ADVANCED STORMWATER STANDARDS COMPILATION

FINAL REPORT

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1. INTRODUCTION

The Vermont Stormwater Management Manual (VSWMM) was first published in April, 2002. Both the Stormwater Section of the Vermont Department of Environmental Conservation (VT DEC) and the professional community have gained valuable experience in working with VSWMM over the past ten years. Over the last decade, substantial advances in the design and range of stormwater treatment practices and site design approaches have occurred nationally, and a number of potential areas for improvement to VSWMM have been identified.

In 2009, the Stormwater Section initiated a process to review VSWMM and identify priority improvements. The Stormwater Section convened a work group which met several times and identified a myriad of potential updates to the manual, including revisiting the basis for the standards related to channel protection volume and infiltration, as well as the treatment of “low impact development” (LID) or green infrastructure approaches.

The next step was to evaluate and research the various issues that were identified by the work group, and to identify options for updating the manual including new standards, credits, and/or stormwater treatment practices.

In 2012, the Stormwater Section contracted with Stone Environmental to complete a more detailed review of the grey literature and identify state of the art stormwater management approaches and specific practices including but not limited to LID, green infrastructure, and other emerging stormwater management concepts.

Following an initial screening of concepts and approaches, and with the goal of informing future discussions about updating VSWMM, four key topics to be investigated were identified in coordination with DEC Stormwater Program staff:

- Site characterization standards and guidelines for infiltration-based practices
- Alternatives to the Channel Protection Volume (CPv) standard
- Integrating Low-Impact Development (LID) concepts into the VSWMM
- Maintenance Plans (requirements for, and implementation of, in other jurisdictions)

In the following sections regarding each topic, the current practice in Vermont as contained in the VSWMM is presented first, followed by a summary of current practice in a range of other jurisdictions as contained in stormwater BMP manuals, state-level regulations and guidance, and other sources. A series of appendices contain details on each topic, organized by state and often extracted directly from the original manuals or references.

2. SITE CHARACTERIZATION STANDARDS AND GUIDELINES

2.1. Current VSWMM Practice

Requirements for site characterization related to infiltration and bioretention practices are contained in Appendix D1 of the 2002 VSWMM. Key requirements include:

- Minimum field infiltration rate of 0.5 inches per hour required; day-lighting underdrained infiltration practices allowed on less permeable soils. On soils with infiltration rates higher than 2 inches/hour, half of the WQv must be treated by an upstream practice does not allow infiltration.
- Testing is to be conducted by a qualified professional. This professional must either be a registered professional engineer in the State of Vermont, a soil scientist or geologist also licensed in the State of Vermont.
- If initial feasibility testing indicates that the soils may be suitable for infiltration practices, concept design testing is completed. The number of concept design test pits (or soil borings) should be per the following table.

Table 1. Infiltration Testing Summary, Table D-1 from VSWMM

Type of Facility	Initial Feasibility Testing	Concept Design Testing (initial testing yields a rate greater than 0.5"/hr)	Concept Design Testing (initial testing yields a rate lower than 0.5"/hr)
I-1 (trench)	1 field percolation test, test pit not required	1 infiltration test and 1 test pit per 50' of trench	practice not acceptable
I-2 (basin)	1 field percolation test, test pit not required	1 infiltration test* and 1 test pit per 200 sf of basin area	practice not acceptable
F-1 (sand filter)	1 field percolation test, test pit not required	1 infiltration test and 1 test pit per 200 sf of filter area (no underdrains required**)	underdrains required
F-5 (bioretention)	1 field percolation test, test pit not required	1 infiltration test and 1 test pit per 200 sf of filter area (no underdrains required**)	underdrains required

*feasibility test information already counts for one test location
** underdrain installation still strongly suggested

Test pits or borings should be within the proposed practice location and extend at least 4 feet below the proposed facility bottom—sufficient to determine depth to water table and bedrock, and to characterize soil texture and describe soils at all horizons. Grain-size sieve analysis and hydrometer tests where appropriate may be used to determine USDA soils classification and textural analysis. Visual field inspection by a qualified professional may also be used, provided it is documented. The use of lab testing to establish infiltration rates is prohibited.

A simple borehole infiltration test method is prescribed in the VSWMM:

- Install casing (solid 6 inch diameter) to 24" below proposed treatment practice bottom.

- Prepare the bottom soil surface, adding sand/gravel to prevent scouring if needed.
- Fill casing with clean water to a depth of 24" and allow to pre-soak for up to twenty-four hours.
- Refill casing with another 24" of clean water and monitor water level for 1 hour.
- Repeat three additional times, for a total of four observations.
- The final field rate (inches/hour) may either be the average of the four observations, or the value of the last observation

No other methods are described or specifically allowed, except that the use of percolation tests as for septic systems to establish infiltration rates is prohibited.

2.2. Options and Recommendations

Seven key areas of current VSWMM practice related to siting and characterization for the use of infiltration BMPs were compared to practices and policies in place in other states:

1. Minimum infiltration rates
2. Minimum depths to groundwater and bedrock
3. Horizontal setback requirements
4. Characterization frequency/type requirements
5. Test pit / boring depth requirements
6. Acceptable infiltration testing methods
7. Required credentials for site characterization professionals

Each area of practice, along with recommendations for improvements in future editions of the VSWMM, is summarized below.

2.2.1. Minimum Infiltration Rates

All of the state stormwater manuals reviewed as part of this effort set a minimum threshold infiltration rate, below which infiltration practices either cannot be sited, or are required to be designed with an underdrain (Table 2). Minimum infiltration rates ranged from 0.1 inches/hour (Pennsylvania) to 0.52 inches/hour (North Carolina and Virginia). Several states, including New Hampshire, Maine, Rhode Island, and New York, set the same minimum infiltration rate as that used by Vermont (0.5 inches/hour). Most states do allow underdrained infiltration practices to be sited on soils with infiltration rates below the minimum thresholds, but they are generally treated as filtration practices.

Table 2. Summary of minimum required soil infiltration rates for siting infiltration practices.

State (and date of manual)	Minimum infiltration rate (inches/hour)
Vermont (2002)	0.5 (unless designed as underdrained, day-lighting facility). If over 2 in/hr, upstream pretreatment required for half the WQv

State (and date of manual)	Minimum infiltration rate (inches/hour)
Pennsylvania (2008)	0.1 - 10
Massachusetts (2008)	0.17; if over 2.4, upstream pretreatment may be required
Minnesota (2008)	0.2
Washington (2012)	Measured native Ksat less than 0.3 in/hr (underdrain required for lower Ksat)
New York (2010)	0.5 (identical to VSWMM)
Maine (2006)	0.5; no greater than 2.41
New Hampshire (2008)	0.5; greater than 10 inches per hour requires pretreatment or soil amendment
Rhode Island (2010)	0.5
North Carolina (2007)	0.52
Virginia (1999)	0.52 - 8.27

In some cases, a maximum infiltration rate is also defined—but there is substantial variation in how states deal with infiltration into highly permeable soils. New York and Massachusetts use a similar requirement to Vermont's, where pre-treatment is generally required up-stream of the infiltration practice if the soil infiltration rate is higher than 2.4 inches/hour. Maine uses a similar maximum infiltration rate, but does not allow infiltration practices on soils with infiltration rates greater than 2.41 inches/hour. Several states, including New Hampshire, Pennsylvania, and Virginia, set a substantially higher maximum infiltration rate (up to 10 inches/hour). Other states (for example, Washington, Rhode Island, and North Carolina) do not set a maximum infiltration rate. Often, where a maximum threshold is not set, pre-treatment requirements are defined by the land use in the area contributing to the infiltration practice. In Washington, for instance, pre-treatment for TSS would be required if any runoff was coming from a pollution-generating surface (Washington DOE, 2012).

Recommendations:

- 0.5 inches/hour is a reasonable minimum infiltration threshold, and is consistent with current practice in several other New England states.
- Consider increasing the infiltration rate threshold for requiring pre-treatment on more permeable soils.

2.2.2. Minimum Depths to Groundwater and Bedrock

Each state manual reviewed set a minimum vertical separation distance between the bottom of any infiltration practices and seasonal high groundwater, bedrock, or other impermeable surfaces (Table 3). Several states set minimum depths to groundwater and bedrock that are more permissive than Vermont's. Pennsylvania, Massachusetts, and North Carolina all set minimum depths to seasonal high groundwater or bedrock of two feet below the bottom of the infiltration practice. Most other states surveyed use a minimum vertical separation of three feet—with more conservative criteria, in a few cases, for practices infiltrating runoff from large areas (an acre or more of impervious area) or if the practice is located in a water supply protection area.

Table 3. Summary of minimum vertical separation requirements for infiltration practices.

State (date of manual)	Minimum depth to groundwater/bedrock for infiltration practices
Vermont (2002)	3 feet from bottom of practice to seasonal water table or bedrock
Washington (2012)	1 foot from bottom of facility to groundwater, bedrock, or impervious for systems serving drainage areas: 1) less than 5,000 sq. ft. of pollution- generating impervious surface, and 2) less than 10,000 sq. ft. of impervious surface; and, 3) less than 3/4 acre of pervious surface. 3 feet from bottom of facility to groundwater, bedrock, or impervious for facilities larger than the above thresholds
Pennsylvania (2008)	2 feet to seasonal high groundwater and bedrock
Massachusetts (2008)	2 feet from bottom of practice to seasonal high water table, bedrock, and/or impermeable layer
North Carolina (2007)	2 feet to seasonal high groundwater and bedrock (4 feet recommended)
Virginia (1999)	2 to 4 feet between bottom of infiltration facility and the existing water table or bedrock
New York (2010)	3 feet from bottom of practice to seasonal water table or bedrock
Rhode Island (2010)	3 feet to seasonal high groundwater or bedrock
Minnesota (2008)	3 feet from bottom of practice to seasonally high water table or bedrock
New Hampshire (2008)	≥ 3 feet to seasonal groundwater or bedrock from bottom of BMP, except: ≥ 4 feet if within groundwater or water supply intake protection area ≥ 1 foot if runoff has been treated prior to entering the BMP
Maine (2006)	3 feet from bottom of practice to seasonal water table 5 feet of saturated overburden above bedrock for practices with contributing areas of one acre or more of impervious area

Two states have set a minimum vertical separation distance of only one foot to seasonal high groundwater if particular conditions are met. New Hampshire's manual allows only one foot of separation if runoff has been treated (80% reduction in TSS or better, (New Hampshire DES, 2008)), while the state of Washington allows one foot of separation for small infiltration practices (treating less than 5,000 sq. ft. of pollution- generating impervious surface, less than 10,000 sq. ft. of total impervious surface, and less than 3/4 acres of pervious surface).

Recommendations:

- The current minimum depths to groundwater and bedrock of 3 feet below the bottom of an infiltration practice is in the middle of the range of separation distances reviewed.
- Consider decreasing the minimum vertical separation distance to limiting features for small infiltration practices that are unlikely to produce substantial groundwater mounding.

Table 4. Summary of Horizontal Setback Requirements for Infiltration Practices

State (date of manual)	Environmental Features			Development Features						
	Slope 15% or Greater	Slope 20% or Greater	Surface water	Property Lines	Soil Absorption System	Private/ individual well	Surface drinking water supply	Public/ community well	Building foundation (upslope)	Building foundation (downslope)
Vermont (2002)					35	100			35	35
New York (2010)					35	100			35	35
Maine (2006)	50		75	25	100	300		Outside Zone II	100	20
Massachusetts (2008)	50	100	50			100	Outside Zone A	Outside Zone I	100	10
Minnesota (2008)	Not allowed	200		10	35	50		50	10	10
New Hampshire (2008)	Not allowed									
North Carolina (2007)						100				
Pennsylvania (2008)		Avoid			50	50		100	100	10
Rhode Island (2010)	25-50		50		15-25	50-100	100-200	200-400	10-50	10-25
Virginia (1999)	50				Consult local HD	100			100	20
Washington (2012)*		50			10+					

*Additional setbacks: 100 feet from closed or active landfill; 10 feet from UST with capacity less than 1,100 gal; 100 feet from UST with capacity over 1,100 gal; for large septic systems see separate rule for setbacks

2.2.3. Horizontal Setback Requirements

The horizontal setbacks from environmental features (such as surface waters) and development-based features (such as property lines, water supply wells, and building foundations) required when designing infiltration practices in Vermont were compared to those specified in other states' manuals (Table 4). The VSWMM contains setback requirements for critical development-based features (wells, soil absorption systems/ leachfields, and building foundations), and these setback distances are generally well within the ranges for similar setbacks prescribed in other states. In all cases outside of Vermont, New York and Minnesota, where setback distances from building foundations are prescribed, the upslope or upgradient separation distance is substantially more conservative than the downslope/downgradient separation requirement.

The VSWMM is silent on the subject of horizontal setbacks to environmental features such as steep slopes or surface waters. Some, but not all, of the other state manuals reviewed contained some guidance on setback distances from both of these features (Table 4). The most common setback distance was 50 feet (for both steep slopes and surface waters).

Recommendations:

- The horizontal setback distances from development-based features in VSWMM are generally consistent with current practice in other states and should be retained.
- Consider changing the building/foundation setback distance to account for the position of the infiltration feature on the landscape (up-slope or down-slope from the building).
- Consider including horizontal setback requirements for environmental features (particularly steep slopes and surface water).

2.2.4. Minimum Soil Characterization Requirements

The minimum requirements for site characterization related to infiltration and bioretention basins in the current VSWMM are substantially more conservative than most other states surveyed (Table 5). The only exception is New York's 2010 stormwater manual, which contains exactly the same requirements as Vermont's manual. The most frequently cited requirement is for one test pit (or soil boring) and infiltration test per 5,000 square feet of infiltration basin or per 100 linear feet of infiltration trench—a standard that appears in the 1992 *Stormwater Manual for Western Washington* and which has since been widely adopted. The minimum tests per square foot of basin area or linear feet of trench are also usually accompanied by a required minimum number of tests per basin (most commonly, 2 test pits or soil borings per trench and 1-3 test pits or soil borings per infiltration basin).

A few of the states surveyed utilize variations on or additions to the basic criteria outlined above. New Hampshire's stormwater manual requires fewer test pits or soil borings (roughly one test pit per 10,000 square feet of infiltration basin area), but requires a greater density of infiltration test locations than most other states surveyed (one infiltration test per 2,500 square feet of infiltration basin area) (New Hampshire DES, 2008). Pennsylvania's manual includes tiered minimum site characterization requirements, depending on the type of development proposed (residential subdivision, high-density/multifamily residential, or large (>1 acre) BMPs) (Pennsylvania DEP, 2008).

An assessment of the response of the water table to artificial recharge at or near the ground surface from infiltration practices, commonly called a mounding analysis, is required for larger practices or marginal site

Table 5: Minimum Soil Characterization Requirements for Infiltration and Bioretention Practices

State (date of manual)	Testing frequency/type requirements
Vermont (2002)	Feasibility testing: one field infiltration test per facility, or previous test data Concept design testing: Must correspond to practice location 1 infiltration test and 1 test pit per 50' of infiltration trench 1 infiltration test and 1 test pit per 200 sf of infiltration basin, sand filter, or bioretention facility area
New York (2010)	Identical to VSWMM
Maine (2006)	None specified (as of Sept. 7, 2012)
Virginia (1999)	1 soil boring per 5,000 sf of infiltration basin area; min. 3 soil borings per basin 1 soil boring per 50 feet of trench length, min. 2 soil borings per trench
Massachusetts (2008)	1 soil boring per 5000 sf of basin area, minimum 3 samples per basin. Min. 2 soil borings per infiltration trench; trenches over 100 ft., 1 boring per additional 50 ft. Must correspond to practice location Mounding analysis required if bottom of practice is less than 4 feet above seasonal groundwater and will attenuate peak discharge from 10-year or higher 24-hour storm
Rhode Island (2010)	1 infiltration test and 1 test pit /5,000 sf for infiltration, pervious pavement, filtration Mounding analysis required if bottom of practice is less than 4 feet above seasonal groundwater and will attenuate peak discharge from 10-year or higher 24-hour storm
North Carolina (2007)	1 test hole per 5,000 sf of infiltrating area, minimum 1 boring and infiltration test per facility (taken within the proposed limits of the BMP).
New Hampshire (2008)	Required in location of infiltration treatment practice Infiltration Basins : Less than 2,500 sf = 1 test pit; 2,500 sf – 20,000 sf = 2 tests; 20,000 sf – 30,000 sf = 3 tests; 30,000 – 40,000 sf = 4 tests; 1 more test for every add'l 10,000 sf. 1 infiltration test per 2,500 sf of basin area, 1 test per 1,000 sf if manmade soils present Infiltration Trenches: 1 test pit and infiltration test per 100 LF; 1 test for each 50 LF of trench if manmade soils present
Pennsylvania (2008)	Single-family subdivisions, on-lot BMPs: 1 test pit per lot, within 25 feet of proposed BMP. Multi-family, high density residential developments: 1 test pit per BMP area or acre Large infiltration areas (basins, commercial, institutional, industrial, and other proposed land uses): 4-6 tests per acre of BMP area. At least 1 infiltration test at the proposed bottom elevation of an infiltration BMP; and a minimum of two tests per Test Pit is recommended.
Washington (2012)	For basins, min. 1 test pit or test hole per 5,000 sf of basin infiltrating surface (min. 2/basin). For trenches, min. 1 test pit or test hole per 200 feet of trench length (min. 2/trench). Installation of at least 3 monitoring wells, and monitoring of water levels through 1 wet season, required (unless depth to groundwater is more than 50 ft. bgs) If using the soil Grain Size Analysis Method for estimating infiltration rates: laboratory testing, at minimum, one-grain size analysis per soil stratum in each test hole within 2.5 times the maximum design water depth, but to not less than 10 feet.

conditions in the Massachusetts, Rhode Island, and Washington stormwater manuals, and is recommended in Minnesota's manual. The purposes of the mounding analysis are generally to ensure that required vertical separation distances between the bottom of infiltration facilities and groundwater can be maintained at larger design storms, to ensure that infiltration facilities can be fully dewatered within 72 hours (or other time period specified in each state's manual), and to demonstrate that the groundwater mound beneath the infiltration facility will not break out above the nearby land surface. In all cases where mounding analyses are required or recommended, the use of analytical methods to solve for ground water mounding based on Hantush (1967) and Glover (1960) are recommended.

In Washington State, the installation of monitoring wells and one year of groundwater level monitoring is also required for sites where infiltration practices are proposed, unless the water table is more than 50 feet below ground surface (Washington DOE, 2012).

Recommendations:

- Align Vermont's test pit and infiltration test spacing for infiltration basins with the widely adopted minimum spacing of 1 test per 5,000 square feet.
- Consider setting a minimum number of test pits or soil borings per practice (for instance, two tests for an infiltration trench or three tests for an infiltration basin.
- Consider requiring a mounding analysis for marginal sites and/or large BMPs.

2.2.5. Test Pit or Soil Boring Depth Requirements

The requirements for the depth of test pits or soil borings used to characterize the soils beneath a proposed infiltration practice varied considerably among the states surveyed (Table 6). Several states' manuals,

Table 6. Summary of Depth Requirements for Test Pits or Soil Borings

State (date of manual)	TP/Boring depth requirements
Vermont (2002)	Minimum 4 feet below proposed facility bottom
Maine (2006)	None in manual
Massachusetts (2008)	None in manual
North Carolina (2007)	None in manual
Virginia (1999)	3 feet below the bottom of the facility
New York (2010)	Minimum 4 feet below proposed facility bottom
Rhode Island (2010)	4 ft below the proposed facility bottom
Minnesota (2008)	Minimum 5 feet below the bottom elevation of proposed infiltration practice.
New Hampshire (2008)	5 feet below expected practice bottom, or to ESHGW or bedrock
Pennsylvania (2008)	72-90 inches or until bedrock or fully saturated conditions are encountered
Washington (2012)	At least 5 times the maximum design depth of ponded water proposed for the infiltration facility, and not less than 10 feet below the base of the facility; continuous sampling required for at least the first 10 feet. If groundwater is less than 15 ft. from facility bottom and mounding analysis needed, determine thickness of the saturated zone.

including those for Maine, Massachusetts, and North Carolina, contained no requirements for the depth of soil characterization. Where characterization depths below the bottom of any proposed infiltration practice were specified, the VSWMM requirement of 4 feet below the proposed practice bottom was in the middle of the range. The state of Washington's requirements are the most intensive of the manuals surveyed, with characterization required to a depth of at least 10 feet below the base of proposed infiltration practices.

Recommendation: Maintain the current VSWMM requirement for test pits or soil borings to extend at least 4 feet below the proposed bottom elevation of any infiltration facility.

2.2.6. Acceptable Infiltration Testing Methods

The infiltration testing method prescribed in VSWMM, derived from Maryland Dept. of Environment guidance released in 1987, remains in fairly widespread use. It appears in several manuals, including those for New York, New Hampshire, Pennsylvania, and Virginia (Table 7). A number of other point testing methods for measuring saturated hydraulic conductivity are commonly recommended in other states surveyed, particularly methods employing double ring permeameters/infiltrometers, Guelph permeameters, and compact constant head or Amoozegar permeameters (Tables 7 and 8). North Carolina's and Washington state's stormwater manuals both prescribe basin flooding or pilot pit infiltration testing methods, where a small basin or pit is excavated with the bottom elevation of the pit at the bottom elevation of the proposed practice, the pit or basin is flooded with water, and the rate of exfiltration from the test basin is measured. Where the manuals surveyed discuss percolation testing (as for on-site wastewater treatment systems), it was usually to prohibit the use of percolation test results in the design of stormwater infiltration practices.

