6-0203.1 The downstream drainage system shall be analyzed to demonstrate the adequacy of the system (§ 6-0203.3), or it shall be shown that there is no adverse impact to the downstream system as well as a proportional improvement of the pre-development conditions (§ 6-0203.4 and § 6-0203.5).

6-0203.2 The extent of the review of the downstream drainage system shall be:

6-0203.2A To a point that is at least 150 feet downstream of a point where the receiving pipe or channel is joined by another that has a drainage area that is at least 90 percent of the size of the first drainage area at the point of confluence; or

6-0203.2B To a point at which the total drainage area is at least 100 times greater than the contributing drainage area of the development site; or

6-0203.2C To a point that is at least 150 feet downstream of a point where the drainage area is 360 acres or greater.

6-0203.2D When using §§ 6-0203.2A and 6-0203.2C for the extent of review, the analysis must be to a point where all the cross-sections are adequate in the farthest downstream reach of 150 feet. A minimum of three cross-sections shall be provided in the 150-foot reach. If the detention method described in § 6-0203.4C is used, the three cross-sections in the farthest downstream reach of 150 feet shall be limited to showing a defined channel or a man-made drainage facility and checking for flooding as described in § 6-0203.4C(3) and § 6-0203.5.

6-0203.2E The Director may require analysis farther downstream when the submitted narrative described in § 6-0204 and all related plats and plans are insufficient to show the true impact of the development on surrounding and other lower lying properties, or if there are known drainage problems downstream.[1]

6-0203.2F Cross-section selection and information shall be determined in accordance with Chapter 5 of the latest edition of the "Virginia Erosion and Sediment Control Handbook" (Virginia Department

[1] These drainage problems may be documented as parts of County watershed or drainage studies, complaints on file with the County, or complaints on file at the offices of County Supervisors.

of Conservation and Recreation) under the section titled “Determination of Adequate Channel.” Cross-sections shall be shown on the plans with equal horizontal and vertical scales.

6-0203.2G If the downstream owner(s) refuse to give permission to access the property for the collection of data, the developer shall provide evidence of this refusal and make arrangements satisfactory to the Director to provide an alternative method for the collection of data to complete the outfall analysis (e.g., through the use of photos, aerial surveys, “as built” plans, County topographic maps, soils maps, and any other relevant information).
6-0203.3 Adequacy of all natural watercourses, channels and pipes shall be verified as follows:

6-0203.3A The developer shall demonstrate that the total drainage area to the point of analysis within the channel is 100 times greater than the contributing drainage area of the development site; or

6-0203.3B(1) Natural watercourses shall be analyzed by the use of a 2-year frequency storm to verify that stormwater will not overtop channel banks nor cause erosion of channel bed or banks;

6-0203.3B(2) All previously constructed man-made channels shall be analyzed by the use of a 10-year frequency storm to verify that stormwater will not overtop channel banks and by the use of a 2-year frequency storm to demonstrate that stormwater will not cause erosion of channel bed or banks;

6-0203.3B(3) Pipes, storm sewer systems and culverts, which are not maintained by VDOT, shall be analyzed by the use of a 10-year frequency storm to verify that stormwater will be contained within the pipe, system, or culvert; and

6-0203.3B(4) Pipes, storm sewer systems and culverts, which are maintained by VDOT, shall be analyzed by the use of the 10-year or greater frequency storm in accordance with VDOT requirements.

6-0203.3C Determinations of the adequacy of drainage systems shall be performed in accordance with methods contained in Chapter 5 of the latest edition of the “Virginia Erosion and Sediment Control Handbook” (Virginia Department of Conservation and Recreation) under the section titled “Determination of Adequate Channel.”

6-0203.4 A proportional improvement and no adverse impact to the downstream drainage system shall be shown by one of the following methods:

6-0203.4A Critical Shear Stress Method

6-0203.4A(1) If the outfall is inadequate due to erosive velocities along the extent of review, which is described in § 6-0203.2, the critical shear stress method may be used to show no adverse impact due to erosive velocities. The erosive work on the channel for the post-development conditions shall be reduced to a level below the erosive work on the channel under pre-development conditions by the required proportional improvement. The required proportional improvement of the downstream system at each inadequate cross-section is the ratio of the post-development C times A (See § 6-0803 for a description of C times A) for the contributing drainage area of the site to the existing development C times A for the entire drainage area at that cross-section. The required proportional improvement is computed as follows:

$P_i = [C_d A_d / C_{cs} A_{cs}] X 100$

Where,
P_i = Required Proportional Improvement (%)
C_d = Runoff Coefficient for the Contributing Drainage Area of the Site in a Post-Development Condition
A_d = Contributing Drainage Area of the Site
C_{cs} = Runoff Coefficient for the Contributing Drainage Area to the Cross Section in an Existing Development Condition
A_{cs} = Contributing Drainage Area to the Cross Section

Each inadequate cross-section along the extent of review shall then be analyzed for the following:

6-0203.4A(2) (107-11-PFM) The shear stress for both the pre-development condition and the post-development condition for the 2-year storm shall be plotted in relation to time at each cross-section. On each graph, the permissible shear stress also shall be plotted. The permissible shear stress is based on the soil type, and may be determined for cohesive soils from Plate 76-6 and for non-cohesive soils from Plate 77-6. The soil type may be determined by field test or the soil type designated on the County soils maps may be used. If the soil type is designated using the County soils maps, the most conservative permissible shear stress for the soil type shall be used. The plans shall indicate how the soil type was determined. The County soil maps are available on the County website and the soil properties are available from the USDA-NRCS website. The area between the permissible shear stress and the actual shear stress on the graph is erosive work on the channel. The erosive work for the post-development condition shall be less than the erosive work for pre-development condition by a percentage equal to the required proportional improvement.

The shear stress on the channel can be calculated using the following formula:

$\tau = \gamma RS$

Where:
τ = shear stress (lb./sq.ft.)
γ = unit weight of water (62.4 lb./ft^{3})
R = hydraulic radius (ft.)
S = slope of the channel bed

6-0203.4B Channel Capacity Method

6-0203.4B(1) If the outfall is inadequate due to inadequate capacity along the extent of review, which is described in § 6-0203.2, the channel capacity method may be used to show no adverse impact due to overtopping. The largest storm that does not exceed the actual channel, pipe, or culvert capacity under pre-development conditions shall be determined for the cross-section that is most frequently over its capacity. The post-development peak flows for the above storm and the 2-year and 10-year storms shall be reduced to a level below the pre-development conditions by a percent equal to the required proportional improvement. See § 6-0203.4A(1) for a description of the required proportional improvement.

6-0203.4C Detention Method [2]

6-0203.4C(1) It shall be presumed that no adverse impact and a proportional improvement will occur if on-site detention is provided as follows and the outfall is discharging into a defined channel or manmade drainage facility:

6-0203.4C(1)(i) Extended detention of the 1-year storm volume for a minimum of 24 hours. If extended detention of the BMP volume (see § 6-0400 *et seq*.) also is provided, the 24 hours shall be applied to the difference between the 1-year storm volume and the BMP volume; and

6-0203.4C(1)(ii) In order to compensate for the increase in runoff volume, the 2-year and 10-year post-development peak rates of runoff from the development site shall be reduced below the respective peak rates of runoff for the site in good forested condition (e.g., for NRCS method, a cover type of "woods" and a hydrologic condition of "good"). This reduction results in a proportional improvement and is computed as follows:

$R_i = [1 - (V_f / V_d)] \times 100$

Where:
R_i = Reduction of Peak Flow Below a Good Forested Condition (%)
V_f = Runoff Volume from the Site in a Good Forested Condition
V_d = Runoff Volume from the Site in a Post-Developed Condition

The calculation of the cumulative volumes shall be based on the NRCS methodology described in § 6-0802 or other methods as approved by the Director.

6-0203.4C(1)(iii) Computations demonstrating the 1½-year post-development peak rate of runoff from the development site does not exceed the 1½-year peak rate of runoff for the site in good forested condition are optional. The 1½- year storm is used to obtain Leadership in Energy and Environmental Design (LEED) certification.

[2] Because of the long detention times resulting from this method, consideration shall be given to hydrology, soils and extended detention when choosing the appropriate landscaping for the detention facility.

6-0203.4C(2) If this method is used, each outfall from the site shall be analyzed independently and the allowable release rate shall be based on the area of the site that drains to the outfall under pre-development conditions.

6-0203.4C(3) If this method is used, the downstream review analysis shall be limited to providing cross-sections to show a defined channel or man-made drainage facility, and checking for flooding of existing dwellings or buildings constructed under an approved building permit from the 100-year storm event for the extent of review described in § 6-0203.2A, B, C and D.

6-0203.4D Other scientifically valid methods, which show no adverse impact regarding erosion or capacity for an inadequate outfall and show proportional improvement, may be approved by the Director.

6-0203.5 In accordance with § 6-0202.4, if an existing dwelling or a building constructed under an approved building permit, which is located within the extent of review described in § 6-0203.2, is flooded by the 100-year storm, the peak flow of the 100-year storm at the development site shall be reduced to a level below the pre-development condition by a percent equal to the required proportional improvement. See § 6-0203.4A(1) for a description of the required proportional improvement.

6-0204 Submission of Narrative Description and Downstream Analysis (91-06-PFM)

6-0204.1 In addition to plats, plans, and other documents that may be required, a description of each outfall of the storm drainage system from the development site shall be submitted as part of the relevant subdivision construction plan or site plan and shall include the following:

6-0204.1A The additional submission shall include a narrative and sketches describing the major elements (pipe, channel, natural watercourse stream, etc.) of each outfall drainage system, including any discharges of non-concentrated surface waters from the development site. Photographs may also be included to assist in the description of the outfall.

6-0204.1B Downstream Review. The downstream review, divided into reaches, as required by § 6-0203, shall:

6-0204.1B(1) Note the existing surrounding topography, soil types, embankments, vegetation, structures, abutting properties, etc., which may be impacted by drainage;

6-0204.1B(2) In cases where the developer seeks to establish that the existing downstream facilities and/or natural waterways are adequate to receive the drainage from the development site, provide sufficient cross-section information, associated graphs, and computations to support the assertion of adequacy, in accordance with § 6-0203.3;

6-0204.1B(3) In cases where the downstream facilities are inadequate and the developer proposes to use the detention method, in accordance with § 6-0203.4C, provide sufficient information to (i) establish the existence of a defined channel or man-made drainage facility to receive the concentrated discharge from the development site, and (ii) demonstrate at least the minimum required proportional improvement, as described in § 6-0203.4C(1), will be achieved;

6-0204.1B(4) In cases where the downstream facilities are inadequate and the developer proposes to use the critical shear stress or channel capacity method, in accordance with § 6-0203.4A and § 6-0203.4B, provide sufficient cross-sections, associated graphs, and computations to demonstrate (i) there will be no adverse impacts and (ii) at least the minimum required proportional improvement, as described in § 6-0203.4A(1), will be achieved;

6-0204.1B(5) Provide sufficient information to demonstrate that (i) there will be no flooding of existing dwellings, or buildings constructed under an approved building permit, by the 100-year storm event, or (ii) any existing flooding condition will not be aggravated by drainage from the development site and a proportional improvement is made in accordance with § 6-0203.5; and

6-0204.1B(6) Include a written opinion, certified, signed, and sealed by the submitting professional, that (i) the requirement of adequacy of the downstream drainage system(s) is met or the development will meet the no adverse impact condition and achieve the required proportional improvement of pre-development conditions; (ii) if any portion of the outfall drainage system is a natural watercourse, the cross-sections analyzed and included on the plan are representative of stream reaches for the entire extent of review for the natural watercourse portion of the system; and (iii) there will be no flooding of existing downstream dwellings, or buildings constructed under an approved building permit, by the 100-year storm event, or that any existing flooding condition will not be aggravated by drainage from the development site.

6-0205 Small Private Drainage System *See current PFM*

6-0300 POLICY ON DETENTION OF STORMWATERS

6-0301 General Policy

6-0301.1 It is the intent of this policy to encourage the use of various methods for the on-site detention of stormwater in the interest of minimizing the adverse effects of increased stormwater runoff (resulting from development of land within the County) on all downstream drainageways.

6-0301.2 (31-90-PFM) It also is the intent of this policy to encourage a regional approach in the implementation of stormwater detention, rather than numerous small, less effective individual on-site ponds.

6-0301.3 Detention facilities must be provided in all storm drainage plans proposed for development in the County submitted for review and approval unless waived by the Director.

6-0301.4 (35-91-PFM) Regional dry ponds or extended dry ponds are the preferred types of stormwater management facility, except in locations where the County's Regional Stormwater Management Plan calls for a wet BMP pond. The use of wet ponds in residential developments is restricted to regional facilities or to residential developments where there are no other reasonable options available for compliance with the water quality requirements.

6-0301.5 (46-94-PFM) A wet pond is a regional wet pond if it is approved as such as a part of the County's regional stormwater management plan. In addition, a wet pond may be deemed by the County to be a regional wet pond if it 1) is the functional equivalent of a regional wet pond or 2) has an upstream watershed area of 100 acres or more, and a detention capacity and BMP capacity capable of serving the entire upstream watershed.

6-0302 Detention Measures

6-0302.1 Except where otherwise prohibited, detention, either alone or in combination with other measures, is an acceptable option for meeting the County and State requirement for protecting receiving waterways from erosion and flooding resulting from (developed) runoff.

6-0302.2 On-site detention of stormwater is desirable in many cases to alleviate existing downstream drainage problems and to preclude the development of new ones.

6-0302.2A Detention is mandatory where the existing downstream drainage system is clearly inadequate and its expansion or improvement is either financially prohibitive or unacceptable for aesthetic or other compelling reasons.

6-0302.2B In some areas of a watershed, detention may cause increased peak flows to occur on the major streams and tributaries. Therefore, the downstream impact must be carefully investigated.

6-0302.2C The Director may prohibit detention of stormwater where and when it is not in the best interests of the County.

6-0302.3 The release rate from ponding areas shall approximate that of the site prior to the proposed development for the design storm, but adequate alternate drainage must be provided to accommodate major storm flows.

6-0302.4 The rooftops of buildings may be used for detention, but care should be taken to design the buildings to accommodate the additional live loading involved if the depth exceeds 3 inches.

6-0302.5 Detention pools or basins in parks (subject to the approval of FCPA), playing fields, parking lots or storage areas can be constructed to reduce peak runoff downstream by providing on-site storage.

6-0302.5A Care must be taken to ensure that such ponds do not become nuisances or health hazards.

6-0302.5B The design engineer should strive to design detention facilities which require minimal maintenance. The maintenance responsibility shall be clearly stated on the plans.

6-0302.5C Where dual purpose facilities are provided, flat grades encountered, or poor draining soils found, provisions for adequate low flow drainage may be required.

6-0302.6 Porous material may be used where practical as an alternative to conventional impervious parking area paving.

6-0302.6A This material would allow the stormwater to be absorbed more readily by the ground rather than adding to additional runoff.

6-0302.6B This practice is not applicable to areas where a high water table exists or where subsoil conditions are not suitable.

6-0302.6C Design engineers are encouraged to investigate and propose experimental uses of new or existing products and methods including porous asphalt pavement where such use may appear appropriate.

6-0302.6D Parking areas surfaced with gravel or rock must be approved by the Director, in accordance with Paragraph 9 of § 11-202 of the Zoning Ordinance, or § 7-0504 *et seq*.

6-0303 Location of Detention Facilities

6-0303.1 (32-90-PFM) All non-regional "wet ponds" (ponds with a permanent water surface) in residentially zoned areas must be maintained by the homeowner's association and a private maintenance agreement must be executed before the construction plan is approved. Dry detention ponds and regional wet detention ponds, including those constructed to serve BMP facilities, located in residentially zoned areas, including condominium developments, shall be within County storm drainage easements, and shall be maintained by DPWES.

6-0303.2 (46-94-PFM) Detention and BMP facilities located in industrial, commercial, institutional, apartment developments and rental townhouses must be maintained by the property owner, and a Private Maintenance Agreement must be executed before the construction plan is approved.

6-0303.3 (38-93-PFM) Retention, detention and/or BMP facilities may not be located in RPAs unless an exception is approved under provisions of Chapter 118 (Chesapeake Bay Preservation Ordinance) of the Code.

6-0303.4 Although this policy is primarily concerned with maintaining post-development peak outflow at the level of the pre-development condition, it may be applied under certain conditions for the purpose of correcting an existing inadequate outfall. When used in this fashion, such a facility also may aid in meeting the requirement for adequate drainage.

6-0303.5 When new development lies in the Occoquan watershed, the provisions of § 6-0400 *et seq*. relating to BMPs also apply.

6-0303.6 (46-94-PFM) Wherever stormwater management facilities are planned in areas within 300 feet of a residence or active recreational area, the design shall be directed specially toward the safety aspects of the facility and shall conform to the requirements of § 6-1606; including such features as mild bottom slopes along the periphery of a detention pond extending out to a point where the depth exceeds 2 feet, flat lateral and longitudinal slopes where concrete low flow channels are used, outlet structures with properly fastened trash racks which will inhibit unauthorized entrance, and posted warning signs.

6-0303.7 In addition, credit for recreational open space shall not be allowed in those areas where detention facilities are located unless the area can reasonably be used for recreational purposes. For example, some detention ponds could be used for active recreational use if the low flows are totally separated from the play areas by a piping system.

6-0303.8 (83-04-PFM, 24-88-PFM) Underground detention facilities may not be used in residential developments, including rental townhouses, condominiums and apartments, unless specifically waived by the Board of Supervisors (Board) in conjunction with the approval of a rezoning, proffered condition amendment, special exception, or special exception amendment.

In addition, after receiving input from the Director regarding a request by the property owner(s) to use underground detention in a residential development, the Board may grant a waiver if an application for rezoning, proffered condition amendment, special exception, and special exception amendment was approved prior to, June 8, 2004, and if an underground detention facility was a feature shown on an approved proffered development plan or on an approved special exception plat. Any decision by the Board to grant a waiver shall take into consideration possible impacts on public safety, the environment, and the burden placed on prospective owners for maintenance of the facilities. Any property owner(s) seeking a waiver shall provide for adequate funding for maintenance of the facilities where deemed appropriate by the Board. Underground detention facilities approved for use in residential developments by the Board shall be privately maintained, shall be disclosed as part of the chain of title to all future homeowners (e.g., individual members of a homeowners' or condominium association) responsible for maintenance of the facilities, shall not be located in a County storm drainage easement, and a private maintenance agreement in a form acceptable to the Director must be executed before the construction plan is approved. Underground detention facilities may be used in commercial and industrial developments where private maintenance agreements are executed and the facilities are not located in a County storm drainage easement.

6-0303.9 (35-91-PFM) Detention or structural BMP facilities, including 10-year flood storage areas associated with such facilities, shall not be located on individual buildable single family attached and detached residential lots, or any part thereof for the purpose of satisfying the detention or BMP requirements of the Subdivision Ordinance or Zoning Ordinance. However, detention and BMP facilities may be constructed on individual lots to satisfy the detention and BMP requirements for each lot. County maintenance for detention and BMP facilities on such individual lots will not be provided.

6-0400 STORMWATER RUNOFF QUALITY CONTROL CRITERIA (38-93-PFM)

6-0401 General Information and Regulations

6-0401.1 The Board has established a Water Supply Protection Overlay District (WSPOD) in the Occoquan Watershed to prevent water quality degradation of the Occoquan Reservoir due to pollutant loadings within the watershed. WSPOD boundaries have been established on the Official Zoning Map. Use limitations are established which require that there shall be water quality control measures designed to reduce the projected phosphorus runoff by at least one-half for any subdivision or use requiring site plan approval unless a modification or waiver is approved by the Director.

6-0401.2 The Board has established Chesapeake Bay Preservation Areas (CBPAs) consisting of RPAs and RMAs throughout the entire County to protect the quality of water in the Chesapeake Bay and its tributaries (Chapter 118 of the Code). RPA and RMA components are identified in § 118-1-7 of the Code. Performance criteria have been established which require that there shall be water quality control measures designed to prevent a net increase in nonpoint source pollution from new development based on average land cover conditions and to achieve a 10-percent reduction in nonpoint source pollution from redevelopment. For purposes of § 6-0400 *et seq*., the average land cover condition is 18-percent imperviousness. These criteria are implemented as follows:

6-0401.2A For new development, the projected total phosphorus runoff pollution load for the proposed development shall be reduced by no less than 40 percent compared to phosphorus loads projected for the development without BMPs. This requirement shall not apply to any development that does not require a site plan pursuant to Article 17 of the Zoning Ordinance, that does not require subdivision approval pursuant to the Subdivision Ordinance, and that does not result in impervious cover of 18 percent or greater on the lot or parcel on which the development will occur.

6-0401.2B (79-03-PFM) For redevelopment of any property not currently served by one or more BMPs, the required reduction in phosphorus loads will be computed for each site based on the following formula:

$[1 - 0.9(\text{“I”}_{pre} / \text{“I”}_{post})] \text{ X } 100 = \%\text{ P removal}$

Where:
“I”_{pre} is the pre-development percent impervious area
“I”_{post} is the post-development percent impervious area

6-0401.2C For redevelopment of any property that is currently and adequately served by one or more BMPs, the projected phosphorus runoff pollution load after redevelopment shall not exceed the existing phosphorus runoff pollution load.

6-0401.2D "Redevelopment" means the substantial alteration, rehabilitation, or rebuilding of a property for residential, commercial, industrial, or other purposes where there is no net increase in impervious area by the proposed redevelopment within an RPA and no more than a net increase in impervious area within an RMA of 20 percent relative to conditions prior to redevelopment, or any construction, rehabilitation, rebuilding, or substantial alteration of residential, commercial, industrial, institutional, recreational, transportation, or utility uses, facilities or structures within an Intensely Developed Area.

6-0401.2E (79-03-PFM) These requirements apply to any development or redevelopment in a CBPA unless a waiver or modification is approved by the Director. Waivers or modifications shall be subject to the following criteria:

6-0401.2E(1) The requested waiver or modification is the minimum necessary to afford relief;

6-0401.2E(2) Granting the waiver or modification will not confer upon the applicant any special privileges that are denied by Chapter 118 of the County Code to other property owners who are subject to its provisions and are similarly situated;

6-0401.2E(3) The waiver or modification is in harmony with the purpose and intent of Chapter 118 of the County Code and is not of substantial detriment to water quality;

6-0401.2E(4) The waiver or modification request is not based upon conditions or circumstances that are self-created or self-imposed;

6-0401.2E(5) Reasonable and appropriate conditions are imposed, as warranted, that will prevent the activity from causing a degradation of water quality; and

6-0401.2E(6) Other findings, as appropriate and required by Chapter 118 of the County Code, are met.

6-0401.3 The Board has also adopted stormwater runoff quality control requirements with certain approved rezoning and special exception applications.

6-0401.4 The water quality control measures described in § 6-0000 *et seq*. are called BMPs. The term BMP refers to a practice, or combination of practices, which has been determined by the Director to be the most effective practicable means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals.

6-0402 Stormwater Quality Control Practices. The BMP policy where required is incorporated into the stormwater management program in the following manner:

6-0402.1 The Director may require the control of off-site areas draining to proposed BMPs which would not operate at the listed phosphorus removal efficiency, because of hydraulic overloading, if these areas were left uncontrolled. Control of off-site areas for this purpose will not be required in excess of an amount which would be considered equivalent to 100 percent site coverage.

6-0402.2 (56-96-PFM) Guidance for the design of BMPs can be found in Chapter 4 of the "Northern Virginia BMP Handbook" (NVPDC/ESI, 1993). Such manual may be modified by the Board to apply specifically to Fairfax County.

6-0402.3 (56-96-PFM) For purposes of § 6-0400 *et seq*., the following standard BMPs, sizing rules, and their associated phosphorus removal efficiencies, based on available water quality planning studies, are accepted:

Table 6.3 Phosphorus Removal Efficiencies (98-07-PFM, 56-96-PFM)

BMP	Sizing Rule	Phosphorus[1] Removal (%)
Extended Detention[2] Dry Pond (48-hour)	Plate 2-6	40
Wet Pond[3]		
Design 1	2.5 x V_r + extended detention	45
Design 2	4.0 x V_r	50
Infiltration[4]		
Design 1	0.5 in./impervious acre	50
Design 2	1.0 in./impervious acre	65
Design 3	2-year, 2-hour storm	70
Natural Open Space[5]	N/A	100
Regional Ponds[6]		
Dry Pond	Plate 2-6	50
Wet Pond	4.0 x V_r	65
Sand Filter[7]	0.5 in./impervious acre	60
Pervious Pavement[8]		
Design 1	Captures and treats a water quality volume of 0.5 in.	
	without infiltration	35
	with infiltration	50
Design 2	Captures and treats a water quality volume of 1.0 in.	
	without infiltration	40
	with infiltration	65

Bioretention Basin/Filter	0.5 in./impervious acre 1.0 in./impervious acre	50 65
Vegetated Swale	Volume Based Design 0.5 in./impervious acre 1.0 in./impervious acre Flow Based Design Hydraulic residence time of 18 minutes	50 65 30
Tree Box Filter	0.5 in./impervious acre 1.0 in./impervious acre	50 65
Vegetated Roof[8]	N/A	40
Reforestation[9]	N/A	70

[1]Phosphorus (as total P), the limiting nutrient for algal productivity in local receiving waters, is used as an indicator of water quality. Measures that control phosphorus also will control many other pollutants.

[2]A minimum drawdown time of 48 hours is required for the BMP storage volume.

[3]V_r is the volume of runoff from the mean storm. It is computed based on an average annual rainfall of 40 in. per year and an average of 100 storms per year multiplied by the rational formula “C” factor. Design One incorporates extended detention above the permanent pool equal to the Plate 2-6 value.

[4]Infiltration may be used only on soils designated by a professional authorized by the State to provide such information as adequate for the purpose. Special attention must be given to construction and maintenance practices for infiltration.

[5]For purposes of BMP efficiencies, “open space” in residential areas is defined as perpetually undisturbed homeowners’ association (or “common”) areas placed in floodplain or conservation easements and without other encumbrances. Full credit for utility easements equal to or less than 25 ft. in width and which meet the above criteria is allowed. The Director may allow “open space” credit for undisturbed areas in utility easements greater than 25 ft. in width on a case by case basis. Any areas located within private lots or with maintained landscaping or active recreational areas are not to be included in “open space” determinations. In nonresidential areas, “open space” is defined as perpetually undisturbed areas placed in floodplain or conservation easements and without other encumbrances. Credit for utility easements equal to or less than 25 ft. in width and which meet the above criteria is allowed. The Director may allow “open space” credit for undisturbed areas in utility easements greater than 25 ft. in width on a case by case basis. Open space used for BMP credit which is not already in a floodplain easement shall be placed in a recorded conservation easement with metes and bounds which shall also be shown on the plat. BMP credit for open space, which is dedicated to the County during the land development process, may be assigned to the remaining portions of the original site on approval by the Board.