Table 7. Summary of Acceptable Methods for Determining Infiltration Rates

		Estimation Methods			Field Measurement Methods					
State (date of manual)	Ksat adjusted for design?	Soil Survey Ksat	Rawls et al 1982 (or similar)	Soil grain size analysis	VSWMM method	Guelph permeameter	Falling head permeameter	Double ring permeameter/ infiltrometer	Amoozegar permeameter	Basin flooding or pit scale infiltration test
Vermont (2002)	No				X					
New York (2010)	No				X					
Virginia (1999)	No				X					
Maine (2006)	No			X				X		
Massachusetts (2008)	No		X			X	X	X	X	
Minnesota (2008)	Yes		X					X		
New Hampshire (2008)	Yes	X			X	X		X	X	
North Carolina (2007)	No							X		X
Pennsylvania (2008)	Yes				X	X		X	X	
Rhode Island (2010)	Yes		X			X	X	X	X	
Washington (2012)	Yes			X						X

Table 8. Descriptions of Infiltration Testing and Saturated Hydraulic Conductivity Estimation Methods

State	Acceptable infiltration testing methods
Vermont (2002)	Point infiltration test method described in rule. (6-inch diameter, 24-inch long solid casing, 24-hour pre-soak, four 1-hour infiltration test periods)

State	Acceptable infiltration testing methods
	Use of laboratory grain size testing to determine infiltration rates prohibited
New York (2010)	Identical to VSWMM
Virginia (1999)	Identical to VSWMM
Maine (2006)	In-place well or permeameter testing, analyses of soil gradation, or other means acceptable to the department
Massachusetts (2008)	In-situ tests not required when "Static" or "Simple Dynamic" Methods, or LID Site Design Credits proposed for sizing stormwater recharge BMPs. In these situations, saturated hydraulic conductivities listed by Rawls 1982 shall be used (based on soil texture and HSG) If “Dynamic Field” sizing method used, saturated hydraulic conductivity testing is required. Acceptable tests include: Guelph permeameter - ASTM D5126-90 Method Falling head permeameter – ASTM D5126-90 Method Double ring permeameter or infiltrometer - ASTM D3385-03 , D5093-02 , D5126-90 Methods Amoozemeter or Amoozegar permeameter – Amoozegar 1992
Minnesota (2008)	If infiltration rate is not measured, an appropriate infiltration rate is selected from a table (based on soil texture and HSG). Rates represent the long-term infiltration capacity. Rate selected based on the least permeable soil horizon within the first five feet below the bottom elevation of the proposed practice. If infiltration rates are measured, tests shall be conducted at the proposed bottom elevation of the practice. If the infiltration rate is measured with a double-ring infiltrometer the requirements of ASTM D3385 shall be used. Measured infiltration rates are adjusted for design purposes to account for long-term infiltration capacity. Recent MN research suggests ~10 infiltration measurements required to capture spatial Ksat variation and compute the mean Ksat values (Gulliver 2011).
New Hampshire (2008)	Default Ksat values may be used for native soils only (choose lowest Ksat value reported in soil survey for soils beneath infiltration practice, apply safety factor of 2) Acceptable methods for field Ksat tests include Guelph Permeameter, Compact Constant Head Permeameter, Double-Ring Infiltrometer (ASTM 3385), and the Borehole Infiltration test (identical to VSWMM). If a Guelph Permeameter or Compact Constant Head Permeameter test is used, the test should be performed a minimum of 3 times for each test location
North Carolina (2007)	Double-ring infiltrometers or basin flooding tests (EPA, 1981). Other widely accepted methods also allowed.
Pennsylvania (2008)	Double-ring infiltrometer tests and percolation tests (as for on-site wastewater systems) discussed specifically. Perc tests not recommended for infiltration basin designs. Other allowable methods not discussed in detail are listed in the manual (identical to those listed for New Hampshire, above).
Rhode Island (2010)	Design infiltration rates shall be determined by using Table 5-3 (Rawls et al. 1982 based only on soil texture), or shall be determined by in-situ rates (using a factor of safety of 2 from the field-derived value). Perc tests are not acceptable. Acceptable test methods identical to those listed for Massachusetts, above.
Washington (2012)	Large Scale Pilot Infiltration Test (PIT): a large-scale in-situ infiltration measurement in a test pit with horizontal surface area of the bottom measuring about 100 square feet (preferred method) Small-Scale Pilot Infiltration Test: as above but TP bottom is 12-32 square feet, suitable for drainage areas less than 1 acre, small or widely dispersed practices, or sites with high infiltration rates and uniform subsurface characteristics Soil Grain Size Analysis Method: Estimate initial Ksat for each defined layer below infiltration feature to a depth of 2.5 times the maximum depth of water, but not less than 10 feet, using a prescribed equation (p. 3-79, equation 1, Massmann and Massmann et al., 2003). Average Ksat determined by calculating harmonic mean at each location; correction applied based on site variability, number of tests conducted, test method uncertainty, clogging potential

Several states allow estimation of saturated hydraulic conductivity values for use in designing infiltration practices, rather than requiring field testing in all instances (Table 7). New Hampshire’s manual was the only document discovered that allows the use of the saturated hydraulic conductivity values contained in the NRCS Soil Survey (the lowest Ksat value reported in the soil survey for soils beneath the proposed infiltration practice must be used) (Table 8). Three states, including Massachusetts and Rhode Island, allow designers to select an appropriate infiltration rate from a table, usually using the soil texture and/or hydrologic soil group of the least permeable soil horizon within the first five feet below the bottom elevation of the proposed infiltration practice. In the Massachusetts and Rhode Island manuals, these infiltration rates are derived generally from the work of Rawls et al. (1982). Minnesota's 2008 stormwater management manual contains a similar table—but the table in the Minnesota manual is based on a review of guidance manuals, other stormwater references , and eight years' worth of infiltration testing results collected during the design of infiltration practices located in the South Washington Watershed District (southeast of St. Paul). Two states (Maine and Washington) allow the use of soil grain size analyses to estimate saturated hydraulic conductivity values for designing infiltration practices. While Maine's stormwater manual allows the practice, little guidance is provided as to its implementation. Washington's manual, in contrast, provides a detailed methodology for collecting soil samples, completing the grain size analyses, and calculating a design infiltration rate based on the resulting grain size distributions (Washington DOE, 2012).

Currently, the VSWMM allows measured infiltration rates to be used as-is for sizing infiltration practices (Table 7). The state manuals reviewed were evenly divided on this practice. Several other states, including Massachusetts, Maine, and New York, use measured infiltration rates without modification in sizing infiltration practices. A number of other states, including New Hampshire and Rhode Island, require that measured infiltration rates be adjusted by a prescribed safety factor in order to account for soil variability, uncertainties in testing methods, eventual clogging of the infiltration facility, and other factors (Tables 7 and 8).

Recommendations:

- The point infiltration test described in the 2002 VSWMM remains consistent with current practice in several other states and should remain an allowable method for measuring saturated hydraulic conductivity.
- Consider describing and allowing other commonly accepted methods for measuring saturated hydraulic conductivity.
- Consider allowing the use of alternate methods for determining Ksat, such as Rawls et al 1982 modified to consider soil texture and HSG—particularly in low-risk situations or for small infiltration practices.
- Consider requiring adjustment of estimated or measured saturated hydraulic conductivity values for use in designing infiltration practices to account for uncertainty due to variable soils, eventual clogging, etc.

2.2.7. Required Credentials for Site Characterization Professionals

Policies regarding the credentials required in order to complete site characterization activities in support of the design of infiltration practices varied considerably between the states surveyed (Table 9). Three states—Maine, North Carolina, and Virginia—do not provide guidance about what credentials are required for professionals completing site characterization activities. Most other states surveyed specify that professionals who can substantiate their qualifications and experience are allowed to carry out evaluations. Often, specific credentials are listed (licensed professional engineer, soil scientist, geologist, etc.). In a few cases, such as in Massachusetts, either a licensing credential or college-level coursework in a related field are sufficient.

Table 9. Summary of Required Credentials for Site Characterization Professionals

State (date of manual)	Required credentials for site characterization professionals
Vermont (2002)	Registered Vermont professional engineer, licensed soil scientist, or licensed geologist
Maine (2006)	Not specified
North Carolina (2007)	Not specified
Virginia (1999)	Not specified
Minnesota (2008)	Highly Recommended that field verification be conducted by a qualified geotechnical professional
Pennsylvania (2008)	Qualified professionals who can substantiate by qualifications/experience their ability to carry out the evaluation
Massachusetts (2008)	*Competent Soils Professional* (an individual with demonstrated expertise in soil science, including, but not limited to, a Massachusetts Registered Professional Engineer, Engineer in Training (EIT certificate) with a concentration in civil, sanitary or environmental engineering, or Bachelor of Arts or Sciences degree or more advanced degree in Soil Science, Geology, or Groundwater Hydrology from an accredited college or university.)
New York (2010)	Registered NY professional engineer, licensed soil scientist, or licensed geologist
New Hampshire (2008)	Qualified professional (certified soil scientist, a professional geologist, or an engineer)
Rhode Island (2010)	Qualified professional (DEM-licensed Class IV soil evaluator or RI-registered PE)
Washington (2012)	Appropriate licensed professional (e.g., engineer, geologist, hydrogeologist)

Recommendations:

- The 2002 VSWMM requirement that a site characterization professional be a registered Vermont professional engineer, licensed soil scientist, or licensed geologist is consistent with current practice in the states surveyed. No changes to this requirement are necessary.
- There are currently no requirements for continuing education related to site characterization practices (nor for any other area of practice in VSWMM)—yet ongoing training and engagement are critical to advancing the improvement of stormwater management practices in Vermont. Consider implementing requirements or recommendations for continuing education, possibly in coordination with the DEC Wastewater Management Division's Licensed Site Designer program

3. CHANNEL PROTECTION TREATMENT STANDARD

The shape (plan and profile) of a stream channel reflects the range of flows conditions that the stream experiences over the course of days, weeks, years and decades. That said, flows above a certain threshold, called “channel-forming” flows, are thought to be more effective at changing the characteristics of the channel. As pervious surfaces like fields and forests are converted to impervious surfaces during development activities, both the volume of runoff and thus the frequency of "channel-forming" events will increase substantially. The primary purpose of a Channel Protection Volume (CPv) standard is to protect stream channels from excessive erosion caused by the increase in runoff from new development. The rationale for this criterion is that runoff will be stored and released in a gradual manner such that critical erosive velocities will rarely be exceeded in downstream channels.

3.1. Current VSWMM Practice

The channel protection treatment standard is described in Section 1.1.2 of the 2002 VSWMM. Key elements include:

- Providing extended detention storage for the one-year, 24-hour rainfall event (Table 10).
    - If the receiving water is a cold water fishery, 12 hours of extended detention is required;
    - If the receiving water is a warm water fishery, 24 hours of extended detention is required.
- Releasing the channel protection volume (CPv) at a roughly uniform rate over the required detention period.
- Calculating the CPv considering runoff from both on-site and any off-site drainage contributing to the point of discharge, using the methodology developed by Harrington (1987) or by an equivalent method for small area hydrology.

Table 10. Rainfall Depths Associated with the 1-Year, 24-Hour Storm Event, Table 1.2 from VSWMM

Vermont County	1-yr, 24-hr Rainfall Depth
Addison	2.2
Bennington	2.3
Caledonia	2.2
Chittenden	2.1
Essex	2.2
Franklin	2.1
Grand Isle	2.1
Lamoille	2.1
Orange	2.2
Rutland	2.3
Washington	2.2
Windham	2.3
Windsor	2.3

3.2. Options and Recommendations

Three areas of current VSWMM practice related to channel protection were compared to practices and policies in place in other states:

1. Design criteria used to protect downstream channels from erosion
2. The rainfall depth used in channel protection calculations (NOAA, TP 40, 1961)
3. Strategies used to reduce thermal stress that could be caused by extended detention in receiving waters designated as cold water fisheries.

Each area, along with recommendations for improvements in future editions of the VSWMM, is summarized below.

3.2.1. Design Criteria for Protecting Downstream Channels

Historically, states have employed a range of design criteria in an effort to protect downstream channels from erosion caused by increased runoff associated with new development. A summary of the approaches to channel protection currently being employed in several other (mostly New England, Mid-Atlantic, and Midwest cold-climate) states is provided in Table 11. In general, these design criteria involve rate-control detention and extended detention facilities. The two most common approaches are:

- Extended detention of the one-year storm event: the 1-year, 24-hour storm is detained for between 12 and 24 hours with runoff stored and released in a gradual manner so that critical erosive velocities are seldom exceeded in downstream channels.
- Two-year control: post-development peak discharge rates are held to two-year pre-development levels, with the idea that keeping downstream flows below the two-year level will minimize erosion.

A few other approaches are seeing more limited application. Washington State has implemented two-year storm “overcontrol” which controls the post-development peak flow rate to 50 percent or less of the predevelopment level (WDE, 2012). Distributed runoff control (DRC), which involves detailed field assessments and hydraulic and hydrologic modeling to determine the hydraulic stress and erosion potential of bank materials, is being implemented in the province of Ontario (OME, 2003).

The CPv standard is an improvement over two-year peak discharge control, which did not protect channels from downstream erosion and could actually contribute to erosion since banks were effectively exposed to a longer duration of erosive bankfull and sub-bankfull events. There is an inherent conflict, however, between design processes and practices that emphasize decentralization and infiltration (as with LID and GSI) and a requirement like CPv, where designers usually must centralize the collection of runoff in order to detain it.

A number of different strategies have been used in other jurisdictions that attempt to resolve the conflict, especially as these jurisdictions move closer to implementing runoff reduction frameworks (see Section 3.2.1.1). The goal of runoff reduction is usually to ensure that no runoff occurs from a particular design storm (often the 90th percentile rainfall event, or the first inch of rainfall regardless of percentile) in the post-development condition. In New York, for example, the CPv standard requires 24-hour extended detention only for the portion of the one-year, 24-hour storm event that cannot be treated using runoff reduction strategies—volume reductions achieved using GSI can be deducted from CPv (New York State DEC, 2010). More information on low impact development practices and how they may be better incorporated into the VSWMM is presented in Section 4 of this report.

Table 11. Summary of Approaches to Channel Protection

State/Province	Extended Detention of the One-Year Storm	Two-Year Control	Other
Vermont	X		
Delaware		X	
Georgia	X		
Maryland	X		
Michigan		X	
Minnesota		X	
New York	X		
Pennsylvania		X	
Rhode Island	X		
Virginia	X		
Washington			X (2-year over-control)
Wisconsin		X	
Ontario			X (distributed runoff control)

3.2.1.1. Runoff Reduction Approach

The runoff reduction approach seeks to maintain the same predevelopment runoff volume delivered to a stream after a site is developed (Chesapeake Stormwater Network, 2009). In its simplest terms, this means achieving the same predevelopment runoff coefficient for every storm, up to a designated storm event. Runoff reduction is defined as the total runoff volume that is reduced through canopy interception, soil infiltration, evaporation, rainfall harvesting, engineered infiltration, extended filtration (e.g., bioretention or dry swales with under drains that delay the delivery of stormwater from small sites to the stream system by six hours or more) or evapotranspiration. Key benefits of a runoff reduction approach are projected to include:

- Post-development hydrology that mimics pre-development hydrology with respect to runoff volume, duration, and velocity.
- Explicit acknowledgment of the hydrologic difference between forest and turf, and disturbed and undisturbed soils, which should create better incentives to conserve forests, reduce mass grading, restore soils, and reforest sites.

Runoff reduction approaches are generally characterized by three design steps (Chesapeake Stormwater Network, 2009):

- Avoid unnecessary site disturbance and minimize the creation of impervious surface;
- Reduce runoff volumes through the use of management practices that provide infiltration, extended filtration, soil amendments, rainwater harvesting and reuse, evapotranspiration; and,

- Employ additional structural controls, as needed, to reduce the peak rate of discharge or reduce the pollutant load concentrations in the runoff volume.

Runoff reduction approaches are site-specific and generally iterative, in that implementation procedures require site designers to optimize the use of site design and non-structural management practices before employing structural controls. This, in turn, increases the complexity associated with both the preparation and regulatory review of proposed stormwater management schemes that employ runoff reduction. States that are currently closest to or are actively implementing a full-blown runoff reduction program (such as Virginia and Minnesota) have typically invested significant time and staff resources in a stepwise, deliberative stakeholder process in order to tailor the approach to their specific water quality concerns.

Recommendations:

- For the time being, the current CPv standard should be left in place. The literature review did not identify specific modifications that might be made to the CPv standard to address channel scour, rather the literature review showed a number of states are pursuing a runoff reduction approach in lieu of more traditional CPv standards.
- Consider establishing a performance-based runoff reduction goal, such as retaining the first inch of runoff on-site, and create a suite of credits and incentives – including, but not limited to, modifying the applicable stormwater treatment standards – to encourage site designers to give priority to achieving the runoff reduction goal.
- Consider tracking the near-term performance and results achieved by runoff reduction programs planned to be brought on-line in many of the Chesapeake Bay states, and commit to re-evaluating whether a mandatory runoff reduction standard should be implemented in Vermont within the next five years.

3.2.2. Rainfall Depth Used in CPv Calculation

The Weather Bureau of the Commerce Department developed and published a Rainfall Frequency Atlas of the United States in May of 1961. Often referred to as "TP-40," the document is composed of rainfall charts for storm events from a 1-year, 30-minute rainfall up to a 100-year, 24-hour event. TP-40 has long been considered the sole source for rainfall distributions and storm rainfall intensities in New England; TP-40 is the basis for the rainfall depths presented in Table 10. Its charts are relied upon by numerous municipalities and local, state and federal agencies, as well as engineers and hydrologists. The rainfall quantities are used for designing many of the stormwater controls that are in place today.

Many scientists and engineers have expressed concern that TP-40 has become increasingly dated as our climate has shifted. As shown in Figure 1, the average annual rainfall in Vermont has increased by more than 3.5 inches in the past century. A substantial proportion of the increase in average annual precipitation has occurred after the publication of TP-40.

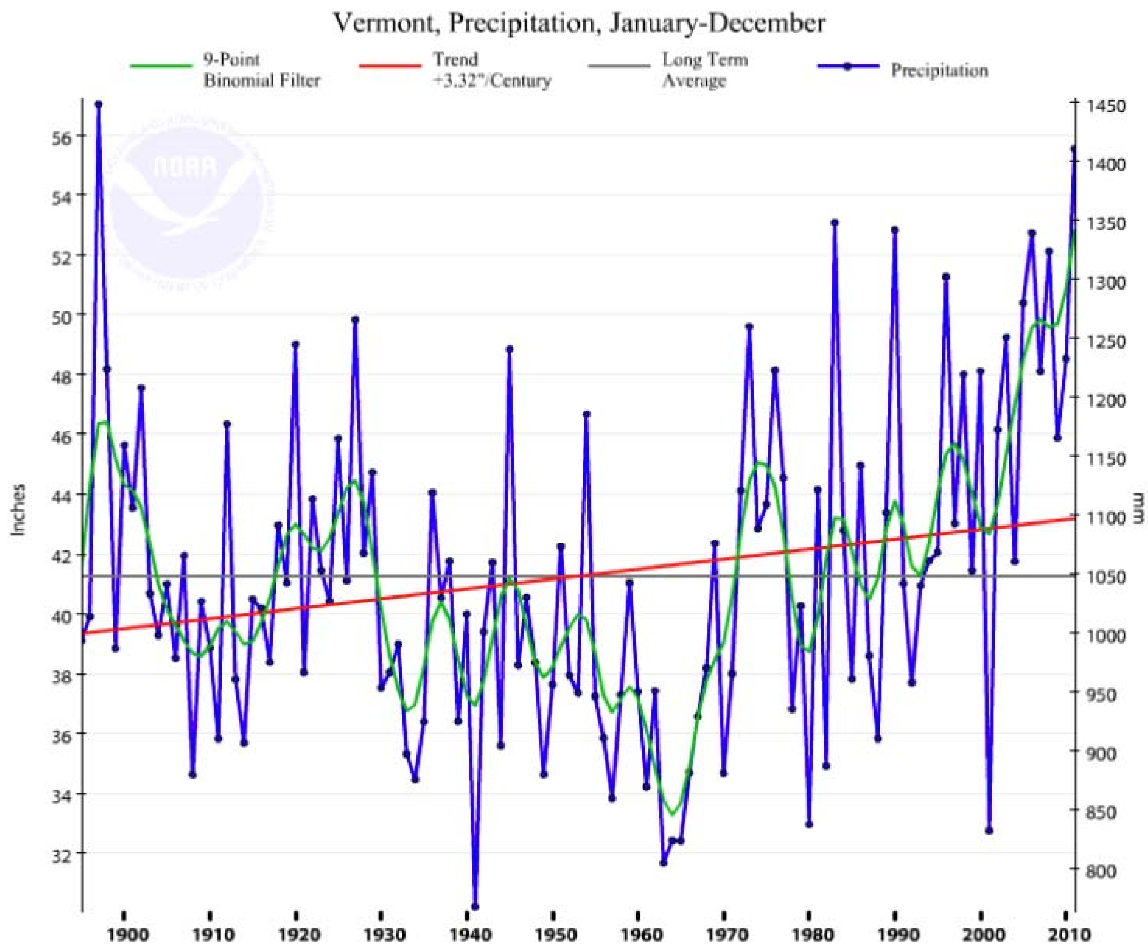

Figure 1: Average Annual Vermont Precipitation, 1895-2011 (NOAA, 2012)

TP-40 is based on a dataset that ended in 1957, and the average length of the daily precipitation records used was less than 30 years. As such, the resultant design storm events are based on records that are nearly 50 years out of date and that cover a much shorter time span (and thus contain less information) than records available today. In addition, relying on TP-40 data implicitly assumes that climate has not changed or fluctuated significantly in the past half century or so. Recent research at Cornell University (Degeaetano, 2009):

> *In the Northeast, the median decrease of both the 50- and 100-yr recurrence interval is nearly 40%. Thus what would be expected to be a 100-yr event based on 1950–79 data occurs with an average return interval of 60 yr when data from the 1978–2007 period are considered. The reduction for recurrence intervals for the 2-yr storm in the Northeast as well as the 2-, 50-, and 100-yr storms in the western Great Lakes and Northwest regions is approximately 30%.*

A recent report by Dr. Alan Betts found that precipitation has increased in Vermont by 15-20% in the past fifty years and that heavy downpours have increased in frequency and intensity across most of the U.S., especially in the Northeast, where there has been a 67% increase in the amount of precipitation falling during very heavy events (Betts, 2011). Researchers at the University of Minnesota have also identified a correlation between increased annual precipitation and higher daily maximum precipitation within that year, suggesting another reason to believe that TP-40 precipitation design values could be underestimates (Skaggs et al, 2006).

Although the typical rainfall and design storm data provided by TP-40 has been updated for certain parts of the country, similar work has not been completed for New England.