[6]Regional ponds are those facilities which are part of the regional stormwater management plan adopted by the Board or substitutes and additions to the plan approved by DPWES. All ponds for which regional BMP credit is requested must be approved by DPWES. Regional ponds generally control a watershed of 100 acres or more in size. However, the Director may allow regional BMP credit for smaller ponds constructed to satisfy requirements of the regional plan.

[7]Sand filters shall be privately owned and maintained.

[8]In applying the computational procedure in Chapter 4 of the Northern Virginia BMP Handbook to demonstrate compliance with the phosphorus removal requirement for the site, the “C” factor for pervious pavements and vegetated roofs should be set at 0.9 to correctly credit the phosphorus removal provided by these controls. This will result in a different weighted “C” factor than that used to compute stormwater runoff.

[9]In applying the computational procedure in Chapter 4 of the Northern Virginia BMP Handbook to demonstrate compliance with the phosphorus removal requirement for the site, the “C” factor ratio for reforestation should be set at 1.0 because reforestation is being treated as a land use credit rather than a structural control.

6-0402.4 Other innovative BMP measures may be permitted but, due to the design variables that could affect their appropriateness and efficiencies, percentages are not listed above. A request for use of these techniques will be reviewed on a case by case basis and approved by the Director as appropriate. The developer must provide full details and supporting data including:

Justification
Technical details with research data supporting efficiencies
Maintenance considerations and program (private maintenance will generally be required for innovative BMP facilities)
Any safety considerations
Aesthetic considerations
Location and interaction with populated areas
Pest control program, if required.

6-0402.5 The efficiencies set forth in § 6-0402.3 apply only to the portion of the site served by each practice; however, credit may be allowed for control of runoff pollution from off-site areas. Additional credit is not allowed for practices in series without the Director’s approval.

6-0402.6 (79-03-PFM) The following options will be considered to comply with the stormwater runoff quality control criteria in RPAs and RMAs:

6-0402.6A Incorporation on the site of BMPs that achieve the required control as set forth in § 6-0401. For the purposes of this subsection, the “site” may include multiple projects or properties that are adjacent to one another or lie within the same drainage area where a single BMP or a system of BMPs will be utilized by those projects in common to satisfy water quality protection requirements;

6-0402.6B Compliance with a locally adopted regional stormwater management program which may include a Virginia Pollution Discharge Elimination System (VPDES) permit issued by the Department of Environmental Quality to a local government for its municipally owned separate storm sewer system discharges, that is reviewed and found by the Chesapeake Bay Local Assistance Board to achieve water quality protection equivalent to that required by this Article (BMP credit for a pro rata share payment to the regional stormwater management program will be computed based on the portion of the site which drains to an existing or proposed regional pond providing water quality control.); or

6-0402.6C Compliance with a site-specific VPDES permit issued by the Department of Environmental Quality, provided that the local government specifically determines that the permit requires measures that collectively achieve water quality protection equivalent to that required by this Article.

6-0402.7 Developers, in coordination with DPWES, are strongly encouraged to seek cooperation with other planned developments in their watershed area in order to construct combined facilities which could serve several developing sites. This regional approach to stormwater management would result in facilities that are not only efficient in terms of stormwater quality control, but are also cost effective and land saving.

6-0402.8 The following information is required on all site and subdivision plans to show compliance with the water quality control requirements of § 6-0000 *et seq*.

6-0402.8A A brief narrative summarizing how water quality control requirements are being provided for the site.

6-0402.8B A map showing all subareas used in the computations of weighted average “C” factors, BMP storage, and phosphorus removal including off-site areas, open space, and uncontrolled areas.

6-0402.8C Open space used for BMP credit should be delineated on the plan sheets with the note “Water quality management area. BMP credit allowed for open space. No use or disturbance of this area is permitted without the express written permission of the Director of the Department of Public Works and Environmental Services.”

6-0402.8D Computations used to determine BMP outflow rates and size outlet structures.

6-0402.8E Computations of BMP facility storage requirements.

6-0402.8F Computations of BMP phosphorus removal for the site.

6-0402.8G Statement of maintenance responsibility for the BMPs (public or private). Additional information may be required by the Director to justify use of nonstandard designs or in unusual situations.

6-0500 POLICY ON OFF-SITE DRAINAGE IMPROVEMENTS *See current PFM*

6-0600 POLICY ON PROPORTIONATE COST OF OFF-SITE DRAINAGE IMPROVEMENTS *See current PFM*

6-0700 POLICY ON WHAT MAY BE DONE IN FLOODPLAINS *See current PFM*

6-0800 HYDROLOGIC DESIGN

6-0801 Acceptable Hydrologies *See current PFM*

6-0802 NRCS Hydrology (27-89-PFM)

NRCS Hydrology consists of Technical Release Number 20 (TR-20) and Technical Release Number 55 (TR-55) including the COE HEC-1 software, NRCS applications. This hydrology is preferred and acceptable for all applications.

6-0803 Rational Formula (47-95-PFM)

The Rational Formula, $Q = C_fCIA$, is acceptable for drainage areas of 200 acres and under, except it is not authorized for designing detention/retention facilities greater than 20 acres. The Rational Formula may be used for the design of detention/retention facilities of 20 acres and less provided that the “C” factor for unimproved areas does not exceed 0.15 on the 2-year storm and the facility is in full compliance with all other requirements of § 6-1600 *et seq*.

Q = Rate of runoff (cfs)
C_f = Correction Factor for ground saturation
C = Runoff Coefficient (ratio of runoff to rainfall)
I = Rainfall Intensity (in./hr.)
A = Area of drainage basin (acres)

C_f Values
1.0 - 10-year or less
1.1 - 25-year
1.2 - 50-year
1.25 - 100-year

6-0803.1 Runoff Coefficient (C) used to compute flow to the point of interest shall be the composite of the “C” factors for all the areas tributary to the point of interest. Table 6.5 gives the runoff coefficients to be used for the different zoning classifications. For cluster areas and when clay soil is encountered the higher values of “C” shall be used.

6-0803.2 (27-89-PFM) Rainfall Intensity (I) shall be determined from the rainfall frequency curves shown in Plate 3-6 or Table 6.6 (for incremental unit hydrograph). The 10-year storm frequency shall be used to design the storm drains (minor drainage systems); the 100-year storm frequency shall be used to design the drainageways of the major drainage system.

6-0803.3 Time of Concentration (t_c) is the sum of the inlet time plus the time of flow in the conduits from the most remote inlet to the point under consideration. Flow time in conduits may be estimated by the hydraulic properties of the conduit. Inlet time is the time required for the runoff to reach the inlet of the storm sewer and includes overland flow time and flow time through established surface drainage channels such as swales, ditches and street gutters.

6-0803.3A Recommended inlet times are also shown in Table 6.5.

6-0803.3B Storm drainage systems may be designed based on zoning classification or type of surface. In general, when designing drainage facilities based on type of surface, the runoff coefficient for each inlet is selected as follows:

$$C = \frac{A_1C_1 + A_2C_2 + \ldots + A_nC_n}{A_1 + A_2 \ldots + A_n}$$

Where:
$A_1, A_2 \ldots A_n$ = Areas of different surfaces
$C_1, C_2 \ldots C_n$ = Runoff coefficients for different types of surface

Select inlet time from Table 6.5 based on C value.

6-0803.3C If an inlet time must be estimated, the following are suggestions to assist the designer:

6-0803.3C(1) Estimate the overload flow time, time for runoff to reach established surface drainage channels such as street gutters and ditches. Plate 4-6 can be used for overland flow.

6-0803.3C(2) Estimate the time of flow through the established surface drainage channels from the channel's hydraulic properties. Plate 5-6 can be used for streets and parking lots that have curb and gutter. The Mannings Equation or methods described in § 6-1000 *et seq*., can be used for swales and ditches.

6-0803.3C(3) Specific procedures of estimating inlet times for use with NRCS hydrology are provided in the NRCS TR-55 manual, "Urban Hydrology for Small Watersheds."

6-0803.3D Judgment should be used in estimating time of concentration or any portion of time of concentration. Often the initial inlet time may be based on the first few inlet areas.

6-0803.3D(1) If the uppermost area has low runoff rates with long times of concentration (such as parks and cemeteries) and major portions of the lower area have high runoff rates with short times of concentration, then the first inlet time may not necessarily be based solely on its own land use.

6-0803.3D(2) The above statements also would be true of the converse case; that is, the uppermost area producing high runoff rates with short times of concentration and the lower areas producing low runoff rates with long time of concentration.

6-0803.4 Area (A). Areas shall be determined from field run topography, current USGS quadrangle sheets, or County Topographical Maps. Watershed maps showing applicable divides, contributing areas and adopted Comprehensive Plan recommendations or existing zoning, whichever is greater, must accompany all computations.

Table 6.5 Runoff Coefficients and Inlet Times (98-07-PFM, 27-89-PFM**)**

Zoning Classification	Runoff Coefficients	% Impervious	Inlet Times (minutes)
Business, Commercial & Industrial	0.80 – 0.90	90	5
Apartments & Townhouses	0.65 – 0.75	75	5-10
Schools & Churches	0.50 – 0.60	50	
Single Family Units Lots 10,000 ft^2 Lots 12,000 ft^2 Lots 17,000 ft^2 Lots ½ acre or more	 0.40 – 0.50 0.40 – 0.45 0.35 – 0.45 0.30 – 0.40	 35 30 25 20	10 - 15[1]
Parks, Cemeteries and Unimproved Areas [2]	0.25 – 0.35	15	To be Computed
TYPE OF SURFACE			
Pavements & Roofs	0.90	100	According to zoning classification of composite runoff coefficient
Lawns	0.25-0.35	0	
Open Water[3,4]	0.9	0	
Reforested Areas[2]	0.25-0.35	0	
Vegetated Roofs[4] Extensive Systems Intensive Systems	 0.50 0.40	N/A[5]	
Pervious Pavement[4] Porous Asphalt Pavement Permeable Pavement Blocks	 (I-1.1)/I (I-3.0)/I I=peak rainfall intensity (in./hr.)	N/A[5]	

1) However, for design of yard inlets, i.e., locations and throat capacities, in residential areas, drainage computations shall use a 5-minute time of concentration, or alternatively, a site specific calculation to justify usage of a longer time of concentration. Computations for design of pipes may continue to use the 10- to 15-minute time of concentration.

2) For unimproved areas containing less than 5% impervious cover and storm frequencies 2-year or less, use C = 0.10 to 0.20.

3) The runoff coefficient for open water areas such as lakes and streams is set at 0.9 because all rainfall falling on open water is converted directly to runoff. For unimproved areas containing less than a total of 5% open water plus impervious cover, the open water areas may be ignored in computing composite runoff coefficients.

4) Composite runoff coefficients for drainage areas that include significant areas of open water, pervious pavements, or vegetated roofs should not be computed directly from the percentage of impervious area. Use the weighted average of the runoff coefficients to compute the runoff.

5) Values for percent imperviousness have not been assigned to pervious pavement and green roofs. For hydrologic purposes, they respond as pervious or partially pervious surfaces. In determining land use for application of Chesapeake Bay Preservation Ordinance development/redevelopment criteria, they are treated as impervious surfaces.

6-0804 Anderson Formula *See current PFM*

6-0805 Other Hydrologies *See current PFM*

6-0806 Incremental Unit Hydrograph – 1 Impervious Acre *See current PFM*

6-0900 CLOSED CONDUIT SYSTEM *See current PFM*

6-1000 OPEN CHANNELS *See current PFM*

6-1100 STORM SEWER APPURTENANCES *See current PFM*

6-1200 CULVERTS *See current PFM*

6-1300 RETENTION, DETENTION, AND LOW IMPACT DEVELOPMENT FACILITIES (98-07-PFM)

6-1301 General Requirements

6-1301.1 Stormwater retention and detention facilities are incorporated in the design of storm drainage systems to reduce the peak rate of discharge of the drainage system, reduce downstream erosion problems, possibly reduce the capital cost of the drainage system and help eliminate the environmental problems normally associated with the increased runoff of stormwater from new developments.

6-1301.2 Detention measures are extremely helpful for development in areas where downstream storm drainage systems are not adequate to receive the increased runoff being generated by the upstream development. These detention measures may be an adequate manner for meeting adequate off-site drainage requirements.

6-1301.3 Some methods for achieving stormwater detention are as follows:

6-1301.3A Rooftop storage

6-1301.3B Parking lot storage including both ponding and percolation trenches

6-1301.3C Retention and detention ponds

6-1301.3D Recreation area storage

6-1301.3E Road embankment storage

6-1301.3F Street and secondary drainage system storage during extreme intensity storms

6-1301.3G Porous asphalt pavement storage in parking areas

6-1301.3H (33-90-PFM) Underground detention structures

6-1301.4 A few of these methods will be further explained in § 6-0000 *et seq*. with examples and design calculations.

6-1301.5 (46-94-PFM) The 2-year, 2-hour and the 10-year, 2-hour storm shall be the minimum used for the design of retention and detention facilities. A 2-year, 24-hour and a 10-year, 24-hour, NRCS Type II storm (consistent with the hydrology specified in § 6-0801 and 6-0802) also may be used for design. Additionally, in the Four Mile Run Watershed, detention shall be provided for the 100-year design storm.

6-1301.6 (46-94-PFM) Emergency spillways in ponds shall be designed to conform with § 6-1600 *et seq.*, except that emergency spillways for ponds with watersheds less than 20 acres may be designed to discharge the 100-year, 2-hour storm. Design of retention and detention facilities require the determination of actual volumes of rainfall occurring in a specific time and the actual volume of storm runoff in the same specified time. Routing of these volumes shall be incorporated in the design calculations.

6-1301.7 Other design parameters include the maximum allowable rate of runoff, characteristics of the developed area, and limitations of the developed area such as the maximum size of storage basin that can be incorporated in the topography, etc.

6-1302 Rooftop Storage

6-1302.1 Rooftop storage shall be designed to detain the 10-year, 2-hour storm, and emergency overflow provisions must be adequate to discharge the 100-year, 30-minute storm (see § 6-1302.5 and Tables 6.18 and 6.19). *Note: See the current PFM for Tables 6.18 and 6.19.*

6-1302.2 If a proper design is submitted for the 10-year storm, sufficient storage will normally be provided for the 2-year storm, and separate calculations need not be made.

6-1302.3 Rainfall from this design storm results in an accumulated storage depth of 3 inches.

6-1302.3A Because roof design in the County is currently based on a snow load of 30 PSF or 5.8 inches of water, properly designed roofs are structurally capable of holding 3 inches of detained stormwater with a reasonable factor of safety.

6-1302.3B Roofs calculated to store depths greater than 3 inches shall be required to show structural adequacy of the roof design.

6-1302.4 No less than two roof drains shall be installed in roof areas of 10,000 square feet or less, and at least four drains in roof areas over 10,000 square feet in area. Roof areas exceeding 40,000 square feet shall have one drain for each 10,000 square feet area.

6-1302.5 Emergency overflow measures adequate to discharge the 100-year, 30-minute storm must be provided.

6-1302.5A If parapet walls exceed 3 inches in height, the designer shall provide openings (scuppers) in the parapet wall sufficient to discharge the design storm flow at a water level not exceeding 5 inches.

6-1302.5B One scupper shall be provided for every 20,000 square feet of roof area, and the invert of the scupper shall not be more than 3½ inches above the roof level. If such openings are not practical, then detention rings shall be sized accordingly.

6-1302.6 Detention rings shall be placed around all roof drains that do not have controlled flow.

6-1302.6A The number of holes or size of openings in the rings shall be computed based on the area of roof drained and runoff criteria.

6-1302.6B The minimum spacing of sets of holes is 2 inches center-to-center.

6-1302.6C The height of the ring is determined by the roof slope and shall be 3 inches maximum.

6-1302.6D The diameter of the rings shall be sized to accommodate the required openings and, if scuppers are not provided, to allow the 100-year design storm to overtop the ring (overflow design is based on weir computations with the weir length equal to the circumference of the detention ring).

6-1302.6E Conductors and leaders shall also be sized to pass the expected flow from the 100-year design storm.

6-1302.7 The maximum time of drawdown on the roof shall not exceed 17 hours.

6-1302.8 Josam Manufacturing Company and Zurn Industries, Inc. market "controlled-flow" roof drains. These products, or their equivalent, are accepted by the County.

6-1302.9 Computations required on plans:

6-1302.9A Roof area in square feet

6-1302.9B Storage provided at 3 inches depth

6-1302.9C Maximum allowable discharge rate

6-1302.9D Inflow-outflow hydrograph analysis or acceptable charts. (For Josam Manufacturing Company and Zurn Industries, Inc. standard drains, the peak discharge rates as given in their charts are acceptable for drainage calculation purposes without requiring full inflow-outflow hydrograph analysis.)

6-1302.9E Number of drains required

6-1302.9F Sizing of openings required in detention rings

6-1302.9G Sizing of ring to accept openings and to pass 100-year design storm

6-1302.10 Example:

Given:

Building with flat roof 200 feet x 50 feet,
Pre-development coefficient of runoff: c = 0.40
Pre-development time of concentration t_c = 10 minute.

Computations:

6-1302.10A Roof Area = 200 ft. x 50 ft. = 10,000 ft^2

6-1302.10B Storage provided at 3 inches of depth: Vol. = (10,000 ft^2)(3 in.)(1/12) = 2,500 ft^3

6-1302.10C Maximum allowable discharge (pre-development rate of runoff)

Q = CIA = (0.4)(5.92)(927.2/.093)(1/43,560)
Q = 0.54 cfs

6-1302.10D From Plate 37-6, One set of holes with 3 inches of water will produce runoff or discharge of 6 gpm or 0.0134 cfs. See Plate 38-6 for a diagram of a typical ponding ring.

6-1302.10E Number of drains required for 10,000 square feet roof area equals two.

6-1302.10F Sizing of openings:

Number of hole sets = allowable discharge divided by 0.0134 cfs/one set of holes
Number of holes = $\frac{\text{0.54 cfs/two drains}}{\text{0.0134 cfs/one set of holes}}$
20.1 sets of holes per drain (use 20 sets of holes)

6-1302.10G Size of ring:

Hole sets spaced 2 inches on center
Circumference = B x diameter
(20 sets) (2 inches/set) = B x diameter
D = 12.73 inches, use 15 inches (see below if separate emergency overflow is not provided).

6-1302.11 If detention rings are to act as emergency overflow measures:

Q100=CIA; t_c = 5 minutes; C = 1.0; A = 10,000 ft^2/43,560 = 0.23 ac.
Q100 = (1.0)(9.84)(0.23 ac.)=2.26 cfs

Weir formula: $Q = CLH^{3/2}$
C = 3.33
L = BD (circumference)
H = 2 in. or 0.17 ft.

Assume all hole sets are clogged and the maximum allowable water depth on the roof is 5 inches, or 2 inches above the 3-inch high ring.

$Q = CLH^{3/2}$
Q (per drain) = 2.26 cfs = $3.33\ BD(0.17)^{3/2}$

D = 3.08 ft. or 36.98 in.
Use diameter of 37 inches

Note: See the current PFM for Tables 6.18 and 6.19.

6-1303 Percolation Trenches (See Plate 41A-6)

6-1303.1 A percolation trench is designed to release stored runoff through percolation into the soil.

6-1303.2 Recharging stormwater back into the ground close to the point of rainfall is one of the more beneficial ways to treat stormwater runoff.

6-1303.2A Not only does it replenish the water table, it also eliminates the need for costly structures and improvements for conveying runoff from the developed site to an adequate outfall.

6-1303.2B The effects of recharging the water table must be analyzed before this method is used for detention.

6-1303.2C It is essential to determine if raising the water table will cause flooding or damage to nearby areas.

6-1303.3 (111-13-PFM, 56-96-PFM) Percolation trenches may be useful only in areas where the soil is pervious and where the water table is lower than the design depth of the trench. The design of the facility shall be in accordance with the soil testing, reporting and meeting procedures of § 4-0700 *et seq*. The use of percolation trenches is undesirable in soil slippage areas.

6-1303.3A (47-95-PFM) Trenches shall be located so that percolation does not saturate soil within 4 feet of public roadway subgrades.

6-1303.4 Design of percolation trenches

6-1303.4A The trench shall be designed to detain the 10-year, 2-hour storm runoff; however, the 100-year design storm should be routed through the system and adequate relief provided – usually in the form of overland relief.

6-1303.4B This method will also automatically provide the required detention for the 2-year storm without additional calculations.

6-1303.4C VDOT #57 stone is recommended for filling the trench. This stone may be assumed to have 40 percent voids.

6-1303.4D Care must be taken, especially during construction, that sediment deposits do not clog the stone, thus preventing runoff from infiltrating into the stone.

6-1303.5 A trench utilizing stone with a high voids ratio may also be used in areas of impervious soil as temporary underground storage.

6-1303.5A Overland runoff enters the trench in the same manner, but release of runoff is controlled by an orifice, weir or other device at a rate not exceeding the pre-development rate of runoff.

6-1303.5B The controlled runoff is usually released to an underground storm sewer system.

6-1303.6 Example of Percolation Trench Design:

6-1303.6A Given: Parking lot area 200 feet x 100 feet, 90 percent impervious area (some planting), rate of infiltration of water into soil as determined by a soils analysis is 0.1 inch/minute.

Determine: The size of percolation trench required for 100 percent infiltration (no runoff).

Calculations:

6-1303.6A(1) Volume of runoff into the trench for 10-year, 2-hour storm and 90 percent impervious surface:

6-1303.6A(1)(a) Total rainfall accumulation = 3 in.

6-1303.6A(1)(b) Vol.(in) = (200 ft.)(100 ft.)(0.9)(0.25 ft.) = 4,500 ft^3

6-1303.6A(2) Assume trench to be 200 ft. long and 5 ft. wide:

6-1303.6A(2)(a) Area of trench = 1,000 ft^2

6-1303.6A(2)(b) Vol.(out) = (1 in./10 minutes)(60 minutes/hour)(2 hours)(1 ft./12 in.)(1,000 ft^2) = 1,000 ft^3

6-1303.6A(3) Vol.(stge.) = Vol.(in) – Vol.(out) = 3,500 ft^3 required storage for runoff (see Table 6.20 and Plate 39-6)

6-1303.6A(3)(a) Using #57 stone at 40 percent voids: Vol. of stone = 3,500/0.40 = 8,750 ft^3

6-1303.6A(3)(b) Therefore, volume of trench = 8,750 ft^3

6-1303.6A(4) Depth of trench = Volume/Area = 8,750 ft^3/1,000 ft^2 = 8.75 ft.

6-1303.6A(5) Rate of Discharge = Q(out) = (1 in./10 minutes)(1 ft./12 in.)(1 minute/60 seconds)(1,000 ft^2) = 0.14 cfs

6-1303.6B As an alternate trench design, assume a trench area of 200 ft. x 10 ft.

6-1303.6B(1) Vol. (out) = 2,000 ft^3 in 2 hours

6-1303.6B(2) Vol. (storage) = 4,500 – 2,000 = 2,500 ft^3

6-1303.6B(3) Vol. of stone = 2,500/0.4 = 6,250 ft^3

6-1303.6B(4) Depth of trench = 6,250/2,000 = 3.13 ft.

6-1303.6B(5) Q(out) = 0.28 cfs

6-1303.7 An inflow-outflow hydrograph would provide a more accurate solution to the required storage.

6-1303.7A The rate of discharge from the trench (or infiltration into the soil) is determined by the area of the trench as well as soil characteristics.

6-1303.7B The rate of inflow to the trench (or rate of runoff from the parking lot) is determined by the hydrographs in Plates 40-6 and 41-6 and the design storm.

Table 6.20 Mass Diagram Analysis

Time	Rainfall Depth ft.	LMP Area ft^2	Vol. (in) ft^3	Rate Out cfs	Time sec.	Vol. (out)	Vol. (storage) = Vol. (in) – Vol. (out) (ft^3)
5	.050	18,000	900	0.14	300	42	858
10	.083	18,000	1,494	0.14	600	84	1,410
15	.107	18,000	1,926	0.14	900	126	1,800
20	.127	18,000	2,286	0.14	1200	168	2,118
30	.154	18,000	2,772	0.14	1800	252	2,520
40	.176	18,000	3,168	0.14	2400	336	2,832
50	.194	18,000	3,492	0.14	3000	420	3,072
60	.208	18,000	3,744	0.14	3600	504	3,240
70	.218	18,000	3,924	0.14	4200	588	3,336
80	.226	18,000	4,068	0.14	4800	672	3,396
90	.235	18,000	4,230	0.14	5400	756	3,474
100	.241	18,000	4,338	0.14	6000	840	3,498
110	.241	18,000	4,338	0.14	6600	924	3,504*
120	.250	18,000	4,500	0.14	7200	1,008	3,492

* Maximum required storage is 3,504 ft^3

6-1304 Pervious Pavement (98-07-PFM)

6-1304.1 Pervious pavement systems use a special asphaltic paving material (porous pavement) or open jointed concrete blocks (permeable pavement blocks) that allow stormwater to flow through the pavement or the open joints at a high rate. Water is temporarily retained below the pavement within an aggregate base and discharged to the storm sewer system or infiltrated into the underlying *in situ* soils. The principal components of pervious pavement systems are porous pavement or permeable pavement blocks, a bedding (choker) course, an optional filter fabric between the bedding course and the aggregate base in permeable pavement block systems, an open-graded aggregate base with a high void ratio, filter fabric to separate the aggregate base from the underlying soils and an underdrain that is connected to the storm drain system. Water quality control is provided by adsorption, filtering, sedimentation, biological action, and infiltration into the underlying soils. Pervious pavement systems reduce the peak rate and volume of stormwater runoff through detention storage and infiltration into underlying soils. Additional infiltration capacity or storage for detention can be obtained by increasing the depth of the aggregate base alone or in combination with storage chambers.

6-1304.1A Pervious pavement systems generally may be classified by the degree of infiltration into the underlying soils (i.e., exfiltration out of the aggregate base) that the systems are designed to achieve.

6-1304.1A(1) No Exfiltration. Systems that do not rely on infiltration of the captured stormwater runoff into the underlying soils are designed to provide water quality control and detention of storm water runoff from small storms. Water that has passed through the pervious pavement is discharged to the storm drain system through an unrestricted underdrain.

6-1304.1A(2) Full or Partial Exfiltration. Systems that provide for full or partial infiltration of the captured stormwater runoff into the underlying soils are designed to provide water quality control and retention of storm water. Such systems rely on infiltration to drain down the water stored in the aggregate base between storms. Pervious pavement systems designed for exfiltration, as utilized in Fairfax County, generally include underdrains that are capped or have restricted outflow. This allows the system to continue to provide water quality control and detention, albeit at reduced levels, if the infiltration capacity of the *in situ* soils is reduced over time due to consolidation of the soil bed or clogging of the soil pores.

6-1304.1B Pervious pavement systems are applicable as a substitute for conventional asphalt or concrete pavement. Pervious pavement systems require reasonably favorable conditions of land slope, subsoil drainage, and groundwater table. Pervious pavement systems are best suited to parking areas that are not subject to muddy conditions that cause sealing or clogging of the pervious material. Examples of suitable locations are parking areas for parks, churches, schools, office buildings, and shopping centers.

6-1304.1C For hydrologic computations using the Rational Method, the runoff coefficient (“C” factor) for porous pavement and permeable pavement block systems shall be computed based on the following formula:

$C = (I - k_p) / I$

Where:
I = design rainfall intensity (in./hr.)
k_p= coefficient of permeability (in./hr.)

Use a coefficient of permeability of 1.1 inches/hour for porous pavement and 3.0 inches/hour for permeable pavement block systems. For hydrologic computations using National Resource Conservation Service (NRCS) methods, use a Curve Number “CN” of 65 for porous pavement and 40 for permeable pavement block systems. For hydraulic computations, use a roughness coefficient (“n” value) of 0.01 for porous pavement and 0.03 for permeable pavement block systems.

6-1304.2 Location and Siting

6-1304.2A Pervious pavement systems may not be located in single family attached or detached residential developments for the purpose of satisfying the detention or water quality control (BMP) requirements of the Subdivision or Zoning Ordinance except as permitted under § 6-1304.2A(1) and § 6-1304.2A(2).

6-1304.2A(1) The Board of Supervisors (Board), in conjunction with the approval of a rezoning, proffered condition amendment, special exception, or special exception amendment, may approve the location of pervious pavement systems in single family attached or detached residential developments in accordance with the following criteria:

6-1304.2A(1)(a) Any decision by the Board shall take into consideration possible impacts on the environment and the burden placed on prospective owners for maintenance of the facilities;

6-1304.2A(1)(b) Pervious pavement must be part of an overall stormwater management design that does not rely exclusively on pervious pavement to meet BMP and detention requirements;

6-1304.2A(1)(c) Adequate funding for maintenance of the facilities shall be provided by the applicant where deemed appropriate by the Board;

6-1304.2A(1)(d) Pervious pavement facilities must be located on homeowners’ association (or “common”) property and may not be located on individual buildable single family attached or detached residential lots, or any part thereof;

6-1304.2A(1)(e) Pervious pavement facilities shall be privately maintained and a private maintenance agreement in a form acceptable to the Director, which may include but is not limited to requirements for third-party inspections and the filing of annual maintenance and inspection reports with the County, must be executed before the construction plan is approved;

6-1304.2A(1)(f) The use of and responsibility for maintenance of pervious pavement facilities shall be disclosed as part of the chain of title to all future homeowners (e.g., individual members of a homeowners' association) responsible for maintenance of the facilities; and

6-1304.2A(1)(g) In addition to the above requirements, reasonable and appropriate conditions may be imposed, where deemed appropriate by the Board, to provide for maintenance of the facilities and disclosure to property owners.

6-1304.2A(2) Pervious pavement systems may be located in single family attached or detached residential developments if the pervious pavement appears as a feature shown on a proffered development plan or a special exception plat approved prior to March 12, 2007.

6-1304.2B Pervious pavement systems may not be located on individual residential lots for the purpose of satisfying the BMP requirements of the Chesapeake Bay Preservation Ordinance.

6-1304.2C Pervious pavement systems that utilize infiltration may not be constructed on fill material.

6-1304.2D Pervious pavement systems may not be constructed in areas where the adjacent slopes are steeper than 20 percent.

6-1304.2E The slope of pervious pavement systems shall be from 1 to 5 percent.

6-1304.2F Setbacks. Pervious pavement systems not designed for infiltration into the underlying *in situ* soils shall be located a minimum of 10 feet horizontally from building foundations preferably down gradient. Pervious pavement systems designed for infiltration into the underlying *in situ* soils shall be located a minimum of 20 feet horizontally from building foundations preferably down gradient. Pervious pavement systems shall be located a minimum of 100 feet horizontally from water supply wells. Pervious pavement systems not designed for infiltration shall be located a minimum of 25 feet horizontally up gradient from septic fields and a minimum of 50 feet horizontally down gradient from septic fields. Pervious pavement systems designed for infiltration shall be located a minimum of 50 feet horizontally from septic fields preferably up gradient.

6-1304.2G The maximum flow length of impervious or pervious surfaces draining onto pervious pavement shall be 100 feet.

6-1304.2H The total drainage area to the pervious pavement shall not be greater than 5 acres.

6-1304.2H(1) The maximum ratio of impervious areas to the area of porous pavement for facilities designed to capture and treat a water quality volume of 0.5 inch is 3.4:1. The maximum ratio of impervious areas to the area of porous pavement for facilities designed to capture and treat a water quality volume of 1.0 inch is 1.2:1.

6-1304.2H(2) The maximum ratio of impervious areas to the area of permeable pavement blocks for facilities designed to capture and treat a water quality volume of 0.5 inch is 11:1. The maximum ratio of impervious areas to the area of permeable pavement blocks for facilities designed to capture and treat a water quality volume of 1.0 inch is 5:1.

6-1304.2I Pervious pavement systems shall not be located in the vicinity of loading docks, vehicle maintenance areas, or outdoor storage areas, where there is the potential for high concentrations of hydrocarbons, toxics, or heavy metals in stormwater runoff entering the facility.

6-1304.2J Pervious pavement systems shall not be located in travelways, areas subject to frequent truck traffic or material storage areas, such as loading docks, where there is potential for settling or high loads of grease and oils.

6-1304.2K Concentrated flow shall not be discharged directly onto pervious pavement.

6-1304.2L For pervious pavement systems utilizing open jointed concrete blocks, handicapped parking spaces and associated pathways shall utilize concrete blocks without open joints.

6-1304.3 Maintenance. Pervious pavement systems must be privately maintained and a private maintenance agreement must be executed before the construction plan is approved. The above does not preclude the use of pervious pavement by the County on County-owned property. County maintained storm and sanitary sewer lines and their easements may be routed through areas of privately maintained pervious pavement.

6-1304.4 General Design Requirements

6-1304.4A Water Quality Volume. For facilities designed to capture and treat the first 0.5 inch of runoff, the required water quality volume is 1,815 cubic feet per acre multiplied by the sum of the impervious area draining to the pervious pavement plus the area of the pervious pavement. For facilities designed to capture and treat the first 1.0 inch of runoff, the required water quality volume is 3,630 cubic feet per acre multiplied by the sum of the impervious area draining to the pervious pavement plus the area of the pervious pavement. The water quality volume must be filtered through the pavement to receive credit.

6-1304.4B Detention. For facilities designed to provide detention, the 2-year, 2-hour storm and the 10-year, 2-hour storm must be routed through the facility or the facility may be designed to infiltrate the 10-year, 2-hour storm volume. Routings shall be performed in accordance with § 6-1300 *et seq*. Inlets shall be provided or the aggregate base extended 2 feet beyond the edge of the pavement to convey stormwater in excess of the water quality volume to the aggregate base or storage chambers below the pervious pavement.

6-1304.4C For facilities designed to provide detention, the maximum water surface elevation for the 10-year 2-hour storm shall be a minimum of 0.5 feet below the pavement bedding course.

6-1304.4D The detention release rate shall be controlled by a valve or cap on the end of the pavement underdrain within the structure.

6-1304.4E Pretreatment. Pretreatment for areas that sheet flow onto the pavement is not required. Inlets shall be designed to provide pretreatment of stormwater to prevent debris and sediments from entering the aggregate base or storage chambers. Where the aggregate base is extended beyond the edge of the pavement to convey stormwater to the aggregate base, an additional layer of filter fabric shall be provided 1 foot below the surface to prevent sediments from getting into the aggregate base.

6-1304.4F Underdrains shall be provided for all pervious pavement systems. The outfall of all underdrains must be in conformance with the adequate drainage requirements of § 6-0200 *et seq*.

6-1304.4G The bottom of the facility shall be a minimum of 4 feet above the groundwater table and bedrock for facilities designed to provide infiltration and a minimum of 2 feet above the groundwater table and bedrock for all other facilities as determined by field run soil borings. The bottom of the facility shall be below the frost line to prevent frost heave of the pavement.

6-1304.4H For facilities designed to provide infiltration, the underdrain shall be restricted as necessary so that the design infiltration rate plus the underdrain outflow rate equals the design draw down rate. The restriction shall be achieved by using an end cap with a hole to act as an orifice or a valve fitted onto the end of the underdrain. Alternatively, a flow control satisfactory to the Director may be provided within the outflow structure. See § 6-1604.1A(2) for orifice calculations. The minimum diameter of any orifice shall be 0.5 inch. Facilities shall be designed to dewater completely within 24 hours. If the facility can drain in the required time without any outflow through the underdrain, the end cap may be provided without a hole.

6-1304.4I (111-13-PFM) For facilities utilizing infiltration, the design of the facility shall be in accordance with the soil testing, reporting and meeting procedures of § 4-0700 *et seq*. Soils with a CBR (minimum 96 hours soaked) less than 5 or that are highly expansive are not suitable for infiltration. Such soils would require compaction or other measures to be used as a pavement subgrade that would compromise their ability to infiltrate water. Pervious pavements on these soils shall be designed for no infiltration with unrestricted underdrains.

6-1304.4J Permeable pavement block systems require edge restraints to prevent movement of the pavement blocks from vehicle loads. Edge restraints may be standard VDOT curbs, standard VDOT combination curb and gutters, or precast or cast in place reinforced concrete borders a minimum 6 inches wide and 18 inches deep constructed with Class A3 concrete. Edge restraints shall be installed flush with the paver blocks.

6-1304.4K (107-10-PFM) Side slopes of the facility excavated below ground may be as steep as the *in situ* soils will permit. The bottom of the excavated bed shall be level or nearly level. All excavation must be performed in accordance with Virginia Occupational Safety and Health (VOSH) requirements. If the facility is located on problem soils, as defined in Section 107-2-1(j) of the County Code, a professional authorized by the State shall specify the maximum acceptable slope for the excavation.

6-1304.4L Variations of the pervious pavement designs in Plates 78-6, 79-6, and 80-6 may be approved by the Director provided the facility meets all of the requirements in § 6-1304 *et seq*.

6-1304.5 Pervious Pavement Design

6-1304.5A Because there is no above ground storage of stormwater runoff, the minimum area of the pervious pavement required to infiltrate the water quality volume into the aggregate base is governed by the permeability of the pavement. The minimum area of the pervious pavement is computed as follows:

$A_p = (WQ_v) / [(k_p/12)(t_s)]$

Where:
A_p = area of pervious pavement (ft^2)
WQ_v = water quality volume (ft^3)
k_p = coefficient of permeability (in./hr.)
t_s = time base of design storm (hrs.)

6-1304.5B For design purposes, the permeability of the pavement is 1.1 inches/hour for porous pavement and 3.0 inches/hour for permeable pavement block systems and the time base of the design storm is 2 hours. After incorporating these values, the above equation reduces to:

$A_p = 5.455 \times WQ_v$ for porous pavement
$A_p = 2.0 \times WQ_v$ for permeable pavement block systems

6-1304.6 Aggregate Base/Storage Chamber Design

6-1304.6A Storage Volume. Storage for detention or infiltration may be provided by a layer of aggregate or aggregate in combination with storage chambers beneath the pervious pavement. Water flows into the storage layer either through an inlet structure or through the pavement. Water flows out of the storage layer either by infiltration into the underlying *in situ* soils or through a restricted underdrain. The design objectives are to infiltrate as much of the water as possible, to assure that there is complete drain down of the facility between storms, to meet the structural requirements for the pavement design, and to meet the physical constraints of the site.

6-1304.6A(1) For facilities designed to infiltrate the water quality volume, the amount of storage required is based on water quality volume minus the infiltration rate into the underlying *in situ* soils and the outflow through the underdrain during the 2 hour filling period. The required storage volume is computed as follows:

$$V_s = WQ_v - [(k_s)(A_s)(t_s) / 12] - [3{,}600(Q_u)(t_s)]$$

Where:
V_s = volume of storage (ft^3)
WQ_v= water quality volume (ft^3)
k_s = soil infiltration rate (in./hr.)
A_s = area of soil bed (ft^2)
t_s = time base of design storm (hrs.)
Q_u = outflow through underdrain (cfs)

6-1304.6A(2) For facilities designed to provide detention in addition to treating the water quality volume, the water quality volume is replaced in the above equation by the total storm runoff volume for the design storm (V_{ds}). The required storage volume is computed as follows:

$$V_s = V_{ds} - [(k_s)(A_s)(t_s) / 12] - [3{,}600(Q_u)(t_s)]$$

6-1304.6B Storage Depth. Typically, the area of the soil bed will be known and the depth of the aggregate layer will be computed from the required storage and the porosity of the aggregate as follows:

For facilities designed to treat only the water quality volume:

$$d_g = V_s / [(n_g)(A_s)]$$

For facilities designed to provide detention add 0.5 feet to the above to provide the required separation (§ 6-1304.4C) between the bedding layer and the 10-year water surface elevation:

$$d_g = V_s / [(n_g)(A_s)] + 0.5$$

Where:
d_g = depth of aggregate layer (ft.)
V_s = volume of storage (ft^3)
n_g = porosity of aggregate
A_s = area of soil bed (ft^2)

The depth of the aggregate layer does not include the thickness of the bedding layer.
For volume calculations, use a porosity of 0.40 for VDOT #2, #3, and #57 stone.

6-1304.6C Check the computed depth of the aggregate layer against the required depth for installation of the underdrain system (4 inches plus the diameter of the largest underdrain pipe) and the required depth of the pavement subbase (see § 7-0500 *et seq*.). The minimum required depth will be the greatest of these three values.

6-1304.6D Check the invert elevation of the aggregate layer against the elevation of the water table and bedrock. Also check that the facility can drain to the intended outfall.

6-1304.6E Facility Drain Time. The final step in the design of the aggregate layer is to compute the time that it takes the facility to drain. The facility must drain completely within 24 hours. The drain time is computed as follows:

$$t_d = V_s / [(k_s)(A_s) / 12 + 3{,}600(Q_u)]$$

Where:
t_d = total drain time for facility (hrs.)
V_s = volume of storage (ft^3)
k_s = soil infiltration rate (in./hr.)
A_s = area of soil bed (ft^2)
Q_u = outflow through underdrain (cfs)

6-1304.6F For facilities designed with unrestricted underdrains, computation of the storage volume, storage depth, and facility drain time are not necessary. However, it is still necessary to check the depth of the aggregate layer against the required depth for the pavement sub-base and the invert elevation of the bottom of the aggregate layer against the elevation of the water table, bedrock, and the intended outfall.

6-1304.6G For facilities designed to provide infiltration, the infiltration rate into the underlying *in situ* soils typically will be less than the flow rate through the pavement and the outflow through the underdrain will be restricted or absent such that some storage will be required. In performing computations of the storage volume, storage depth, and facility drain time, initially assume that the underdrain is capped and there is no outflow through the underdrain. If the allowable depth of the storage layer based on the elevation of the groundwater table or bedrock is insufficient to provide the necessary storage volume, storage may be increased by increasing the area of the aggregate layer and soil bed or by incorporating storage chambers. Alternatively, the underdrain may be provided with an orifice to decrease the amount of storage needed. If the total drain time of the facility is in excess of 24 hours, it will be necessary to increase the area of the aggregate base and soil bed or provide an orifice and recompute the total drain time through the facility. Outflow through the orifice may not exceed the pre-development peak flow rates for the 2-year and 10-year storms.

6-1304.7 Underdrains. Underdrains shall consist of perforated pipe ≥ 4 inches in diameter placed in a layer of washed VDOT #57 stone. VDOT #2 or #3 stone may be substituted for #57 stone when #2 or #3 stone is used for the aggregate base. There shall be a minimum of 2 inches of aggregate above and below the pipe. Laterals shall be a minimum of 4-6 inches in diameter. Main collector lines and manifolds shall be a minimum of 6-8 inches in diameter. Underdrains shall be laid at a minimum slope of 0.5 percent. Underdrains shall have a maximum internal spacing of 20 feet on center and extend to within 10 feet of the perimeter of the aggregate base. Underdrains not terminating in an observation well/clean-out shall be capped. Underdrain pipe connected to structures shall be nonperforated within 1 foot of the structure. Cleanouts and observation wells shall be nonperforated within 1 foot of the surface. All stone shall be washed with less than 1 percent passing a #200 sieve.

6-1304.8 Materials Specifications

6-1304.8A Open jointed concrete blocks shall have a minimum thickness of 3 1/8 inches and conform to ASTM C 936-01 Standard Specification for Solid Concrete Interlocking Pavement Units. Joint openings shall be a minimum of 10 percent of the surface area of the pavement after installation. Joint openings shall be filled with VDOT #8, #8P, or #9 stone. VDOT #8 stone is recommended. VDOT #8P or #9 stone may be used where needed to fill narrow joints. All stone shall be washed with less than 1 percent passing a #200 sieve.

6-1304.8B Porous asphalt pavement shall be a minimum of 2.5 inches thick and conform to VDOT Road and Bridge Specifications for Asphalt Materials (Section 210) and Asphalt Cement (Section 211) except for aggregate gradation. The asphalt mix shall be 5.75 percent to 6.0 percent of dry aggregate by weight. The asphalt binder shall be modified with an elastomeric polymer to produce a binder meeting the requirements of PG 76-22 (AASHTO MP-1) and applied at a rate of 3.0 percent by total weight of the binder. Drain down of the asphalt binder shall be no greater than 0.3 percent (ASTM D 6390). The aggregate gradation shall be as specified in Table 6.21. Porous asphalt pavement shall have a minimum connected void space of 18 percent.

Table 6.21 Aggregate Gradation	
U.S. Standard Sieve Size	**Percent Passing**
1/2 in.	100
3/8 in.	92-98
#4	34-40
#8	14-20
#16	7-13
#30	0-4
#200	0-2

6-1304.8C The bedding course for open jointed pavement blocks shall consist of 1.5 - 3 inches of washed VDOT #8, #8P, or #9 stone. VDOT #8 stone is recommended. VDOT #8P or #9 stone may used to match the stone used in the joint openings. The thickness of the bedding course is to be based on the block manufacturer's recommendation. The bedding course for porous asphalt pavement shall consist of 1 to 2 inches of washed VDOT #57 stone. All stone shall be washed with less than 1 percent passing a #200 sieve.

6-1304.8D The aggregate base course shall consist of washed VDOT #57 stone. The thickness of the base course is determined by runoff storage needs, the infiltration rate of *in situ* soils, structural requirements of the pavement sub-base, depth to watertable and bedrock, and frost depth conditions. VDOT #2 or #3 stone may be substituted as the base course material provided an adequate choker course of VDOT #57 stone is provided between the aggregate base course and the bedding course. All stone shall be washed with less than 1 percent passing a #200 sieve.

6-1304.8E Underdrains shall be PVC pipe conforming to the requirements of ASTM F758, Type PS 28 or ASTM F949; HDPE pipe conforming to the requirements AASHTO M252 or M 294, Type S; or other approved rigid plastic pipe with a smooth interior. Underdrains shall be perforated with four rows of 3/8-inch holes with a hole spacing of 3.25 ± 0.25 inches or a combination of hole size and spacing that provides a minimum inlet area ≥ 1.76 square inches per linear foot of pipe or be perforated with slots 0.125 inch in width that provides a minimum inlet area ≥ 1.5 square inches per linear foot of pipe.

6-1304.8F Filter fabric. Filter fabric shall be a needled, non-woven, polypropylene geotextile meeting the requirements listed in Table 6.22. Heat-set or heat-calendared fabrics are not permitted.

Table 6.22 Filter Fabric Specifications	
Grab Tensile Strength (ASTM D4632)	≥ 120 lbs
Mullen Burst Strength (ASTM D3786)	≥ 225 lbs/in^2
UV Resistance (ASTM D4355)	70% strength after 500 hours
Flow Rate (ASTM D4491)	≥ 125 gal./min./ft^2
Apparent Opening Size (AOS) (ASTM D4751)	US #70 or #80 sieve

6-1304.9 Construction Specifications

6-1304.9A The owner shall provide for inspection during construction of the facility by a licensed professional. (In accordance with standard practice, the actual inspections may be performed by an individual under responsible charge of the licensed professional.) The licensed professional shall certify that the facility was constructed in accordance with the approved plans. The licensed professional's certification along with any material delivery tickets and certifications from the material suppliers and results of the inspections required under § 6-1304.9G(11) or § 6-1304.9H(6) and § 6-1304.9H(7) shall be submitted to the County prior to bond release. For projects requiring as-built plans, the required certification and supporting documents shall be submitted with or incorporated in the as-built plans. For projects that do not require as-built plans, the required certification and supporting documents shall be submitted with the RUP or non-RUP request.

6-1304.9B Pervious pavement facilities shall be constructed after the drainage area to the facility is completely stabilized. Erosion and sediment controls for construction of the facility shall be installed as specified in the erosion and sediment control plan. Preliminary grading of the area where pervious pavement is to be installed may be performed at the time the rest of the site is mass graded provided that positive drainage is maintained and the area is stabilized. For pervious pavement applications that will utilize infiltration, preliminary grading shall be a minimum of 2 feet above the final design elevation of the bottom of the aggregate base and the area shall be immediately stabilized with no further construction traffic until the pervious pavement is installed.

6-1304.9C Areas where pervious pavement is to be installed should not be used for temporary sediment basins. Where unavoidable, the invert of the sediment basin shall be a minimum of 2 feet above the final design elevation of the bottom of the aggregate base.

6-1304.9D For facilities designed for full or partial exfiltration, the floor of the facility shall be scarified to a minimum depth of 6 inches to reduce soil compaction and leveled before the filter fabric and stone are placed. Any areas of the facility where a temporary sediment basin was located also shall have 2-3 inches of sand incorporated into the *in situ* soils.

6-1304.9E Filter fabric shall be placed on the bottom and sides of the facility. Strips of fabric shall overlap by a minimum of 2 feet. Fabric shall be secured a minimum of 4 feet beyond the edge of the excavation. Following placement of the aggregate and again after placement of the pavement or pavers, the filter fabric should be folded over placements to protect installation from sediment inputs. Excess filter fabric should not be trimmed until the site is fully stabilized.

6-1304.9F After installation of the filter fabric over the soil subgrade, a 2-inch lift of aggregate shall be placed for the underdrain bedding. Underdrain piping shall be installed and sufficient aggregate shall be placed around and over the underdrain pipe to prevent damage to the pipe prior to compaction. Aggregate shall be placed in 4- to 8-inch lifts and compacted with a static roller. At least four passes should be made with a minimum 10-ton static roller. The initial passes of the roller can be with vibration to consolidate the base material. The final passes should be without vibration. No visible movement should occur in the base material when compaction is complete.

6-1304.9G Installation of open jointed pavement blocks

6-1304.9G(1) The bedding course shall be placed in a single lift. The bedding course shall be leveled and pressed (choked) into the aggregate base with at least four passes of a 10-ton steel drum static roller. The bedding material should be moist to facilitate movement into the aggregate base. (Note: Install optional filter fabric per engineer's specifications prior to placement of bedding course.)

6-1304.9G(2) Edge restraints for open jointed pavement blocks shall be in place prior to installation of the bedding course and pavement blocks.

6-1304.9G(3) Prior to placement of the pavers, ¾ - 1 inch of the compacted bedding material shall be loosened and smoothed to an even surface.

6-1304.9G(4) Pavers may be placed by hand or with mechanical installers. Compact and seat pavers into the bedding material with a low amplitude 5,000 lb.-ft., 75 to 95 Hz plate compactor.

6-1304.9G(5) Gaps at the edge of the paved areas shall be filled with cut pavers or edge units. When required, pavers shall be cut with a paver splitter or masonry saw. Cut pavers shall be no smaller than one-third of the full unit size.

6-1304.9G(6) Fill the openings and joints with aggregate until it is within ½ inch of the top surface. Remove excess aggregate by sweeping pavers clean. Compact the pavers again, vibrating the aggregate into the openings. Apply additional aggregate to the openings and joints, filling them completely. Remove excess aggregate by sweeping and compact the pavers. This will require at least two passes with the compactor.

6-1304.9G(7) Do not compact within 3 feet of the unrestrained edges of the pavers.

6-1304.9G(8) The system must be thoroughly swept to remove any sediment or excess aggregate immediately after construction.

6-1304.9G(9) Proof roll the surface after installation is complete.

6-1304.9G(10) The area shall be inspected for settlement. Any blocks that settle shall be reset and re-inspected.

6-1304.9G(11) The facility shall be inspected at 18-30 hours after a significant rainfall (0.5-1.0 inch) or artificial flooding to determine that the facility is draining properly.

6-1304.9H Installation of porous asphalt pavement

6-1304.9H(1) The choker course shall be placed in a single lift. The choker course shall be leveled and pressed (choked) into the aggregate base with at least four passes of a 10-ton steel drum static roller. The choker course material should be moist to facilitate movement into the aggregate base.

6-1304.9H(2) Porous asphalt pavement is installed similarly to regular asphalt pavement. The pavement shall be laid in a single lift over the choker course. The laying temperature shall be between 230 degrees F and 260 degrees F, with a minimum air temperature of 50 degrees F, to make sure that the surface does not stiffen before compaction.

6-1304.9H(3) Compaction of the surface course should be completed when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.

6-1304.9H(4) The mixing plant shall certify to the aggregate mix, the abrasion loss factor, and the asphalt content in the mix. The asphalt mix shall be tested for its resistance to stripping by water using ASTM 1664. If the estimated coating area is not above 95 percent, additional antistripping agents shall be added to the mix.

6-1304.9H(5) The mix shall be transported to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.

6-1304.9H(6) The full permeability of the pavement surface shall be tested by application of clean water at a rate of at least 5 gpm over the surface. All water must infiltrate directly without puddle formation or surface runoff.

6-1304.9H(7) The facility shall be inspected at 18-30 hours after a significant rainfall (0.5-1.0 inch) or artificial flooding to determine that the facility is draining properly.

6-1304.10 Plan Submission Requirements

6-1304.10A Plan view(s) with topography showing all hydraulic structures including underdrains.