Recommendation:

- Currently, there is no viable, comprehensive alternative to TP-40 available for Vermont. In order to ensure the long-term sufficiency of the stormwater practices that are currently being designed and constructed in Vermont, the State should identify strategies that could be employed to develop an understanding of the anticipated rainfall depth for different design storm conditions under current climate scenarios.

3.2.3. Strategies for Cold-Water Fisheries Protection

In addition to stormwater management design and channel protection considerations, the CPv standard's extended detention requirements also attempt to address concerns related to thermal stress. The longer stormwater is stored in a surface system exposed to direct sunlight, the more already-elevated summer runoff temperatures may increase. Although heated stormwater potentially can affect any aquatic ecosystem, it is especially a concern in habitats capable of supporting cold water fish, such as trout.

The potential for thermal stress in water bodies across the state is high, since over 60% of Vermont's streams are small, cold water habitats (VTDEC, 2012). Moreover, in many instances, thermal stress occurs in concert with other stresses to compound effects on aquatic organisms. The VSWMM currently addresses this concern by reducing the CPv extended detention requirement to 12 hours if the receiving stream is a cold water fishery.

Based on the Watershed Management Division's own evaluation, thermal impacts are an important stressor on Vermont's aquatic habitats. While excessively high temperatures impair a relatively small number of stream miles in Vermont, the impacts in those locations are significant. The 2010 statewide water quality assessment suggests that for rivers and streams, 76 miles are impaired due to excessively high temperature, and an additional 480 miles experience thermal stress. DEC's *Surface Water Management Strategy* specifically notes the need to "improve stormwater regulations and promote stormwater Best Management Practices to include temperature controls and favor infiltration over detention" (VTDEC, 2012).

Recent research at the University of New Hampshire Stormwater Center (UNHSC) evaluating the thermal impacts of a range of stormwater treatment systems found that infiltration and filtration systems are best able to buffer runoff temperatures (UNHSC, 2011). UNHSC researchers also found that while gravel wetlands, and to a lesser extent bioretention treatment practices, have a large surface area, they buffer runoff temperatures because the filtration practices have a deep subsurface footprint. Additionally, the permanent pool of water in a retention pond can act as a heat sink during periods of extreme heat.

A number of states have incorporated specific measures into their stormwater manuals to avoid and mitigate thermal impacts associated with stormwater discharges, including requiring thermal exchange with "thermal sinks" through infiltration or storage in underground structures, thermal exchange during conveyance and discharge through riparian zones, and reuse of stormwater. For example, the Maine *Stormwater Best Management Practices Manual* requires that "[u]nless the receiving water is a lake, major river or tidal water, stormwater management systems should either incorporate strategies to avoid heating of the stormwater or to effectively cool it down (22°C or cooler)" (MEDEP, 2011a).

Specific measures other agencies are promoting include:

- Maine Department of Environmental Protection requires that detention practice outlet structures draw water from the bottom of a deep pool or through an under-drained gravel trench;
- North Carolina Extension recommends that vegetative treatment practices, such as stormwater wetlands and bioretention areas, be planted with broadleaf vegetation to ensure they are well-shaded; and,
- EPA encourages infiltration practices, as well as strategies that emphasize the capture and reuse of stormwater runoff, in areas tributary to cold water habitats.

Recommendation:

- Consider adding requirements to the VSWMM that limit the temperature of stormwater discharges to cold water habitats to 22°C or less.

4. INTEGRATING LID CONCEPTS INTO THE VSWMM

Since the publication of the Vermont Stormwater Management Manual in 2002, the stormwater management field as a whole has made substantial progress in understanding the performance and benefits of Low-Impact Development (LID) concepts, non-structural site design strategies, and structural best management practices. The US EPA defines LID as "an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage that treat stormwater as a resource rather than a waste product" (US EPA, 2012).

A number of states have, over the last several years, been examining or actively implementing runoff reduction (RR) frameworks as a means to ensure that LID concepts, including both non-structural site design strategies and decentralized structural BMPs that emphasize re-use or infiltration, are prioritized in development plans. The idea and basic design steps involved in using a RR approach to design and permit development or re-development projects was described in Section 3.2.1.1.

The 2002 VSWMM contains a series of stormwater runoff credits to reduce required treatment volumes for implementing what are essentially principles of LID site design, but the credits are voluntary and thus may not be widely used. In addition, a wide range of "green infrastructure" stormwater treatment practices have come into wider use over the last decade, but are not explicitly included as acceptable practices in the VSWMM. Structural treatment practices that have become more widely accepted—and that have been installed in Vermont despite not being explicitly included in VSWMM—include pervious pavement, green roofs, and runoff reclamation/storage/re-use (cisterns, rain barrels, etc.).

Here, Vermont's current practices regarding LID and its place in the state's stormwater regulations and manual are compared to current practice in a selection of other states. The states selected for review in this section were primarily in New England (Maine, Massachusetts, New Hampshire, New York, and Rhode Island) and the mid-Atlantic (New Jersey and Pennsylvania). Minnesota's current practice was also included, as a cold-weather state that is working towards implementing low-impact development practices as the "industry standard" for all future development. Stormwater management requirements for federal government installations mandated by the Energy Independence and Security Act of 2007 (EISA) are also included for comparative purposes where applicable.

4.1. Current Practice

In Vermont, Stormwater Construction Permits are administered through an NOI process for any project creating one acre or more of disturbance, and are approved separately from post-construction State Stormwater permits. A separate State Stormwater Permit (which may be coverage under a general permit in watersheds without stormwater impairment, coverage under a general permit developed for stormwater impaired watersheds, or an individual permit) is required for:

- New impervious surfaces greater than 1 acre;
- Redevelopment of existing impervious, where the redeveloped portion of the existing impervious surface is equal to or greater than one (1) acre;

- Expansions greater than 5,000 square feet if the total resulting impervious surface is greater than 1 acre (only the portion of the expansion over 1 acre is required to obtain coverage) (Vermont DEC, 2011)

Discharges of regulated stormwater runoff must obtain permit coverage consistent with the treatment standards within the Vermont Stormwater Management Manual (VSWMM) (Vermont DEC, 2002). Volume I of the manual describes treatment standards, acceptable BMPs that can be used to meet the treatment standards, and a series of voluntary Stormwater Management Credits—which are awarded for using a series of LID non-structural practices when developing projects.

Treatment standards in the VSWMM include:

- Water Quality Treatment Standard (WQv)
    - "The objective of the WQTS is to capture 90 percent of the annual storm events, and to remove 80 percent of the average annual post development total suspended solids load (TSS), and 40 percent of the total phosphorus (TP) load" (Vermont DEC, 2002).
- Channel Protection (CPv) (also, see discussion in Section 3 above)
    - "To protect stream channels from degradation, storage of the channel protection volume (CPv) shall be provided by means of 12 to 24 hours of extended detention storage (ED) for the one-year, 24-hour rainfall event. If a stormwater discharge is to a coldwater fish habitat, 12 hours of extended detention is required and if a stormwater discharge is to a warmwater fish habitat, 24 hours of extended detention is required" (Vermont DEC, 2002).
    - The 5th printing of the VSWMM added a provision to this standard that "For projects that have disconnected the majority of impervious surfaces per use of the credits in Section 3 such that routing to a detention facility is not achieved, the designer may use an alternative design standard. In these cases, the designer shall demonstrate that the postdeveloped peak discharge from the disconnected portion of the site for the one-year storm is no greater than the peak discharge from the same portion of the site as modeled as if 12-hour detention were provided."
- Groundwater Recharge (Rev)
    - "The average annual recharge rate for the prevailing hydrologic soil group(s) (HSG) shall be maintained in order to preserve existing water table elevations" (Vermont DEC, 2002). Either the Percent Area or Percent Volume method of calculation may be used, and both non-structural and structural methods may be used to demonstrate compliance with this standard.
- Overbank Flood Protection (Qp10)
    - "The post-development peak discharge rate shall not exceed the pre-development peak discharge rate for the 10-year, 24-hour storm event" (Vermont DEC, 2002).
- Extreme Flood Protection (Qp100)
    - "The post-development peak discharge rate shall not exceed the pre-development peak discharge rate for the 100-year, 24-hour storm event" (Vermont DEC, 2002).

Volume I, Section 3 of the VSWMM details a series of six voluntary, non-structural practices which, if applied to a project, result in the granting of stormwater credits that can reduce the required WQv and REv, thus reducing the size and cost of structural BMPs (Vermont DEC, 2002). These non-structural practices include:

- Credit 1. Natural Area Conservation
- Credit 2. Disconnection of Rooftop Runoff
- Credit 3. Disconnection of Non-Rooftop Runoff
- Credit 4. Stream Buffers
- Credit 5. Grass Channels
- Credit 6. Environmentally Sensitive Rural Development

Worksheets are provided in the permit application forms for use in demonstrating compliance with minimum criteria for each of the non-structural credits, and there are also worksheets for use in applying the credits to reduce the WQv for both flow based and volume based practices. The REv worksheet does not include such guidance for demonstrating compliance using non-structural practices.

Several structural LID practices are currently included in the VSWMM as acceptable stormwater treatment practices, including:

- Stormwater wetlands (including gravel wetlands and extended detention wetlands)
- Infiltration practices (basins and trenches)
- Filtering systems (sand filters, organic filters, and bioretention, e.g., “rain gardens”)
- Open channels (dry swales, wet swales, and grass channels)

Filter strips are included in VSWMM as a “limited applicability treatment practice”, and as such, only limited description, specifications, and design details are included for this practice.

4.2. Options and Recommendations

Five key areas of current VSWMM practice related to incorporating LID site design and structural management practices were compared to practices and policies in place in other states:

1. Overall strategies for integrating LID concepts into regulations and manuals
2. Regulatory requirements for using LID strategies or practices to meet stormwater treatment standards
3. Credit systems or incentives for implementing LID strategies and practices
4. Range of non-structural BMPs included in manuals
5. Range of structural BMPs included in manuals

Each area of practice, along with recommendations for improvements in future editions of the VSWMM, is summarized below. In addition, it is worth noting that several other state BMP manuals give separate guidance for pre-treatment practices from the treatment practices themselves; VSWMM does not. A brief discussion of how pre-treatment is being explicitly addressed in some manuals is included at the end of this section.

4.2.1. Overall Strategies for Integrating LID Concepts

The shift in overall attitude of the stormwater management community away from the sole use of structural BMPs and towards embracing LID approaches and practices—at least in concept—is illustrated vividly in the manuals and policies researched for this report. Federal guidance includes a robust series of U.S. EPA resources related to LID and "green infrastructure". Of particular note is guidance issued by the U.S. EPA regarding implementation of the Energy Independence Security Act (ESIA) of 2007—which requires the development or redevelopment of any Federal facility with a footprint of over 5,000 square feet to

All of the state-level stormwater management manuals reviewed except Vermont's contain explicit references to and definitions for "Low Impact Development", "Better Site Design", or a substantially equivalent philosophy of development site design. The levels to which these concepts are carried forward from the states' BMP manuals into regulations, and the extent to which stormwater designers are required or encouraged to implement LID practices, varies widely between the states surveyed. Table 12 summarizes the overall approaches to implementing LID being used in current practice.

The states surveyed in this review fell into one of three broad groups in terms of the level to which LID approaches have been internalized into state-level regulations, policies, and practical guidance:

- In LID approaches included in state stormwater manual but not in regulations; application of LID principles encouraged but no incentives or requirements included in regulations/manuals
- LID approaches included in stormwater manual and in regulations; optional credit systems offered (particularly for non-structural site design strategies)
- LID approaches integrated through BMP manual, regulations, permit application/NOI forms, and other related state-level policy guidance

While each of the states reviewed has integrated LID principles and practices into its manual to some extent, the true integration of LID as a standard development methodology is far from universally adopted, and the states have each taken an individual and unique path towards implementation. In New Hampshire and New York, for instance, recently-updated stormwater BMP manuals (revised in 2008 and 2010, respectively) provide summaries of the problems associated with conventional stormwater management approaches, and chapters on "non-structural site design techniques" and "green infrastructure practices". However, the states' regulations do not mandate or even encourage LID approaches, and few or no tools are available to applicants that facilitate adoption of these practices or allow applicants to demonstrate that they are including non-structural LID site design approaches in their projects. At the other end of the spectrum, Rhode Island's

Table 12. Summary of state-level strategies for integrating LID concepts into regulations and manuals

State	Overall strategy for implementing LID approaches/practices
Vermont	No specific mention of LID in manual or regulations, but voluntary credit system in place for using six non-structural stormwater management practices
Federal Facilities (EISA of 2007)	
Maine	Use of LID practices to meet General Standards encouraged but not required
Massachusetts	Environmentally sensitive site design and low impact development techniques must be considered for projects subject to the Stormwater Management Standards; credit system for selected non-structural practices
Minnesota	“Better Site Design” practices are encouraged but not required in current rules and manual; optional credit for using non-structural better site design techniques. The state is currently engaged in research and a deliberative process to make “Minimal Impact Design Standards” the industry standard for development activities.
New Hampshire	Strong emphasis on LID planning and related structural measures in manual, but no in-rule requirements or incentives
New Jersey	State stormwater rules specify that non-structural practices must be used to the maximum extent practicable in meeting stormwater standards for any new major development; manual provides guidance in how to meet in-rule requirements.
New York	Strong emphasis on LID planning and related structural practices in manual, including unified approach for sizing green infrastructure for runoff reduction and structural practices—but no in-rule requirements or incentives
Pennsylvania	State regulations do not explicitly require LID, but BMP manual emphasizes “Better Site Design”, and construction site disturbance NOI and permit application form provide explicit direction and associated worksheets to utilize non-structural BMPs first.
Rhode Island	*Stormwater Design and Installation Standards Manual* incorporates LID as the "industry standard" for development. A coordinated stormwater permitting initiative ensures that Fresh Water Wetlands, Water Quality Certification, Underground Injection Control, and RIPDES programs all require use of this manual.

recently updated (2011) stormwater management regulations, BMP manual, and associated permit application forms represent an example of state-level integration of LID as the “industry standard” for development and redevelopment. Additionally, Rhode Island’s Dept. of Environmental Management made a concerted effort to streamline environmental permitting for related programs within their Office of Water Resources. Permit applications within their Fresh Water Wetlands, Water Quality Certification, Underground Injection Control, and Rhode Island Pollution Discharge Elimination System programs all must include a stormwater management plan and reference the same stormwater BMP manual—and approval under any of these programs also constitutes approval of the project’s stormwater management plan (Rhode Island DEM, 2011).

Recommendations:

- Include non-structural LID techniques more explicitly in VSWMM—either by more directly integrating incentives into the design standards and permit application process, or by changing the process of demonstrating compliance with the VSWMM’s stormwater treatment standards to preferentially require utilization of non-structural stormwater management practices.

- Regardless of whether non-structural LID approaches are integrated more closely into VSWMM, consider adding content to Volume I regarding the benefits of structural and non-structural LID practices—possibly by adding LID site design practices to the Accepted Stormwater Treatment Practices in Section 2.
- Consider convening a broad-based advisory group, including regulators, researchers, design professionals, maintenance providers, and others in the stormwater management field. States that have successfully shifted their regulatory and permitting systems towards using LID, "Better Site Design", or other similar frameworks for designing and permitting development / redevelopment projects, have done so only after an extensive stakeholder involvement and deliberative process.

4.2.2. Regulatory Requirements for using Non-Structural LID Practices

While other New England and Mid-Atlantic states have made substantial headway in describing the benefits of LID or similar approaches in manuals and guidance documents, the movement towards adopting a seamless integration of non-structural LID practices into stormwater permitting and regulatory treatment standards is progressing more slowly. Several states, including Vermont, Minnesota, Maine, New Hampshire, and New York, have no regulatory requirement that non-structural LID practices be considered in the site design process for new development or redevelopment (Table 13). The stormwater management community in Minnesota, however, is currently engaged in a substantial research and planning process with the goal of making "Minimal Impact Design Standards" (MIDS) the industry standard for future development in the state (Minnesota PCA, 2012). The development of MIDS is based on LID and has similar goals of managing storm water on site and maintaining the rate and volume of predevelopment stormwater reaching receiving waters—with a performance goal for new development to control stormwater runoff volumes and retain the post-construction runoff volume on site for 1.1 inches of runoff from impervious surfaces statewide (roughly equivalent to the 95%, 24-hour storm, though the performance goal is based on rainfall depth rather than a specific design storm).

States that have implemented a requirement that non-structural LID practices be considered in formulating development projects have taken one of three approaches:

- Single NOI and application for construction and post-construction, tight integration of non-structural LID requirements
- Separate NOIs and applications/permitting processes for construction and post-construction, tight integration of non-structural LID requirements
- Separate NOIs and applications/permitting processes for construction and post-construction, LID site design credit to encourage use of non-structural LID practices

Pennsylvania and New Jersey have implemented tightly integrated systems of regulations, guidance manuals, permitting applications, and associated guidance that both lead and force applicants to consider non-structural LID measures first when designing projects (Table 13). Both of these states utilize a single NOI-based

Table 13. Summary of regulatory requirements for implementing non-structural LID approaches

State	Permitting requirements mandating use of LID
Vermont	None
Maine	None
New Hampshire	None
New York	None
Minnesota	No requirement currently; state is engaged in a collaborative, deliberate planning process to make Minimal Impact Design Standards (MIDS) the industry standard for all development.
Federal Facilities (EISA of 2007)	Specific standard of retaining the 95th percentile event; no practices mandated, but green infrastructure practices encouraged
Massachusetts	Environmentally sensitive site design and low impact development techniques must be considered for projects subject to the Stormwater Management Standards—but no specific regulatory standards for how to consider.
New Jersey	To the maximum extent practicable, erosion control, groundwater recharge, stormwater runoff quantity, and stormwater runoff quality standards must be met by incorporating nonstructural stormwater management strategies at N.J.A.C. 7:8-5.3 into the design. Nonstructural Strategies Point System developed to assist planners, designers, and regulators in determining that nonstructural strategies have been used to the “maximum extent practicable” The LID Checklist contained in Appendix A of the New Jersey Stormwater BMP Manual includes a rigorous alternatives analysis for each LID measure.
Pennsylvania	Construction site disturbance NOI and permit application form provides explicit direction and associated worksheets to utilize non-structural BMPs first. Runoff Volume Control Standard (combined WQv and Channel Protection) in state BMP manual requires that least the first one inch (1.0”) of runoff from new impervious surfaces shall be permanently removed from the runoff flow via reuse, evaporation, transpiration, and/or infiltration.
Rhode Island	Minimum Standard 1: LID Site Planning and Design Strategies explicitly requires “LID site planning and design strategies must be used to the maximum extent practicable in order to reduce the generation of the water runoff volume for both new and redevelopment projects. All development proposals must include a completed Stormwater Management Plan checklist (Appendix A) and Stormwater Management Plan for review by the approving agency that shows compliance with this standard”. LID site planning measures can be used to meet Minimum Standards 2 (groundwater recharge) and 3 (water quality). Minimum Standard 4 (channel protection) may be waived if post-development peak discharge without attenuation is less than 2 cfs for the 1-year, 24-hour storm.

application process for both construction site disturbance and post-construction stormwater management practices (Pennsylvania DEP, 2006 and New Jersey DEP, 2010). Rhode Island’s stormwater permitting regime is similar to Vermont’s, with the filing of separate construction site disturbance NOIs and post-construction stormwater management permit applications. Rhode Island’s post-construction stormwater permitting program’s Minimum Standard 1 explicitly requires “LID site planning and design strategies must be used to the maximum extent practicable in order to reduce the generation of the water runoff volume for both new and redevelopment projects” (RI DEM, 2011). Like New Jersey and Pennsylvania, Rhode Island’s stormwater regulations are tightly integrated into the stormwater BMP manual, permit application forms, associated worksheets, and other related guidance.

Massachusetts recently implemented a requirement that “environmentally sensitive site design and low impact development techniques must be considered for projects subject to the Stormwater Management Standards” (Massachusetts DEP, 2008 v1c1). Instead of integrating this requirement completely into the remaining treatment standards and permitting application documents, applicants are required to submit a Stormwater Report and associated checklist with their applications (Massachusetts DEP, 2008 [stormwater report checklist]). A portion of the Stormwater Report documents what environmentally sensitive design and LID techniques (both structural and non-structural) were considered during the planning and design of the project. A series of LID Site Design Credits are offered to encourage designers to consider and integrate these measures in their projects (see Section 4.2.3).

Recommendations:

- Develop and implement an approach similar to that being used in Massachusetts, where applicants are required to document how non-structural LID approaches were considered during project planning and design. This approach offers an opportunity to help raise awareness and acceptance of LID and better site design practices within the design community.
- Evaluate the pros and cons of creating a single NOI and permit application for construction site disturbance and post-construction stormwater management.

4.2.3. Credit Systems and Incentives for Implementing Non-Structural LID Practices

As with the movement towards adopting a seamless integration of non-structural LID practices into stormwater permitting and regulatory treatment standards, the progress of the states towards implementing credit systems or other incentives to encourage the use of these practices is highly variable. Table 14 shows a summary of whether individual states offer incentives or credits, and which stormwater treatment standards can be fulfilled

Table 14. Summary of Stormwater Treatment Standards Eligible for Non-Structural LID Credits or Incentives by State

State (date of manual)	Stormwater Treatment Standard				
	WQv	REv	CPv	Qp10	WQv depth
Vermont	X (partial)	X			0.9 inches
New Hampshire	No credits or incentives offered				
New York	No credits or incentives offered				
Federal Facilities (EISA of 2007)	Green infrastructure encouraged but allowable non-structural measures will vary by state				
Maine	X	X	Only applies to larger sites	Only applies to larger sites	1.0 inch for impervious area plus 0.4 inch for developed landscaped area
Massachusetts	X	X	X (LID can be used but no incentives)	X (LID can be used but no incentives)	1.0 inch for impervious with higher pollutant loads; 0.5 inches for other impervious
Minnesota	X (partial)	No separate standard			0.5 inches in normal watersheds; 1.0 inch for Special or impaired waters
Pennsylvania	X (up to 25% of required volume)	X (up to 25% of required volume)	X (up to 25% of required volume)	X (up to 25% of required volume)	1.0 inch from new impervious surfaces
New Jersey	Non-structural LID strategies required to be used to MEP				
Rhode Island	Non-structural LID strategies required to be used to MEP				

using these credits. The specific non-structural LID practices that are eligible for credits or incentives in each state, where such incentives are provided, are summarized in Table 15.

A number of states offer neither credits nor incentives for implementing non-structural LID practices. New York and New Hampshire, for instance, have neither regulatory mandates for including non-structural LID practices, nor credit or incentive programs geared toward the same purpose (Table 14). At the opposite end of the spectrum, New Jersey's and Rhode Island's stormwater permitting require consideration and inclusion of non-structural LID measures is an integral and mandatory part of the site design process (Section 4.2.2).

The state of Maine has no specific mandate or credit/incentive programs that encourage designers to utilize non-structural LID approaches be used in designing new development—but the state's General Standards nonetheless provide effective incentives. The General Standards essentially require retaining or infiltrating 1 inch of rainfall from impervious surfaces plus 0.4 inches of precipitation from landscaped, developed areas (Maine DEP, 2008), and are roughly equivalent to Vermont's Water Quality Volume and Groundwater Recharge Volume standards. The General Standards can be met entirely by using properly designed and sited buffers rather than structural practices where site conditions are appropriate (Maine DEP, 2010). The buffers are classified by type of development as follows, but they effectively incentivize LID practices similar to Vermont's runoff disconnection and natural area conservation credits (Table 15):

- Buffer adjacent to residential, largely pervious or small impervious areas
- Buffer with stone bermed level lip spreader (for parking lots or other, larger impervious areas)
- Buffer downhill of a road
- Ditch turn out buffer
- Buffer downgradient of a single family residential lot

Additionally, Maine's Flooding Standard (stormwater management system must detain, retain, or infiltrate stormwater from 24-hour storms of the 2-year, 10-year, and 25-year frequencies, such that post-development peak flows do not exceed pre-development) only applies to development projects that involve more than 3 acres of impervious surface or over 20 acres of total developed area (Maine DEP, 2008). This approach should be considered cautiously from a land use perspective, because similar to Vermont and Massachusetts' ERSD credit, it may unintentionally promote the further distribution of smaller-scale development projects across the landscape.

Several states do offer credits or incentives to encourage the use of non-structural LID practices, which are similar to or more extensive than those currently offered in VSWMM. Minnesota's stormwater BMP manual, for instance, offers a suite of credits for non-structural practices that are nearly identical to Vermont's (Table 15). Like Vermont's credit system, Minnesota's contains a limitation that even if the application of credits would result in no calculated WQv, a minimum water quality volume equal to 0.2 watershed inches should be maintained (Minnesota PCA, 2005). This credit system, in contrast to Vermont's, also explicitly allows the post-development curve number (CN) used to compute the channel protection, overbank, or extreme flooding volumes for the contributing buffer or other practice areas to be assumed as "woods in good condition", "grass in good condition", etc. when applying most of the credits when calculating curve numbers for the total site (Minnesota PCA, 2005). While this is the current state of practice in Minnesota, the state's MIDS initiative has a more ambitious performance goal of retaining at least the first 1.1 inches of runoff from post-development impervious surfaces, and a robust set of modeling methods and credit tools are being developed to assist the stormwater community in meeting this performance standard (Minnesota PCA, 2012).

Table 15. Summary of Non-Structural LID practices Eligible for Credits or Incentives by State

	Non-Structural LID Practice						
State	**Natural Area Conservation**	**Disconnection of Rooftop Runoff**	**Disconnection of Non-Rooftop Runoff**	**Stream Buffers**	**Grass Channels**	**Environmentally Sensitive Rural Development**	**Other**
Vermont	X	X	X	X	X	X	
New Hampshire			None				
New York			None				
Maine	X	X	X				Buffers based on development type
Massachusetts		X	X			X	
Minnesota	X	X	X	X	X		Site Reforestation or Prairie Restoration
Pennsylvania		X	X				Minimum Soil Compaction, Protect Existing Trees
New Jersey	Non-structural LID strategies required to be used to MEP						
Rhode Island	Non-structural LID strategies required to be used to MEP						

The Massachusetts DEP has established an “LID Site Design Credit” to encourage developers to incorporate LID techniques in projects subject to the Stormwater Management Standards (Massachusetts DEP, 2008 v3ch1). Three credits are available to designers: Environmentally Sensitive Development (identical in concept to Vermont’s Environmentally Sensitive Rural Development credit), Disconnected Rooftop Runoff (as for Vermont’s Disconnection of Rooftop Runoff credit), and Disconnected Non-Rooftop Runoff (as for Vermont’s Disconnection of Non-Rooftop Runoff credit). While credits are not offered when designers use LID practices to meet Standard 2 (control of the 2-year and 10-year, 24-hour storms to pre-development peak discharge rates), LID practices are specifically listed, along with extended dry detention basins and wet basins, as BMPs that slow runoff rates through storage and gradual release (Massachusetts DEP, 2008 v1ch1).

Pennsylvania is among the states that require non-structural LID measures to be considered first (Section 4.2.2). However, in practice, the incentive for designers to fully integrate these practices into development or redevelopment projects is relatively small (Table 14). Non-structural LID measures can only be credited for up to 25% of the otherwise required treatment volumes for any of the state’s stormwater standards. In contrast to Vermont’s and Minnesota’s credit strategies, however, this smaller volume reduction can be credited across water quality, groundwater recharge, and peak control stormwater management standards, rather than being restricted only to REv and WQv.

Recommendations:

- Enhance the effectiveness of the existing system of credits by developing explicit guidance on applying for multiple credits, and providing worksheets for non-structural practices to clarify how such practices can be used to meet current treatment standards.
- Consider allowing combinations of non-structural LID credits to apply fully to WQv and REv in cases other than the ESRD credit.
- Consider adding specific guidance on adjusting CN for larger storms, similar to the guidance offered in Minnesota's 2005 stormwater BMP manual.
- Develop strategies to enhance awareness and utilization of the "alternate design standard" option.

4.2.4. Range of Non-Structural LID BMPs Included in Manuals

The wide variety of non-structural, low-impact BMPs in use in Vermont and other New England and Mid-Atlantic states is summarized in Table 16. In this table, the non-structural BMPs are organized from left to right, roughly following the LID site design philosophy of first avoiding the impacts of increased post-development stormwater runoff, then reducing or minimizing impacts, and, finally, managing remaining impacts at the source using decentralized runoff reduction and treatment practices. With only a few exceptions, the extent to which the use of each individual non-structural BMP was encouraged or mandated varied considerably between the manuals and states included in this review, illustrating the state of flux regarding implementation of non-structural LID practices among the states.

Nearly all of the states surveyed, including Vermont, include at least one incentive or requirement that designers can use to "avoid impacts" of increased post-development runoff in their stormwater management manuals. Setting aside natural areas, whether woodlands, riparian buffers, or floodplains, and protecting them against future development is the most commonly applied measure (Table 16). The concept of clustered (particularly residential) development, whether referred to as Environmentally Sensitive Rural Development, Environmental Site Design, Open Space Development, Conservation Subdivision Design, or another term, bridges the space between "avoiding impacts" and "reducing impacts", as it combines the preservation of natural areas with the idea of minimizing impervious cover. This concept is in use in several states, including Massachusetts, Rhode Island, and New York—and it is one of the most commonly utilized non-structural LID incentives offered in VSWMM.

Table 16. Summary of non-structural LID BMPs included in stormwater management manuals.

	Type of non-structural LID BMP															
State (date of manual)	**Natural area conservation**	**Riparian buffer/ floodplain protection**	**ESD/ESRD/Open Space Dev.**	**Limit site clearing/ grading**	**Minimize soil compaction**	**Drainage to stream or shoreline buffer**	**Minimize impervious areas**	**Rooftop disconnection**	**Non-rooftop disconnection**	**Minimize connected impervious**	**Filter Strips / Vegetated buffers**	**Grass Channels**	**Water-retaining landscaping**	**Manage stormwater at source**	**Reforestation/ revegetation**	**Soil restoration**
Vermont (2002)			X			X		X	X		X	XX				
Federal Facilities (EISA of 2007)		XX													XX	
Maine				X			X			X	XX			X		
Massachusetts			X					X	X							
Minnesota	X		X			X	X	X	X	XX	XX	X		X	X	X
New Hampshire	X			X	X		X	X	X	X	XX					
New Jersey	XX	XX		XX	XX		XX			XX	XX	XX	XX	XX		
New York	XX	X	X	X			X	XX			XX	X		X		X
Pennsylvania	X	X		X	X			X	X		XX				XX	XX
Rhode Island	XX	XX	XX	XX			XX	XX	XX					XX	XX	

XX: Standard design technique/practice

X: Design technique/practice eligible for incentive, or described in manual but not necessarily a standard practice or part of a mandated approach

Several non-structural LID practices targeted at reducing impervious cover (and thus the impacts of increased runoff) during site development or redevelopment were included in the majority of the state stormwater BMP manuals reviewed. Four of the practices in Table 16 fell under the category of “reducing impacts”:

- Limit site clearing/ grading;
- Minimize impervious areas;
- Minimize soil compaction; and
- Drainage to stream or shoreline buffer.

Limiting the extent of site clearing and grading, especially after sensitive or valuable natural resources areas have been protected, maximizes conservation of existing site vegetation and minimizes the need for soil restoration and re-vegetation (Pennsylvania DEP, 2006). In Rhode Island, for instance, this practice is defined as site fingerprinting to the extent needed for building footprints, construction access, and safety (for example, limiting clearing and grading to 15 feet beyond a building pad or 5 feet beyond a road bed/shoulder) (Rhode Island DEM, 2011 sw checklist). The practice is also endorsed, recommended, or required in the stormwater BMP manuals for Maine, New Hampshire, New York, New Jersey, and Pennsylvania—but is not included in VSWMM (Table 16).

Reduction of impervious cover includes employing strategies to reduce the amount of rooftops, parking lots, roadways, sidewalks and other surfaces that do not allow rainfall to infiltrate into the soil, in order to reduce the volume of stormwater runoff, increase groundwater recharge, and reduce pollutant loadings that are generated from a site (New York DEC, 2010 manual ch 5). VSWMM provides a list of strategies for limiting impervious cover and a design example (in Volume 1, Section 3.8), but does not offer a specific credit or incentive for designers that implement this strategy. Impervious area reduction is generally not a part of other states’ LID credit or incentive strategies, but the practice is more robustly described in the manuals for Maine, Minnesota, New Hampshire, and New York, and is a required component of the non-structural LID practice toolbox in New Jersey and Rhode Island (Table 16).

The practice of minimizing soil compaction often goes hand in hand with limiting site clearing / grading and reducing impervious cover—and as such, not as many states specifically describe this non-structural BMP as a stand-alone strategy eligible for credit or required to be considered during the site design process. New Jersey does require designers to describe measures that will be implemented to minimize soil compaction in their manual’s LID Checklist (New Jersey DEP, 2004), though the manual itself does not provide detailed guidance for implementing this strategy. In contrast, New Hampshire’s and Pennsylvania’s stormwater BMP manuals both include detailed descriptions of strategies for minimizing soil compaction, although the practice is not required to be considered or implemented by designers in those states (New Hampshire DES, 2008; New Jersey DEP, 2004).

Of the stormwater BMP manuals and policies surveyed, only Vermont and Minnesota specifically include the practice of capturing runoff from pervious or impervious areas adjacent to a stream or lakeshore buffer, and treating runoff though overland flow passing through that buffer (Table 16). Many of the other states surveyed however, do include this non-structural practice as an applied example of riparian buffer protection (see, for example, the “Preservation of Buffers” practices described in Section 5.1.2 of New York’s 2010 stormwater manual). Pennsylvania’s stormwater manual specifically identifies floodplains and riparian buffers as examples of “sensitive and special value features” that should be protected from development (Pennsylvania DEP, 2006).

As development occurs, an increase the amount of stormwater runoff generated is unavoidable even when the strategies to reduce impacts described above are fully deployed. There are several non-structural LID site design practices, however, which can be used to manage this stormwater at or very close to the source. Specific practices identified in the state stormwater manuals reviewed (Table 16) include:

- Rooftop disconnection
- Non-rooftop disconnection
- Minimize connected impervious
- Grass Channels
- Filter strips / vegetated buffers

Recognizing the benefit of allowing runoff from rooftops, driveways, parking lots, and other types of impervious cover to be directed to pervious surfaces for infiltration or filtering by overland flow, VSWMM offers Stormwater Management Credits for both rooftop runoff disconnection and non-rooftop disconnection (Vermont DEC, 2002). This practice is consistent with credits offered or considerations required in several other states (see Section 4.2.3 for further discussion). A few states, including Maine and New Hampshire, also describe disconnection as "minimizing connected impervious surfaces", though the application is essentially identical in practice (Table 16).

The use of grass channels to reduce the volume of runoff and pollutant concentrations during smaller storms is treated as a practice eligible for a Stormwater Management Credit in VSWMM, as well as being included in VSWMM as a standard BMP (Vermont DEC, 2002). As with the practice of offering credits for drainage to lakeshore or stream buffers, Minnesota is the only other state reviewed where this credit is currently offered. Minnesota and New York offer descriptions of grass channels as non-structural BMPs, and New Jersey includes grass channels as a structural treatment practice (Table 16). Most states include a grass variant in their standard practice descriptions for vegetated swales/bioswales (Section 4.2.5).

Filter strips (or vegetated buffers) are another example of a practice that may be considered either non-structural or structural, depending on the specific application or jurisdiction. While filter strips are listed as a "Limited Applicability Stormwater Management Practice" in VSWMM, most other manuals reviewed included filter strips and vegetated buffers, often including level spreaders, as a "green" (in the case of New York's 2010 manual) or standard structural practice (Table 16). New York's, New Jersey's, and Pennsylvania's stormwater BMP manuals provide detailed guidance regarding filter strips including applicability, design considerations, construction specifications, and maintenance and cost issues.

A few states include site restoration practices such as reforestation/revegetation and soil restoration as examples of non-structural LID practices (Table 16). Pennsylvania's stormwater BMP manual, however, is the only manual reviewed that provided detailed descriptions of, and standards for, both of these practices as standard BMPs (Pennsylvania DEP, 2006). Another robust resource for soil restoration may be found in Washington State's "Soils for Salmon" initiative (Washington Organic Recycling Council, 2010), which provides both simple information on soil preservation and restoration for homeowners, and detailed guidance for developers.

Recommendations:

- Consider adding a broader range of practices eligible for incentives to VSWMM, encouraging designers to utilize non-structural LID practices during development and redevelopment projects. Examples of non-structural practices offered fairly commonly in other states as extensive description, incentives, or requirements for consideration that are not in the current VSWMM include:
  - Natural area conservation and/or riparian and lakeshore buffer or floodplain preservation
  - Limiting site clearing / grading
- Consider creating a more robust description of strategies for minimizing impervious cover
- Consider shifting the purpose of the current Stream Buffer Credit to include incentives for floodplain protection.
- Consider strengthening the Grass Channels credit (Credit 5), such that open drainage systems eligible for this credit are designed as wet or dry swales, as is the practice in a number of other states.
- Consider adding filter strips (with or without berms and level spreaders) to the list of Acceptable Stormwater Treatment Practices, and providing more detailed guidance regarding proper siting, design, construction, and operation in VSWMM.

4.2.5. Range of Structural LID BMPs Included in Manuals

Low Impact Development (LID) Structural Best Management Practices (BMPs) manage stormwater runoff at its source by infiltrating, filtering, storing, evaporating, or detaining runoff to minimize its pollution potential and environmental impact (Vermont DEC, 2010). A substantial number of the structural BMPs classified as Acceptable Stormwater Treatment Practices in the 2002 VSWMM are either in keeping with the philosophy of LID, or can easily be applied in the context of low-impact site design. The range of structural LID practices included in the manuals reviewed is summarized in Table 17. In this table, the structural BMPs are organized from left to right, roughly following the organization of Water Quality STPs included in Volume 1 of VSWMM where applicable:

- Volume reduction without infiltration (green roofs, rainwater capture and reuse)
- Stormwater wetlands (including gravel wetlands and extended detention wetlands)
- Infiltration (trenches and basins)
- Filtering practices (sand filters, organic filters, and bioretention)
- Open channels (dry swales, wet swales, grass channels)

The extent to which the use of each individual structural BMP was encouraged or mandated varied much less than for the non-structural LID BMPs among the manuals and states included here. In a few cases, VSWMM is substantially behind current practice in other states—especially for providing guidance and specifications for

Table 17. Summary of structural LID BMPs included in stormwater management manuals.

State (date of manual)	Type of structural LID BMP															
	Green roofs	Rainwater harvesting for use	Constructed SW Wetland	Infiltration basin/trench	Infiltration planters	Trees / tree boxes	Porous pavements	Dry well	Subsurface structures	Leaching catch basins	Bioretention +rain gardens	Sand Filter	Vegetated soil / organic filter	Vegetated swales/ bioswales	Level spreader	Stream daylighting
Vermont (2002)			XX	XX							XX	XX	XX	XX		
Federal Facilities (EISA of 2007)	XX	XX	XX		XX	XX	XX				XX			XX		
Maine	X	XX		XX			XX				XX		XX	XX	XX	
Massachusetts				XX			XX	XX	XX	XX	XX					
Minnesota	XX	XX	XX	XX			XX		XX		XX			XX		
New Hampshire	XX	XX		XX			XX				XX			XX		
New Jersey	X		XX	XX			XX	XX			XX	XX	XX			
New York	XX	XX	X	XX	XX	XX	XX	XX	XX		XX	XX		XX		XX
Pennsylvania	XX	XX	XX	XX		X	XX	XX			XX		XX	XX	XX	
Rhode Island	XX	X	XX	XX	XX	XX	XX		XX		XX	XX	XX	XX		XX

XX: Standard design technique/practice

X: BMP endorsed in manual, but detailed guidance for implementing not provided green roofs, rainwater harvesting for reuse, and porous pavement. Most of the stormwater BMP manuals reviewed have also, in addition to describing stormwater treatment practices by broad grouping, added practice specific technical descriptions and specifications for at least some individual BMPs. For example, Massachusetts' BMP manual includes separate practice descriptions for infiltration basins and infiltration trenches (Massachusetts DEP, 2010), while Pennsylvania's includes separate specifications for all infiltration practices—including everything from pervious pavement to vegetated swales (Pennsylvania DEP, 2006).

Each grouping of structural BMPs, and the range of specific practices included within each group, are discussed in more detail below.

Volume reduction without infiltration

Green roofs are planted rooftop systems that endow the roof with hydrologic characteristics that more closely match those of surface vegetation than of the roof (Pennsylvania DEP, 2006). Vegetated roof covers can be optimized to achieve water quantity and water quality benefits—and if appropriately designed, even thin vegetated covers can provide significant rainfall retention and detention functions. Green roofs are not included in VSWMM, but guidance is now broadly available (Table 17). Projects utilizing green roofs have recently been constructed in Vermont, most notably at Heritage Aviation and the Burlington International Airport parking garage, as well as at UVM's Aiken Center. Green roofs are also included as a practice for consideration on residential and small commercial sites in a guide for applying LID practices published by Vermont DEC's Water Quality Division in 2010. The most thorough treatment of green roofs as a standard BMP among the state stormwater BMP manuals reviewed here can be found in Pennsylvania's (2006) and New York's (2010) stormwater manuals.

Rainwater harvesting for beneficial reuse, and particularly the storage and reuse of rooftop runoff, can reduce potable water needs for uses such as irrigation and fire protection while also reducing stormwater discharges (Pennsylvania DEP, 2006). Storage and reuse techniques range from small, residential systems such as rain barrels, to large cisterns storing runoff for irrigation, vehicle washing, or even, with minimal treatment, to non-potable reuse such as toilet flushing, clothes washing, or boiler make-up. Rainwater harvesting is not included in VSWMM but is treated as a standard BMP in several states, including such cold-climate states as Minnesota, Maine, and New Hampshire (Table 17). Several projects involving stormwater reuse have implemented in Vermont, including cisterns installed at the City of St. Albans public works garage and at Heritage Aviation, where the collected water is used for vehicle washing. The practice of rainwater harvesting via rain barrels or cisterns is also endorsed in Vermont DEC's *LID Guide for Residential and Small Commercial Sites* (Vermont DEC, 2010). Pennsylvania's treatment of the subject in their 2006 stormwater BMP manual is the most detailed of the manuals reviewed.

Stormwater Wetlands

Wetlands for stormwater treatment are a long-standing and well-established group of BMPs, many of which are easily adaptable to the LID framework. In this case, the range of practices included in VSWMM is reasonably consistent with that in the range of manuals and guidance reviewed (Table 18).

Infiltration Practices

As with stormwater wetlands, infiltration basins and trenches are well-established structural BMPs, and the practices included in VSWMM compare reasonably well with other manuals and guidance reviewed (Table 17).

Pervious pavement is a permeable surface course underlain by a gravel bed which provides temporary storage for peak rate control and promotes infiltration (Pennsylvania DEP, 2006). This practice has become much more widely applied in the last decade on walking paths, sidewalks, playgrounds, plazas and tennis courts, as well as for driveways and lower-traffic areas such as parking stalls and overflow parking. All BMP manuals reviewed except Vermont's include pervious pavement as an acceptable STP (Table 17), though Pennsylvania's (2006) and New York's (2010) manuals, again, provide the most detailed information regarding applicability, design specifications, and maintenance.

Drywells are sometimes applied in Vermont stormwater designs, and a design schematic for a drywell is included in the VSWMM design example for rooftop runoff disconnection (Credit 2). However, drywells are not listed as an acceptable STP, and no other design guidance is provided in VSWMM. Several states, including New York and Massachusetts, do include drywells as an acceptable stormwater BMP and provide associated applicability and design specifications, but this inclusion is not universal (Table 17). In Vermont, any consideration given to adding drywells as an acceptable STP in the VSWMM should be coordinated with the *Wastewater System and Potable Water Supply Rules* (Vermont DEC, 2007), which specifically prohibit the use of drywells for infiltrating septic tank effluent in new construction.

Other infiltration practices such as infiltration planters and tree box filters are becoming more common, especially in urban environments and for redevelopment. Infiltration planters and tree boxes are included as acceptable STPs in New York's (2010) and Rhode Island's (2011) stormwater manuals (Table 17). However, these practices were not yet strongly endorsed in BMP manuals from colder-climate states, such as Maine, New Hampshire, or Minnesota.