6-1304.10B Cross section(s) of the facility with elevations showing the following as required: elevations and dimensions of inlet, outlet, underdrain, pavement course, bedding course, choker course, aggregate base, storage chambers, filter fabric, groundwater table and bedrock.

6-1304.10C Sizing computations for the facility including volume of storage and surface area of the facility required and provided.

6-1304.10D Hydrologic calculations for the facility.

6-1304.10E Infiltration calculations as appropriate.

6-1304.10F Soils analysis and testing results for facilities that utilize infiltration including the elevation of the groundwater table and bedrock.

6-1304.10G A discussion of the outfalls from the facility is to be included in the outfall narrative.

6-1304.10H Construction and materials specifications.

6-1304.11 Pervious Pavement Design Example:

6-1304.11A Given:

Parking lot area = 20,000 ft^2
Area of regular pavement (A_i) = 10,000 ft^2
Area of porous asphalt pavement (A_p) = 10,000 ft^2
Coefficient of permeability of porous asphalt pavement (k_p) = 1.1 in./hr.
Design infiltration rate of *in situ* soils (k_s) = 0.26 in./hr. (one-half of field measured rate of 0.52 in./hr.)
Porosity of gravel (n_g) = 0.40

6-1304.11B Determine the required area of the porous asphalt pavement (A_p) for a water quality volume (WQ_v) of 1.0 inch per acre (3,630 ft^3) of impervious pavement plus 1.0 inch per acre (3,630 ft^3) of porous asphalt pavement. For design purposes, assume that the water quality volume can flow through the pervious pavement without surface runoff.

6-1304.11B(1) The water quality volume is:
WQv= 3,630 ft^3 (20,000 ft^2 / 43,560 ft^2) = 1,667 ft^3

6-1304.11B(2) The required area of the porous asphalt pavement is:

$A_p = 5.455 \times WQ_v = 5.455 \times 1{,}667 = 9{,}094\ ft^2$
Area provided 10,000 $ft^2 \geq$ 9,094 ft^2 OK

Note that as long as the ratio of impervious area to porous asphalt pavement meets the requirements of § 6-1304.2G ($\leq$ 3.4:1 for a water quality volume of 0.5 inches and $\leq$ 1.2:1 for a water quality volume of 1.0 inch), the area of the porous asphalt pavement will be sufficient to treat the water quality volume. In this example the ratio of impervious area to pervious pavement is 1:1.

6-1304.11C Determine the required storage volume (V_s) and depth (d_g) of the gravel layer to provide for infiltration of the entire water quality volume (WQ_v) (1,667 ft^3). The design infiltration rate (k_s) is equal to half of the field measured rate of 0.52 in/hr. Assume that the area of the soil bed (A_s) is equal to the area of the porous asphalt pavement (A_p). Ignore any additional storage that may be provided by the underdrain pipes and assume that there is no outflow (Q_u) through the underdrain.

6-1304.11C(1) The required storage volume is:

$$V_s = WQ_v - [(k_s)(A_s)(t_s) / 12] - [3{,}600(Q_u)(t_s)]$$
$$= 1{,}667 - [0.26(10{,}000)(2) / 12] - 0$$
$$= 1{,}233.7\ ft^3$$

Use: $V_s = 1{,}234\ ft^3$

6-1304.11C(2) Compute the depth of the gravel storage area for a soil bed area of 10,000 square feet and a storage volume of 1,234 ft^3.

$$d_g = V_s / [(n_g)(A_s)]$$
$$= 1{,}234 / [(0.40)(10{,}000)]$$
$$= 0.31\ ft.$$

6-1304.11C(3) Check the computed depth of the aggregate layer against the required depth for installation of the underdrain system and the required depth of the pavement subbase. The minimum required depth will be the greatest of these three values.

Check the depth between the bottom of the gravel storage area and the groundwater table and bedrock elevations from soil borings. Also check that the facility can drain to the intended outfall.

6-1304.11C(4) Compute the total drain time for the facility for a soil bed area of 10,000 square feet and a storage volume of 1,667 cubic feet (must be less than 24 hours).

$t_d = V_s / [(k_s)(A_s) / 12 + 3{,}600(Q_u)]$
$= 1{,}667 / [(0.26)(10{,}000) / 12 + 0]$
$= 7.7$ hrs. $\leq$ 24 hrs. OK

6-1304.11D Redesign the facility to provide detention of the 10-year, 2-hour storm in addition to water quality control and to maximize infiltration. Note that an inlet or an extension of the aggregate base beyond the edge of the pavement will be required to deliver the storm volume in excess of the water quality volume (1,667 cubic feet) to the gravel storage layer. The 10-year, 2-hour storm volume is 3 inches per acre (10,890 cubic feet) of impervious pavement and 3 inches per acre (10,890 cubic feet) of porous asphalt pavement. Assume the gravel storage layer fills in 2 hours and that there is no outflow through the orifice during the filling period.

6-1304.11D(1) The 10-year 2-hour storm volume is:

$V_{10} = 10{,}890\ ft^3\ (20{,}000\ ft^2 / 43{,}560\ ft^2)$
$= 5{,}000\ ft^3$

6-1304.11D(2) Determine the required storage volume (V_s).

$V_s = V_{10} – [(k_s)(A_s)(t_s) / 12] – [3{,}600(Q_u)(t_s)]$
$= 5{,}000 – [0.26(10{,}000)(2) / 12] – 0$
$= 4{,}567\ ft^3$

6-1304.11D(3) Compute the depth of the gravel storage area for a soil bed area of 10,000 square feet and a storage volume of 4,567 cubic feet.

$d_g = V_s / [(n_g)(A_s)] + 0.5$
$= 4{,}567 / [(0.40)(10{,}000)] + 0.5$
$= 1.64$ ft.

Check the depth between the bottom of the gravel storage area and the groundwater table and bedrock elevations from soil borings. If 1.64 feet is too deep, adjust the depth by providing additional storage in pipes or chambers or by enlarging the footprint of the facility.

6-1304.11D(4) Compute the total drain time for the facility for a soil bed area of 10,000 square feet and a storage volume of 4,567 cubic feet. (Must be less than 24 hours.)

$t_d = V_s / [(k_s)(A_s) / 12 + 3{,}600(Q_u)]$
$= 4{,}567 / [(0.26)(10{,}000) / 12 + 0]$
$= 21.1$ hrs. $\leq$ 24 hrs. OK

6-1304.11E As a final example, assume that there is no infiltration into the *in situ* soils and we want to address an inadequate outfall by providing maximum detention of the 10-year storm. This will require that the entire 10-year storm volume be stored in the gravel storage layer and an orifice be designed for the underdrain system to keep the total drain time for the facility to less than 24 hours.

6-1304.11E(1) Compute the depth of the gravel storage area for a soil bed area of 10,000 square feet and a storage volume of 5,000 cubic feet.

$d_g = V_s / [(n_g)(A_s)] + 0.5$
$= 5{,}000 / [(0.40)(10{,}000)] + 0.5 = 1.75$ ft.

Check the depth between the bottom of the gravel storage area and the groundwater table and bedrock elevations from soil borings. If 1.75 feet is too deep, adjust the depth by providing additional storage in pipes or chambers or by enlarging the footprint of the facility.

6-1304.11E(2) Size an orifice to keep the total drain time for the facility to 24 hours for a maximum water level of 1.25 feet in the gravel storage layer (0.5 feet below the bedding layer) and a storage volume of 5,000 cubic feet. Assume that the invert of the orifice is the same as the invert of the underdrain and that the orifice has a diameter of 2 inches. The average energy head (H_o) above the centroid of the opening will be half of the maximum water level minus 2 inches (0.167 feet) for the pipe bedding minus 1 inch (0.083 feet), half of the diameter of the orifice.

The required discharge rate is computed from:

$Q_u = (V_{10} / t_d) / 3{,}600$
$= (5{,}000 / 24) / 3{,}600$
$= 0.0579$ cfs

The size of the required orifice is computed using the standard orifice equation (see § 6-1604.1A(2)):

$A = Q_o / C(2gH_o)^{1/2}$

Where:
Q_o = discharge (cfs)
C = orifice coefficient, typically set at 0.6 for sharp edged orifices but may vary depending on orifice geometry
A = flow area (ft^2)
g = acceleration of gravity, 32.2 ft./sec²
H_o = energy head above centroid of opening (ft.)

The average energy head is:
$H_o = (1.25 – 0.167 - 0.083) / 2 = 0.5$

The orifice area is:
$A= 0.0579 / 0.6[(64.4)(0.5)]^{1/2} = 0.017 \text{ ft}^2$

The diameter of the orifice is:
$D= 2(A / \pi)^{0.5}$
$= 2(0.017 / 3.1416)^{0.5}$
= 0.147 ft. = 1.76 in.

The computed diameter of the orifice is less than the assumed diameter. Therefore, the average energy head will be slightly higher than the value used in the computations and the facility will drain within 24 hours.

6-1304.11F Inflow-outflow hydrograph routings would provide a more accurate solution for these examples.

6-1305 Retention and Detention Ponds

6-1305.1 Small ponds created by constructing low earth dams across natural drainage courses or by excavating and regrading of a development site provide capacity for stormwater runoff detention.

6-1305.1A The ponds may be located in areas where other site development is expensive or unsuitable or may be made an integral part of the site landscaping designs.

6-1305.1B Stormwater permanently retained in these ponds may be considered a potential resource suitable for a variety of uses, including firefighting, irrigation supplies and recreational sources.

6-1305.1C In addition to providing stormwater discharge reduction capabilities, detention ponds provide storage for sediment and pollution control in runoff, especially during the construction phase of development.

6-1305.1D (46-94-PFM) If embankments are used to dam natural drainage courses, they must be designed in accordance with § 6-1600 *et seq*.

6-1305.2 (46-94-PFM) Detention ponds and their primary outlet or principal spillway shall be designed to detain the increased runoff generated by development of a site based on the 2-year and the 10-year frequency design floods. Emergency or secondary spillways for detention ponds shall be designed in accordance with § 6-1600 *et seq*., except where the watershed is less than 20 acres, in which case the Spillway Design Flood hydrograph may be obtained using the Rational Method.

6-1305.3 Outlets and emergency spillways shall be placed on either undisturbed ground or on a stabilized foundation and not in fill areas.

6-1305.4 (32-90-PFM) The planting of trees and other landscaping, except grass and other ground covers approved by the Director, on the structural embankment of any earth dam which intermittently or permanently impounds water, including stormwater management facilities, is prohibited.

6-1305.5 (32-90-PFM) All plans containing an earth dam which intermittently or permanently impounds water shall include a restrictive easement which covers the entire structural embankment and prohibits the planting of trees and all other landscaping, except grass and other ground covers approved by the Director. This easement shall be recorded in the Land Records of the County and shall run with the land.

6-1305.6 Design calculations for detention ponds shall be submitted with the site drainage plan and shall generally include the following:

6-1305.6A (46-94-PFM) Hydrographs of the 2-year, 10-year, emergency spillway and freeboard design storm inflow to the facility.

6-1305.6B Volume of storage vs. depth of storage curve.

6-1305.6C Outlet design calculations.

6-1305.6D Head discharge curve for the selected outlet size.

6-1305.6E (46-94-PFM) The routed or discharge hydrograph from the facility for the 2-year, 10-year, emergency spillway and freeboard design inflows.

6-1305.6F (46-94-PFM) Emergency spillway design calculations for ponds shall conform with the requirements of § 6-1603.

6-1305.6G (46-94-PFM) Embankment design computations shall conform to the requirements of § 6-1605.

6-1305.6H Calculations or effects (if any) on established floodplain boundaries.

6-1305.7 Other items that shall be included with or on the plans are:

6-1305.7A (46-94-PFM) When possible, the shape of the pond should conform with the natural topography.

6-1305.7B (46-94-PFM) Identification of required easements.

6-1305.7C Landscaping and fencing around detention ponds when access exposes the public to unusual risk.

6-1305.7D Properly executed maintenance agreements.

6-1305.7E (46-94-PFM) For wet detention ponds a drain valve shall be provided in accordance with § 6-1604.

6-1305.7F (35-91-PFM) The developer shall be required to provide and post signs informing the public where detention and retention ponds are to be located. Signs must be located so as to be visible from the adjoining lots and roadways from which the facilities may be viewed. The number of signs required for a site will depend upon the sight characteristics to meet the above visibility requirements. Signs shall be maintained by the developer from the time the plans for the ponds are approved by DPWES until bond release. At the time of bond release, the signs shall be removed by the developer. See Plate 41B-6 for details.

6-1305.8 (46-94-PFM) Example of Detention Pond Design (for a detention pond with a watershed less than 20 acres):

6-1305.8A Given: A hypothetical 10-acre site to be developed into a commercial shopping center. Design a detention pond in an existing natural drainage course. The natural topography limits the maximum height of the pond to 6 feet, allowing 1-foot freeboard, the maximum height of water will be 5 feet.

6-1305.8B Calculations:

Pre-development Runoff:

Runoff coefficient: C = 0.30
Time of concentration: t_c = 15 minutes
Rainfall intensity:
I = 3.5 in./hr. for 2-year frequency storm from Plate 3-6
I = 5.1 in./hr. for 10-year frequency storm from Plate 3-6
Q_{2yr} = CIA = (0.30) (3.5 in./hr.) (10 acre) = 10.5 cfs
Q_{10yr} = CIA = (0.30) (5.1 in./hr.) (10 acre) = 15.3 cfs

Therefore, the maximum allowable runoff from the detention pond from the primary outlet(s) shall be limited to 10.5 cfs on the 2-year storm and 15.3 cfs on the 10-year storm.

Runoff after Development:

Runoff coefficient: C = 0.9
Impervious area = (0.90)(10 acres) = 9 impervious acres. Time of concentration: t_c = 5 minutes

6-1305.8B(1) (46-94-PFM) From unit hydrograph (see Table 6.6) for 5-minute time of concentration, plot inflow hydrograph for a 9 impervious acre area (see Plate 42-6).

6-1305.8B(2) On the same graph, plot a straight line from the zero intercept to a point on the hydrograph at the 10.5 cfs point. The area between these 2 curves is the approximate volume of storage required. The planimetered area = 9.2 in^2. The approximate volume = (9.20)(4,050) = 37,300 cubic feet.

6-1305.8B(3) Limiting depth of storage is 5 feet. Assuming the 2-year storm storage requirement will be approximately 75 percent of the 10-year storage requirement, we have Vol. 10-year/37,300 = 100/75 or 49,600 ft^3, say 50,000 ft^3, for 5 feet of depth. Hence, design detention pond to have a surface area of 10,000 square feet.

6-1305.8B(4) Outflow pipe design – use FHWA culvert charts in the VDOT Drainage Manual. Assume HW/D = 2.0 to 3.0

From concrete pipe culvert with inlet control chart at 10.5 cfs outflow: Diameter of culvert is 15 inches to 18 inches. Assume 15 inches outlet pipe.

6-1305.8B(5) Plot the volume of storage vs. the depth of storage curve and the depth of storage vs. the discharge curve. The first curve is obtained from topography and grading data and the second curve is obtained from FHWA culvert charts for the selected pipe size (see Plate 43-6).

6-1305.8B(6) Route the 2-year inflow hydrograph through detention facility by using Plates 42-6 and 43-6. Following is a narrative of the procedure.

6-1305.9 The basic equation for determining the volume of storage required in a detention facility is that the volume of storage equals the volume of flow into the facility minus the volume of flow released from the facility (see established format in Table 6.23).

6-1305.9A For each 5 minute increment of time, the rate of flow into the facility is determined from the inflow hydrograph on Plate 42-6, is averaged with the rate of flow for the previous 5 minute increment, and this average value is multiplied by the time increment of 5 minutes or 300 seconds to obtain the incremental volume in for that particular 5 minute period (Column 3 of Table 6.23).

Table 6.23 2-Year Storm Routing

	1	2	3	4	5	6	7	8	9	10	11	12
Time	**In-flow Rate cfs**	**Avg Inflow Rate cfs**	**Vol. ft³**	**Storage Carry-over ft³**	**Total ft³**	**Trial WS El. ft.**	**Out-flow Rate cfs**	**Avg Outflow Rate cfs**	**Vol Out ft³**	**Bal in Storage ft³**	**Cor-resp WS El. ft.**	
0	0		0				0					
		24.5						1.0				
5	49		7,350		7,350	.9	2.0		300	7,050	.7	ok
		42						3.95				
10	35		12,600	7,050	19,650	1.8	5.9		1,185	18,465	1.8	ok
		29.3						7.0				
15	23.5		8,780	18,465	27,245	2.6	8.1		2,100	25,145	2.5	ok
		21.5						8.5				
20	19.5		6,440	25,145	31,585	3.0	9.0		2,550	29,030	2.9	ok
		18						9.3				
25	16.5		5,400	29,030	34,340	3.3	9.6		2,790	31,640	3.2	ok
		15.5						9.7				
30	14		4,650	31,640	36,290	3.4	9.8		2,910	33,380	3.3	ok
		12.8						9.8				
35	11.5		3,840	33,380	37,220	3.4	9.8		2,940	34,280	3.4	ok
		10.8						9.8				
40	10		3,240	34,280	37,520	3.4	9.8		2,940	34,580	3.4	ok
		9.3						9.8				
45	8.5		2,800	34,580	37,380	3.4	9.8		2,940	34,440	3.4	ok
		7.8						9.7				
50	7.0		2,340	34,440	36,780	3.3	9.6		2,910	31,350	3.2	ok

Therefore, the maximum storage required is 34,580 ft³, maximum depth of storage is 3.4 ft., and the maximum rate of discharge is 9.8 cfs.

6-1305.9B This incremental volume is summed with the balance in storage (Column 10 and Column 4) to yield the accumulated storage at the end of the particular time increment (Column 5).

6-1305.9C A trial water surface elevation is assumed and, from Plate 43-6, the rate of runoff or outflow is determined. These values are placed in Columns 6 and 7, respectively.

6-1305.9D An average outflow rate is calculated in Column 8, and multiplied by the time increment of 300 seconds to determine the volume released from the detention facility (Column 9).

6-1305.9E Volume (in) minus volume (out) equals storage (Column 10), and is compared to the trial water surface elevation assumed.

6-1305.9E(1) If the values differ by more than 0.1 feet, assume a new trial water surface elevation and repeat the process.

6-1305.9E(2) If the values are less than 0.1 foot different, the routing for that 5-minute increment is balanced and the procedure is repeated for the next 5-minute increment, and so on.

6-1305.9F When the balance of runoff in storage (Column 10) begins to decrease in value, the detention pond is beginning to draw down and the maximum required volume of detention has been reached.

6-1305.9G The maximum rate of outflow, maximum required storage and maximum height of storage can be read directly from Table 6.23.

6-1305.9G(1) This particular problem yields the following results:

Q_{2yr} (max) = 9.8 cfs
Vol. of provided storage = 34,580 ft^3
Max height of storage = 3.4 ft.

6-1305.9G(2) These quantities compare favorably with the assumed 2-year design of the pond and meet the 10.5 cfs maximum outflow requirements established above.

6-1305.10 Proceed now to the second stage of detention, which limits the 10-year storm to the predeveloped peaks.

6-1305.10A Calculations:

6-1305.10A(1) Predevelopment Runoff:

Runoff Coefficient: C = 0.30
Time of Concentration: t_c = 15 minutes
Rainfall Intensity: I = 5.10 in./hr. for 10-year frequency storm from Plate 3-6

Q = CIA = (0.30)(5.10 in./hr.)(10 acres) = 15.3 cfs
Therefore, the maximum allowable runoff from the detention pond from the primary outlet shall be limited to 15.3 cfs.

6-1305.10A(2) Runoff after Development:

Runoff Coefficient: C = 0.9
Impervious Area = (0.90)(10 acres) = 9 acres
Time of Concentration: t_c = 5 minutes

6-1305.10B From unit hydrograph for 5 minute time of concentration, plot inflow hydrograph for a 9 impervious acre area (see Plate 44-6).

6-1305.10C On the same graph, plot a straight horizontal line along the 5 cfs discharge rate which is an assumption that the average outflow rate from the lower pipe is half the peak rate found on the 2-year routing above (i.e. 9.8/2 or say 5 cfs).

6-1305.10C(1) Since 34,580 cubic feet of storage is required to fulfill the 2-year detention requirement let us find out approximately at what time this volume would be fully utilized.

6-1305.10C(2) To approximate this time strike a vertical line at say 15 minutes and 25 minutes and measure the volumes between the inflow and assumed constant rate outflow. The values are 31,800 cubic feet and 44,000 cubic feet respectively.

6-1305.10C(3) This gives a difference of 12,200 cubic feet in 10 minutes or a rate of change of approximately 1,220/minute.

6-1305.10C(4) Since at 15 minutes we have used 31,800 cubic feet and we are looking for the time when 34,580 cubic feet will be required, we take 34,580 cubic feet - 31,800 cubic feet - 2,780 cubic feet/1,220 cubic feet/minute = 2.2 minutes additional or say 17 minutes (15 minutes + 2.2 minutes).

6-1305.10C(5) Hence at 17 minutes the lower pond 2-year detention facility is full; we draw a new discharge line from 17 minutes average flow of 5 cfs to the allowable discharge rate of 15.3 cfs on the inflow hydrograph curve and measure the volume between the inflow and outflow lines.

6-1305.10C(6) This gives a first approximation value of about 46,500 cubic feet or the amount of total storage required to accommodate both the 2-year and 10-year storms.

6-1305.10D Using the elevation – storage curve, we find the depth in the pond will be approximately 4.6 feet.

6-1305.10D(1) At this depth the 15-inch diameter pipe will discharge approximately 12.2 cfs.

6-1305.10D(2) With a permissible outflow of 15.3, this leaves a balance of 15.3 – 12.2 = 3.1 cfs to be provided by another opening.

6-1305.10D(3) Assuming a weir or slot of depth 4.6 feet – 3.4 feet = 1.2 feet of head we can approximate the length from the weir formula $Q = 3LH^{3/2}$ or L = 0.8 feet, say 1-foot long slot on a vertical riser beginning at elevation 3.4 feet.

6-1305.10E An elevation – discharge curve is developed for this slot and added to the 15-inch diameter pipe curve on Plate 43-6 beginning at elevation 3.4 feet.

6-1305.10F The routing is then performed as was done on the 2-year storm and is shown on Table 6.24.

6-1305.10F(1) This results in a peak discharge out of 14.8 cfs at elevation 4.5 feet.

6-1305.10F(2) It reaches the peak at time 35 minutes and utilized 44,490 cubic feet of storage.

6-1305.10F(3) These quantities again compare favorably with the assumed 10-year design parameters, and meet the 15.3 cfs maximum outflow requirements established above.

6-1305.10G (46-94-PFM) The emergency spillway shall be designed to meet the requirements of § 6-1603 and § 6-1604, except as noted in § 6-1305.2.

6-1305.10H When the depth of storage exceeds 4.5 feet, outflow is expected to continue through the primary spillway as well as through the secondary emergency spillway.

6-1305.10H(1) (46-94-PFM) As an example, assume the outflow culvert pipe is clogged and the emergency spillway is a weir designed to pass the entire 100-year storm:

Q(100) = CIA = (0.9)(9.84 in./hr.)(10 acres) = 88.6 cfs

Q (weir) = $CLH^{1.5}$
C = 3.0; H = 0.9 ft.; Therefore, L = $(88.6 / (3.0)(0.9)^{1.5}$ = 34.6 ft.

6-1305.10H(2) The banks of the pond, the overflow weir, and the outlet channel must be adequately protected from erosion, and the capacity of the emergency overflow channel must be sufficient to pass the 100-year storm. Energy dissipaters will be required as appropriate.

Table 6.24 10-Year Storm Routing

	1	2	3	4	5	6	7	8	9	10	11	12
Time	**In-flow Rate cfs**	**Avg Inflow Rate cfs**	**Vol ft³**	**Storage Carry-over ft³**	**Total ft³**	**Trial WS El. ft.**	**Out-flow Rate cfs**	**Avg Outflow Rate cfs**	**Vol Out ft³**	**Bal in Storage ft³**	**Cor-resp WS El. ft.**	
0	0		0				0					
		33						1.4				
5	66		9,900		9,900	.9	2.3		420	9,480	.9	ok
		56						5.3				
10	47		16,300	9,480	26,280	2.5	7.8		1,590	24,690	2.5	ok
		39.3						8.8				
15	31.5		11,775	24,690	36,465	3.4	9.8		2,640	33,825	3.4	ok
		28.8						10.6				
20	26		8,625	33,825	42,450	3.8	11.4		3,180	39,270	3.9	ok
		24						12.8				
25	22		7,200	39,270	46,470	4.9	14.2		3,840	42,630	4.3	ok
		20.3						14.5				
30	18.5		5,550	42,630	48,180	4.4	14.8		4,350	43,830	4.4	ok
		17						14.8				
35	15.5		5,100	43,830	48,930	4.4	14.8		4,440	44,490	4.5	ok
		14.5						14.8				
40	13.5		4,350	44,490	48,840	4.4	14.8		4,440	44,400	4.4	ok
		12.5						14.5				
45	11.5		3,750	44,400	48,150	4.3	14.2		4,350	43,800	4.4	ok

Therefore, the maximum storage required is 44,490 ft³, maximum depth of storage is 4.5 feet, and the maximum rate of discharge is 14.8 cfs.

6-1305.10I Kentucky 31 tall fescue, the standard grass for most planting, has limitations for use in detention ponds. If the roots are saturated for more than three days, the grass will die. If the drawdown time is less than three days, it can be used. For non-shaded locations, bermuda grass makes good cover, and is very water tolerant. It may be seeded or sprigged. If sprigged on 1-foot centers in the spring or early summer prior to July 1, a good ground cover will develop in about six weeks. Reed canary grass is another satisfactory and water tolerant cover. It grows to a height of 3-4 feet. It will grow in some shade but must be seeded in the fall from the current year's crop.

6-1305.10J (46-94-PFM) Table 6.6 and Plate 40-6 show inflow hydrographs for various 10-year, 2-hour storms with times of concentration from 5 minutes to 30 minutes.

6-1306 Maintenance Design Considerations

6-1306.1 The maintenance impact of stormwater management and BMP facilities is considered to be a primary concern to the County and to the future operation of these facilities.

6-1306.2 Engineers in the preparation of plans for construction are urged to include maintenance and operation of these facilities as one of the primary design considerations.

6-1306.3 The following shall be included in design considerations:

6-1306.3A All access ways shall be designated on plans and cleared, graded, or constructed with the facility construction.

6-1306.3B Proximity of facilities to public right-of-way shall be considered in order to minimize the length of access way.

6-1306.3C Multiple accesses on major facilities should be provided.

6-1306.3D Standard drainage easement agreements are not acceptable for access; therefore, special access easement agreements are to be executed which shall preclude planting of shrubs, construction of fences and other structures within the easement.

6-1306.3E Grading of the access to and around facilities shall not create steep slopes (maximum 3:1) in order to accommodate easy access for maintenance vehicles.

6-1306.3F (46-94-PFM) All facilities, including wet ponds, underground chambers, etc., shall provide accessibility with an all-weather vehicular access way with a minimum 12-feet wide surface. Surfaces may be made of geosystems such as Geogrid, Grassrings, Geoweb, or Grasscrete or may be made of asphalt, concrete or gravel. The specific situation and physical conditions shall be considered when choosing surface materials and access ways shall be designed to support the anticipated maintenance vehicles.

6-1306.3F(1) When a private pipestem driveway is used for maintenance access to a stormwater management facility, the pavement section shall be constructed in accordance with Plates 23-7 and 24-7. A CBR test is required for the shared portion of the pipestem driveway, and for CBR test values less than 10, 1 inch of additional aggregate subbase shall be provided for each point below 10. Pavement sections based on Plate 23-7 may provide an equivalent thickness index through the use of thicker asphaltic concrete layers.

6-1306.3G As these facilities are generally in close proximity to dwellings and may be subject to vandalism, principal spillways and other devices shall be designed to minimize tampering.

6-1306.3H (72-01-PFM) Underground chambers shall provide two or more access points, at least one of which shall be a 4-foot x 4-foot access door, double leaf, aluminum, BILCO Model JD-2AL or approved equal, for each major storage chamber or run of pipe for ventilation and cleaning, and be large enough to accommodate cleaning equipment. Access doors installed in areas subject to vehicle loads shall be BILCO Model JD-2AL H 20 or approved equal. Generally, the minimum height where possible, shall be 72 inches, in order to facilitate maintenance.

6-1306.3I (46-94-PFM) The design of the dry pond bottom shall include a concrete low flow channel (trickle ditch) in accordance with § 6-1604. The minimum pond floor grade shall be 2 percent minimum into the trickle ditch.

6-1306.3J (46-94-PFM) Trash racks for ponds shall be designed and provided in accordance with § 6-1604. Where trash racks are provided, they shall be removable as a unit by unbolting, without destroying the structure. Access to the trash rack shall be provided immediately above the rack in the underground chambers.

6-1306.3K Where pipe storage is permitted all pipes shall be reinforced concrete with parged joints in facilities maintained by DPWES. Any other material shall be specifically approved by the Director.

6-1306.3L Where utilized, underground chambers shall be only appurtenant structures to the site and through drainage storm sewer systems. The stormwater management facilities shall not be incorporated as an in-line system, but be designed as a parallel or perpendicular appurtenant structure.

6-1306.3M Underground chambers shall provide a smooth contoured bottom to facilitate silt and debris removal.

6-1307 Bioretention Filters and Basins (98-07-PFM)

6-1307.1 Bioretention filters and basins (a.k.a. rain gardens) are landscaped areas in shallow depressions that are subject to temporary ponding of stormwater runoff. The principal components of bioretention facilities are plants that tolerate fluctuations in soil moisture and temporary ponding of water, a mulch layer, an engineered soil media, a gravel layer, and an underdrain that is connected to the storm drain system or day lighted. The soil media is highly permeable and well drained. Water quality control is provided by filtering storm water runoff through the soil media and mulch, biological and chemical reactions in the soil, mulch, and root zone, plant uptake, and infiltration into the underlying soil. The void spaces in the soil can be used to store runoff for detention or infiltration to provide reductions in the peak rate and volume of stormwater runoff. Additional infiltration capacity or storage for detention can be obtained by using a gravel layer alone or in combination with storage chambers below the soil media.

6-1307.1A Bioretention filters are designed to provide water quality control and detention of storm water runoff from small storms. Bioretention filters include underdrains that allow water that has passed through the soil media to be freely discharged.

6-1307.1B Bioretention basins are designed to provide water quality control and retention of storm water. Bioretention basins rely on infiltration into the underlying *in situ* soils to drain down between storms. Bioretention basins, as utilized in Fairfax County, generally include underdrains that are capped or have restricted outflow. This allows a bioretention basin to be converted to a bioretention filter if the infiltration capacity of the *in situ* soils is reduced over time due to clogging of the soil pores.

6-1307.1C Bioretention facilities are best suited for small drainage areas that have low sediment loads. Pretreatment techniques that allow runoff to flow from impervious surfaces through well-established lawns, naturally vegetated buffers, or specially constructed filter strips are used to remove coarse and fine grained sediments that may otherwise clog the surface of facilities. Level spreaders or stone energy dissipaters may be used to prevent concentrated flow from creating scour paths within the facility. Bioretention facilities should not be located where wooded areas would not otherwise need to be cleared as part of the site development.

6-1307.1D (102-08-PFM) Trees within bioretention facilities may be used to meet the requirements of Chapter 122 of the Code and § 12-0000 *et seq.* of the PFM.

6-1307.2 Location and Siting

6-1307.2A In residential areas, bioretention facilities and their appurtenant structures must be located on homeowner association (or “common”) property and may not be located on individual buildable single-family attached or detached residential lots or any part thereof for the purpose of satisfying the detention or water quality control (BMP) requirements of the Subdivision or Zoning Ordinance except as noted herein. The Director may approve the location of bioretention facilities on individual buildable single-family detached lots for subdivisions creating no more than three lots where it can be demonstrated that the requirement is not practical or desirable due to constraints imposed by the dimensions or topography of the property and where adequate provisions for maintenance are provided. Such approval by the Director shall be in writing and shall specify such conditions deemed necessary to ensure the effectiveness, reliability, and maintenance of the proposed facilities.

6-1307.2B Bioretention facilities may be located on individual single-family detached residential lots that are not part of a bonded subdivision to satisfy the BMP requirements of the Chesapeake Bay Preservation Ordinance for construction on the lot.

6-1307.2C Bioretention facilities that utilize infiltration may not be constructed on fill material.

6-1307.2D Bioretention facilities may not be constructed on slopes steeper than 15 percent.

6-1307.2E Setbacks. Bioretention filters shall be located a minimum of 10 feet horizontally from building foundations preferably down gradient. Bioretention basins shall be located a minimum of 20 feet horizontally from building foundations preferably down gradient. Bioretention facilities shall be located a minimum of 100 feet horizontally from water supply wells. Bioretention filters shall be located a minimum of 25 feet horizontally up gradient from septic fields and a minimum of 50 feet horizontally down gradient from septic fields. Bioretention basins shall be located a minimum of 50 feet horizontally from septic fields preferably up gradient. Bioretention facilities shall be set back a minimum of 2 feet from property lines.

6-1307.2F Bioretention facilities shall not be located in the vicinity of loading docks, vehicle maintenance areas, or outdoor storage areas, where there is the potential for high concentrations of hydrocarbons, toxics, or heavy metals in stormwater runoff.

6-1307.2G The maximum drainage area to a bioretention filter shall be 2 acres. The maximum impervious area draining to a bioretention filter shall be 1 acre. The maximum drainage area to a bioretention basin shall be 1 acre. The maximum impervious area draining to a bioretention basin shall be 0.5 acre.

6-1307.2H No minimum size is specified for bioretention facilities to allow for application on sites with limited space or topographic constraints. Bioretention facilities should be “footprinted” into the available landscape to minimize land disturbance.

6-1307.2I Bioretention facilities may be designed as online or offline facilities. Offline facilities are preferred and are mandatory when any part of the inflow to the facility is from flow in a County storm drainage easement.

6-1307.3 Maintenance

6-1307.3A Bioretention facilities and their appurtenant structures must be privately maintained and a private maintenance agreement must be executed before the construction plan is approved. Bioretention facilities may not be located in County storm drainage easements. The above does not preclude the use of bioretention facilities by the County on County-owned property.

6-1307.3B Maintenance access must be provided for all bioretention facilities not located on individual buildable single family detached lots in accordance with § 6-1306. For bioretention facilities located on individual buildable single family detached lots, maintenance access shall be considered as an integral part of the design and designated on the plan.

6-1307.3C Bioretention facilities shall be posted with permanent signs designating the area as a water quality management area. Signs shall state that the facility is a water quality management area, water may pond after a storm, and the area is not to be disturbed except for required maintenance. Signs shall be posted at approximately 150-foot intervals along the perimeter of the bioretention area with a minimum of one sign for each facility. (See Plate 81-6.)

6-1307.4 General Design Requirements

6-1307.4A Water Quality Volume. For facilities designed to capture and treat the first 0.5 inch of runoff, the required water quality volume is 1,815 cubic feet per acre of impervious area. For facilities designed to capture and treat the first 1.0 inch of runoff, the required water quality volume is 3,630 cubic feet per acre of impervious area. The water quality volume must be captured and filtered through the system.

6-1307.4B Detention. For facilities designed to provide detention, the 2-year, 2-hour storm and the 10-year, 2-hour storm must be routed through the facility; or the facility may be designed to infiltrate the 10-year, 2-hour storm volume; or the facility may be designed to filter the 10-year 2-hour storm volume. Except where the facility is designed to filter the 10-year, 2-hour storm volume, a drop inlet with a trash rack or screen shall be provided to convey stormwater in excess of the water quality volume to a gravel layer or storage chambers below the soil media.

6-1307.4C For on-line facilities, the inlet must be designed to pass the peak flow rate for the 10-year storm. For off-line facilities, a flow splitter shall be used to capture the design storm (typically the water quality volume) and pass larger flows around the facility.

6-1307.4D Pre-Treatment. Pre-treatment shall be provided at all points of concentrated inflow to facilities. Pre-treatment generally consists of a vegetated filter strip or channel and an energy dissipation device. However, space constraints (e.g., parking lot islands) may limit the ability to provide a vegetated filter strip or channel. Where space permits, vegetated filter strips or channels shall be provided. Energy dissipation devices are required for all facilities at points of concentrated inflow. Where inflow is in the form of sheet flow, a vegetated filter strip shall be provided where space permits. Guidelines for sizing vegetated filter strips and channels are provided in Tables 6.25 and 6.26.

Table 6.25 Pretreatment Filter Strip Sizing

Inflow Surface	**Impervious**				**Pervious**			
Maximum Inflow Approach Length	35 ft.		75 ft.		75 ft.		150 ft.	
Filter Strip % Slope (6% max)	≤ 2	≥ 2	≤ 2	≥ 2	≤ 2	≥ 2	≤ 2	≥ 2
Minimum Filter Strip Length Feet	10	15	20	25	10	12	15	18

Table 6.26 Pretreatment Vegetated Channel Sizing* (101-08-PFM)

% Impervious	**≤ 33%**		**34% - 66%**		**≥ 67%**	
Channel Slope (4% max)	≤ 2%	≥ 2%	≤ 2%	≥ 2%	≤ 2%	≥ 2%
Min. Length feet	25	40	30	45	35	50

* 1 acre drainage area. 2-foot wide channel bottom.

6-1307.4E The maximum surface storage depth from the top of the mulch layer to the elevation of the overflow weir or drop inlet shall be 1 foot.

6-1307.4F Berms used to pond water in bioretention facilities shall be a maximum of 2.0 feet in height measured from the downstream toe-of-slope to the top of the berm. The width of the top of the berm shall be a minimum of 2.0 feet. The side slopes of the berm shall be a maximum of 3:1. Berms and overflow weirs shall be sodded and pegged in accordance with the most recent edition of the "Virginia Erosion and Sediment Control." Facilities with berms that are equal to or less than 2.0 feet in height or excavated facilities will not be subject to the requirements of § 6-1600 (Design and Construction of Dams and Impoundments).

6-1307.4G (107-11-PFM) The side slopes of the facility above ground shall be a maximum of 3:1. Where space permits, gentle side slopes (e.g., 5:1) are encouraged to blend the facility into the surrounding landscape. Side slopes of the facility excavated below ground may be as steep as the *in situ* soils will permit. All excavation must be performed in accordance with Virginia Occupational Safety and Health (VOSH) requirements. If the facility is located on problem soils, as defined in Section 107-2-2 (j) of the County Code, a professional authorized by the State shall specify the maximum acceptable slope.

6-1307.4H An outlet structure must be provided to convey the peak flow for the 10-year storm. The outlet structure may be a drop inlet or weir. A minimum freeboard of 6 inches shall be provided from the maximum elevation of the 10-year storm to the top of the facility.

6-1307.4I An emergency overflow weir shall be provided for all facilities with berms. The emergency overflow weir must have the capacity to pass the peak flow from the 100-year storm without overtopping the facility. If the facility design includes a weir in the berm to convey the peak flow for the 10-year storm, it also may be designed to function as the emergency overflow weir. The minimum weir length shall be 2 feet.

6-1307.4J The outfall of all outlet structures, emergency overflow weirs, and underdrains must be in conformance with the adequate drainage requirements of § 6-0200 *et seq*.

6-1307.4K Underdrains shall be provided for all bioretention filters and basins except that facilities on individual single-family detached residential lots that are not part of a bonded subdivision may be constructed without underdrains if the underdrain cannot be daylighted on the lot or connected to a storm sewer structure. If there are no underdrains, observation wells shall be installed to monitor drainage from the facility.

6-1307.4L The depth between the bottom of the facility and groundwater table or bedrock shall be a minimum of 4 feet for bioretention basins and a minimum of 2 feet for bioretention filters as determined by field run soil borings.

6-1307.4M For facilities designed to provide infiltration, the underdrain shall be restricted as necessary so that the design infiltration rate plus the underdrain outflow rate equals the design draw down rate. The restriction shall be achieved by using an end cap with a hole to act as an orifice or a valve fitted onto the end of the underdrain. Alternatively, a flow control satisfactory to the Director may be provided within the overflow structure. See § 6-1604.1A(2) for orifice calculations. The minimum diameter of any orifice shall be 0.5 feet. Facilities shall be designed to dewater completely within 48 hours. If the facility can drain in the required time without any outflow through the underdrain, the end cap may be provided without a hole.

6-1307.4N The minimum soil media depth shall be 2.5 feet. If large trees and shrubs are to be installed, soil depths shall be increased to a minimum of 4 feet. The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed. A layer of 2-3 inches of mulch shall be placed on top of the soil media.

6-1307.4O (111-13-PFM) For facilities utilizing infiltration, the design of the facility shall be in accordance with the soil testing, reporting and meeting procedures of § 4-0700 *et seq*.

6-1307.4P Variations of the bioretention filter and basin designs in Plates 82-6, 83-6, 84-6, 85-6, and 86-6 may be approved by the Director provided the facility meets all of the requirements in § 6-1307 *et seq*.

6-1307.5 Filter Bed Design

6-1307.5A The required surface area of the filter is based on the volume of water to be treated and the available storage in the ponding area computed as follows:

$A_f = WQ_v/h_f$

Where:
A_f = area of filter (ft^2)
WQ_v = water quality volume (ft^3)
h_f = maximum ponding depth (ft.)

6-1307.5B The drain time through the filter is based on the volume of water to be treated and the hydraulic properties of the soil media in accordance with Darcy's law computed as follows:

$t_f = (WQ_v)(d_f) / [(k_f / 12)(0.5h_f+d_f)A_f]$

Where:
T_f = drain time through filter (hrs.)
WQ_v = water quality volume (ft^3)
d_f = depth of filter (ft.)
k_f = coefficient of permeability (in./hr.)
h_f = maximum ponding depth (ft.)
A_f = area of filter (ft^2)

6-1307.5C A coefficient of permeability of 1.5 inches/hour for the soil media shall be used for sizing calculations. The water quality volume must drain through the filter section in 24 hours. In determining the drain time through the filter, assume that the rainfall event has ended and the ponding depth is at the maximum elevation prior to the initiation of drawdown.

6-1307.6 Gravel Layer/Storage Chamber Design

6-1307.6A Storage Volume. Storage for detention or infiltration may be provided by a layer of gravel or gravel in combination with storage chambers beneath the soil media. Water flows into the storage layer either through an inlet structure or through the soil media layer. Water flows out of the storage layer either by infiltration into the underlying *in situ* soils or through a restricted underdrain. The design objectives are to infiltrate as much of the water as possible, to provide sufficient storage so that water can drain freely through the filter without being backed-up, to assure that there is complete drain down of the facility between storms, and to meet the physical constraints of the site.

6-1307.6A(1) For facilities designed to infiltrate the water quality volume, the amount of storage required is based on the flow rate through the filter minus the infiltration rate into the underlying *in situ* soils and the outflow through the underdrain during the filling period. The required storage volume is computed as follows:

$V_s = WQ_v – [(k_s)(A_s)(t_f) / 12] – [3,600(Q_u)(t_f)]$

Where:
V_s = volume of storage (ft^3)
WQ_v = water quality volume (ft^3)
k_s = soil infiltration rate (in./hr.)
A_s = area of soil bed (ft^2)
t_f = drain time through filter (hrs.)
Q_u = outflow through underdrain (cfs)

6-1307.6A(2) For facilities designed to provide detention in addition to filtering the water quality volume, the water quality volume is replaced in the above equation by the total storm runoff volume for the design storm (V_{ds}). The required storage volume is computed as follows:

$V_s = V_{ds} - [(k_s)(A_s)(t_f) / 12] – [3,600(Q_u)(t_f)]$

6-1307.6B Storage Depth. Typically, the area of the soil bed will be known (approximately equal to the area of filter bed for larger facilities) and the depth of the gravel layer will be computed from the required storage and the porosity of the gravel as follows:

$d_g = V_s / [(n_g)(A_s)]$

Where:
d_g = depth of gravel layer (ft.)
V_s = volume of storage (ft^3)
n_g = porosity of gravel
A_s = area of soil bed (ft^2)

6-1307.6C After determining the depth of the gravel layer, check the invert elevation against the elevation of the water table and bedrock. Also check that the facility can drain to the intended outfall.

6-1307.6D Facility Drain Time. The final step in the design of the gravel layer is to compute the time that it takes the facility to drain. The facility must drain completely within 48 hours after the water quality volume has been captured by the filter section. The drain time is computed as follows:

$t_d = V_s / [(k_s)(A_s) / 12 + 3,600(Q_u)] + t_f$

Where:
t_d = total drain time for facility (hrs.)
V_s = volume of storage (ft^3)
k_s = soil infiltration rate (in./hr.)
A_s = area of soil bed (ft^2)
Q_u = outflow through underdrain (cfs)
t_f = drain time through filter (hrs.)

6-1307.6E For facilities designed as bioretention filters with unrestricted underdrains, computation of the storage volume, storage depth, and facility drain time are not necessary. However, it is still necessary to check the invert elevation of the gravel layer against the elevation of the water table, bedrock, and the intended outfall.

6-1307.6F For facilities designed as bioretention basins, the infiltration rate into the underlying *in situ* soils typically will be less than the flow rate through the filter and the outflow through the underdrain will be restricted or absent such that some storage will be required. In performing computations of the storage volume, storage depth, and facility drain time, initially assume that the underdrain is capped and there is no outflow through the underdrain. If the allowable depth of the storage layer based on the elevation of the groundwater table or bedrock is insufficient to provide the necessary storage volume, storage may be increased by increasing the area of the filter and soil bed or by incorporating storage chambers. Alternatively, the underdrain may be provided with an orifice to decrease the amount of storage needed. If the total drain time of the facility is in excess of 48 hours, it will be necessary to provide an orifice and recompute the total drain time through the facility. Outflow through the orifice may not exceed the pre-development peak flow rates for the 2-year and 10-year storms.

6-1307.6G A porosity of 0.40 for VDOT #57 stone shall be used for volume calculations.

6-1307.7 Underdrains. Underdrains shall consist of pipe ≥ 4 inches in diameter placed in a layer of washed VDOT #57 stone. There shall be a minimum of 2 inches of gravel above and below the pipe. Laterals shall be a minimum of 4-6 inches in diameter. Main collector lines and manifolds shall be a minimum of 6-8 inches in diameter. Underdrains shall be laid at a minimum slope of 0.5 percent. Underdrains shall extend to within 10 feet of the boundary of the facility and have a maximum internal spacing of 20 feet on center. Underdrains shall be separated from the soil media by geotextile fabric or a 2- to 3-inch layer of washed VDOT #8 stone or 1/8- to 3/8-inch pea gravel. Underdrains not terminating in an observation well/clean-out shall be capped. The portion of underdrain piping beneath the planting soil bed must be perforated. All remaining underdrain piping, including cleanouts, must be nonperforated. All stone shall be washed with less than 1 percent passing a #200 sieve.

6-1307.8 Observation Wells and Cleanouts. There shall be a minimum of one observation well or cleanout per 1,000 square feet of surface area. Observation wells and cleanouts shall be a minimum of 6 inches in diameter with a screw, or flange type cap to discourage vandalism and tampering extending above the BMP water surface elevation. Cleanouts shall be provided at the end of all pipe runs. Cleanouts and observation wells shall be solid pipe except for the portion below the planting soil bed which must be perforated. Observation wells that are not connected to underdrain piping shall be anchored to a footplate at the bottom of the facility.

6-1307.9 Materials Specifications

6-1307.9A The bioretention soil media shall be composed of a mixture of 60-75 percent washed sand, 5-15 percent organic compost meeting the requirements of Table 6.27, and 10-35 percent topsoil. Topsoil shall be a sandy loam, loamy sand, silt loam or loam per USDA textural classification. The textural class of the topsoil shall be verified by a laboratory analysis. Topsoil shall be of uniform composition, containing no more than 8 percent clay, free of stones, stumps, brush, roots, or similar objects larger than 2 inches. Topsoil shall be free of Bermuda Grass, Quackgrass, Johnson Grass, Mugwort, Nutsedge, Poison Ivy, Canadian Thistle, Tearthumb, or other noxious weeds. Sand shall meet AASHTO M-6, ASTM C-33, or VDOT Section 202 Grade "A" Fine Aggregate specifications. Sand shall be clean and free of deleterious materials. The final soil mixture shall not contain any material or substance that may be harmful to plant growth, or a hindrance to plant growth or maintenance. The final soil mixture shall meet the requirements in Table 6.28. Each bioretention area shall have a minimum of one soil test performed on the final soil mixture. Test results and materials certifications shall be submitted to DPWES prior to bond release.

6-1307.9B Mulch shall be double shredded aged hardwood bark with a particle size greater than 0.5 inches. Mulch shall be well aged, uniform in color, and free of salts, harmful chemicals, and extraneous material including soil, stones, and plant material. Well aged mulch is mulch that has been stockpiled or stored for 6-12 months.

6-1307.9C Underdrains shall be PVC pipe conforming to the requirements of ASTM F758, Type PS 28 or ASTM F949; HDPE pipe conforming to the requirements AASHTO M252 or M 294, Type S; or approved equivalent pipe. Underdrains shall be perforated with four rows of 3/8-inch holes with a hole spacing of 3.25 ± 0.25 inches or a combination of hole size and spacing that provides a minimum inlet area $\geq$ 1.76 square inches per linear foot of pipe or be perforated with slots 0.125 inches in width that provides a minimum inlet area $\geq$ 1.5 square inches per linear foot of pipe.

6-1307.9D Filter fabric. Filter fabric shall be a needled, non-woven, polypropylene geotextile meeting the requirements listed in Table 6.29. Heat-set or heat-calendared fabrics are not permitted.

Table 6.27 Compost Specifications	
pH	6.0-8.0
Soluble Salts (electrical conductivity)	< 5 dS/m
Nutrient Content (dry weight basis)	Nitrogen – 1% or above Phosphorus – 1% or above Potassium – 1% or above
Organic Matter Content (dry weight basis)	50-60%
Moisture Content (wet weight basis)	40-50%
Particle Size (aggregate size)	Pass through a 1/2 inch screen or smaller
Maturity Indicator (percentage of control)	> 80% of control
Stability (CO_2 evolution)	0-4 mg CO_2C per g OM per day
Trace Elements/Heavy Metals	Meet U.S. EPA Class A standard, 40 CFR § 503.13. Tables 1 and 3
Pathogens	Meet U.S. EPA Class A standard, 40 CFR § 503.32(a)

Table 6.28 Soil Media Specifications	
pH	5.5-6.5
Total Organic Matter by Loss on Ignition (ASTM F1647, Method A)	≥ 1.5% (dry weight)
Soluble Salts	≤ 500 ppm

Table 6.29 Filter Fabric Specifications	
Grab Tensile Strength (ASTM D4632)	≥ 120 lbs.
Mullen Burst Strength (ASTM D3786)	≥ 225 lbs./in^2
UV Resistance (ASTM D4355)	70% strength after 500 hours
Flow Rate (ASTM D4491)	≥ 125 gal./min./ft^2
Apparent Opening Size (AOS) (ASTM D4751)	US #70 or #80 sieve

6-1307.10 Bioretention Planting Plans

6-1307.10A Bioretention planting plans and specifications shall be prepared by a certified landscape architect, horticulturist, or other qualified individual who has knowledge of the environmental tolerance, ecological functions, and ecological impacts of plant species. Planting plans shall be prepared in accordance with the requirements of § 12-0500.

6-1307.10B Depending on the bioretention planting plan type and application as detailed in § 6-1307.10G, a mixture of trees, shrubs, and perennial herbaceous plants with a high density of fibrous roots is required. Selected plants must be able to tolerate highly variable moisture conditions, generally dry with brief periods of inundation. Depending on site conditions, selected plants also must be able to tolerate exposure to wind and sun, as well as salt and toxins in runoff from roads, parking lots, and driveways. The use of native plant species is preferred. The acceptability of proposed plant materials will be determined by the Director. Guidance on the use and selection of plants for bioretention facilities is available from Urban Forest Management.

6-1307.10C All plants shall conform to the latest version of American Standard for Nursery Stock published by the American Nursery and Landscape Association (ANSI Z60.1) for quality and sizing. Trees and shrubs shall be nursery grown unless otherwise approved and shall be healthy and vigorous, free from defects, decay, disfiguring roots, sun-scald, injuries, abrasions, diseases, insects, pests, and all forms of infestations or objectionable disfigurements as determined by the Director.

6-1307.10D Trees shall be a minimum of 1-inch caliper. Shrubs shall be a minimum of 2-gallon container size and herbaceous plants shall be a minimum of 6-inch diameter container size. Variations in size may be approved by the Director, based on the requirements of the specific plants listed in the schedule.

6-1307.10E The planting plan shall provide for plant community diversity and should consider aesthetics from plant form, color, and texture year-round. The bioretention facility design and selection of plant material shall serve to visually link the facility into the surrounding landscape. If trees and shrubs are part of the design, woody plant species shall not be placed directly within the inflow section of the bioretention facility.

6-1307.10F All plantings must be well established prior to release of the conservation deposit. Nursery stock trees and shrubs required by the approved plan shall be viable (healthy and capable of developing a trunk and branch structure typical for their species) at the time the conservation deposit is released.