Filtering Practices

As with the basic infiltration practices and stormwater wetland practices described above, the range of filtering practices included in VSWMM compares well with the other manuals reviewed—except with regard to bioretention practices. In the 2002 VSWMM, it is not at all clear that "bioretention" practices are essentially identical in application to "rain gardens". Every other BMP manual reviewed has made this transition (Table 17), providing clear guidance for both small-scale infiltrating or filtering rain gardens and larger bioretention features more akin to the design example included in VSWMM. Rain garden siting and design guidance is provided in Vermont DEC's *LID Guide for Residential and Small Commercial Sites* (Vermont DEC, 2010), and Minnesota's (2008) stormwater BMP manual includes both substantial information on bioretention design and information regarding designing these features for freezing climates.

Open channels

The wet and dry swale practices included in VSWMM are reasonably consistent with current practice in other states (Table 17). Most other stormwater manuals, however, have discontinued the use of grass channels as a practice sufficient to provide a full water quality treatment function. The practice-level descriptions of open channel systems in Minnesota's (2008) and Pennsylvania's (2006) manuals indicate that grass channels can be utilized for pre-treatment, but that in these cases another downstream BMP must provide additional water quality treatment, while Massachusetts' and New Jersey's manuals are completely silent on the subject of open channels as a stormwater treatment BMP (Table 17).

Level spreaders

VSWMM contains no practice-specific guidance regarding the design or applicability of level spreaders—yet this practice is employed as a portion of several other Acceptable STPs. Examples include the "stone diaphragm" in the bioretention design example; the "pea gravel diaphragm" in the dry swale, wet swale, and grass channel design examples; the "stone drop" in the filter strip design example; and, finally, the "level spreader" in the Stream Buffer Credit design example. Several states' stormwater BMP manuals, including those for Pennsylvania (2006) and Maine (2008) offer design specifications that may prove useful in augmenting VSWMM guidance.

Recommendations:

- Include green roofs, rainwater harvesting for reuse, and permeable pavement as acceptable STPs in future versions of VSWMM.
- Expand the description and design specifications for bioretention facilities to specifically include infiltrating and filtering "rain gardens".
- Remove grass channels from the selection of Acceptable STPs available in VSWMM for the purpose of water quality treatment.
- Though the treatment effectiveness and pollutant removal efficiencies of acceptable STPs was not treated specifically here, substantial research and subsequent design improvement has taken place in the stormwater community in the last decade. The documentation contained in VSWMM Appendix D3 should be revised to include the current state of knowledge.
- Consider separate practice descriptions for each BMP, instead of (or in addition to) organizing Volume 1, Section 2 of VSWMM by class of structural treatment practice. This would be especially useful for filtering practices, where the state of practice for sand filters, organic filters, and bioretention has substantially both grown and diverged since the 2002 VSWMM became effective.
- Consider adding drywells as an acceptable STP, especially if adequate pre-treatment is provided and potential conflicts with other State regulations can be addressed.
- Consider adding tree box filters and/or infiltration planters as Limited Applicability STPs
- Consider adding specifications for level spreaders, either as an Acceptable or Limited Applicability STP.

4.2.6. Structural Stormwater Pre-Treatment Practices

Pre-treatment systems are designed to provide initial treatment of stormwater runoff prior to discharge into the primary water quality STP, thereby enhancing the performance of and/or extending the useful life of the STP. Some of the most common pre-treatment systems include:

- Sediment forebays
- Vegetated filter strips
- Oil and grit separators
- Deep sump catch basins

The selection of a specific pre-treatment practice is driven by the characteristics of the stormwater runoff and/or the needs of the primary STP. Although VSWMM does not preclude the use of any of these pre-treatment practices, the fact that they are not addressed as stand-alone elements of the larger treatment train means that discussion of these practices is less robust. As such, stormwater designers may not always select the pre-treatment practice best suited for a particular application. This need may become more acute as incentives (both voluntary and regulatory) increase for designers to employ less familiar green infrastructure STPs in managing stormwater runoff. Examples of state stormwater manuals that employ separate descriptions and specifications for pre-treatment practices include Massachusetts (2008) and Rhode Island (2010).

Recommendation:

- Consider creating a stand-alone section of the VSWMM dedicated to pre-treatment practices, in order to highlight the relative strengths and weaknesses of each practice in different settings.

5. MAINTENANCE PLANS

Timely and effective inspection and maintenance are crucial to ensuring satisfactory of stormwater treatment over the design life of a system. Regular and thorough inspection is essential to proper management and informed regulatory oversight. Operation and maintenance requirements across the state regulations, manuals, and policies reviewed run the gamut from non-existent all the way to system-specific directions complete with maintenance instruction and inspection templates.

5.1. Vermont's Current Inspection and Maintenance Requirements

Vermont's general permits for new development and previously permitted discharges (General Permits 3-9015 and 3-9010, respectively) require that all permitted stormwater collection, treatment, and control systems be properly operated and maintained. These permits also mandate that systems be inspected by the permittee on a semi-annual basis using provided operation, maintenance, and inspection. These checklists can be found in Appendix D8 of the VSWMM. The following checklists are provided:

- Stormwater Pond/Wetland Operation Maintenance and Management Inspection Checklist
- Infiltration Trench Operation, Maintenance, and Management Inspection Checklist
- Sand/Organic Filter Operation Maintenance, and Management Inspection Checklist
- Bioretention Operation, Maintenance, and Management Inspection Checklist
- Open Channel Operation, Maintenance, and Management Inspection Checklist

According to General Permits 3-9010 and 3-9015, inspections are to be completed each year after snow cover has melted in the spring, and prior to snowfall in the fall. These inspection reports must be submitted to VTDEC by June 1st and December 1st, respectively.

Links to templates for inspection reports are provided on the front page of the VT DEC Stormwater website. These forms differ from those found in Appendix D8. The forms can be found at the following addresses:

http://www.vtwaterquality.org/stormwater/docs/sw_semi-inspection.pdf
http://www.vtwaterquality.org/stormwater/docs/sw_annual_inspection_report.pdf.

The inspection forms linked on the website are not practice-specific and do not mention or refer to the practice-specific inspection forms required by the general permits that are provided in Appendix D8 of the VSWMM. The general permits specifically require use of the practice-specific inspection forms provided by the VTDEC in the VSWMM.

Stormwater discharges to Vermont's list of impaired waters that are not accounted for by a MS4 permit are covered by *General Permit 3-9030 for Designated Discharges to the Bartlett, Centennial, Englesby, Morehouse and Potash Brook Watersheds*. General Permit 3-9030 requires that the permittee must "at all times properly operate, inspect and maintain all stormwater BMPs that are installed or used by the permittee to achieve and maintain compliance" with said permit. It also requires an annual inspection that should occur after the spring snow melt and prior to June 15. A report noting all problem areas and all corrective measures taken is to be submitted to VTDEC by December 31st of each year. There are no specific guidance documents or requirements provided for maintenance or inspections. General Permit 3-9030 does not mention the maintenance guidelines or inspection templates provided in Appendix D8 of the VSWMM.

5.2. Operation, Inspection, and Maintenance Strategies Used by Other Entities

Other states and municipalities use a variety of strategies to ensure proper maintenance and inspection of stormwater management systems, which are summarized in Table 18. Typically, some degree of maintenance is required—but the degree of operation/maintenance and oversight that is required, as well as the amount of guidance provided by the state, varies considerably. The strategies used by the states reviewed fell into three broad groups:

- A general requirement is included in permit conditions that stormwater systems be properly operated and maintained
- Periodic inspections and routine maintenance are explicitly required, and some general guidelines are provided
- Periodic inspections and routine maintenance are explicitly required, and specific guidance, as well as standard templates or checklists covering inspection and maintenance activities, is provided

5.2.1. Other States' Requirements Mandated by Permit or Otherwise

Some states require development of a stormwater inspection and maintenance plan specific to each site without providing much guidance other than a list of what should be included in the plan (Table 18). The following are examples of items commonly expected to be part of a site-specific operation, inspection and maintenance manual:

- Contact information for the permit holder
- As-built plans and/or plan showing all locations stormwater practices
- Letter of compliance from designer
- Copy of deed covenant, easements/rights-of-way, executed maintenance agreement, etc.
- Inspection and maintenance schedules
- Inspection checklists
- Inspection and maintenance log

A number of states, including Rhode Island, New York, New Hampshire, and Delaware that have specific rules that require an inspection and maintenance plan (I&M plan) be prepared for each permitted site (Table 18). These manuals must clearly identify required inspection activities, schedules, and record keeping requirements. Typically specific maintenance activities and schedules are prescribed for each BMP. States where such a manual is not required often still have specific maintenance expectations but do not require preparation of a titled document.

The following sections describe the most common elements of I&M plans required in other states.

Table 18. Summary of operation, maintenance, and inspection strategies.

State	Site Specific O&M Plan	General Maintenance Plan	Vegetated Swale	Tree Box Filter	Media Filter	Bioretention	Infiltration Trench	Extended Detention/Dry Pond	Rain Garden/ Flow-Through Planters	Wet Pond	Sand Filtration	Infiltration Basin	Filter Strip	Underground Detention	Constructed Wetland	Riparian Buffer	Permeable Pavement	Rooftop Runoff Management	Proprietary Systems	Open Channels
Vermont	X					T	T					T			T					T
California			T	T	T	T	T	T	T											
Connecticut	X																			
Delaware	G	G				T	T	T		T	G	T	G	T						
New Hampshire	G																			
New Jersey	X																			
New York	G					T	T			T	T									
North Carolina			T			T	T	T		T	T		T		T	T	T	T	T	
Pennsylvania	X																			
Rhode Island	G					T	T	T		T	T						T			T
Washington	X																			
West Virginia	X																			

X= general requirement for proper maintenance included in permit conditions
G= inspection and maintenance explicitly required, some guidelines provided
T= inspection and maintenance explicitly required, standard templates for maintenance and inspection provided.

5.2.1.1. Declaration of Responsible Entity and Funding Provisions

The I&M plan often identifies the party responsible for system upkeep (typically the permittee or the property owner). Several states including Connecticut, Delaware, and New Hampshire, specifically require this to be documented in the I&M plan (Table 18). Measures can be included to maintain a link between maintenance responsibilities and a responsible party when ownership changes. This can be accomplished through a deed-covenant, easement, right-of-way, or other available means. Some states require that stormwater management practices be recorded in the land records.

Rhode Island and Connecticut require that a funding source be identified for the performance of I&M activities. Pennsylvania allows for the transfer of I&M responsibilities to other entities such as a non-profit, conservation district, or private entity.

5.2.1.2. Annotated Design Plan

Several states including Delaware, New Hampshire, and Rhode Island, require annotated design plans detailing the location of stormwater treatment practices and the associated inspection and maintenance needs; notes on required inspection and maintenance activities are often included (Table 18). Typically, the plan sheet is required to be updated with as-built conditions and verified by the design engineer if the constructed practices varied from the original design. Exceptions are sometimes made for simpler systems constructed from standardized plans.

5.2.1.3. Design and Construction Certification

It is important to ensure that stormwater management facilities are constructed in accordance with the plans and specifications. Requiring post-construction certification is one approach for ensuring proposed facilities are properly installed. Connecticut's stormwater management rules call for post-construction certification; specific requirements include (Connecticut DEP, 2004):

- As-built plans of completed structures
- Letter of compliance from the designer
- Post-Construction documentation to demonstrate compliance with maintenance activities

5.2.1.4. Inspection/Maintenance Schedule and Log

Clear maintenance schedules and tracking logs aid the permit-holder in maintaining the stormwater system while enabling the regulatory agency to check for permit compliance. Several states, including Connecticut, Delaware, New Hampshire, and Washington require a formalized inspection and maintenance schedule (Table 18). Additionally, a log is typically required to document when inspections were performed and what maintenance work was completed.

5.2.1.5. Maintenance Requirement Templates

Standard maintenance templates are a common technique used to help ensure comprehensive maintenance activities are conducted routinely. Templates typically provide practice-specific instructions for inspection and maintenance needs. The sheets are often fillable-electronic documents that allow the permittee to add site-specific information. The result is a consistent, quality-controlled document that provides essential information for the most common practices that can be applied to individual sites. Creation of templates helps to ensure that minimum standards are clearly communicated to initial and future permittees. States such as Delaware, North Carolina, and Rhode Island as well as Alameda County, California utilize standard maintenance templates for each specific or group stormwater control and treatment practices (Table 18). Vermont currently provides maintenance guidelines for each category of STP in the SWMM but it does not go so far as to provide maintenance plan templates. Links to examples of templates can be found Appendix D.

5.2.1.6. Inspection Form Templates

Inspection form templates can help ensure effective and consistent inspection and evaluation of stormwater control and treatment practices. Having standardized forms helps to ensure that adequate information is gathered and recorded on a timely basis. This information can then be used to make effective decisions about the frequency and timing of routine facility maintenance. Alameda County, California; Delaware, New York, and Rhode Island all utilize standardized templates that are easily be applied to specific sites (Table 18). The State of California also provides inspection form templates for standard practices but with a slightly different approach that may result in increased objectivity of the inspections. Vermont offers some inspection form templates in Appendix D8 of the VSWMM. Links to examples of inspection form templates can be found in Appendix D.

5.2.1.7. Signage

A unique requirement imposed by New York State is that stormwater control and treatment sites have signage describing the treatment practice. Proper signage can help identify treatment areas that should, for instance, not be mowed by a grounds crew, and can help prevent unwanted disturbance on the part of uninformed parties such as contracted landscapers.

5.3. Recommendations

Vermont's current inspection and maintenance requirements are part of the general stormwater discharge permits. These requirements differ slightly from those found in "Chapter 18: Stormwater Management" of the Vermont's *Environmental Protection Rules*. The following are options for improving the utility of inspection and maintenance efforts:

- Inspection and maintenance requirements should be made consistent across all of Vermont's rules, permits and webpages.
- Consider including more specific information and expanding the universe of practices addressed by maintenance requirements and guidance that is provided in Section 2.7 of the VWSMM.
- Consider expanding the inspection forms found in Appendix D8 of the VWSMM. Additionally, all of these forms could be offered as fillable PDF or Microsoft Word document formats so that they are more convenient to permit applicants.
- Evaluate the utility of requiring designers to develop a practice-specific I&M plan.

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APPENDICES

APPENDIX A: SITE CHARACTERIZATION FOR INFILTRATION PRACTICES, DETAILS BY STATE

A.1. Maine

Site suitability and characterization criteria for infiltration practices include:

2. Soil Permeability: The permeability of the soil at the depth of the base of the proposed infiltration system must be no less than 0.50 inches per hour and no greater than 2.41 inches per hour. Permeability must be shown to be reasonably consistent across the proposed infiltration area and shall be determined by in-place well or permeameter testing, by analyses of soil gradation, or other means acceptable to the department.

Information on horizontal separation distances for infiltration BMPs is scattered throughout Chapter 6 of the manual (Maine DEP, 2011).

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A.2. Massachusetts

MA Stormwater Handbook, Structural BMP specifications for bioretention areas with infiltration—Volume 2 planning considerations include “Determine the infiltrative capacity of the underlying native soil by performing a soil evaluation in accordance with Volume 3. Do not use a standard septic system (i.e., Title 5) percolation test to determine soil permeability.” (Volume 2, Chapter 2, page 26).

Vol. 2 information for bioretention (p 23-28) does not contain specifics for # of tests needed per unit area

Table IB.1 - Site Criteria for Infiltration Basins (p. 88)

1. The contributing drainage area to any individual infiltration basin should be restricted to 15 acres or less.
2. The minimum depth to the seasonal high water table, bedrock, and/or impermeable layer should be 2 ft. from the bottom of the basin.
3. The minimum infiltration rate is 0.17 inches per hour. Infiltration basins must be sized in accordance with the procedures set forth in Volume 3.
4. One soil sample for every 5000 ft. of basin area is recommended, with a minimum of three samples for each infiltration basin. Samples should be taken at the actual location of the proposed infiltration basin so that any localized soil conditions are detected.
5. Infiltration basins should not be used at sites where soils have 30% or greater clay content, or 40% or greater silt clay content.

6. Infiltration basins should not be placed over fill materials.
7. The following setback requirements should apply to infiltration basin installations:
   - Distance from any slope greater than 15% - Minimum of 50 ft.
   - Distance from any soil absorption system- Minimum of 50 ft.
   - Distance from any private well - Minimum of 100 ft., additional setback distance may be required depending on hydrogeological conditions.
   - Distance from any public groundwater drinking supply wells - Zone I radius, additional setback distance may be required depending on hydrogeological conditions.
   - Distance from any surface drinking water supply - Zone A
   - Distance from any surface water of the commonwealth (other than surface water supplies and their tributaries) - Minimum of 50 ft.
   - Distance from any building foundations including slab foundations without basements - Minimum of 10 ft. downslope and 100 ft. upslope.

Table IT.1 - Site Criteria for Infiltration Trenches (p. 97)

1. The contributing drainage area to any individual infiltration trench should be restricted to 5 acres or less.
2. The minimum depth to the seasonal high water table, bedrock, and/or impermeable layer should be 2 ft. from the bottom of the trench.
3. The minimum acceptable soil infiltration rate is 0.17 inches per hour. Infiltration trenches must be sized in accordance with the procedures set forth in Volume 3.
4. A minimum of 2 soil borings should be taken for each infiltration trench. Infiltration trenches over 100 ft. in length should include at least one additional boring location for each 50 ft. increment. Borings should be taken at the actual location of the proposed infiltration trench so that any localized soil conditions are detected.
5. Infiltration trenches should not be used at sites where soils have 30% or greater clay content, or 40% or greater silt clay content. Infiltration trenches will not function adequately in areas with hydrologic soils in group D and infiltration will be limited for hydrologic soils in group C.
6. Infiltration trenches should not be placed over fill materials.
7. The following setback requirements apply to infiltration trench installations:
   - Distance from any slope greater than 5% to any surface exposed trench: minimum of 100 ft.
   - Distance from any slope greater than 20% to any underground trench: minimum of 100 ft.
   - Distance from septic system soil absorption system: minimum of 50 ft.

- Distance from any private well: minimum of 100 feet, additional setback distance may be required depending on hydrogeological conditions.
- Distance from any public groundwater drinking water supplies: Zone I radius, additional setback distance may be required depending on hydrogeological conditions.
- Distance from any surface water supply and its tributaries: Zone A
- Distance from any surface water of the Commonwealth (other than surface drinking water supplies and their tributaries): minimum of 150 ft downslope and 100 ft upslope.
- Distance from any building foundations including slab foundations without basements: minimum of 20 ft.

Stormwater Recharge Requirements: pages 5-32 of Volume 3, Chapter 1.

Minimum infiltration rate: 0.17 inches/hour at the actual location where infiltration is proposed on site soil (p. 6)

Rapid Infiltration Rate: Rapid infiltration rate for purposes of stormwater infiltration is considered to be saturated hydraulic conductivity greater than 2.4 inches/hour at the specific location(s) where infiltration is proposed (p. 6)

SOIL EVALUATION

An evaluation must be undertaken to classify the Hydrologic Soil Groups (HSG) soils on site using classification methodologies developed by U.S. Natural Resources Conservation Service (NRCS). The Hydrologic Soil Groups are used in conjunction with impervious areas on a site to calculate the Required Recharge Volume.

The following steps are required to identify the Hydrologic Soil Groups on a site:

STAGE 1) Review NRCS (formerly SCS) Soil Surveys

STAGE 2) Determine Site Conditions at Specific Location Where Recharge is Proposed, including:

- Soil Textural Analysis using NRCS methods
  - The number of locations where the soil textural analysis must be conducted at the actual point(s) where stormwater recharge is proposed depends on the type and size of the infiltration BMP. The BMP Specifications in Volume 2, Chapter 2 list the number of test locations needed for specific infiltration BMPs.
- Depth to seasonal high groundwater
  - Seasonal high groundwater represents the highest groundwater elevation. Depth to seasonal high groundwater may be identified based on redox features in the soil (see Fletcher and Venneman listed in References). When redox features are not available, installation of temporary push point wells or piezometers should be considered. Ideally, such wells should be monitored in the spring when groundwater is highest and results compared to nearby groundwater wells monitored by the USGS to estimate whether regional groundwater is below normal, normal or above normal (see: http://ma.water.usgs.gov). Procedures

identified by MassDEP Title 5 Soil Evaluator Course, Chapter 4 may also be used. See: http://www.mass.gov/dep/water/compliance/sech4.pdf.

- When "Dynamic Field" Method is proposed for sizing, a field-derived saturated hydraulic conductivity must be determined as part of the site investigation.
  - Field test methods to assess saturated hydraulic conductivity for the "Dynamic Field" method must simulate the "field-saturated" condition. See ASTM D5126-90 (2004) Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone. The saturated hydraulic conductivity analysis must be conducted by the Competent Soils Professional. Acceptable tests include:
    - Guelph permeameter - ASTM D5126-90 Method
    - Falling head permeameter – ASTM D5126-90 Method
    - Double ring permeameter or infiltrometer - ASTM D3385-03 , D5093-02 , D5126-90 Methods
    - Amoozemeter or Amoozegar permeameter – Amoozegar 1992
  - A Title 5 percolation test is not an acceptable test for saturated hydraulic conductivity. Title 5 percolation tests overestimate the saturated hydraulic conductivity rate.
  - The number of test locations is dependent on the type and size of the infiltration BMP. The BMP Section in Volume 2, Chapter 2 lists the number of test locations needed for specific infiltration BMPs.
  - For the "Dynamic Field" method, the tests results for saturated hydraulic conductivity measured in the field must use the lowest of the values recorded for sizing the stormwater recharge BMP, and not an average.
- For the "Static" and "Simple Dynamic" Methods, the saturated hydraulic conductivity is determined using the Rawls Rate associated with the slowest of the Hydrologic Soil Groups determined to exist at the point where recharge is actually proposed.
  - Example: Assume three samples are taken at a proposed infiltration basin in the actual soil layer where recharge is proposed. Two samples indicate sandy soils. The last sample indicates a sandy loam soil. The Rawls Rates used for the exfiltration analysis must use the sandy loam rate and not the sandy soil rate. Soils must not be composited for purposes of the soil textural analysis.
- When the "Static" or "Simple Dynamic" Methods or LID Site Design Credits are proposed for sizing stormwater recharge BMPs, in-situ tests for saturated hydraulic conductivity are not required for purposes of the Stormwater Standards and the saturated hydraulic conductivities listed by Rawls 1982 (see Table 2.3.3) shall be used (p. 10)

STAGE 3: Identify Hydrologic Soil Groups On-site and At Location Where Recharge Proposed

STAGE 4: Prepare a Plan identifying Hydrologic Soil Groups for the Site

“The "Static" Method [for determining storage volume in the treatment practice] assumes that there is no exfiltration until the entire recharge device is filled to the elevation associated with the Required Recharge Volume. The two "Dynamic" Methods assume stormwater exfiltrates into the groundwater as the storage chamber is filling. The "Simple Dynamic" Method assumes that the Required Recharge Volume is discharged to the infiltration BMP over 2 hours and exfiltrates over the 2-hour period at the Rawls Rate. The "Dynamic Field" Method assumes that the Required Recharge Volume discharges to the infiltration BMP over 12 hours and infiltrates at no more than 50% of the in-situ saturated hydraulic conductivity rate. The "Static" Method produces a larger storage volume than either Dynamic Method and produces the most conservative result. The "Dynamic Field" Method may be used only for sizing an infiltration BMP that is used solely for disposal of stormwater (i.e., 80% TSS removal must occur prior to directing runoff to the infiltration BMP).” (p. 17)

Table 2.3.3. from the MA Stormwater Manual: 1982 Rawls Rates

Texture Class	NRCS Hydrologic Soil Group (HSG)	Infiltration Rate (Inches/Hour)
Sand	A	8.27
Loamy Sand	A	2.41
Sandy Loam	B	1.02
Loam	B	0.52
Silt Loam	C	0.27
Sandy Clay Loam	C	0.17
Clay Loam	D	0.09
Silty Clay Loam	D	0.06
Sandy Clay	D	0.05
Silty Clay	D	0.04
Clay	D	0.02

MOUNDING ANALYSIS (p. 28-29)

Mounding analysis is required when the vertical separation from the bottom of an exfiltration system to seasonal high groundwater is less than four (4) feet and the recharge system is proposed to attenuate the peak discharge from a 10-year or higher 24-hour storm (e.g., 10-year, 25-year, 50-year, or 100-year 24-hour storm). In such cases, the mounding analysis must demonstrate that the Required Recharge Volume (e.g., infiltration basin storage) is fully dewatered within 72 hours (so the next storm can be stored for exfiltration). The mounding analysis must also show that the groundwater mound that forms under the recharge system will not break out above the land or water surface of a wetland (e.g., it doesn’t increase the water sheet elevation in a Bordering Vegetated Wetland, Salt Marsh, or Land Under Water within the 72-hour evaluation period).

The Hantush or other equivalent method may be used to conduct the mounding analysis. The Hantush method predicts the maximum height of the groundwater mound beneath a rectangular or circular recharge area. It assumes unconfined groundwater flow, and that a linear relation exists between the water table elevation and water table decline rate. It results in a water table recession hydrograph depicting exponential decline. The Hantush method is available in proprietary software and free on-line calculators on the Web in automated format. If the analysis indicates the mound will prevent the infiltration BMP from fully draining within the 72-hour period, an iterative process must be employed to determine an alternative design that drains within the 72-hour period.

Mounding analysis is also needed when recharge is proposed at or adjacent to a site classified as contaminated, was capped in place, or has an Activity and Use Limitation (AUL) that precludes inducing runoff to the groundwater, pursuant to MGL Chapter 21E and the Massachusetts Contingency Plan 310 CMR 40.0000; or is a solid waste landfill pursuant to 310 CMR 19.000; or groundwater from the recharge location flows directly toward a solid waste landfill or 21E site. In this case, the mounding analysis must determine whether infiltration of the Required Recharge Volume will cause or contribute to groundwater contamination.

Massachusetts Department of Environmental Protection. 2008. Massachusetts Stormwater Handbook. Revised February 2008. Accessed at http://www.mass.gov/dep/water/laws/policies.htm#storm on August 13, 2012.

Massachusetts Department of Environmental Protection. 2008. Massachusetts Stormwater Handbook, Volume 2, Chapter 2: Structural BMP Specifications for the Massachusetts Stormwater Handbook. Accessed at http://www.mass.gov/dep/water/laws/v2c2.pdf on August 13, 2012.

A.3. Minnesota

Overall context: “While the Manual has no regulatory authority in and of itself, it seeks to provide a sound technical basis for stormwater management design and implementation. This can be coordinated on a statewide level through existing laws and regulations.” (p. 119); <1 acre of disturbance triggers state-level Minnesota Pollution Control Authority involvement via construction stormwater permitting program. Local authorities may have more stringent standards and separate review procedures.

(see also Page 198, Table 8.6 Infiltration Rates Observed in Infiltration Practices Operating in Minnesota)

Site characterization (and design) criteria for infiltration practices (p. 431-458)

Infiltration systems should be located in permeable soils and a **minimum 3-foot distance is REQUIRED from the bottom of the practice to the seasonally high water table, bedrock or other impeding layer** per the Minnesota Pollution Control Agency Construction General Permit (CGP).

2.1. Physical Feasibility Initial Check (p. 439)

Maximum drainage areas:

- Dry well – 1 acre.
- Infiltration Trench – 5 acres.
- Underground Infiltration System – 10 acres.
- Infiltration Basin – between 5 and 50 acres.

Site Topography and Slopes: HIGHLY RECOMMENDED that infiltration practices be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20%, and that slopes in contributing drainage areas be limited to 15%.

Soils: **HIGHLY RECOMMENDED that native soils in proposed infiltration areas have a minimum infiltration rate of 0.2 inches per hour** (typically Hydrologic Soil Group A, B and C soils). Initially, soil infiltration rates can be estimated from NRCS soil data, and confirmed with an on-site infiltration evaluation or geotechnical investigation (see Step 6 of the Design Procedures section for investigation procedures). It is HIGHLY RECOMMENDED that native soils have silt/clay contents less than 40% and clay content less than 20%, and that infiltration practices not be situated in fill soils.

Depth to Ground Water Table and Bedrock: **Minimum vertical distance of 3 feet between the bottom of the infiltration practice and the seasonally high water table or bedrock layer** (see also Step 8 under the Design Procedure section).

Site Location / Minimum Setbacks: It is HIGHLY RECOMMENDED that infiltration practices not be hydraulically connected to structure foundations or pavement, to avoid seepage and frost heave concerns, respectively. If ground water contamination is a concern, it is RECOMMENDED that ground water mapping be conducted to determine possible connections to adjacent ground water wells. The following (Table 12.INF.2) minimum setbacks are REQUIRED by the Minnesota Department of Health for the design and location of infiltration practices.

Minimum setbacks (p. 437):

- Setback from Minimum Distance [feet]
- Property Line: 10
- Building Foundation (Minimum with slopes directed away from the building): 10
- Private Well: 50
- Public Water Supply Well: 50
- Septic System Tank/Leach Field: 35

Field verification of site suitability (p. 451)

If the initial evaluation indicates that an infiltration practice would be a good BMP for the site, it is RECOMMENDED that a **minimum of three soil borings or pits be dug (in the same location as the proposed infiltration practice)** to verify soil types and infiltration capacity characteristics and to determine the depth to ground-water and bedrock.

It is RECOMMENDED that the minimum depth of the soil borings or pits be five feet below the bottom elevation of the proposed infiltration practice.

It is HIGHLY RECOMMENDED that soil profile descriptions be recorded and include the following information for each soil horizon or layer (Source: Site Evaluation for Stormwater Infiltration, Wisconsin Department of Natural Resources Conservation Practice Standards, 2004):

- Thickness, in inches or decimal feet
- Munsell soil color notation
- Soil mottle or redoximorphic feature color, abundance, size and contrast
- USDA soil textural class with rock fragment modifiers
- Soil structure, grade size and shape
- Soil consistency, root abundance and size
- Soil boundary
- Occurrence of saturated soil, impermeable layers/lenses, ground-water, bedrock or disturbed soil

- It is HIGHLY RECOMMENDED that the field verification be conducted by a qualified geotechnical professional.

Sizing infiltration practice (p. 452-453)

Infiltration Rates: If the infiltration rate is not measured, the Table 12.INF.7 provides infiltration rates for the design of infiltration practices. These infiltration rates represent the long-term infiltration capacity of a practice and are not meant to exhibit the capacity of the soils in the natural state. Select the design infiltration rate from the Table 12.INF.7 based on the least permeable soil horizon within the first five feet below the bottom elevation of the proposed infiltration practice.

Table 12.INF.7, Design Infiltration Rates, from the Minnesota stormwater manual

Hydrologic Soil Group	Soil Textures*	Corresponding Unified Soil Classification**	Infiltration Rate [inches/hour]
A	Gravel, sand, sandy gravel, silty gravel, loamy sand, sandy loam	**GW** – Well-graded gravel or well-graded gravel with sand **GP** – Poorly graded gravel or poorly graded gravel with sand	1.63
		GM – Silty gravel or silty gravel with sand **SW** – Well-graded sand or well-graded sand with gravel **SP** – Poorly graded sand or poorly graded sand with gravel	0.8
B	Loam, silt loam	**SM** – Silty sand or silty sand with gravel	0.6
		ML – Silt **OL** – Organic silt or organic silt with sand or gravel or gravelly organic silt	0.3
C	Sandy clay loam	**GC** – Clayey gravel or clayey gravel with sand **SC** – Clayey sand or clayey sand with gravel	0.2
D	Clay, clay loam, silty clay loam, sandy clay, silty clay	**CL** – Lean clay or lean clay with sand or gravel or gravelly lean clay **CH** – Fat clay or fat clay with sand or gravel or gravelly fat clay **OH** – Organic clay or organic clay with sand or gravel or gravelly organic clay MH – Elastic silt or elastic silt with sand or gravel	< 0.2

Source: Thirty guidance manuals and many other stormwater references were reviewed to compile recommended infiltration rates. All of these sources use the following studies as the basis for their recommended infiltration rates: Rawls, Brakensiek and Saxton (1982); Rawls, Gimenez and Grossman (1998); Bouwer and Rice (1984); and Urban Hydrology for Small Watersheds (NRCS). The rates presented in this infiltration table use the information compiled from these sources as well as eight years of infiltration rates collected in various infiltration practices located in the South Washington Watershed District.

*U.S. Department of Agriculture, Natural Resources Conservation Service, 2005. National Soil Survey Handbook, title 430-VI. (Online) Available: http://soils.usda.gov/technical/handbook/.

**ASTM standard D2487-00 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

The infiltration capacity and existing hydrologic regime of natural basins are inheritably different than constructed practices and may not meet the General Permit requirements for constructed practices. In the event that a natural depression is being proposed to be used as an infiltration system, the design engineer must demonstrate the following information: infiltration capacity of the system under existing conditions (inches/hour), existing drawdown time for the high water level (HWL) and a natural overflow elevation. The design engineer should also demonstrate that operation of the natural depression under post-development conditions mimics the hydrology of the system under pre-development conditions.

If the infiltration rates are measured the tests shall be conducted at the proposed bottom elevation of the infiltration practice. If the infiltration rate is measured with a double-ring infiltrometer the requirements of ASTM D3385 shall be used for the field test. The measured infiltration rate shall be divided by a correction factor selected from Table 12.INF.8. The correction factor adjusts the measured infiltration rates for the occurrence of less permeable soil horizons below the surface and the potential variability in the subsurface soil horizons throughout the infiltration site. This correction factor also accounts for the long-term infiltration capacity of the stormwater management facility.

To select the correction factor from Table 12.INF.8, determine the ratio of the design infiltration rates for each location an infiltration measurement was performed. To determine this ratio, the design infiltration rate (Table 12.INF.7) for the surface textural classification is divided by the design infiltration rate for the least permeable soil horizon. For example, a device with a loamy sand (0.8"/hr.) at the surface and least permeable layer of loam (0.3"/hr.) will have a design infiltration rate ratio of about 2.7 and thus a correction factor of 3.5. The depth of the least permeable soil horizon should be within five feet of the proposed bottom of the device or to the depth of a limiting layer. In this exercise, if an infiltration rate of 2.5"/hr is measured, the adjustment rate would be 0.71"/hr.

Table 12.INF.8 Total Correction Factors Divided into Measured Infiltration Rates, from the Minnesota stormwater manual

Ratio of Design Infiltration Rates[2]	Correction Factor
1	2.5
1.1 to 4.0	3.5
4.1 to 8.0	4.5
8.1 to 16.0	6.5
16.1 or greater	8.5
[1] The method used to evaluate measured infiltration rates was developed by the Wisconsin Department of Natural Resources and is published in *Site Evaluation for Stormwater Infiltration (1002) Wisconsin Department of Natural Resources Conservation Practice Standards 02/04.* [2] Ratio is determined by dividing the design infiltration rate (Table 12.INF.9) for the textural classification at the bottom of the infiltration device by the design infiltration rate (Table 12.INF.9) for the textural classification of the least permeable soil horizon. The least permeable soil horizon used for the ratio should be within five feet of the bottom of the device or to the depth of the limiting layer.	

Ground-water mounding analysis (p. 455).

Ground water mounding, the process by which a mound of water forms on the water table as a result of recharge at the surface, can be a limiting factor in the design and performance of infiltration practices. A minimum of 3 feet of separation between the bottom of the infiltration practice and seasonally saturated soils (or from bedrock) is REQUIRED (5 feet RECOMMENDED) to maintain the hydraulic capacity of the practice and provide adequate water quality treatment. A ground water mounding analysis is RECOMMENDED to verify this separation for infiltration practices.

The most widely known and accepted analytical methods to solve for ground water mounding are based on the work by Hantush (1967) and Glover (1960). The maximum ground water mounding potential should be determined through the use of available analytical and numerical methods. Detailed ground water mounding analysis should be conducted by a trained hydrogeologist or equivalent as part of the site design procedure.

Minnesota Stormwater Steering Committee. 2008. The Minnesota Stormwater Manual. Effective November 2005; version 2 effective January 2008. Accessed at http://www.pca.state.mn.us/publications/wq-strm9-01.pdf on July 12, 2012.

A.4. New Hampshire

Standardized Test Pit/boring protocol (vol 2 pg 14 of SW manual)

Test pits or borings required in location of infiltration treatment practice to 5 ft below expected practice bottom, or to ESHGW or bedrock, whichever is less.

Minimum # of tests:

Infiltration Basins Less than 2,500 sf: 1 test

Infiltration Basins 2,500 sf or more:

- 2,500 sf – 20,000 sf = 2 tests
- 20,000 sf – 30,000 sf = 3 tests
- 30,000 – 40,000 = 4 tests
- 1 additional test for every additional 10,000 sf.

Infiltration Trenches :

- 0 LF – 100 LF = 1 test
- 100 LF – 200 LF = 2 tests
- 200 LF – 300 LF = 3 tests
- 1 additional test for every additional 100 LF.

Default Ksat values may be used for native soils only.

Field Ksat tests should be measured with a Guelph Permeameter; a Compact Constant Head Permeameter; a Double-Ring Infiltrometer (ASTM 3385), where the inner ring is at least 12 inches in diameter; or a Borehole Infiltration test, see Table 2-3 for the testing protocol.

Minimum number of infiltration tests (Table 2-4, which is mislabeled in the text)

- Infiltration Basins (no manmade soils present): 1 test for each 2,500 sf of basin area
- Infiltration Basins (manmade soils present): 1 test for each 1,000 sf of basin area

- Infiltration Trenches (no manmade soils present): 1 test for each 100 LF of trench
- Infiltration Trenches (manmade soils present): 1 test for each 50 LF of trench

New Hampshire Department of Environmental Services. 2008. New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design. Version 1.0, effective December 2008. Accessed at http://des.nh.gov/organization/commissioner/pip/publications/wd/documents/wd-08-20b.pdf on August 27, 2012.

A.5. New York

Infiltration testing requirements below are substantively identical to Vermont's SWMM.

Appendix D of the state's stormwater manual includes requirements for infiltration testing (Table D-1 below summarizes the requirements):

Type of Facility	Initial Feasibility Testing	Concept Design Testing rate greater than 0.5"/hr)	Concept Design Testing (initial testing yields a [illegible]
I-1 (trench)	1 field percolation test, test pit not	1infiltration test and 1 test pit per 50' of trench	not acceptable practice
I-2 (basin)	1 field percolation test, test pit not	1 infiltration test* and 1 test pit per 200 sf of basin area	not acceptable practice
F-1(sand filter)	1 field percolation test, test pit not	1 infiltration test and 1 test pit per 200 sf of filter area	underdrains required
F-6 (bioretention)	1 field percolation test, test pit not	1 infiltration test and 1 test pit per 200 sf of filter area	underdrains required

*feasibility test information already counts for one test location
** underdrain installation still strongly suggested

- Test pits or borings must extend 4 feet below the practice bottom elevation (or to groundwater or bedrock if these conditions are within 4 feet of practice bottom elevation).
- No documentation of seasonal high groundwater conditions required.
- Infiltration testing procedure in manual is for a percolation test, not a Ksat measurement.

New York State Department of Environmental Conservation. 2010. New York State Stormwater Management Design Manual. Revised August 2010. Accessed at http://www.dec.ny.gov/docs/water_pdf/swdm2010entire.pdf on July 12, 2012.

A.6. North Carolina

Chapter 16 (Infiltration devices) of North Carolina's Stormwater BMP Manual specifies the following: "A site-specific hydrogeologic investigation shall be performed to establish the suitability of site soils for the BMP. To be suitable for infiltration, underlying soils must have an infiltration rate of 0.52 inches per hour or greater, as initially determined from NRCS soil textural classification (typically hydrologic soil groups A and B) and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test hole per 5,000 ft2 of infiltrating area, with a minimum of one boring and infiltration test per facility (taken within the proposed limits of the BMP). Double-ring infiltrometers or basin flooding tests should be used (EPA, 1981). Other widely accepted methods may also be used. The highest measurement should be discarded when computing the average hydraulic conductivity for the site." The Manual also stipulates:

- Infiltration devices cannot be used on soils with infiltration rates of less than 0.52 inches/hour.
- Minimum 2 feet to seasonal high groundwater and bedrock (4 feet recommended), min. 100 feet from water supply wells.

North Carolina Department of Environment and Natural Resources. 2007. DWQ Stormwater BMP Manual & BMP Forms. Effective July 2007, revised September 1, 2010. Accessed at http://portal.ncdenr.org/web/wq/ws/su/bmp-manual/ on July 12, 2012.

A.7. Pennsylvania

PA's stormwater manual guidance applies to all persons conducting or planning to conduct activities that require a written post-construction stormwater management plan.

Chapter 6 covers structural BMPs including infiltration structures. References in this chapter to Appendix C, Site Evaluation and Soil Testing

INFILTRATION TESTING: A MULTI-STEP PROCESS

Infiltration Testing is a four-step process to obtain the necessary data for the design of the stormwater management plan. The four steps include:

1. Background Evaluation

- Based on available published and site specific data
- Includes consideration of proposed development plan
- Used to identify potential BMP locations and testing locations
- Prior to field work (desktop)
- On-site screening test

2. Test Pit (Deep Hole) Observation

- Includes Multiple Testing Locations
- Provides an understanding of sub-surface conditions

- Identifies limiting conditions
- A Test Pit consists of a backhoe-excavated trench, 2-1/2 to 3 feet wide, to a depth of between 72 inches and 90 inches, or until bedrock or fully saturated conditions are encountered. The trench should be benched at a depth of 2-3 feet for access and/or infiltration testing.
- The number of Test Pits varies depending on site conditions and the proposed development plan. General guidelines are as follows:
  - For single-family residential subdivisions with on-lot BMPs, one test pit per lot is recommended, preferably within 25 feet of the proposed BMP area. Verification testing should take place when BMPs are sited at greater distances.
  - For multi-family and high density residential developments, one test pit per BMP area or acre is recommended.
  - For large infiltration areas (basins, commercial, institutional, industrial, and other proposed land uses), multiple test pits should be evenly distributed at the rate of four (4) to six (6) tests per acre of BMP area.

3. Infiltration Testing

- Must be conducted on-site
- Different testing methods available
- Alternate methods for - additional-Screening and Verification testing

4. Design Considerations

- Determination of a suitable infiltration rate for design calculations
- Consideration of BMP drawdown
- Consideration of peak rate attenuation

Infiltration tests should be conducted in the field. Tests should not be conducted in the rain or within 24 hours of significant rainfall events (>0.5 inches), or when the temperature is below freezing. However, the preferred testing is between January and June, the wet season. Percolation tests carried out between June 1 and December 31 should use a 24 hour presoaking before the testing. This procedure is not required for Infiltrometer testing, or permeometer testing.

At least one test should be conducted at the proposed bottom elevation of an infiltration BMP, and a minimum of two tests per Test Pit is recommended. More tests may be warranted if the results for first two tests are substantially different. The highest rate (inches/hour) for test results should be discarded when more than two are employed for design purposes. The geometric mean should be used to determine the average rate following multiple tests.

Methodologies discussed in this protocol include:

- Double-ring Infiltrometer tests.
- Percolation tests (such as for on-site wastewater systems and described in Pa Code Chapter 73).

A Double-ring Infiltrometer test estimates the vertical movement of water through the bottom of the test area. The outer ring helps to reduce the lateral movement of water in the soil. A percolation test allows water movement through both the bottom and sides of the test area. For this reason, the measured rate of water level drop in a percolation test must be adjusted to represent the discharge that is occurring on both the bottom and sides of the percolation test hole.

For infiltration basins, it is strongly advised that an Infiltration Test be carried out with an infiltrometer (not percolation test) to determine the saturated hydraulic conductivity rate. This precaution is taken to account for the fact that only the surface of the basin functions to infiltrate, as measured by the test. Alternatively, permeability test procedures that yield a saturated hydraulic conductivity rate can be used (see formulas developed by Elrick and Reynolds (1992), or others for computation of hydraulic conductivity and saturated hydraulic conductivity).