6-1307.10G Bioretention Planting Plan Types and Applications

6-1307.10G(1) Wooded planting plans. Wooded bioretention facilities are appropriate where the facility is located at wooded edges, in the rear of residential lots, or where a wooded buffer is required. Design guidelines include:

6-1307.10G(1)(a) A density of 10 trees per 1,000 square feet of basin shall be used.

6-1307.10G(1)(b) A minimum of three species of trees and three species of shrubs shall be planted, with trees located on the perimeter to maximize shading of the bioretention area;

6-1307.10G(1)(c) Of the three species of trees, at a minimum one shall be a mid or understory species; 30-50 percent of the total quantity of trees planted shall be mid or understory trees;

6-1307.10G(1)(d) Two to three shrubs shall be planted for each tree (2:1 to 3:1 ratio of shrubs to trees);

6-1307.10G(1)(e) At least three species of perennial herbaceous ground cover shall be planted;

6-1307.10G(1)(f) (106-10-PFM) Where the basin is planted at the specified density, interior and peripheral parking lot landscaping and 10-year tree canopy credit will be granted if planting conforms to the requirements of Article 13 of the Zoning Ordinance and Chapter 122 of the Code (Tree Conservation Ordinance) and PFM § 12-0000 *et seq.*

6-1307.10G(1)(g) Trees planted in wooded bioretention facilities may also fulfill the requirements of transitional screening if the planting conforms to the provisions of Article 13-300 of the Zoning Ordinance.

6-1307.10G(2) Ornamental garden planting plans. Ornamental garden bioretention facilities are appropriate on commercial sites, as a focal point within residential developments or located in the front yard of an individual residential lot. Design guidelines include:

6-1307.10G(2)(a) The facility should be considered as a mass planting bed with plants that have ornamental characteristics linking it to the surrounding landscape;

6-1307.10G(2)(b) The facility should contain a variety of plant species which will add interest to the facility with each changing season;

6-1307.10G(2)(c) A mixture of trees, shrubs and perennial herbaceous groundcover at an approximate ratio of 10 percent trees, 20 percent shrubs and 70 percent perennials shall be planted;

6-1307.10G(2)(d) When the size or location of the facility precludes the use of large shade trees, use of small ornamental trees shall be considered. Alternatively, a mixture of shrubs and perennials at an approximate ratio of 40 percent shrubs, 60 percent perennials may be used;

6-1307.10G(2)(e) Spacing of plant material is species specific and will be subject to review and approval of the Director. In general the facility shall be planted at a density that the vegetation will cover 80-90 percent of the facility after the second growing season.

6-1307.10G(3) Meadow garden planting plans. Meadow garden bioretention facilities lack woody material and are appropriate for small facilities, either on commercial or residential sites. Design guidelines include:

6-1307.10G(3)(a) Plant material shall consist of a variety of grasses and wildflowers. Other groundcovers, rushes and sedges may be part of the mixture as well;

6-1307.10G(3)(b) Species of different heights, texture, as well as flowering succession shall be selected;

6-1307.10G(3)(c) Spacing of plant material is species specific and will be subject to review and approval of the Director. In general the facility shall be planted at a density that the perennial herbaceous vegetation will cover 80-90 percent of the facility after the second growing season.

6-1307.11 Construction Specifications

6-1307.11A The owner shall provide for inspection during construction of the facility by a licensed design professional. (In accordance with standard practice, the actual inspections may be performed by an individual under responsible charge of the licensed professional.) The licensed professional shall certify that the facility was constructed in accordance with the approved plans. The licensed professional's certification along with any material delivery tickets and certifications from the material suppliers and results of the tests and inspections required under § 6-1307.9A, § 6-1307.11D, and § 6-1307.11K shall be submitted to the County prior to bond release. For projects requiring as-built plans, the required certification and supporting documents shall be submitted with or incorporated in the as-built plans. For projects that do not require as-built plans, the required certification and supporting documents shall be submitted with the RUP or non-RUP request.

6-1307.11B Bioretention facilities shall be constructed after the drainage area to the facility is completely stabilized. Erosion and sediment controls for construction of the facility shall be installed as specified in the erosion and sediment control plan.

6-1307.11C The components of the soil media shall be thoroughly mixed until a homogeneous mixture is obtained. It is preferable that the components of the soil media be mixed at a batch facility prior to delivery to the site. The soil media shall be moistened, as necessary, to prevent separation during installation.

6-1307.11D The soil media shall be tested for pH, organic matter, and soluble salts prior to installation. If the results of the tests indicate that the required specifications are not met, the soil represented by such tests shall be amended or corrected as required and retested until the soil meets the required specifications. If the pH is low, it may be raised by adding lime. If the pH is too high, it may be lowered by adding iron sulfate plus sulfur.

6-1307.11E For bioretention basins, the floor of the facility shall be scarified or tilled to reduce soil compaction and raked to level it before the filter fabric, stone, and soil media are placed.

6-1307.11F The soil media may be placed by mechanical methods with minimal compaction in order to maintain the porosity of the media. Spreading shall be by hand. The soil media shall be placed in 8- to 12-inch lifts with no machinery allowed over the soil media during or after construction. The soil media should be overfilled above the proposed surface elevation as needed to allow for natural settlement. Lifts may be lightly watered to encourage settlement. After the final lift is placed, the soil media shall be raked to level it, saturated, and allowed to settle for at least one week prior to installation of plant materials.

6-1307.11G Fill for the berm and overflow weir shall consist of clean material free of organic matter, rubbish, frozen soil, snow, ice, particles with sizes larger than 3 inches, or other deleterious material. Fill shall be placed in 8- to12-inch lifts and compacted to prevent settlement. Compaction equipment shall not be allowed within the facility on the soil bed. The top of the berm and the invert of the overflow weir shall be constructed level at the design elevation.

6-1307.11H Plant material shall be installed per § 12-0705.

6-1307.11I Planting shall take place after construction is completed and during the following periods: March 15 through June 15 and Sept. 15 through Nov. 15, unless otherwise approved by the Director.

6-1307.11J All areas surrounding the facility that are graded or denuded during construction of the facility and are to be planted with turf grass shall be sodded.

6-1307.11K The facility shall be inspected at 12-24 and 36-48 hours after a significant rainfall (0.5-1.0 inches) or artificial flooding to determine that the facility is draining properly. Results of the inspection shall be provided to DPWES prior to bond release.

6-1307.12 Plan Submission Requirements

6-1307.12A Plan view(s) with topography at a contour interval of no more than one foot and spot elevations throughout the facility showing all hydraulic structures including underdrains.

6-1307.12B Cross section(s) of the facility showing the following: elevations and dimensions of berm, inlet, outlet, underdrain, soil media, underlying gravel layer, storage chambers, filter fabric, groundwater table, and bedrock.

6-1307.12C Plant schedule and planting plan specifying species, quantity of each species, stock size, type of root stock to be installed and amount of tree cover claimed for each tree species or spacing of shrubs and perennials within facility. Planting plan shall be in conformance with § 12-0515.

6-1307.12D Sizing computations for the facility including volume of storage and surface area of facility required and provided.

6-1307.12E Hydrologic calculations for the facility.

6-1307.12F Design calculations and specifications for all hydraulic structures including inlet structures, overflow weirs, and underdrain piping.

6-1307.12G Infiltration calculations as appropriate.

6-1307.12H Soils analysis and testing results for facilities that utilize infiltration. Elevation of groundwater table and/or bedrock.

6-1307.12I A discussion of the outfalls from the facility is to be included in the outfall narrative.

6-1307.12J Construction and materials specifications.

6-1307.13 Bioretention Design Example:

6-1307.13A Given:

Drainage area to the facility = 20,000 ft^2;
Impervious area (A_i) = 15,000 ft^2;
Depth of filter (d_f) = 2.5 ft.
Maximum ponding depth (h_f) = 1.0 ft.
Coefficient of permeability of filter bed (k_f) = 1.5 in./hr.
Design infiltration rate of *in situ* soils (k_s) = 0.35 in./hr. (one-half of field measured rate of 0.7 in./hr.);
Porosity of gravel (n_g) = 0.40

6-1307.13B Determine the required area of the filter bed (A_f) for a water quality volume (WQ_v) of 1.0 inches per impervious acre (3,630 cubic feet).

6-1307.13B(1) The water quality volume is:

$$WQ_v = 3{,}630\ ft^3\ (15{,}000\ ft^2 / 43{,}560\ ft^2)$$
$$= 1{,}250\ ft^3$$

6-1307.13B(2) The area of the filter bed is:

$$A_f = WQ_v / h_f$$
$$= 1{,}250 / 1.0 = 1{,}250\ ft^2$$

6-1307.13B(3) Compute the drain time through the filter for a filter area of 1,250 square feet (Must be less than 24 hours).

t_f = $(WQ_v)(d_f) / [(k_f /12)(0.5h_f+d_f)A_f]$
= (1,250)(2.5) / [(1.5/12)(0.5(1.0)+2.5)1,250]
= 6.67 hrs. $\leq$ 24 hrs. OK

If the facility is to be designed as a bioretention filter, the sizing computations are complete and a standard underdrain will be installed with no flow restriction.

6-1307.13C Determine the required storage volume (V_s) and depth (d_g) of the of the gravel layer to provide for infiltration of the entire water quality volume (WQ_v) (1,250 ft^2). The design infiltration rate (k_s) is equal to half of the field measured rate of 0.7 in/hr. Assume that the area of the soil bed (A_s) is equal to the area of the filter (A_f). Ignore any additional storage that may be provided by the underdrain pipes and assume that there is no outflow (Q_u) through the underdrain.

6-1307.13C(1) The required storage volume is:

$V_s = WQ_v – [(k_s)(A_s)(t_f) / 12] – [3,600(Q_u)(t_f)]$
= 1250 – [0.35(1,250)(6.67) / 12] – 0
= 1,006.8 ft^3

Use: V_s = 1,007 ft^3

6-1307.13C(2) Compute the depth of the gravel storage area for a soil bed area of 1,250 square feet and a storage volume of 1,007 cubic feet.

$d_g = V_s / [(n_g)(A_s)]$
= 1007 / [(0.40)(1,250)]
= 2.01 ft.

Use d_g = 2.0 ft.

Check the depth between the bottom of the gravel storage area and the groundwater table and bedrock elevations from soil borings.

6-1307.13C(3) Compute the total drain time for the facility for a filter area and soil bed area of 1,250 square feet, a storage volume of 1,007 cubic feet, and a drain time through the filter of 6.67 hours (Must be less than 48 hours.).

$t_d = V_s / [(k_s)(A_s) / 12 + 3,600(Q_u)] + t_f$
= 1007 / [(0.35)(1,250) / 12 + 0] + 6.67
= 34.3 hrs. $\leq$ 48 hrs. OK

If the soil infiltration rate is less than the coefficient of permeability of the filter and there is no outflow through the underdrain, the total drain time for the facility can also be computed from:

$t_d = WQ_v / [(k_s)(A_s) / 12]$
$= 1250 / [(0.35)(1,250) / 12]$
$= 34.3$ hrs.

6-1307.13D Redesign the facility to provide detention of the 10-year, 2-hour storm in addition to water quality control and to maximize infiltration. Note that a drop inlet will be required to deliver the storm volume in excess of the 1,250 cubic feet captured by the filter section to the gravel storage layer. The 10-year, 2-hour storm volume is 3 inches (10,890 cubic feet) per impervious acre. Assume the gravel storage layer fills in 2 hours and that there is no outflow through the orifice during the filling period.

6-1307.13D(1) The 10-year, 2-hour storm volume is:

$V_{10} = 10,890\ ft^3\ (15,000\ ft^2 / 43,560\ ft^2)$
$= 3,750\ ft^3$

6-1307.13D(2) Determine the required storage volume (V_s).

$V_s = V_{10} – [(k_s)(A_s)(t_f) / 12] – [3,600(Q_u)(t_f)]$
$= 3750 \ – [0.35(1,250)(6.67) / 12] – 0$
$= 3,506.8\ ft^2$

6-1307.13D(3) Compute the depth of the gravel storage area for a soil bed area of 1,250 square feet and a storage volume of 2,963 cubic feet.

$d_g = V_s /[(n_g)(A_s)]$
$= 3,507 / [(0.40)(1,250)]$
$= 7.01$ ft.

Check the depth between the bottom of the gravel storage area and the groundwater table and bedrock elevations from soil borings. If 7.01 feet is too deep, adjust the depth by providing additional storage in pipes or chambers or by enlarging the footprint of the facility.

6-1307.13D(4) Size an orifice for the underdrain system to keep the total drain time for the facility to less than 48 hours.

The required discharge rate is computed from:

$Q_u = [(V_{10} / t_d) – (k_s \times A_s) / 12] / 3{,}600$
$= [(3750 / 48) – (0.35 \times 1250) / 12)] / 3{,}600$
$= 0.0116$ cfs

The size of the required orifice is computed using the standard orifice equation (see § 6-1604.1A(2)):

$Q_o = CA(2gH_o)^{1/2}$

Where:
Q_o = discharge (cfs)
C = orifice coefficient, typically set at 0.6 for sharp edged orifices but may vary depending on orifice geometry
A = flow area (ft^2)
g = acceleration of gravity (32.2 ft./sec^2)
H_o = energy head above centroid of opening (ft.)

There are two unknowns in this equation, the orifice area and the energy head. One approach is to assume an orifice size. Based on the assumed orifice size, the average energy head required for the design flow rate can be computed and compared to the depth of the gravel storage area. If the energy head is less than half the depth of the gravel storage area we can safely assume that the facility will drain in 48 hours.

Try the minimum size orifice (0.5-inch diameter; 0.001364 square feet).

$H_o = [(Q_o/CA)^2] / 2g$
$= [(0.0116 / 0.6*0.001364)^2] / 64.4$
$= 3.12$ ft. $\geq$ 0.5 x 7.01 ft. <u>not</u> OK;

Try a 5/8-inch diameter orifice (0.002131 ft^2).

$H_o = [(Q_o / CA)^2] / 2g$
$= [(0.0116 / 0.6*0.002131)^2] / 64.4$
$= 1.28$ ft. $\leq$ 0.5 x 7.01 ft. OK

6-1307.13E Inflow- outflow hydrograph routings would provide a more accurate solution for these examples.

6-1308 Vegetated Swales (98-07-PFM)

6-1308.1 Vegetated swales are open, shallow channels with vegetation covering the side slopes and bottom that collect and slowly convey stormwater runoff to downstream discharge points. The principal components of vegetated swales are a dense covering of plants, with a deep root system to resist scouring, that tolerate fluctuations in soil moisture and temporary ponding of water, check dams to pond water along the length of the swale, an engineered soil media, and an underdrain in a gravel layer that is connected to the storm drain system or daylighted. The soil media is highly permeable and well drained. Water quality control is provided by sedimentation, filtering of stormwater runoff through the vegetation and soil media, biological and chemical reactions in the soil and root zone, plant uptake, and infiltration into the underlying soils. Reductions in the peak rate of runoff are achieved due to increases in the time of concentration compared to conventional conveyance systems and the temporary storage provided by the check dams and the void spaces in the soil and underdrain gravel. Infiltration into the underlying soils may provide some volume reduction. Vegetated swales are best suited for small drainage areas that have low sediment loads.

6-1308.2 Location and Siting

6-1308.2A In residential areas, vegetated swales and their appurtenant structures must be located on homeowner association (or "common") property and may not be located on individual buildable single-family attached or detached residential lots or any part thereof for the purpose of satisfying the detention or water quality control (BMP) requirements of the Subdivision or Zoning Ordinance except as noted herein. The Director may approve the location of vegetated swales on individual buildable single-family detached lots for subdivisions creating no more than three lots where it can be demonstrated that the requirement is not practical or desirable due to constraints imposed by the dimensions or topography of the property and where adequate provisions for maintenance are provided. Such approval by the Director shall be in writing and shall specify such conditions deemed necessary to ensure the effectiveness, reliability, and maintenance of the proposed facilities.

6-1308.2B Vegetated swales may be located on individual single-family detached residential lots that are not part of a bonded subdivision to satisfy the BMP requirements of the Chesapeake Bay Preservation Ordinance for construction on the lot.

6-1308.2C Vegetated swales may not be located in the VDOT right-of-way without specific approval from VDOT.

6-1308.2D Setbacks. Vegetated swales shall be located a minimum of 10 feet horizontally from building foundations preferably downgradient. Vegetated swales shall be located a minimum of 100 feet horizontally from water supply wells. Vegetated swales shall be located a minimum of 25 feet horizontally up gradient from septic fields and 50 feet horizontally down gradient from septic fields. Vegetated swales shall be set back a minimum of 2 feet from property lines.

6-1308.2E Vegetated swales shall not be located in the vicinity of loading docks, vehicle maintenance areas, or outdoor storage areas, where there is the potential for high concentrations of hydrocarbons, toxics, or heavy metals in stormwater runoff.

6-1308.2F In order to maintain healthy growth, swales vegetated solely with grass shall be located so that they receive a minimum of six hours of sunlight daily during the summer months throughout the entire length of the swale.

6-1308.2G The maximum drainage area to a vegetated swale shall be 2 acres. The maximum impervious area draining to a vegetated swale shall be 1 acre.

6-1308.2H Vegetated swales typically are designed as online conveyance systems but may be used offline as pre-treatment for other types of BMPs.

6-1308.3 Maintenance

6-1308.3A Vegetated swales and their appurtenant structures must be privately maintained and a private maintenance agreement must be executed before the construction plan is approved. Vegetated swales may not be located in County storm drainage easements. The above does not preclude the use of vegetated swales by the County on County-owned property.

6-1308.3B Maintenance access must be provided for all vegetated swales not located on individual buildable single family detached lots in accordance with § 6-1306 except that the access way may have a grass surface rather than an all-weather surface. For vegetated swales located on individual buildable single family detached lots, maintenance access shall be considered as an integral part of the design and designated on the plan.

6-1308.3C Vegetated swales shall be posted with permanent signs designating the area as a water quality management area. Signs for vegetated swales with check dams (swales designed to capture and treat the water quality volume) shall state that the facility is a water quality management area, water may pond after a storm, and the area is not to be disturbed except for required maintenance. Signs for vegetated swales (grass) without check dams shall state that the facility is a water quality management area and that the grass is to be maintained at a 4- to 8-inch height. Signs shall be posted at approximately 150-foot intervals along the length of the vegetated swale on alternating sides with a minimum of one sign for each swale. See Plate 81-6.

6-1308.4 General Design Requirements

6-1308.4A Vegetated swales may be designed to capture and treat the water quality volume using check dams or as simple conveyance systems without check dams. Swales designed as simple conveyance systems are not as effective in reducing pollutants as swales designed to capture and treat the water quality volume. Swales designed as simple conveyance systems are more commonly vegetated with grass. Swales designed to capture and treat the water quality volume are more commonly vegetated similarly to bioretention facilities.

6-1308.4B Pre-treatment. Bioretention soil media is not cohesive and must be protected from erosive forces. Energy dissipation devices with level spreaders shall be provided at all points of concentrated inflow to vegetated swales.

6-1308.4C The hydraulic capacity of vegetated swales shall be calculated using the procedures found in §6-1000 of the PFM. For grass swales, an "n" value of 0.2 shall be used for flow depths up to 4 inches decreasing to 0.03 at a depth of 12 inches. For swales vegetated with a combination of native grasses, other types of ground covers, and shrubs an "n" value of 0.15 shall be used.

6-1308.4D Vegetated swales shall be designed to convey the 10-year peak discharge within the channel and with a minimum freeboard of 6 inches at all check dams. The maximum velocity for the 2-year peak discharge shall be 3 feet per second.

6-1308.4E Swales shall be trapezoidal in shape to provide an even distribution of flow along the channel bottom. The bottom width of swales shall be 2-10 feet. Side slopes shall be no steeper than 3:1. Swales may vary in width along their length to conform to site topography and design goals.

6-1308.4F The longitudinal slope of vegetated swales shall be 1-5 percent.

6-1308.4G Underdrains shall be provided for all vegetated swales.

6-1308.4H The depth between the bottom of the gravel underdrain and the groundwater table or bedrock shall be a minimum of 2 feet as determined by field run soil borings.

6-1308.4I The minimum soil media depth shall be 2.0 feet for vegetated swales designed to capture and treat the water quality volume (swales with check dams). If trees and large shrubs are to be installed, soil depths shall be increased to a minimum of 4 feet. The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed. A layer of 2-3 inches of mulch shall be placed on top of the soil media in areas not planted with vegetation. Biodegradable erosion control netting conforming to Standard and Specification 3.36 of the "Virginia Erosion and Sediment Control Handbook," 3rd edition, 1992, shall be used to retain the mulch and surface soils until the surface of the swale is established.

6-1308.4J The minimum soil media depth shall be 1.0 foot for vegetated swales (grass) designed to filter the water quality design flow (swales without check dams).

6-1308.4K The outfall of all vegetated swales and underdrains must be in conformance with the adequate drainage requirements of § 6-0200 *et seq*.

6-1308.4L Variations of the vegetated swale designs in Plates 87-6, 88-6, and 89-6 may be approved by the Director provided the facility meets all of the requirements in § 6-1308 *et seq*.

6-1308.5 Water Quality Volume Based Design

6-1308.5A For facilities designed to capture and treat the first 0.5 inches of runoff, the required water quality volume is 1,815 cubic feet per acre of impervious area. For facilities designed to capture and treat the first 1.0 inch of runoff, the required water quality volume is 3,630 cubic feet per acre of impervious area. The water quality volume must be ponded behind the check dams so that it can be filtered through the soil media.

6-1308.5B Check dams shall be provided along the length of the swale to provide storage of the water quality volume. The maximum height of check dams shall be 1.5 feet. Check dams shall be located and sized such that the ponded water does not reach the toe of the next upstream check dam or create a tailwater condition on incoming pipes. The length of the channel segment over which water is ponded is a function of the slope of the swale and the height of the check dam computed as follows:

$L = h / s$

Where:
L = length of channel segment (ft.)
H = height of check dam (ft.)
S = channel slope (ft./ft.)

Channel segment lengths for various combinations of check dam height and channel slope that may be used for preliminary design are listed in Table 6.30. In determining the minimum spacing between check dams, add 5 feet to the computed channel segment length to assure that the ponded water does not reach the toe of the next upstream check dam.

Table 6.30 Channel Segment Length
ft.

		Check Dam Height ft.		
		0.5	**1.0**	**1.5**
Channel Slope %	**1**	50	100	150
	2	25	50	75
	3	16.7	33.3	50
	4	12.5	25	37.5
	5	10	20	30

6-1308.5C The volume stored behind a check dam is the average channel cross-section area at the ponding elevation multiplied by the length of the channel reach subject to ponding. Because the channel cross-section area is zero at the head of the reach, the average cross-section area is one half of the channel cross-section area at the low point of the check dam. The storage volume provided behind an individual check dam is computed as follows:

$V_s = L \times 0.5A_s$

Where:
V_s = volume of storage (ft^3)
L = length of channel segment (ft.)
A_s = cross-section area (ft^2) at the check dam

The channel cross-section area for a trapezoidal channel is computed as follows:

$A = by + Zy^2$

Where:
b = bottom width
y = flow depth
Z = side slope length per unit height (e.g., Z = 3 if side slopes are 3H:1V)

The channel cross-section area of a trapezoidal channel with 3:1 side slopes for various combinations of check dam height and bottom width that may be used for preliminary design are listed in Table 6.31.

Table 6.31 Channel Cross-section Area
ft^2

		Check Dam Height ft.		
		0.5	**1.0**	**1.5**
Bottom Width ft.	**2**	1.75	5.0	9.75
	3	2.25	6.0	11.25
	4	2.75	7	12.75
	5	3.25	8	14.25
	6	3.75	9	15.75
	7	4.25	10	17.25
	8	4.75	11	18.75
	9	5.25	12	20.25
	10	5.75	13	21.75

6-1308.6 Water Quality Design Flow Method

6-1308.6A For grass swales that function primarily as conveyance systems, swale design for water quality treatment is based on the peak flow from a 2-inch, 24-hour storm. The peak water quality flow should be increased along the swale length to reflect inflows. If a single design flow is used, the flow at the outlet shall be used.

6-1308.6B The peak water quality flow shall be conveyed at a maximum depth equal to or less than 3 inches.

6-1308.6C The maximum velocity for the peak water quality flow shall be 1.0 ft./sec. Flow velocity is computed using the continuity equation:

$V_{wq} = Q_{wq} / A_{wq}$

Where:
V_{wq} = design flow velocity (ft./sec.)
Q_{wq} = design flow (cfs)
A_{wq} = cross-sectional area (ft^2) of flow at design depth

6-1308.6D The minimum hydraulic residence time (i.e., the time for water to travel the full length of the swale) shall be 18 minutes. The minimum hydraulic residence time may be reduced to 9 minutes if the majority of flow enters at the head of the swale. The swale length required to achieve a minimum hydraulic residence time of 18 minutes (1,080 seconds) is:

$L = 1080V_{wq}$

Where:
L = minimum swale length (ft.)
V_{wq} = design flow velocity (ft./sec.)

6-1308.6E The minimum swale length for swales designed using the water quality design flow method shall be 100 feet. The minimum length may be achieved with multiple swale segments connected by culverts with energy dissipaters.

1308.7 Underdrains. Underdrains shall consist of pipe ≥ 6 inches in diameter placed in a layer of washed VDOT #57 stone. There shall be a minimum of 2 inches of gravel above and below the pipe. The underdrain shall begin within 10 feet of the upstream boundary of the swale. Underdrains shall be separated from the soil media by geotextile fabric or a 2- to 3-inch layer of washed VDOT #8 stone or 1/8- to 3/8-inch pea gravel. Underdrain pipe shall be perforated. All stone shall be washed with less than 1 percent passing a #200 sieve.

6-1308.8 Cleanouts. Cleanouts shall be placed every 100 feet along the length of the swale beginning at the upper end of the swale with a minimum of one cleanout per swale. Cleanouts shall be a minimum of 6 inches in diameter with a screw, or flange type cap to discourage vandalism and tampering. Cleanouts shall be nonperforated pipe except for the portion below the planting soil bed which must be perforated. For swales with check dams, the cap shall be above the BMP water surface elevation. For swales without check dams, the cap shall be above the ground surface.

6-1308.9 Materials Specifications

6-1308.9A The bioretention soil media shall meet the requirements of § 6-1307.9A. Each vegetated swale shall have a minimum of one soil test performed on the final soil mixture. Test results and materials certifications shall be submitted to DPWES prior to bond release.

6-1308.9B Mulch shall meet the requirements of § 6-1307.9B.

6-1308.9C Underdrains shall meet the requirements of § 6-1307.9C.

6-1308.9D Filter fabric. Filter fabric shall meet the requirements of § 6-1307.9D.

6-1308.9E Check dams. Check dams may be constructed of non-erosive material such as wood, gabions, rip-rap, or concrete. Earthen berms or bio-logs also may be used to create check dams. Whatever material is used, check dams shall be designed to prevent erosion where the check dams intersect the channel side walls. Check dams shall be anchored into the swale wall a minimum of 2 feet on each side with the toe protected by a suitable non-erodible material (e.g., stone). A notch or depression shall be placed in the top of the check dam to allow the 2-year flow to pass without coming into contact with the check dam abutments.

6-1308.10 Vegetated Swale Planting Plans

6-1308.10A Planting plans are required for all vegetated swales planted with a mixture of shrubs, perennial herbaceous plants, and trees (optional). Planting plans are not required for vegetated swales only planted with grass.

6-1308.10B (102-08-PFM) Vegetated swale planting plans and specifications shall be prepared by a certified landscape architect, horticulturist, or other qualified individual who has knowledge of the environmental tolerance, ecological functions, and ecological impacts of plant species. Planting plans shall be prepared in accordance with the requirements of § 12-0515.

6-1308.10C A mixture of shrubs and perennial herbaceous plants with a high density of fibrous roots is required. The use of trees is optional. Selected plants must be able to tolerate highly variable moisture conditions, generally dry with brief periods of inundation, retard and withstand stormwater flows, and filter pollutants. Depending on site conditions, selected plants also must be able to tolerate exposure to wind and sun, as well as salt and toxins in runoff from roads, parking lots, and driveways. The use of native plant species is preferred. The acceptability of proposed plant materials will be determined by the Director. Guidance on the use and selection of plants for vegetated swales is available from Urban Forest Management.

6-1308.10D Plant materials shall meet the requirements of § 6-1307.10C and § 6-1307.10D.

6-1308.10E The planting plan shall provide for plant community diversity and should consider aesthetics from plant form, color, and texture year-round. The vegetated swale design and selection of plant material shall serve to visually link the facility into the surrounding landscape. If trees and shrubs are part of the design, woody plant species shall not be placed directly within the inflow section of the swale.

6-1308.10F All plantings must be well established prior to release of the conservation deposit. Nursery stock trees and shrubs required by the approved plan shall be viable (healthy and capable of developing a trunk and branch structure typical for their species) at the time the conservation deposit is released.

6-1308.10G Design Guidelines for Vegetated Swale Planting Plans

6-1308.10G(1) The facility should be considered as a mass planting bed with plants that have ornamental characteristics linking it to the surrounding landscape;

6-1308.10G(2) The facility should contain a variety of plant species which will add interest to the facility with each changing season;

6-1308.10G(3) A mixture of shrubs and perennial herbaceous groundcover at an approximate ratio of 25 percent shrubs and 75 percent perennials shall be planted;

6-1308.10G(4) If trees are part of the design, only small ornamental trees may be used (Category I & II per Table 12.17). Trees may be substituted for shrubs up to an approximate ratio of 10 percent trees, 20 percent shrubs, and 70 percent perennials;

6-1308.10G(5) The plants shall be placed along the bottom of the swale. The side slopes of the swale shall be fully stabilized with vegetation. Spacing of plant material is species specific and will be subject to review and approval of the Director. In general the facility shall be planted at a density that the vegetation will cover 80-90 percent of the facility after the second growing season.

6-1308.11 Grassed Swale Vegetation. A dense cover of water-tolerant, erosion-resistant grass must be established. The selection of an appropriate species or mixture of species is based on several factors including climate, soils, topography, and sun tolerance. Grasses used in swales shall have the following characteristics: a deep root system to resist scouring; a high stem density, with well-branched top growth; water-tolerance; resistance to being flattened by runoff; and an ability to recover growth following inundation. Swales shall be sodded and pegged to provide immediate stabilization of the swale.

6-1308.12 Construction Specifications

6-1308.12A The owner shall provide for inspection during construction of the facility by a licensed professional. (In accordance with standard practice, the actual inspections may be performed by an individual under responsible charge of the licensed professional.) The licensed professional shall certify that the facility was constructed in accordance with the approved plans. The licensed professional's certification along with any material delivery tickets and certifications from the material suppliers and results of the tests and inspections required under § 6-1308.9A, § 6-1308.12D, and § 6-1308.12J shall be submitted to the County prior to bond release. For projects requiring as-built plans, the required certification and supporting documents shall be submitted with or incorporated in the as-built plans. For projects that do not require as-built plans, the required certification and supporting documents shall be submitted with the RUP or non-RUP request.

6-1308.12B Vegetated swales shall be constructed after the drainage area to the facility is completely stabilized. Erosion and sediment controls for construction of the facility shall be installed as specified in the erosion and sediment control plan.

6-1308.12C The components of the soil media shall be thoroughly mixed until a homogeneous mixture is obtained. It is preferable that the components of the soil media be mixed at a batch facility prior to deliver to the site. The soil media shall be moistened, as necessary, to prevent separation during installation.

6-1308.12D The soil media shall be tested for pH, organic matter, and soluble salts prior to installation. If the results of the tests indicate that the required specifications are not met, the soil represented by such tests shall be amended or corrected as required and retested until the soil meets the required specifications. If the pH is low, it may be raised by adding lime. If the pH is too high, it may be lowered by adding iron sulfate plus sulfur.

6-1308.12E The soil media may be placed by mechanical methods with minimal compaction in order to maintain the porosity of the media. Spreading shall be by hand. The soil media shall be placed in 8- to 12-inch lifts with no machinery allowed over the soil media during or after construction. The soil media should be overfilled above the proposed surface elevation as needed to allow for natural settlement. Lifts may be lightly watered to encourage settlement. After the final lift is placed, the soil media shall be raked to level it, saturated, and allowed to settle for at least one week prior to installation of plant materials.

6-1308.12F Fill for earthen check dams shall consist of clean material free of organic matter, rubbish, frozen soil, snow, ice, particles with sizes larger than 3 inches, or other deleterious material. Fill shall be placed in 8- to 12-inch lifts and compacted to prevent settlement. Compaction equipment shall not be allowed within the facility on the soil bed. The top of the check dam shall be constructed level at the design elevation.

6-1308.12G Plant material shall be installed per § 12-0705.

6-1308.12H Planting shall take place after construction is completed and during the following periods: March 15 through June 15 and Sept. 15 through Nov. 15, unless otherwise approved by the Director.

6-1308.12I All areas surrounding the facility that are graded or denuded during construction of the facility and are to be planted with turf grass shall be sodded.

6-1308.12J Vegetated swales designed to capture and treat the water quality volume shall be inspected at 12-24 and 36-48 hours after a significant rainfall (0.5-1.0 inch) or artificial flooding to determine that the facility is draining properly. Results of the inspection shall be provided to DPWES prior to bond release.

6-1308.13 Plan Submission Requirements

6-1308.13A Plan view(s) with topography at a contour interval of no more than one foot and spot elevations throughout the facility showing all hydraulic structures including underdrains.

6-1308.13B Typical cross section(s) of the swale showing the following: dimensions of swale, underdrain, soil media, underlying gravel layer, filter fabric, groundwater table, and bedrock. Cross section(s) of the check dams.

6-1308.13C Profile showing the following: invert of the swale, gravel underdrain and pipe, groundwater table, bedrock, and check dams.

6-1308.13D Detail(s) of check dams.

6-1308.13E Plant schedule and planting plan specifying species, quantity of each species, stock size, type of root stock to be installed and amount of tree cover claimed for each tree species or spacing of shrubs and perennials within facility. Planting plan shall be in conformance with § 12-0515.

6-1308.13F Sizing computations for the facility including volume of storage, channel cross-section, and spacing of check dams required and provided.

6-1308.13G Hydrologic and hydraulic calculations for the swale.

6-1308.13H Field run soil borings used to determine the elevation of the groundwater table and/or bedrock.

6-1308.13I A discussion of the outfalls from the facility is to be included in the outfall narrative.

6-1308.13J Construction and materials specifications.

6-1308.14 Vegetated Swale Water Quality Volume Design Example:

6-1308.14A Given:

Drainage area to the swale = 30,000 ft^2
Impervious area (A_i) = 10,000 ft^2
Slope of swale (s) = 2.5%
Length of swale = 200 ft.

6-1308.14B Determine the required check dam height and spacing and channel cross-section for a water quality volume (WQ_v) of 0.5 inches per impervious acre (1,815 ft^3).

6-1308.14B(1) The water quality volume is:

$$WQv = 1{,}815\ ft^3\ (10{,}000\ ft^2 / 43{,}560\ ft^2)$$
$$= 417\ ft^3$$

6-1308.14B(2) Select height and spacing of check dams. For a channel slope of 2.5 percent, the channel segment lengths subject to ponding for check dam heights of 0.5, 1.0, and 1.5 feet are:

$$L = h / s$$
$$= 0.5\ ft./0.025 = 20\ ft.$$
$$= 1.0\ ft./0.025 = 40\ ft.$$
$$= 1.5\ ft./0.025 = 60\ ft.$$

To determine the minimum spacing between check dams, add 5 feet to the computed channel segment length to assure that the ponded water does not reach the toe of the next upstream check dam. To determine the number of check dams, divide the total channel length by the minimum spacing and round down to the nearest whole number. If the computed value is a whole number, subtract one. This gives us minimum spacings of 25, 45, and 65 feet for check dam heights of 0.5, 1.0, and 1.5 feet, respectively.

The volume of water ponded behind an individual check dam is the required water quality volume divided by the number of check dams. For 7, 4, and 3 check dams, the required storage volumes are 59.6, 104.3, and 139 cubic feet, respectively.

The minimum required cross-section areas are:

$$
\begin{aligned}
Ax &= 2.0(Vs / L) \\
&= 2.0(59.6\ ft^3 / 20\ ft.) = 5.96\ ft^2 \\
&= 2.0(104.3\ ft^3 / 40\ ft.) = 5.22\ ft^2 \\
&= 2.0(139.0\ ft^3 / 60\ ft.) = 4.64\ ft^2
\end{aligned}
$$

From Table 6.31, it can be seen that a trapezoidal channel with 0.5-foot high check dams would need to exceed the allowable channel bottom width to provide the required storage volume. A trapezoidal channel with a 3-foot bottom width and 1.0-foot high check dams would work as would a trapezoidal channel with a 2-foot bottom width and 1.5-foot high check dams. The results of the above computations are summarized in Table 6.32.

Table 6.32 Example Problem

	Check Dam Height		
	0.5	**1.0**	**1.5**
Number of Check Dams	7	4	3
Spacing of Check Dams	25 ft.	45 ft.	65 ft.
Storage Volume (Vs)	59.6 ft^3	104.3 ft^3	139.0 ft^3
Cross-section Area (Required)	5.96 ft^2	5.22 ft^2	4.64 ft^2
Cross-section Area (Provided)	--	6.0 ft^2	9.75 ft^2
Channel bottom width	--	3 ft.	2 ft.

6-1308.15 Vegetated Swale Water Quality Flow Design Example

6-1308.15A Given:

Drainage area to the swale = 30,000 ft^2
Impervious area (A_i) = 10,000 ft^2
Hydrologic Soil Group (HSG) of pervious area = "C"
Time of concentration T_c = 0.25 hr.
Time of travel Tt = 0.15 hr per 100 ft.
Slope of swale (s) = 2.5 %
Length of swale = 200 ft.

Assume that flow enters uniformly along the length of the swale. Therefore, the required minimum hydraulic residence time required is 18 minutes (§ 6-1308.6D).

6-1308.15B Calculate the design flow for a 20-inch, 24-hour storm using standard NRCS methods. The swale was modeled as two subareas and two 100-foot long reaches. T_c for the first 100-foot reach of the swale consists of 6 minutes for sheet flow to the swale and 9 minutes travel time in the swale. The resulting design flow is 0.54 cfs at the outlet of the swale. (Note that computation of the 2-year and 10-year storm flows should use a combined $T_c + T_t$ of 0.1 hour because of the lower "n" value and travel time in the swale at higher flow depths.)

6-1308.15C Flow in the swale is calculated based on Manning's equation for open channel flow.

$$Q = \frac{1.49}{n} A R^{0.67} s^{0.5}$$

Where:
Q = flow rate (cfs)
n = Manning's roughness coefficient (unitless)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft.)
s = longitudinal slope (ft./ft.)

For shallow flow depths in swales, channel side slopes may be ignored in the initial estimation of the bottom width. The following equation (a simplified form of Manning's equation) may be used to estimate the swale bottom width:

$$b = Q_{wq} n_{wq} / 1.49 y^{1.67} s^{0.5}$$

Where:
b = bottom width of swale (ft.)
Q_{wq} = water quality design flow (cfs)
n_{wq} = Mannings roughness coefficient for shallow flow conditions (unitless)
y = design flow depth (ft.)
s = longitudinal slope (ft./ft.)

6-1308.15D The design flow velocity is computed using the continuity equation.

$V_{wq} = Q_{wq} / A_{wq}$

Where:
V_{wq} = design flow velocity (ft./sec.)
$A_{wq} = by + Zy^2$ = cross-sectional area (ft^2) for a trapezoidal cross-section
Z = side slope length per unit height (e.g., Z = 3 if side slopes are 3H:1V)

6-1308.15E Determine the maximum allowable velocity for a hydraulic residence time of 18 minutes.

V_{wq} = L / 1,080
= 200 ft. / 1,080 sec.
= 0.19 ft./sec.

6-1308.15F Compute the estimated bottom width and design flow velocity using a flow depth of 3 inches (0.17 feet).

$b = 0.54(0.2)/1.49(0.25^{1.67})(0.025^{0.5})$ = 4.6 ft.

$V_{wq} = 0.54 / [(4.6)(0.25) + (3)(0.25^2)]$ = 0.40 ft./sec.

0.40 ft./sec. > 0.19 ft./sec. Not OK

6-1308.15G Recompute the estimated bottom width and design flow velocity using a flow depth of 2 inches (0.17 feet).

$b = 0.54(0.2) / 1.49(0.17^{1.67})(0.025^{0.5})$
= 8.8 ft.

$Vwq = 0.54 / [(8.8)(0.17) + (3)(0.17^2)]$
= 0.34 ft./sec.

0.34 ft./sec. > 0.19 ft./sec. Not OK

6-1308.15H At this point it is clear that in order to achieve the 18-minute hydraulic residence time required the slope of the channel must be reduced or a longer channel constructed. We can do both simultaneously by constructing a channel with the same upstream and downstream invert elevations along a sinusoidal path. Try a 300-foot long channel. The resulting slope is 1.7 percent. The maximum allowable velocity for the channel would now be:

V_{wq} = L / 1,080
= 300 ft. / 1,080 sec.
= 0.29 ft./sec.

6-1308.15I Recompute the estimated bottom width and design flow velocity using a flow depth of 2 in. (0.17 ft.) and a slope of 1.7%.

$b = 0.54(0.2) / 1.49(0.17^{1.67})(0.017^{0.5})$
= 10.7 ft.

10.7 ft. > 10 ft. Not OK

$Vwq = 0.54 / (10.7*0.17 + 3*0.17^2)$
= 0.28 ft./sec.

0.28 ft./sec. < 0.29 ft./sec. OK

6-1308.15J Although the velocity is acceptable, the swale bottom width is greater than the maximum allowable width. Repeat the procedure of lengthening the swale until an acceptable result is achieved.

6-1309 Tree Box Filters (98-07-PFM)

6-1309.1 A tree box filter is a type of bioretention filter contained in a precast or cast-in-place concrete structure. The principal components of a tree box filter are an inlet structure, a concrete box, a tree grate, plants that tolerate fluctuations in soil moisture and temporary ponding of water, a mulch layer, an engineered soil media, and an underdrain in a gravel layer that is connected to the storm drain system. The soil media is highly permeable and well drained. Water quality control is provided by filtering storm water runoff through the soil media and mulch, biological and chemical reactions in the soil, mulch, and root zone and plant uptake.

6-1309.1A Tree box filters are best suited for small drainage areas that have low sediment loads such as parking lots, courtyards, and along privately maintained streets.

6-1309.1B (106-10-PFM, 102-08-PFM) Trees in tree box filters may be used to meet the requirements of Chapter 122 of the Code and § 12-0000 *et seq*. of the PFM. Minimum planting area and minimum distance to barriers as required by § 12-0510.4E(5) must be met to use trees in tree box filters to meet 10-year tree canopy requirements. Use of some small trees may be possible (Category I and II).

6-1309.2 Location and Siting

6-1309.2A In residential areas, tree box filters and their appurtenant structures must be located on homeowner association (or "common") property and may not be located on individual buildable single-family attached or detached residential lots or any part thereof.

6-1309.2B Tree box filters may be located in the right-of-way subject to approval by VDOT.

6-1309.2C Tree box filters shall not be located in the vicinity of loading docks, vehicle maintenance areas, or outdoor storage areas, where there is the potential for high concentrations of hydrocarbons, toxics, or heavy metals in stormwater runoff unless effective pre-treatment is provided to reduce the concentrations.

6-1309.2D The maximum impervious area draining to a tree box filter shall be 0.25 acre.

6-1309.3 Maintenance

6-1309.3A Tree box filters and their appurtenant structures must be privately maintained and a private maintenance agreement must be executed before the construction plan is approved. Tree box filters may not be located in County storm drainage easements. The above does not preclude the use of tree box filters by the County on County-owned property.

6-1309.3B Maintenance access must be provided for all tree box filters. Access routes shall be depicted on plans for all facilities not located in parking lots or along streets.

6-1309.3C Tree box filters shall be stenciled (or a plaque provided) on the inside of the box in a location clearly visible upon removal of the tree grate designating the tree box as a water quality management facility. The stenciling or plaque shall state that the facility is a water quality management facility, water may pond after a storm, and the facility is not to be disturbed except for required maintenance.

6-1309.4 General Design Requirements

6-1309.4A Water Quality Volume. For facilities designed to capture and treat the first 0.5 inches of runoff, the required water quality volume is 1,815 cubic feet per acre of impervious area. For facilities designed to capture and treat the first 1.0 inches of runoff, the required water quality volume is 3,630 cubic feet per acre of impervious area. The water quality volume must be captured and filtered through the system.

6-1309.4B Flow Rate Based Design. For facilities whose treatment capacity is based on a maximum flow rate, the design methodology shall be approved by the Director.

6-1309.4C Tree box filters shall be located adjacent to a storm drain inlet to capture runoff that bypasses the system during heavy rainfall events.

6-1309.4D The top of the structure shall include a grate that will allow vegetation to grow through it and that is capable of supporting H-20 loads. The grate shall be removable for maintenance.

6-1309.4E The inlet structure shall be a standard curb inlet meeting VDOT requirements. A stone energy dissipater or other approved method shall be provided at the end of the inlet throat running along the entire length of the inlet at the surface of the soil media.

6-1309.4F Tree boxes shall be constructed of precast or cast-in-place reinforced concrete meeting VDOT requirements for drainage structures.

6-1309.4G To reduce construction costs, the bottom of the box may be left open in areas where there is potential for infiltration.

6-1309.4H The maximum surface storage depth from the top of the mulch layer to the bottom of the grate shall be 1 foot.

6-1309.4I An underdrain connected to the storm drain system shall be provided for all tree box filters. The outfall of all underdrains must be in conformance with the adequate drainage requirements of § 6-0200 *et seq*.

6-1309.4J The minimum soil media depth shall be 2.5 feet. The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed. A layer of 2-3 inches of mulch shall be placed on top of the soil media.

6-1309.4K Variations of the tree box filter design in Plate 90-6 may be approved by the Director provided the facility meets all of the requirements in § 6-1309 *et seq*.

6-1309.5 Filter Bed Design. The required surface area of the filter is based on the volume of water to be treated and the available storage in the ponding area computed as follows:

$A_f = WQ_v / h_f$

Where:
A_f = area of filter (ft^2)
WQ_v = water quality volume (ft^3)
h_f = maximum ponding depth (ft.)

6-1309.6 Underdrains. Underdrains shall consist of perforated pipe ≥ 4 inches in diameter placed in a layer of washed VDOT #57 stone. There shall be a minimum of 2 inches of gravel above and below the pipe. Underdrains shall be laid at a minimum slope of 0.5 percent. Underdrains shall extend the length of the box from one wall to within 6 inches of the opposite wall and may be centered in the box or offset to one side. Underdrains shall be separated from the soil media by geotextile fabric or a 2- to 3-inch layer of washed VDOT #8 stone or 1/8- to 3/8-inch pea gravel. Underdrains shall include a cleanout with a locking cap that extends 6 inches above the soil media and is accessible by removing the grate. Cleanouts shall be nonperforated pipe equal to or greater in diameter than the underdrain pipe. All stone shall be washed with less than 1 percent passing a #200 sieve.

6-1309.7 Materials Specifications

6-1309.7A The bioretention soil media shall meet the requirements of § 6-1307.9A. A minimum of one soil test shall be performed on the final soil mixture. Test results and materials certifications shall be submitted to DPWES prior to bond release.

6-1309.7B Mulch shall meet the requirements of § 6-1307.9B.

6-1309.7C Underdrains shall meet the requirements of § 6-1307.9C.

6-1309.7D Filter fabric. Filter fabric shall meet the requirements of § 6-1307.9D.

6-1309.8 Tree Box Filter Planting

6-1309.8A A tree box filter shall be planted with a small tree or shrub that is able to tolerate highly variable moisture conditions, generally dry with brief periods of inundation. The selected plants must not have a root zone density or characteristics that will rapidly displace the soils or clog the underdrain. Depending on site conditions, selected plants also must be able to tolerate exposure to wind and sun, as well as salt and toxins in runoff from roads, parking lots, and driveways. The use of native plant species is preferred. The acceptability of proposed plant materials will be determined by the Director. Guidance on the use and selection of plants for tree box filters is available from Urban Forest Management.

6-1309.8B Plant materials shall meet the requirements of § 6-1307.10C and § 6-1307.10D.

6-1309.8C All plantings must be well established prior to release of the conservation deposit. Nursery stock trees and shrubs required by the approved plan shall be viable (healthy and capable of developing a trunk and branch structure typical for their species) at the time the conservation deposit is released.

6-1309.9 Construction Specifications

6-1309.9A The owner shall provide for inspection during construction of the facility by a licensed professional. (In accordance with standard practice, the actual inspections may be performed by an individual under responsible charge of the licensed professional.) The licensed professional shall certify that the facility was constructed in accordance with the approved plans. The licensed professional's certification along with any material delivery tickets and certifications from the material suppliers and results of the tests and inspections required under § 6-1309.7A, § 6-1309.9D, and § 6-1309.9H shall be submitted to the County prior to bond release. For projects requiring as-built plans, the required certification and supporting documents shall be submitted with or incorporated in the as-built plans. For projects that do not require as-built plans, the required certification and supporting documents shall be submitted with the RUP or non-RUP request.

6-1309.9B Tree box filters shall be constructed after the drainage area to the facility is completely stabilized. Erosion and sediment controls for construction of the facility shall be installed as specified in the erosion and sediment control plan. The concrete box may be installed with the other elements of the storm drainage collection system provided that it is flushed of any accumulated sediments prior to installation of the underdrain, filter fabric and soil media components.

6-1309.9C The components of the soil media shall be thoroughly mixed until a homogeneous mixture is obtained. It is preferable that the components of the soil media be mixed at a batch facility prior to delivery to the site. The soil media shall be moistened, as necessary, to prevent separation during installation.

6-1309.9D The soil media shall be tested for pH, organic matter, and soluble salts prior to installation. If the results of the tests indicate that the required specifications are not met, the soil represented by such tests shall be amended or corrected as required and retested until the soil meets the required specifications. If the pH is low, it may be raised by adding lime. If the pH is too high, it may be lowered by adding iron sulfate plus sulfur.

6-1309.9E The soil media shall be placed by hand with minimal compaction in order to maintain the porosity of the media. Spreading shall be by hand. The soil media shall be placed in 8- to12-inch lifts with no machinery allowed over the soil media during or after construction. The soil media should be overfilled above the proposed surface elevation as needed to allow for natural settlement. Lifts may be lightly watered to encourage settlement. After the final lift is placed, the soil media shall be raked to level it, saturated, and allowed to settle for at least one week prior to installation of plant materials.

6-1309.9F Plant material shall be installed per § 12-0705.

6-1309.9G Planting shall take place after construction is completed and during the following periods: March 15 through June 15 and Sept. 15 through Nov. 15, unless otherwise approved by the Director.

6-1309.9H The facility shall be inspected at 12 - 24 hours after a significant rainfall (0.5-1.0 inch) or artificial flooding to determine that the facility is draining properly. Results of the inspection shall be provided to DPWES prior to bond release.

6-1309.10 Plan Submission Requirements

6-1309.10A Plan view(s) with topography at a contour interval of no more than one foot and spot elevations throughout the facility showing all hydraulic structures including underdrains.

6-1309.10B Cross section of the facility showing the following: elevations and dimensions of the structure, inlet, outlet, underdrain, soil media, and underlying gravel layer, and filter fabric.

6-1309.10C Plant schedule specifying species, quantity of each species, stock size, type of root stock to be installed and amount of tree cover claimed for each tree species. Planting schedule shall be in conformance with § 12-0515.1E.

6-1309.10D Sizing computations for the facility including volume of storage and surface area of facility required and provided.

6-1309.10E Hydrologic calculations for the facility.

6-1309.10F Design calculations and specifications for all hydraulic structures including inlet structures and underdrain piping.

6-1309.10G A discussion of the outfalls from the facility is to be included in the outfall narrative.

6-1309.10H Construction and materials specifications.

6-1309.11 Tree Box Filter Design Example:

6-1309.11A Given:

Impervious area (A_i) draining to the facility = 1,500 ft^2
Maximum ponding depth (h_f) = 1.0 ft.

6-1309.11B Determine the required area of the filter bed (A_f) for a water quality volume (WQ_v) of 0.5 inch per impervious acre (1,815 ft^3).

6-1309.11C The water quality volume is:

WQ_v = 1,815 ft^3 (1,500 ft^2 / 43,560 ft^2)
= 62.5 ft^3

6-1309.11D The area of the filter bed is:

$A_f = WQ_v / h_f$
= 62.5 / 1.0 = 62.5 ft^2

6-1309.11E The minimum size tree filter box would be:

$\sqrt{62.5}$ = 7.9 ft. Use a square 8-foot x 8-foot box. A rectangular 6-foot x 11-foot box could also be used.