Other testing methodologies and standards that are available but not discussed in detail in this protocol include (but are not limited to):

- Constant head double-ring infiltrometer
- Testing as described in the Maryland Stormwater Manual Appendix D.1 using 5-inch diameter casing.
- ASTM 2003 Volume 4.08, Soil and Rock (I): Designation D 3385-03, Standard Test Method for Infiltration Rate of Soils in Field Using a Double-Ring Infiltrometer.
- ASTM 2002 Volume 4.09, Soil and Rock (II): Designation D 5093-90, Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring.
- Guelph Permeameter
- Constant Head Permeameter (Amoozemeter)

Site considerations and constraints (p. 13 of Appendix C):

- maintain a 2-foot clearance above regularly occurring seasonally high water table.
- Maintain a minimum depth to bedrock of 2-feet to assure adequate pollutant removal.
- soils underlying infiltration devices should have infiltration rates between 0.1 and 10 inches per hour,
- Infiltration BMPs should be sited so that any risk to groundwater quality is minimized, at least 50 feet from individual water supply wells, and 100 feet from community or municipal water supply wells.
- Infiltration BMPs should be sited so that they present no threat to sub-surface structures, at least 10 feet down gradient or 100 feet up gradient from building basement foundations, and 50 feet from septic system drain fields unless specific circumstances allow for reduced separation distances
- Avoid severe slopes (>20%), and toes of slopes
- In general, soils of Hydrologic Soil Group D will not be suitable for infiltration.

- The minimum safety factor for design purposes that may used for any type of tests is two (2). For percolation tests in loams and finer soils (silty loam, clay loams, silty clay loams, sandy clay loams, clays) a minimum design safety factor of three (3) is recommended after using the reduction formula in Protocol 1, Site Evaluation and Soil Infiltration Testing. Therefore, a percolation rate of 0.5 inches per hour (after reduction formula) should generally be considered as a rate of 0.25 inches per hour when designing an infiltration BMP for a sandy loam. The same rate for a loam would yield a design rate of 0.17 inches/hour.

Pennsylvania Department of Environmental Protection, Bureau of Watershed Management. 2008. Pennsylvania Stormwater Best Management Practices Manual. Revised December 30, 2008. Accessed at http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305 on August 13, 2012.

A.8. Rhode Island

Rhode Island's soil and infiltration testing guidance (Appendix H-1) was adapted from the Massachusetts Stormwater Manual, Volume 3 (2008):

- Minimum field infiltration rate of 0.5 inches per hour is required
- Testing is to be conducted by a qualified professional (DEM-licensed Class IV soil evaluator or RI-registered PE)
- Initial feasibility testing should be conducted to determine whether full-scale testing is necessary and is meant to screen unsuitable sites and reduce testing costs.

The number of design test pits (or borings) shall be per the following table:

Type of Facility	Design Testing
Infiltration Practice*/Infiltrating Permeable Pavement Practices	1 infiltration test and 1 test pit per 5,000 ft^2
Filter Practice**	1 infiltration test and 1 test pit per 5,000 ft^2 (no underdrains required if infiltration rate > 0.5 in/hr***)
Dry Swale**	1 infiltration test and 1 test pit per 1,000 ft of dry swale (no underdrains required if infiltration rate > 0.5 in/hr ***)

*For use with residential rooftop runoff, testing requirements are reduced to 1 infiltration test and 1 test pit per 5 lots assuming consistent terrain and NRCS soil series. If terrain and soil series are not consistent, then requirements increase to 1 infiltration test and 1 test pit per 1 lot.
**When proposed as a treatment/infiltration system. If proposed as strictly a filtration practice, infiltration testing analysis not strictly required but a test pit or boring is required to verify depth to seasonal high groundwater or bedrock.
***Underdrain installation still strongly suggested.

- Test pits/borings shall extend to a depth of 4 ft below the proposed facility bottom.
- Depth to groundwater table and bedrock will be determined (if within 4 ft of proposed bottom) upon initial digging or drilling. Depth to water will be determined again 24 hours later when conducting soil borings or drilling wells.

- A DEM-licensed Class IV soil evaluator or RI-registered PE may establish seasonal high groundwater depth in test pits based on redoximorphic features and need not revisit the site 24 hours later.

Field test methods to assess saturated hydraulic conductivity must simulate the "field saturated" condition and must be conducted at the depth of the bottom of the proposed infiltrating practice. Design infiltration rates shall be determined by using a factor of safety of 2 from the field-derived value. See ASTM D5126-90 (2004) Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone. The saturated hydraulic conductivity analysis must be conducted by the DEM licensed Class IV soil evaluator or RI-registered PE. Acceptable tests include:

- Guelph permeameter - ASTM D5126-90 Method
- Falling head permeameter – ASTM D5126-90 Method
- Double ring permeameter or infiltrometer - ASTM D3385-033, D5093-024, D5126-90 Methods
- Amoozemeter or Amoozegar permeameter – Amoozegar 1992

Page 5-27 on design infiltration rates for infiltration practice design:

Design infiltration rates (fc) shall be determined by using Table 5-3, or shall be determined by in-situ rates (using a factor of safety of 2 from the field-derived value) established by one of the approved methods listed in Appendix H.1.3 (rates derived from standard percolation tests are not acceptable).

Table 5-3 Design Infiltration Rates for Different Soil Textures (Rawls et al., 1982)

USDA Soil Texture	Design Infiltration Rate (fc) (in/hr)	Design Infiltration Rate (fc) (ft/min)
Sand	8.27	0.0115
Loamy Sand	2.41	0.0033
Sandy Loam	1.02	0.0014
Loam	0.52	0.0007
Silt Loam	0.27	0.0004

Rhode Island Department of Environmental Management and Coastal Resources Management Council. 2010. Rhode Island Stormwater Design and Installation Standards Manual. Revised December 2010, effective January 1, 2011. Accessed at http://www.dem.ri.gov/pubs/regs/regs/water/swmanual.pdf on July 9, 2012.

A.9. Virginia

While SCS soil surveys and other available sources may be appropriate for a pre-engineering feasibility study, final design and acceptance should be based on an actual subsurface analysis and permeability tests.

In general, the following information should be included in a site-specific subsurface or geotechnical study:

1. Soil permeability

The soil types within the subsoil profile, extending a minimum of 3 feet below the bottom of the facility, should be identified to verify the infiltration rate or permeability of the soil. **Soil textures acceptable for use**

with infiltration systems include those with infiltration rates between 0.52 inches per hour and 8.27 inches per hour, and include loam, sandy loam, and loamy sand.

A safety factor of 2 should be applied to the infiltration rate determined from the soil analysis.

2. Depth to the seasonal high groundwater table and bedrock.

A distance of 2 to 4 feet is required between the bottom of an infiltration facility and the existing water table or bedrock.

3. Topographic conditions

infiltration practices should be located in areas in which the slope does not exceed 20% (5H:1V).

The use of stormwater management infiltration systems on fill material is not recommended

Nearby building foundations should be at least 10 feet up-gradient of the infiltration system

Proximity to septic systems is also a concern and local health officials should be consulted for guidance on minimum setbacks.

infiltration practices should be a minimum of 100 feet from any water supply well where the runoff is from commercial or industrial impervious parking areas.

For "appropriate geotechnical techniques", readers are referred to: Maryland Department of Environment. Standards & Specifications for Infiltration Practices. 1987. [*Maryland's testing requirements for infiltration practices are identical to Vermont's for all practical purposes*.]

A Darcy's Law approach is recommended for sizing water quality infiltration BMPs. This will assume that the drain time of the facility is controlled by one-dimensional flow through the bottom surface.

MINIMUM STANDARD 3.10A: INFILTRATION BASIN

Drainage areas served by infiltration basins should be limited to less than 50 acres

The seasonal high groundwater table or bedrock should be located at least 2 to 4 feet below the bottom of the basin

A minimum of one soil boring log should be required for each 5,000 square feet of infiltration basin area (plan view area) and under no circumstances should there be less than three soil boring logs per basin (Washington State DOE, 1992).

Infiltration basins should be a minimum of 50 feet from any slope greater than 15%. The use of infiltration basins on fill sites is not permitted. Also, infiltration basins should be a minimum of 100 feet up-slope and 20 feet down-slope from any buildings.

All infiltration basins should be designed to completely drain stored runoff within 2 days following the occurrence of a storm event.

MINIMUM STANDARD 3.10B: INFILTRATION TRENCH

Drainage areas served by infiltration trenches should be limited to less than 5 acres

The same general criteria presented for the design of infiltration basins apply to trenches

A minimum of one soil boring log should be required for every 50 feet of trench length. A minimum of two soil boring logs should be required for each proposed trench location (Washington State DOE, 1992).

Infiltration trenches should be located 20 feet down-slope and 100 feet up-slope from building foundations. The use of infiltration trenches on fill sites is not permitted.

Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation. 1999. Virginia Stormwater Management Handbook, Volume II. First Edition, 1999. Accessed at http://dcr.cache.vi.virginia.gov/stormwater_management/documents/Volume_II.pdf on August 14, 2012.

Maryland Department of Environment and the Center for Watershed Protection. 2000. Maryland Stormwater Design Manual, Volumes I and II. Effective October 2000, Revised May 2009). Accessed at http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/MarylandStormwaterDesignManual/Documents/www.mde.state.md.us/assets/document/appendixd1.pdf on August 14, 2012.

A.10. Washington

Volume III, Chapter 3, 3.3.5 Site Characterization Criteria (for infiltration facilities)

Subsurface Characterization:

1. Subsurface explorations (test holes or test pits) to a depth below the base of the infiltration facility of at least 5 times the maximum design depth of ponded water proposed for the infiltration facility, but not less than 10 feet below the base of the facility. However, at sites with shallow ground water (less than 15 feet from the estimated base of facility), if a ground water mounding analysis is necessary, determine the thickness of the saturated zone.

Continuous sampling (representative samples from each soil type and/or unit within the infiltration receptor) is required to a depth below the base of the infiltration facility of 2.5 times the maximum design ponded water depth, but not less than 10 feet. For large infiltration facilities serving drainage areas of 10 acres or more, perform soil grain size analyses on layers up to 50 feet deep (or no more than 10 feet below the water table).

2. If proposing to estimate the infiltration rate using the soil grain size analysis method, obtain samples adequate for the purposes of that gradation/classification testing.

- For basins, at least one test pit or test hole per 5,000 ft2 of basin infiltrating surface (in no case less than two per basin).
- For trenches, at least one test pit or test hole per 200 feet of trench length (in no case less than two per trench).

The depth and number of test holes or test pits, and samples, should be increased if conditions are highly variable and more samples are necessary to accurately estimate the performance of the infiltration system. The exploration program may be decreased if conditions are relatively uniform. In high water table sites, subsurface exploration sampling need not be conducted lower than two (2) feet below the ground water table.

3. Prepare detailed logs for each test pit or test hole and a map showing the location of the test pits or test holes. Logs must include at a minimum, depth of pit or hole, soil descriptions, depth to water, presence of stratification.

4. Ground water monitoring wells (or driven well points if expected shallow depth to ground water) installed to locate the ground water table and establish its gradient, direction of flow, and seasonal variations, considering both confined and unconfined aquifers. For facilities serving a drainage area less than an acre, establish that the depth to ground water or other hydraulic restriction layer will be at least 10 feet below the base of the facility. Use subsurface explorations or information from nearby wells.

In general, a minimum of three wells per infiltration facility, or three hydraulically connected surface or ground water features, are needed to determine the direction of flow and gradient. If surrounding site conditions indicate that gradient and flow direction are not critical one monitoring well may be sufficient. Alternative means of establishing the ground water levels may also be considered. If the ground water in the area is known to be greater than 50 feet below the proposed facility, detailed investigation of the ground water regime is not necessary.

Monitoring through at least one wet season is required, unless substantially equivalent site historical data regarding ground water levels is available.

5. If using the soil Grain Size Analysis Method for estimating infiltration rates: laboratory testing as necessary to establish the soil gradation characteristics and other properties as necessary, to complete the infiltration facility design. At a minimum, conduct one-grain size analysis per soil stratum in each test hole within 2.5 times the maximum design water depth, but not less than 10 feet.

Soil Testing:

Soil characterization for each soil unit encountered should include grain-size distribution (if using the grain size analysis method to estimate infiltration rates), visual grain size classification, percent clay content (include type of clay, if known), color/mottling, variations and nature of stratification, and cation exchange capacity (CEC) and organic matter content for each soil type and strata (if the facility will provide treatment as well as flow control).

Infiltration Receptor:

Infiltration receptor (unsaturated and saturated soil receiving the stormwater) characterization should include:

1. The information obtained from ground water monitoring in #4 of the Subsurface Characterization above.

2. An assessment of the ambient ground water quality, if that is a concern.

3. An estimate of the volumetric water holding capacity of the infiltration receptor soil (the soil layer below the infiltration facility and above the seasonal high-water mark, bedrock, hardpan, or other low permeability layer).

4. Determination of:

- Depth to ground water table and to bedrock/impermeable layers.
- Seasonal variation of ground water table based on well water levels and observed mottling.
- Existing ground water flow direction and gradient.
- Lateral extent of infiltration receptor.
- Horizontal hydraulic conductivity of the saturated zone to assess the aquifer's ability to laterally transport the infiltrated water.

- Impact of the infiltration rate and volume at the project site on ground water mounding, flow direction, and water table; and the discharge point or area of the infiltrating water. Conduct a ground water mounding analysis at all sites where the depth to seasonal ground water table or low permeability stratum is less than 15 feet from the estimated bottom elevation of the infiltration facility, and the runoff to the infiltration facility is from more than one acre.

3.3.6 Design Saturated Hydraulic Conductivity – Guidelines and Criteria

Measured (initial) saturated hydraulic conductivity (Ksat)rates can be determined using in-situ field measurements, or, if the site has soils unconsolidated by glacial advance, by a correlation to grain size distribution from soil samples. Three methods are provided for measuring or estimating initial saturated hydraulic conductivity (Ksat) rates at a site. Measured saturated hydraulic conductivity is used to determine the design (long-term) infiltration rate, then the design (long-term) infiltration rate is used for routing and sizing the basin/trench, and for checking for compliance with the maximum drawdown time of 48 hours. The methods are:

1. Large Scale Pilot Infiltration Test (PIT): a large-scale in-situ infiltration measurement in a test pit with horizontal surface area of the bottom measuring about 100 square feet (preferred method; not a standard test but a practical field procedure recommended by Ecology's Technical Advisory Committee)
2. Small-Scale Pilot Infiltration Test: a smaller in-situ infiltration measurement in a test pit where the horizontal surface area of the bottom is 12-32 square feet (can be substituted for the large-scale PIT where the drainage area to the infiltration site is less than 1 acre; where testing is for bioretention or permeable pavement that serve small drainage areas or are widely dispersed; or where the site has a high infiltration rate and the site geotechnical investigation suggests uniform characteristics)
3. Soil Grain Size Analysis Method: For each defined layer below the infiltration pond to a depth below the pond bottom of 2.5 times the maximum depth of water in the pond, but not less than 10 feet, estimate the initial saturated hydraulic conductivity (Ksat) in cm/sec using the following relationship (see Massmann 2003, and Massmann et al., 2003). For large infiltration facilities serving drainage areas of 10 acres or more, soil grain size analyses should be performed on layers up to 50 feet deep (or no more than 10 feet below the water table).

$$\log_{10}(K_{sat}) = -1.57 + 1.90D_{10} + 0.015D_{60} - 0.013D_{90} - 2.08f_{fines}$$ (p. 3-79, equation 1)

Where, D_{10}, D_{60} and D_{90} are the grain sizes in mm for which 10 percent, 60 percent and 90 percent of the sample is more fine and f_{fines} is the fraction of the soil (by weight) that passes the number-200 sieve (K_{sat} is in cm/s).

Once the Ksat for each layer has been identified, determine the effective average Ksat below the pond. Ksat estimates from different layers can be combined using the harmonic mean.

In all cases, correction factors are applied to the initial Ksat values obtained from the PIT test or Grain Size Method to produce appropriate design infiltration rates. Correction factors account for site variability, number of tests conducted, uncertainty of the test method, and the potential for long-term clogging due to siltation and bio-buildup (see Table 3.3.1, page 3-82 for more detail if needed).

Washington Department of Ecology. 2012. Stormwater Management Manual for Western Washington. Effective August 1, 2012. Accessed at https://fortress.wa.gov/ecy/publications/publications/1210030.pdf on August 14, 2012.

APPENDIX B: CHANNEL PROTECTION TREATMENT STANDARD, DETAILS BY STATE

B.1. Chesapeake Bay States

Chesapeake Stormwater Network developed a technical memorandum that provides the scientific basis for a workable engineering framework to design effective combinations of runoff reduction and stormwater treatment practices (Chesapeake Stormwater Network, 2008). Environmental Site Design (ESD) principles are applied in a process to conserve natural areas and soils first, apply ESD reduction practices, apply engineered runoff reduction practices, apply standard treatment practices—and pay mitigation fees if compliance cannot be achieved. Appendix A includes details of how runoff reduction rates were derived for select stormwater treatment practices (STPs), including green roofs, rooftop disconnection, raintanks and cisterns, permeable pavement, grass channels, bioretention, dry swales, infiltration, and soil amendment (compost). Appendix B includes details on derivation of pollutant removal rates for select STPs, including green roofs, permeable pavement, grass channels, bioretention, water quality swales, extended detention, filtration, wetlands, and wet ponds. Appendix C provides design factors for runoff reduction, total nitrogen reduction, and total phosphorus reduction as design guidance at two different treatment levels, while Appendix D provides minimum design criteria for select ESD practices.

Chesapeake Stormwater Network (CSN). (March 2008). CSN Technical Bulletin No. 4 – Technical Support for the Bay-wide Runoff Reduction Method, Version 2.0. Accessed at http://chesapeakestormwater.net/wp-content/plugins/download-monitor/download.php?id=6 on June 15, 2012.

The runoff reduction approach seeks to maintain the same predevelopment runoff volume delivered to a stream after a site is developed (Chesapeake Stormwater Network, 2009). *In its simplest terms, this means achieving the same predevelopment runoff coefficient for every storm, up to a designated storm event. Runoff reduction is defined as the total runoff volume that is reduced through canopy interception, soil infiltration, evaporation, rainfall harvesting, engineered infiltration, extended filtration or evapotranspiration. Extended filtration includes bioretention or dry swales with under drains that delay the delivery of stormwater from small sites to the stream system by six hours or more.*

Benefits of the runoff reduction approach include:

- *Provides an objective way to measure the aggregate performance of environmental site design, runoff reduction, and conventional stormwater treatment practices together.*
- *Mimics predevelopment hydrology with respect to runoff volume, duration and velocity which should provide an added level of stream channel protection.*
- *Enhances the degree and reliability of nutrient load removal.*
- *Eliminates the use of stormwater credits and makes use of runoff reduction practices an integral element of on-site compliance.*

- *Collapses recharge, water quality and, in some cases, channel protection sizing requirements into a single volume, depending on the unique characteristics of the receiving stream and the intensity of its subwatershed development.*
- *Explicitly acknowledges the hydrologic difference between forest and turf, and disturbed and undisturbed soils, which creates strong incentives to conserve forests, reduce mass grading, restore soils and reforest sites.*

How can recharge, water quality, and channel protection sizing requirements be collapsed into a single volume?

Water quality =”treatment volume”, a variation of the 90% capture rule established in the MDE (2000) stormwater manual (which is identical to to the Water Quality Volume standard in VT’s 2002 SWMM). The 90th percentile rainfall event is defined as one-inch of rainfall in most parts of the Bay watershed (although it can range from 0.9 to 1.2 inches). The variation is that the treatment volume is defined by multiplying the 90th percentile rainfall depth by three site cover runoff coefficients present at the site (forest, turf, and impervious cover). Runoff coefficients are calculated by cover type and by hydrologic soil group, and the coefficients are based on field research.

$$Tv = \frac{P * (Rv_I * \%I + Rv_T * \%T + Rv_F * \%F) * SA}{12}$$

Where

Tv = Runoff reduction volume in acre feet

P = Target Rainfall Depth

Rv_I = runoff coefficient for impervious cover (Table 1 below)

Rv_T = runoff coefficient for turf cover or disturbed soils (Table 1 below)

Rv_F = runoff coefficient for forest cover (Table 1 below)

% I = percent of site in impervious cover

%T = percent of site in turf cover

%F = percent of site in forest cover

SA = total site area, in acres

Table 1. Site Cover Runoff Coefficients

Soil Condition	Runoff Coefficient
Forest Cover	0.02 to 0.05*
Disturbed Soils	0.15 to 0.25*
Impervious Cover	0.95

*Range dependent on original Hydrologic Soil Group (HSG)	
Forest	A: 0.02 B: 0.03 C: 0.04 D: 0.05
Disturbed Soils	A: 0.15 B: 0.20 C: 0.22 D: 0.25

“The treatment volume can be set for water quality and/or channel protection volume rainfall depth, depending on the characteristics of the receiving stream and the intensity of development in its subwatershed. This avoids the segregation of WQ and CPv requirements that is inherent in many state stormwater manuals, and should reduce compliance costs, at low intensity sites”. (CSN, 2009).

Runoff reduction (RRv) is defined as the total runoff volume reduced through canopy interception, soil infiltration, evaporation, rainfall harvesting, engineered infiltration, extended filtration or evapo-transpiration. The RRv is considered to be fully inclusive of the treatment volume at a development site, and designers are strongly encouraged by combining runoff reduction and stormwater treatment practices in a series to maximize the degree of runoff and pollutant reduction achieved at a site. If the Channel Protection rainfall depth is used to define the treatment volume, it provides an attractive alternative to the 24 hour extended detention Channel Protection volume first advanced in the 2000 MDE manual (the 2000 MDE manual’s CPv standard, 12-hour to 24-hour extended detention storage for the one-year, 24-hour storm event, is identical to Vermont’s 2002 SWMM). Even if ED is still needed to comply, the runoff reduction volume used for water quality can be directly subtracted from CPv (CSN, 2009).

Determining Compliance using the Runoff Reduction Method

The runoff reduction method relies on a four step compliance procedure:

Step 1: Apply ESD Practices to Minimize IC, Grading and Loss of Forest Cover—essentially, implement environmental site design practices prior to site layout. Minimize impervious cover and mass grading, and maximize retention of forest cover, natural areas and undisturbed soils.

Step 2: Compute Post Development Land Cover—use a spreadsheet to compute the three site runoff coefficients, and calculate a site-specific target treatment volume and phosphorus load reduction limit.

Step 3: Apply Runoff Reduction Practices—experiment with combinations of the nine runoff reduction practices on the site. Estimate the spatial area to be treated by each runoff reduction practice, and chip away at the required treatment volume within each drainage area on the site.