6-1310 Vegetated Roofs (98-07-PFM)

6-1310.1 A vegetated roof (a.k.a. green roof) is a roof system consisting of the structural components of the roof, a waterproof membrane, a drainage layer, a layer of growth media, and plants. Depending on the type of plants and the waterproof membrane specified, an irrigation system and a root barrier also may be provided. Vegetated roofs reduce the peak rate and volume of stormwater runoff through interception of rainfall and evapotranspiration. Vegetated roofs improve water quality by capturing and filtering airborne depositional pollutants and by plant uptake of dissolved pollutants. Additionally, a vegetated roof provides reductions in energy use for heating and cooling, improvements in air quality, and aesthetic benefits. Vegetated roofs are classified as extensive or intensive systems based on the depth of the growth media and function of the roof.

6-1310.1A Extensive systems are shallow systems, having a growth media depth of 3-6 inches, a low unit weight, low construction cost, low plant diversity, and minimal maintenance requirements. Extensive systems are constructed when the primary purpose is to achieve environmental benefits and typically are only accessible for maintenance and inspection. Extensive systems may be constructed on slopes of up to 33 percent.

6-1310.1B Intensive systems have a growth media depth of 6 inches or greater, a greater unit weight, increased design sophistication and construction costs, increased plant diversity, greater water holding capacity, and increased maintenance requirements compared to extensive systems. Intensive systems often are accessible and provide an amenity for occupants of the building. Intensive systems may not be constructed on slopes greater than 10 percent.

6-1310.2 General Requirements

6-1310.2A Vegetated roofs may be used on non-residential buildings (commercial, industrial, and institutional uses), parking structures, multi-family residential buildings including condominiums and apartments, and mixed-use buildings with a residential component.

6-1310.2B Vegetated roofs may not be used on single family detached or attached units for the purpose of satisfying the detention or water quality control (BMP) requirements of the Subdivision or Zoning Ordinance. Vegetated roofs may not be used on single family detached units in nonbonded subdivisions to satisfy the BMP requirements of the Chesapeake Bay Preservation Ordinance.

6-1310.2C Vegetated roofs must be privately maintained and a private maintenance agreement must be executed before the construction plan is approved.

6-1310.2D Post-development hydrology. For hydrologic computations using the Rational Method, the runoff coefficient “C” values for vegetated roofs in Table 6.5 shall be used. For hydrologic computations using Natural Resource Conservation Service (NRCS) methods, a curve Number “CN” value of 65 shall be used for intensive systems and a value of 70 shall be used for extensive systems. Other values may be approved by the Director, depending on the composition and depth of the growth media and the slope of the roof, upon submission of a hydrologic analysis of the water retention capacity of the system.

6-1310.3 Design of Vegetated Roofs

6-1310.3A Extensive vegetated roof systems shall have a minimum growth media depth of 3 inches and a maximum growth media depth of 6 inches. The Director may approve growth media depths less than 3 inches for systems constructed on existing buildings when necessary because the structural design of the roof is not sufficient to carry the greater loads. Adjustments to the assigned runoff coefficients and curve numbers will be necessary to account for the reduced water holding capacity of the growth media.

6-1310.3B Intensive vegetated roof systems shall have a minimum growth media depth of 6 inches. A maximum growth media depth is not specified for intensive vegetated roof systems. Unless needed to accommodate small trees or large shrubs, the growth media depth should not be greater than 12 inches. Intensive vegetated roof systems may include subareas with different growth media depths to accommodate different types of plants.

6-1310.3C The drainage layer below the growth media shall be designed to convey stormwater to the roof downspouts, conductors, and leaders without backing water up into the growth media. Roof areas draining to an individual roof drain may not exceed 4,300 square feet unless internal drainage conduits are provided. Internal drainage conduits shall be designed to convey the 10-year storm.

6-1310.3D Roof drains and emergency overflow measures shall be sized in accordance with the Virginia Uniform Statewide Building Code (USBC).

6-1310.3E Vegetated roofs shall have a minimum slope of 2 percent to provide for adequate drainage. The slope of extensive systems shall not be greater than 33 percent. The slope of intensive systems shall not be greater than 10 percent. Extensive systems with slopes equal to or greater than 17 percent will require supplemental slope stabilization measures (e.g., raised grids) to hold the growth media and plants in place.

6-1310.3F Access to vegetated roofs for maintenance and inspection shall be provided unless waived by the Director. Access shall be provided by an interior stairway through a penthouse or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and having a minimum dimension of 24 inches, or by a terrace door with a minimum clear opening width of 32 inches. The access requirement may be waived by the Director for roofs no greater than 12 feet above finished grade and less than 1000 square feet in area.

6-1310.3G Provisions for the safety of maintenance and inspection workers (e.g., parapets, railings, secured rings for safety harnesses, etc.) shall be incorporated in the design of all roofs.

6-1310.3H A vegetation-free zone is recommended along the perimeter of the roof and around all roof penetrations to act as a fire break and to facilitate maintenance and inspection. This zone should be a minimum of 24 inches in width along the perimeter of the roof and a minimum of 12 inches around all roof penetrations. The width of the vegetation-free zone around the perimeter of the roof may be reduced from 24 inches to 12 inches where application of the 24-inch requirement would result in a reduction of the roof area available for greening of greater than 15 percent.

6-1310.4 Design and Construction Specifications of Vegetated Roof Components. Vegetated roofs typically consist of the structural components of the roof, a waterproof membrane, a root barrier (if required), a protective layer, a drainage layer, filter fabric, a layer of growth media, and plants. Vegetated roofs may also include an optional thermal insulation layer, a leak detection system, and an irrigation system. Specifications for the optional components of vegetated roofs are not provided herein but should meet any applicable Virginia USBC requirements. Variations on the vegetated roof system designs in Plates 91-6 and 92-6 may be approved by the Director provided the facility meets all of the requirements of §6-1310 *et seq*.

6-1310.4A Waterproof membrane. The waterproof membrane that separates the drainage system and growth media from the structural components of the roof can consist of several different systems including modified bitumen, rubberized asphalt, polyvinyl chloride (PVC), thermoplastic polyolephin (TPO), chlorosulfonated polyethylene (CSPE), and ethylene propylene diene monomer (EPDM) systems. Membranes impregnated with pesticides or herbicides are not allowed. Waterproofing must meet Virginia USBC requirements.

6-1310.4B Root barrier. A PVC, polypropelene, or polyethelene membrane ≥ 30 mil thick hot-air welded at the seams or approved equivalent is required to protect modified bitumen and rubberized asphalt waterproofing from root penetration. A root barrier is not required for PVC, EPDM, or CSPE membranes.

6-1310.4C Protective layer. A perforation resistant protective layer is required to protect the waterproofing and root barrier (if required) from damage. The protective layer shall be a polypropylene non-woven needled fabric with a density (ASTM D3776) $\geq$ 6 oz./yard^2 and a puncture resistance (ASTM D4833) $\geq$ 220 pounds or approved equivalent.

6-1310.4D Drainage layer. The drainage layer shall be a single or composite system capable of conveying stormwater that drains through the growth media. Drainage layers may be a granular drainage media, synthetic geocomposite, or synthetic mat and may include internal drain pipes.

6-1310.4D(1) Granular drainage media shall be a non-carbonate mineral aggregate meeting the requirements listed in Table 6.33.

Table 6.33 Granular Drainage Media Specifications

Saturated Water Permeability (ASTM E2396)	≥ 25 in./min.
Total Organic Matter, by Wet Combustion (MSA)	≤ 1 %
Abrasion Resistance (ASTM C131)	≤ 25 % loss
Soundness (ASTM C88)	≤ 5 % loss
Porosity (ASTM C29)	≥ 25 %
pH	6.5 – 8.0
Grain-size Distribution (ASTM C136)	
Passing US #8 sieve	≤ 1%
Passing 1/4 in. sieve	≤ 30%
Passing 3/8 in. sieve	≥ 80%

6-1310.4D(2) For non-grid systems, a drainage system consisting of deformed polyethylene sheet with a transmissivity (ASTM D4716) greater than or equal to 24 gallons per minute per foot of width.

6-1310.4E Filter fabric. Filter fabric shall be a non-woven, root penetrable, needled, polypropylene geotextile meeting the requirements listed in Table 6.34. Heat-set or heat-calendared fabrics are not permitted.

Table 6.34 Filter Fabric Specifications

Unit Weight (ASTM D3776)	≤ 4.25 oz./yd^2
Grab Tensile Strength (ASTM D4632)	≥ 90 lbs.
Mullen Burst Strength (ASTM D3786)	≥ 135 lbs./in^2
UV Resistance (ASTM D4355)	70% strength after 500 hours
Permittivity (ASTM D4491)	≥ 2 sec^{-1}

6-1310.4F Growth media. Growth media shall be a mineral and organic mixture that provides sufficient nutrients and water holding capacity to support the proposed plant materials. Tables 6.35, 6.36, and 6.37 provide specifications for the growth media that must be adapted to the specific application by a competent professional.

Table 6.35 Growth Media Specifications

Total Organic Matter by Loss on Ignition (ASTM F1647, Method A)	3 - 15% (dry weight)
Maximum Water Capacity (ASTM E2399)	≥ 45 % (Vol.) for intensive systems ≥ 35 % (Vol.) for extensive systems
Non-capillary Pore Space (void ratio) at Field Capacity, 0.333 bar (MSA)	≥ 15% (Vol.)
Saturated Water Permeability (ASTM D2434)	≥ 0.7 in./hr. for intensive systems ≥ 1.4 in./hr. for extensive systems
pH	6.5 – 8.0
Nitrate + Ammonium, N (in $CaCl_2$)	≤ 80 mg/l
Phosphorus, P_2O_2 (in CAL)	≤ 200 mg/l
Potassium, K2O (in CAL)	≤ 700 mg/l
Magnesium, Mg (in $CaCl_2$)	≤ 160 mg/l

Table 6.36 Mineral Fraction Grain-size Distribution (ASTM D422) for Intensive Sites

Clay ≤ 0.000079 in.	3 - 10%
Silt ≤ 0.0029 in.	10 – 17%
Passing US #60 sieve	10 – 40%
Passing US #18 sieve	30 – 100%
Passing 1/4 in. sieve	70 – 100%
Passing 3/8 in. sieve	90 – 100%

Table 6.37 Mineral Fraction Grain-size Distribution (ASTM D422) for Extensive Sites

Clay ≤ 0.000079 in.	0%
Silt ≤ 0.0029 in.	0 – 15%
Passing US #60 sieve	10 – 40%
Passing US #18 sieve	30 – 100%
Passing 1/4 in. sieve	70 – 100%
Passing 3/8 in. sieve	90 – 100%

6-1310.4G Plants. The planting plan and specifications shall be prepared by a certified landscape architect, horticulturist, or other individual who is knowledgeable about the environmental tolerance and ecological functions and impacts of plant species.

6-1310.4G(1) Plant materials selected shall be shallow rooted, self-sustaining, and tolerant of direct sunlight, drought, wind, and frost. Plant materials for extensive systems may include mosses, sedums, herbaceous plants, and grasses. Plant materials for intensive systems may include mosses, sedums, herbaceous plants, grasses, shrubs and small trees. Invasive species that may disrupt or harm native plant communities shall not be used. The acceptability of proposed plant materials will be determined by the Director. Guidance on the use and selection of plants for vegetated roofs is available from Urban Forest Management.

6-1310.4G(2) Plants may be installed by vegetation mats, plugs, potted plants, sprigs, or direct seeding.

6-1310.4G(3) The planting plan shall be designed to achieve 90 percent coverage within two years of installation.

6-1310.4H Measures for irrigation shall be provided to ensure plant viability during long periods of drought unless waived by the Director. At a minimum, a hose bib shall be provided for manual irrigation. If automated irrigation is provided, the additional dead load shall be incorporated in the roof system design. The requirement to provide measures for irrigation may be waived by the Director for roofs no greater than 12 feet above finished grade and less than 1,000 square feet in area.

6-1310.5 Construction Requirements

6-1310.5A The owner shall provide for inspection during construction of the facility by a licensed professional. (In accordance with standard practice, the actual inspections may be performed by an individual under responsible charge of the licensed professional.) The licensed professional shall certify that the facility was constructed in accordance with the approved plans. The licensed professional’s certification along with any material delivery tickets and certifications from the material suppliers shall be submitted to the County prior to bond release. For projects requiring as-built plans, the required certification and supporting documents shall be submitted with or incorporated in the as-built plans. For projects that do not require as-built plans, the required certification and supporting documents shall be submitted with the RUP or non-RUP request.

6-1310.5B Foot and equipment traffic on the roof shall be minimized. Traffic over the waterproof membrane must be strictly controlled until the protective layer and drainage layer are installed.

6-1310.5C The organic and mineral components of the growth media shall be thoroughly mixed prior to installation. It is preferable that the components of the growth media be mixed at a batch facility prior to delivery to the site. The media shall be moistened, as necessary, to prevent separation during installation.

6-1310.5D The growth media shall be soaked at a rate of 30 gallons per 100 square feet and allowed to drain thoroughly before planting.

6-1310.5E Erosion Control. A bio-degradable jute mesh with an aperture of 0.375-1.0 inch and a tensile strength (ASTM D4632) $\geq$ 20 pounds or approved equivalent shall be provided when establishing plants from sprigs and/or seed.

6-1310.5F Plant installation shall occur during the following periods: March 15 through June 15 and Sept. 15 through Nov. 15, unless otherwise approved by the Director.

6-1310.5G Shrubs and potted plants must be hardened off adequately prior to planting.

6-1310.5H The roof should be checked for leakage, slippage of membranes and soil erosion after planting.

6-1310.5I Plantings must be well established prior to release of the conservation deposit. The conservation deposit will be held for a minimum of one year after installation of the plantings and shall only be released if the 90 percent coverage required by § 6-1310.4G(3) is achieved. If ninety percent coverage is not achieved, the area shall be replanted to achieve the minimum required coverage and the conservation deposit held for an additional year.

6-1310.6 Plan Submission Requirements

6-1310.6A Plan view(s) showing facility dimensions, planting plan, layout for internal drains (if provided as part of the drainage layer), roof access, walkways, roof penetrations, and setbacks from roof lines.

6-1310.6B Cross section of proposed roof system showing the waterproof membrane, root barrier, protection layer, drainage layer, filter fabric, soil media depth, and emergency overflow system. See Plates 91-6 & 92-6.

6-1310.6C Specifications for the waterproof membrane, root barrier (if provided), protection layer, drainage layer, filter fabric, and soil media.

6-1310.6D Plant list specifying species, size, and number of proposed plants, seeding rates, planting procedures, and specifications for erosion control.

6-1310.6E Construction requirements, sequence, and procedures including a list of certifications required to be provided to the County.

6-1310.6F Roof area in square feet that is vegetated.

6-1310.6G A note shall be placed on the cover sheet stating that the site plan includes a vegetated roof on the proposed building to meet stormwater and water quality control requirements and that construction of the vegetated roof is required with the building. The note shall also state that the building plans shall include a statement signed and sealed by the licensed professional submitting the building design that:

6-1310.6G(1) The vegetated roof design on the building plans is in conformance with the vegetated roof design on the approved site plan;

6-1310.6G(2) Additional requirements for all items such as roof membranes, drains, irrigation systems, and safety rails shall comply with the requirements of the Virginia USBC;

6-1310.6G(3) Access to the vegetated roof has been provided in accordance with Public Facilities Manual § 6-1310.3F;

6-1310.6G(4) Provisions for the safety of maintenance and inspection workers have been incorporated in the design of the vegetated roof in accordance with Public Facilities Manual § 6-1310.3G; and

6-1310.6G(5) Manual or automated irrigation has been provided in accordance with Public Facilities Manual § 6-1310.4H.

6-1311 Reforestation (98-07-PFM)

6-1311.1 (102-08-PFM) Reforestation is the establishment of a forest ecosystem on open ungraded areas. Forest ecosystems reduce the peak rate and volume of stormwater runoff through interception of rainfall by leaves and the forest duff layer, plant uptake and evapotranspiration, and infiltration into the soil. Forest ecosystems improve water quality by capturing and filtering airborne depositional pollutants, plant uptake of dissolved pollutants, and infiltration into the soil. Tree canopies provide energy conservation for buildings, screening, and other benefits in addition to stormwater management. Reforested areas may be used to meet the tree cover requirements of §12-0000 *et seq*. and Chapter 122 of the Code. Ten-year canopy credit equivalent to the square footage of the area will be given for reforested areas that have been planted, and are established in accordance with the provisions of this section.

6-1311.2 General Requirements

6-1311.2A Reforested areas shall be placed in restrictive easements that include limited provisions for management practices necessary to assure the establishment of a healthy forest ecosystem. In residential areas, reforested areas must be located on homeowner association (or “common”) property and may not be located on individual buildable single family detached or attached residential lots, or any part thereof for the purpose of satisfying the detention or water quality control (BMP) requirements of the Subdivision or Zoning Ordinance. Reforested areas may not be located on individual residential lots in nonbonded subdivisions to satisfy the BMP requirements of the Chesapeake Bay Preservation Ordinance.

6-1311.2B Reforested areas shall be privately managed and maintained.

6-1311.2C Post-development hydrology. A runoff coefficient “C” for reforested areas found in Table 6.5 shall be used for hydrologic computations using the Rational Method. The Curve Number “CN” for use with Natural Resources Conservation Service methods shall be based upon woods in good condition and the underlying Hydrologic Soil Group.

6-1311.2D Reforested areas shall be posted with permanent signs designating the area as a Conservation Area. Signs shall state that the area has been reforested as a Low Impact Development practice and no disturbance or cutting of vegetation is allowed. Signs must be a minimum of 8 inches by 10 inches mounted on posts at a height of 4 feet to 6 feet and placed at approximately 150-foot intervals along the perimeter of the reforested area. See Plates 81-6.

6-1311.2E In order to maximize the infiltration capacity, structure, and biota of the existing soil profile below the amended soil layer, areas to be reforested shall not be graded as part of the site development. The only land disturbance allowed is that which is necessary to amend the soils and install plantings.

6-1311.3 Design of Reforested Areas

6-1311.3A Reforestation plans and specifications shall be prepared by a certified landscape architect, horticulturist, or other individual who is knowledgeable about the environmental tolerance, ecological functions, and impacts of plant species.

6-1311.3B Except as noted below, reforested areas shall have a minimum contiguous area of 6,000 square feet, be generally regular in shape, and have a minimum width of 35 feet. The Director may approve areas less than 6,000 square feet in size or with minimum widths less than 35 feet provided such areas are contiguous to existing naturally vegetated areas that are preserved with restrictive easements or other long-term protective mechanisms or that are in uses associated with long-term preservation.

6-1311.3C Reforested areas shall be designed to replicate adjacent forest communities using similar percentages of major indicator species or species that can adapt to abiotic conditions present in the area to be reforested. If there is no adjacent forest community to mimic, the area may be planted with pioneer species, such as Virginia pine, black locust, eastern red cedar, red maple, and persimmon.

6-1311.3D (106-10-PFM) Reforested areas shall consist of a mixture of overstory trees, understory trees, and shrubs. Generally, overstory trees correspond to Category 3 or 4 trees and understory trees correspond to Category 1 or 2 trees as listed in Table 12.17 in §12-0000 *et seq*. At least 25 percent of the area shall be planted with trees from nursery stock. For nursery stock, deciduous trees must be a minimum of 1-inch caliper and evergreen trees must be a minimum of 6 feet in height. For areas planted with nursery stock, the density of overstory trees shall be a minimum of 100 trees per acre and the density of understory trees shall be a minimum of 200 trees per acre. Nursery stock may be replaced by transplanted material as approved by the Director. For areas planted with bareroot seedlings (See § 12-0705.5B), the density of the trees shall be double that required for nursery stock. The density of shrubs shall be a minimum of 1089 plants per acre. Shrubs must be a minimum of 18 inches in height.

6-1311.3E To curtail the spread of disease or insect infestation in a plant species, no more than 70 percent of the trees, seedlings, and shrubs required to be planted shall be of one genus. In addition, no more than 35 percent of the deciduous trees shall be of a single species and no more than 35 percent of the evergreen trees shall be of a single species. Seedlings shall be randomly mixed and placed approximately 8-10 feet apart in a random pattern with shrubs placed surrounding seedlings. Additional guidance on appropriate species for soils and groundwater conditions can be found in § 12-0000.

6-1311.3F Tree planting credit may be given for existing trees within the planting area. A planting credit of one 1-inch caliper nursery stock overstory tree shall be given for each 150 square feet of existing overstory tree canopy and a planting credit of one 1-inch caliper nursery stock understory tree shall be given for each 75 square feet of existing understory tree canopy.

6-1311.3G Compacted soils will limit root growth and establishment of the forest ecosystem. Subsoiling (tilling) and soil amendments are required to relieve soil compaction and restore soil function in previously disturbed soils except as noted below.

6-1311.3G(1) Subsoiling and soil amendments are not required if the *in situ* bulk density of the existing soil, as measured by the sand cone test (ASTM D1556), is less than the value in Table 6.38 for the corresponding soil type or compaction, as measured by the cone penetration test (ASTM D3441), is less than 300 lb./square inch in the top 15 inches of soil. A minimum of one density measurement or test shall be performed per 1,000 square feet.

6-1311.3G(2) Testing of *in situ* soils to determine compaction is not required if soils will be amended at pre-approved rates in accordance with § 6-1311.5.

Table 6.38 Bulk Densities That May Effect Root Growth[1]

Soil Texture	lb./ft^3
Sands, loamy sands	105.50
Sandy loams, loams	101.76
Sandy clay loams, loams, clay loams	99.88
Silts, silt loams	99.88
Silt loams, silty clay loams	96.76
Sandy clays, silty clays, some clay loams (35- 45% clay)	93.02
Clays (>.45% clay)	86.77

[1] From “Protecting Urban Soil Quality: Examples for Landscape Codes and Specifications,” USDA 2003

6-1311.4 Subsoiling and Soil Amendment Specifications

6-1311.4A (106-10-PFM) The topsoil layer shall have a minimum depth of 8 inches except for areas within the dripline of existing trees in or adjacent to the area to be reforested, where subsoiling may adversely impact existing tree roots. Compacted soils within the dripline of existing trees shall be addressed by the use of mulch. The mulch shall consist of a minimum of 3 inches of organic mulch that shall be placed on the topsoil layer at final grade. Mulch shall consist of wood chips, bark chips, or shredded bark that has been aged for a minimum of 4 months. Mulch beds must be kept free of any grass, weeds, vines and any other plant or condition that might hinder the establishment of the tree canopy.

6-1311.4B Subsoils below the amended topsoil layer shall be scarified to a depth of at least 4 inches.

6-1311.4C A minimum of 2 inches of organic mulch shall be placed on the topsoil layer at final grade for stabilization purposes after planting. Mulch shall consist of wood chips, bark chips, or shredded bark, that has been aged for a minimum of four months. Alternatively, a native seed mixture combined with appropriate stabilization measures may be used.

6-1311.5 Construction Specifications for Subsoiling with Soil Amendments. The following construction specifications are designed to achieve an 8-inch depth of topsoil and scarification of compacted subsoil 4 inches below the topsoil layer for a total uncompacted depth of 12 inches.

6-1311.5A Scarify or till subgrade to 8 inches depth. The entire surface shall be scarified except for the area within the drip lines of existing trees to be retained.

6-1311.5B Place and rototill 3 inches of organic compost meeting the requirements of Table 6.27 into 5 inches of soil.

6-1311.5C Water thoroughly and allow soil to settle for one week.

6-1311.5D Rake beds to smooth and remove surface rocks larger than 2 inches in diameter.

6-1311.5E Planting should occur as soon as feasible after the soil has been amended.

6-1311.5F After planting, mulch planting beds with 2 inches of organic mulch. Mulch shall consist of wood chips, bark chips, or shredded bark, that has been aged for a minimum of four months. Alternatively, a native seed mixture combined with appropriate stabilization measures may be used. Installation of the above stabilization measures shall be in accordance with the "Virginia Erosion and Sediment Control Handbook," 3rd edition, 1992.

6-1311.5G An inspection report shall be provided to DPWES for review prior to bond release. This report shall include observed survival rates of plantings, replacement plantings installed, material delivery tickets, and certifications from material suppliers. For projects requiring as-built plans, the required inspection report and supporting documents shall be submitted with or incorporated in the as-built plans. For projects that do not require as-built plans, the required report and supporting documents shall be submitted with the RUP or non-RUP request.

6-1311.6 Planting Requirements

6-1311.6A Planting procedures for trees, shrubs and seedlings shall be in conformance with § 12-0705.

6-1311.6B Planting of the reforested area should be done with minimal mechanical disturbance to the existing trees and shrubs to be preserved and given credit per § 6-1311.3F. The planting should be done by hand or mechanical auger.

6-1311.6C Plantings must be well established prior to release of the conservation deposit. The conservation deposit will be held for a minimum of two years after the initial installation of the plantings. Ninety percent or more of the minimum number of nursery stock trees and shrubs required by the approved plan shall be viable (healthy and capable of developing a trunk and branch structure typical for their species) at the time the conservation deposit is released. Sixty-seven percent or more of the initial tree seedling density required by the approved plan shall be viable at the time the conservation deposit is released. If these minimum percentages are not met at the time of inspection, additional nursery stock trees, nursery stock shrubs, and seedlings shall be planted at densities necessary to achieve the required minimum percentages of viability of the initial plantings based on the observed mortality rates. For example, if the plan called for 500 seedlings to be planted, a minimum of 335 seedlings (67 percent) must be viable more than two years after installation. If 250 seedlings were viable (a deficit of 85 viable plants) at the time of inspection (2.5 years after installation), 170 replacement seedlings would need to be planted, based on the observed mortality rate (50 percent), prior to release of the conservation deposit. Replacement seedlings shall be selected such that the resulting mixture of surviving and replacement plants will generally achieve the mixture of understory trees and overstory trees shown on the approved plan as determined by the Director.

6-1311.7 Plan Submission Requirements

6-1311.7A Plant schedule and planting plan specifying species, quantity of each species, stock size, type of root stock to be installed, and spacing of proposed plants within the reforested area.

6-1311.7B Reforested areas shall be delineated on the plan sheets with the note: "Reforestation Area. This area is being replanted for Low Impact Development credit. No disturbance other than that necessary to implement the planting plan allowed."

6-1311.7C Construction specifications for soil amendments (if provided) and planting procedures.

6-1311.7D *In situ* soil test results if performed (See § 6-1311.3G).

6-1400 FLOODPLAIN *See current PFM*

6-1500 ON-SITE MAJOR STORM DRAINAGE SYSTEM *See current PFM*

6-1600 DESIGN AND CONSTRUCTION OF DAMS AND IMPOUNDMENTS *See current PFM*

6-1700 POLICY ON WHAT MAY BE DONE IN CHESAPEAKE BAY PRESERVATION AREAS *See current PFM*