Step 4: Compute Phosphorus Reduction by RRPs and Conventional STPs—use the spreadsheet to check whether the phosphorus load reduction has been achieved at the site. Removal by previously entered runoff reduction practices is automatically calculated, and the designer can then add conventional STPs such as filtering practices or linear wetlands to meet remaining requirements, if needed.

-------end of extracts from CSN 2008 technical guidance------------

An example of the spreadsheet model used to implement the Runoff Reduction Method in the state of Virginia, with associated documentation, is available at http://www.dcr.virginia.gov/lr2f.shtml. The spreadsheets (one for new development, and one for redevelopment) are designed to help users plan combinations of stormwater

BMPs for a particular site in order to meet regulatory standards. Total Phosphorus (TP) is used as the target pollutant for compliance with Water Quality criteria, but Total Nitrogen (TN) is also calculated. BMP designs address TN removal, as well as the removal of other stormwater pollutants. Compliance is based on the overall site, but the spreadsheet allows stormwater BMP planning on a drainage area basis. Each site has a Treatment Volume (Tv), which is calculated using post-development land covers (forest and open space, managed turf, impervious cover). Stormwater BMPs are assigned runoff reduction and pollutant removal rates, which vary for each practice based on the "level of design" used. Level 1 designs represent good, current design standards with regard to sizing and BMP features, while Level 2 BMPs have design enhancements to increase runoff reduction and pollutant removal performance. There is a tab in the spreadsheet for Channel and Flood Protection, which is intended to assist users in complying with the Water Quantity part of the regulations (4 VAC50-60-66). The spreadsheet assists users with computing runoff volumes and Curve Numbers (CN), which are meant to be used in available hydrologic and hydraulic models and programs to calculate peak discharges for various design storms and verify compliance. *If Runoff Reduction practices are used for Water Quality compliance, then these are given credit for Channel Protection and Flood Control, chiefly by allowing the user to compute an Adjusted CN. The designer, with concurrence from the local program authority, may also take other hydrologic "credits" for RR practices, such as increasing the time of concentration (Tc).*

Chesapeake Stormwater Network. 2009. Technical Support for the Baywide Runoff Reduction Method. Page updated April 2009. Accessed at http://chesapeakestormwater.net/2009/04/technical-support-for-the-baywide-runoff-reduction-method/ on July 10, 2012.

As of mid-2011, all of the Chesapeake Bay watershed states were in the process of (or had already implemented) a variation on the runoff reduction methodology for determining compliance with stormwater regulations (Schueler, 2011). The table below, extracted from the memo, illustrates the current status of each state's program:

Bay STATE	Runoff Reduction?	Required RR Volume [1]	Channel Protection?	Status [2]	Notes
DC	**YES**	1.1 to 2.7	**No**	**2011**	2.7 in for small area of the city
EPA	**YES**	1.5 to 1.7	**YES**	**2010**	Federal projects only
DE	**YES**	1.5 to 2.6	**YES**	**2011**	Manual coming out this year
MD	**YES**	1.0 to 2.6	**YES**	**2010**	
PA	**YES**	1.0 to 2.5	**YES**	**2010**	Guidance being converted to regs
NY	**YES**	0.2 to 0.6	**YES**	**2010**	RR part of Total WQv of 1 inch
VA	**YES**	1.0	**YES**	**2011**	Also has a P-based load req
WV	**YES**	1.0	**No**	**2010**	Manual coming out this year

Notes: [1] the rainfall depth for which the runoff reduction volume is computed

[2] Estimated year in which the regulations are adopted, actual implementation may be later due to grandfathering

A number of technical issues were encountered during the process of adopting runoff reduction in the Bay states. Key issues and lessons learned include:

- Provide a flexible definition of runoff reduction
- Define conditions where infiltration is not allowed
- Small is not always beautiful (meaning that LID practices such as bioretention, swales, permeable pavers, etc. can potentially be used to treat substantial contributing drainage areas)
- Allow for practice over-control (over-control within individual practices often means that designers comply with regulations without having to treat every inch of impervious cover)
- Use compliance spreadsheets
- Redevelopment (requirements vary substantially between the Bay states; these requirements have been the area of biggest push-back from developers and smart-growth advocates)
- Non-structural runoff reduction credits (big issue is defining minimum conditions to qualify for credit, and outlining how to accept, inspect, and maintain them)
- Intensive training is essential (design community much farther behind the learning curve than expected; little experience with green roofs, rainwater harvesting, dry swales, permeable pavers, bioretention) (all above from Schueler, 2011)

Schueler, Tom. 2011. Status of Runoff Reduction Implementation in the Bay States. Memo to the Minnesota MIDS Workgroup, April 11, 2011. Accessed at http://www.pca.state.mn.us/index.php/view-document.html?gid=15798 on July 11, 2012.

B.2. Minnesota

Minnesota's Stormwater Manual primarily addresses the post-construction requirements of the NPDES MS4 permit program; it is advisory but intended for all stormwater practitioners (city planners, engineering consultants, contractors, state or local regulators, watershed managers, etc.).

Minnesota's CGP references an "enhanced runoff control" criterion, where the post-development runoff rate and volume need to be maintained for both the one-year 24-hour and two-year 24-hour storm. This criterion has some channel protection applicability, but it only applies to special waters designated in the CGP permit, including wilderness areas, trout lakes, lake trout lakes, and scientific and natural areas (Minn. Stormwater Committee, 2008).

The recommended channel protection criterion is to provide 24 hours of extended detention for the runoff generated from the 1-year 24-hour design storm (Minnesota Stormwater Steering Committee, 2008). This runoff volume stored and gradually released over a 24-hour period so that critical erosive velocities in downstream channels are not exceeded over the entire storm hydrograph. The one-year, 24-hour rainfalls range between 1.8 and 2.5 inches across the State of Minnesota Maximum extended detention time should be limited to 12 hours in trout streams to minimize stream warming, provided erosive velocities can be avoided.

As part of Version 2.0 revisions to the Manual, a special study was completed to evaluate a rate control recommendation from the MPCA's Protecting Water Quality in Urban Areas (2000). This document recommends using one-half of the peak runoff rate from the 2-yr, 24-hr pre-development event. This recommendation does, in fact, result in slightly less erosion potential than the 1-yr, 24-hr extended detention noted above under worst case wet years (Minnesota Stormwater Steering Committee, 2008, Appendix O).

There does not appear to be any activity in the MIDS workgroups around updating the channel protection criterion – rather, the focus is on a big-picture performance goal: "For new, nonlinear developments that create more than one acre of new impervious surface on sites without restrictions, stormwater runoff volumes will be controlled and the post-construction runoff volume shall be retained on site for 1.1 inches of runoff from impervious surfaces statewide" (Minnesota Pollution Control Authority, 2012). (Performance goals for redevelopment and linear projects are still under development as of August 2012.)

Minnesota Stormwater Steering Committee. 2008. The Minnesota Stormwater Manual. Effective November 2005.; version 2 effective January 2008. Accessed at http://www.pca.state.mn.us/publications/wq-strm9-01.pdf on July 12, 2012.

Minnesota Pollution Control Authority. 2012. Minimal Impact Design Standards (MIDS): Enhancing stormwater management in Minnesota. Website last updated August 17, 2012. Accessed at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/stormwater-minimal-impact-design-standards-mids.html on August 23, 2012.

B.3. New York

Channel protection requirement:

> Stream Channel Protection Volume Requirements (Cpv) are designed to protect stream channels from erosion. In New York State this goal is accomplished by providing 24-hour extended detention of the one-year, 24-hour storm event, remained from runoff reduction. Reduction of runoff for meeting stream channel protection objectives, where site conditions allow, is encouraged and the volume reduction achieved through green infrastructure can be deducted from CPv. Trout waters may be exempted from the 24-hour ED requirement, with only 12 hours of extended detention required to meet this criterion. (Center for Watershed Protection, 2010, Chapter 4, Section 4-4)

Center for Watershed Protection. 2010. New York State Stormwater Management Design Manual. Prepared for New York State Department of Environmental Conservation. Revised August 2010. Ellicott City, MD. Accessed at http://www.dec.ny.gov/docs/water_pdf/swdm2010entire.pdf on July 9, 2012.

B.4. Pennsylvania

For any size of regulated activity, do not increase the post-development total runoff volume for all storms equal to or less than the 2-year/24-hour event. For projects less than 1 acre at least the first 1 inch of runoff from new impervious surfaces shall be permanently removed from the runoff flow — i.e. it shall not be released into the surface Waters of this Commonwealth. Removal options include reuse, evaporation, transpiration, and infiltration.

Pennsylvania Department of Environmental Protection. 2006. Pennsylvania Stormwater Best Management Practices Manual, Chapter 3: Stormwater Management Principles and Recommended Control Guidelines. Effective December, 2006. Accessed at http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNavPage=| on September 28, 2012.

B.5. Rhode Island

Minimum Standard 4: Conveyance and Natural Channel Protection—"Open drainage and pipe conveyance systems must be designed to provide adequate passage for flows leading to, from, and through stormwater management facilities for at least the peak flow from the 10-year, 24-hour Type III design storm event. Protection for natural channels downstream must be supplied by providing 24-hour extended detention of the one-year, 24-hour Type III design storm event runoff volume. If a stormwater discharge is proposed in a watershed draining to a cold-water fishery, additional restrictions apply for surface detention practices based on the distance from the discharge point to streams (and any contiguous natural or vegetated wetlands) as described in Section 3.3.4. Consult DEM's Water Quality Regulations – Appendix A to determine if a project is in a watershed directly draining to a cold-water fishery. This standard is designed to prevent erosive flow within natural channels and drainageways."

Rhode Island Department of Environmental Management and Coastal Resources Management Council. 2010. Rhode Island Stormwater Design and Installation Standards Manual. Revised December 2010, effective January 1, 2011. Accessed at http://www.dem.ri.gov/pubs/regs/regs/water/swmanual.pdf on July 9, 2012.

B.6. Vermont (VTrans)

Comprehensive Environmental, Inc. 2012. Stormwater Practices Research Project, Final Report. Report prepared for the Vermont Agency of Transportation, dated April 24, 2012. Accessed at http://www.aot.state.vt.us/progdev/Sections/M&R%20Info/Research%20Projects%20-%20Completed/VTrans%20Stormwater%20Research%20Final%20Report2012.pdf on July 9, 2012.

A recommendation was made to use the "Modified Runoff Curve Number Method" as a means to "quantitatively account for the reduction in runoff volume resulting from various Low Impact Development practices in the sizing of facilities to control runoff rates and volumes" (p. 8). The VSWMM currently allows credits for LID practices, but these are primarily focused on reduction of required treatment volumes (WQv and Recharge). The current credit system does not specifically provide for hydrologic adjustments for these practices (except for actual reductions in impervious surface) when sizing practices to meet CPv, Overbank, or Extreme storm protection standards.

---------Extract below is from pages 25-29 of the CEI report-------------

Alternative 3: Modified Runoff Curve Number Method.

This method involves the development of an adjusted Runoff Curve Number (RCN*) that directly accounts for the runoff volume reduction that results from infiltration. The adjusted RCN* can then be used to size "event storm" control devices using conventional hydrologic modeling techniques. This method is described in detail below.

The Modified Runoff Curve Number Method

Initial research for this study identified reference documents that provide guidance for other methods that account for sizing of STPs for measures that do not reduce total impervious cover, but that account for reductions in "effective impervious cover" through practices such as infiltration.3 The study team conducted further review of these documents and material referenced by them, and recommended a methodology adapted from McCuen's "Change in Curve Number Method4" that can be used for the following:

1. Accounting for Runoff Captured by Infiltration Practices – The method can be applied to account for the hydrologic effects of infiltration practices, where the total volume of runoff intercepted by these practices has been determined by design. The method includes an alternative for using modified Runoff Curve Numbers (RCNs) in TR-55 and TR-20 based models, to account for LID practices in the estimation of peak discharge rates, for sizing of stormwater practices for channel protection and flood control.

2. Estimating Infiltration Volume to Control Peak Discharge – The method may be used to estimate the total amount of infiltration volume (in watershed inches) required to be captured by BMPs/STPs, where it is desired to meet a specific peak discharge rate. The method uses TR-55 methodology to account for changes in initial abstraction, time of concentration, and runoff curve number to develop a target storage volume for recharge practices that may be dispersed through a site.

Accounting for Runoff Captured by Infiltration Practices

This method consists of the following procedure:

1. For the design rainfall of interest (P, inches), estimate the post-development runoff depth (Qa, inches) corresponding to the conventionally determined RCN for the contributing area.
2. Estimate the volume of runoff (V, cubic feet) captured and infiltrated by the proposed practices (see discussion under "Volume Credits" below). Convert this volume to runoff depth (ΔQ) based on watershed area (A, acres):

$$\Delta Q = \frac{V * (12 \text{ in/ft})}{A * (43560 \text{ ft}^2\text{/acre})}$$

3. Deduct this runoff depth (ΔQ) from Qa to obtain an estimate of the runoff depth from the modified site:

$$Qm = Qa - \Delta Q$$

4. Compute a modified RCN* that represents the theoretical land cover that would yield the modified runoff depth for the design rainfall (note that RCN* will differ for each rainfall event):

$$RCN^* = \frac{200}{(P+2Qm+2) - \sqrt{(5PQm+4Qm^2)}}$$

5. 5. Use this modified RCN* and the post-development time of concentration (Tc) as the basis for hydrologic modeling to size conveyance facilities and to design STPs for peak rate control to meet the ANR requirements for Channel, Overbank, and Flood Protection. As noted above, a different RCN* will be required for each rainfall depth analyzed.

Volume Credits for the Modified Runoff Curve Number Method

Table 3-1 presents the basis for estimating infiltration volumes associated with various STPs. All volumes computed following these guidelines should be converted to cubic feet for use in the equations described above. Practices should be designed to meet applicable VTrans and ANR requirements. (See page 27 of the VTrans report for table)

Estimating Infiltration Volume to Control Peak Discharge

The McCuen method provides for a procedure to estimate the total volume of runoff to be captured and infiltrated on a site to meet a target peak discharge rate from the contributing watershed. The method uses basic TR-55 computational methods.

An example of where such a method could be applied would include the selection and sizing of LID practices (including dispersed measures as well as infiltration basins and similar BMPs/STPs) so that post-development peak rates are equal to or less than existing-condition peak rates (for instance, to meet overbank flood or extreme storm protection criteria).

The procedure is as follows:

1. Determine hydrologic parameters for the base condition (e.g., existing conditions) as applicable to the analysis. These include Area, Soil Hydrologic Groups, Land Use Cover and corresponding Runoff Curve Number, and Time of Concentration.
2. Determine the corresponding post development hydrologic parameters.
3. Compute the estimated Runoff Volume: Qb (in inches) for "before development" and Qa (in inches) for "after development" without adjustment for infiltration storage.
4. Compute the corresponding Unit Peak Discharges, qub and qua (in units of cubic feet per second per square mile) from Exhibit 4-II of TR-55 (Reprinted as Figure 1.4 in Volume 1 of the Vermont Stormwater Handbook). To estimate the unit peak discharge rates, the analyst will need to determine initial abstraction from TR-55 Table 4.1.
5. Estimate the required infiltration storage (ΔQ) to achieve the desired pre- development peak rate. This is explained as follows:

    Pre-development peak flow = qb = (qub)(A)(Qb)

    where : qb is the discharge in cubic feet per second, and

    A is the contributing area in square miles

    Post-development peak flow (without control) = qa = (qua)(A)(Qa)

    Post-development peak flow (controlled)= qa* = (qua)(A)(Qa - ΔQ)

    The procedure solves for ΔQ, such that qa*= qb , that is:

    (qua)(A)(Qa - ΔQ) = (qub)(A)(Qb) , or solving for ΔQ:

    ΔQ = Qa – (qub/qua)(Qb)
6. The value of ΔQ (required infiltration storage) from this procedure will be in units of "inches." If the volume needs to be expressed in units of cubic feet for sizing recharge practices, use the following equation:

    V = ΔQ(A)(43560)/12

where A is the drainage or watershed area in acres.

Note that the volume determined by the above procedure not only accounts for the increase in volume of runoff from impervious surfaces, but also for the influence of the developed surfaces on Initial Abstraction and Time of Concentration.

-----------end CEI report extract-------------

B.7. Virginia

CHANNEL PROTECTION CRITERIA (CPv)

Historically, two-year peak discharge control has been the most widely applied local criteria to control channel erosion in most states, and many communities continue to use it today. Two-year peak control seeks to keep the post-development peak discharge rate for the 2-year/24-hour design storm at pre-development rates. The reasoning behind this criterion is that the bankfull discharge for most streams has a recurrence interval of between 1 and 2 years, with approximately 1.5 years as the most prevalent (Leopold, 1964 and 1994), and maintaining this discharge rate should act to prevent downstream erosion.

Recent research, however, indicates that two-year peak discharge control does not protect channels from downstream erosion and may actually contribute to erosion since banks are exposed to a longer duration of erosive bankfull and sub-bankfull events (MacRae, 1993, MacRae, 1996, McCuen and Moglen, 1988). Thus, while two-year peak discharge control may have some value for overbank flood control, it is not effective as a channel protection criterion, since it may actually extend the duration of erosive velocities in the stream and increase downstream channel erosion.

Regulators are being encouraged to adopt new channel protection criteria (and eliminate two-year peak discharge control requirements) when they revise or adopt local stormwater ordinances. Some examples of the channel protection criteria that are in use today are shown in Table 2.

Table 2: Example Channel Protection Criteria

MD,VT,GA,NY	24 hour detention of the one-year 24 hour storm
WA	Match predevelopment peaks for duration of storms from 0.5 to 50 years using simulation models
ONT	Distributed Runoff Control
WI/MN	Infiltrate excess runoff volume from 2 year storm
Various	Control two year storm to one year levels
Various	Performance criteria, such as outlet energy controls, level spreaders, maintenance of stream buffers

The most widely recommended channel protection criterion in the last few years is to provide 24 hours of extended detention for the runoff generated from the 1-year/24-hour design storm. This runoff volume is stored and gradually released over a 24-hour period so that critical erosive velocities in downstream channels are not exceeded over the entire storm hydrograph. As a very rough rule of thumb, the storage capacity needed to provide channel protection is about 60% of the one-year storm runoff volume. This channel protection criterion has recently been adopted by the States of Maryland, New York, Vermont, and Georgia, and is relatively easy to compute at most development sites using hydrologic models. *However, as noted above, some stormwater experts are beginning to question whether even this design criterion will result in BMPs that are larger and more costly than needed to actually protect receiving channels.*

INTEGRATING MS-19 WITH CHANNEL RESULTING PROTECTION CRITERIA

One aim pertaining to the water quantity control criteria in the Stormwater Management (SWM) Regulations is to integrate the channel protection criteria currently set forth in the Erosion and Sediment (E&S) Control Regulations into the SWM Regulations, and having the E&S Control then refer to the SWM regulations.

As currently constructed, MS-19 has nearly two pages of specific criteria related to stream channel protection. However, the over-riding requirements are stated as performance criteria aiming to assure that runoff discharges into and adequate channel (NOT outfall), and that receiving channels/streams are protected from sediment deposition, erosion, and damage due to increases in volume, velocity and peak flow of stormwater runoff for the stated design storm (4 VAC 50-30-40.19). Furthermore, all protective measures are to be employed in a manner which minimizes impacts on the physical, chemical and biological integrity of the receiving waters (4 VAC 50-30-40.19.k).

There appears to be broad agreement that the channel protection criteria that Virginia has been requiring for many years is not working effectively. This is evidenced by the significant amount of stream channel degradation that has taken place, even with the current requirements in place. There also appears to be broad agreement among local and state government officials and consulting engineers and site designers that the criteria need to be improved to provide better protection and better accountability. The existing performance criteria appear to be reasonable for achieving the goal of effective channel protection. The challenge for the Work Group will be to improve the more specific criteria in a manner that comports with the general performance criteria.

Virginia Department of Conservation and Recreation. 2008. DCR SWM/E&S “Quantity Control” Criteria Discussion. Water Quantity Workgroup handout from meeting on May 20, 2008. Accessed at http://www.dcr.virginia.gov/documents/stmquanconcrit.pdf on August 22, 2012.

Channel protection requirement (Stream Channel Protection, 4VAC50-60-70, Virginia DCR, 2011):

A. Properties and receiving waterways downstream of any land-disturbing activity shall be protected from erosion and damage due to changes in runoff rate of flow and hydrologic characteristics, including but not limited to, changes in volume, velocity, frequency, duration, and peak flow rate of stormwater runoff in accordance with the minimum design standards set out in this section.

B. The permit-issuing authority shall require compliance with subdivision 19 of 4VAC50-30-40 of the Erosion and Sediment Control Regulations, promulgated pursuant to Article 4 (§ 10.1-560 et seq.) of Chapter 5 of Title 10.1 of the Code of Virginia (essentially, reduction of the two-year post-developed peak rate of runoff back to pre-development rate).

C. The permit-issuing authority may determine that some watersheds or receiving stream systems require enhanced criteria in order to address the increased frequency of bankfull flow conditions (top of bank) brought on by land-disturbing activities. Therefore, in lieu of the reduction of the two-year post-developed peak rate of runoff, the land development project being considered shall provide 24-hour extended detention of the runoff generated by the one-year, 24-hour duration storm (4VAC50-60-70.C).

D. In addition to subsections B and C of this section permit-issuing authorities, by local ordinance may, or the board by state regulation may, adopt more stringent channel analysis criteria or design standards to ensure that the natural level of channel erosion, to the maximum extent practicable, will not increase due to the land-disturbing activities. These criteria may include, but are not limited to, the following:

- Criteria and procedures for channel analysis and classification.
- Procedures for channel data collection.
- Criteria and procedures for the determination of the magnitude and frequency of natural sediment transport loads.
- Criteria for the selection of proposed natural or man-made channel linings.

Subsection C above provides one potential solution to channel analysis related issues—reducing the flow rate sufficiently to minimize reaction by the channel. Extended detention of the 1-year storm event would be provided in lieu of detention of the 2-year frequency storm, released at the pre-developed rate, particularly for sensitive stream channels or channels experiencing erosion under existing conditions. This is being recognized as a significantly more effective criterion for protecting natural channels (VDCR, n.d.). This alternative may not solve the channel erosion concern—yet comprehensive analyses of channel geomorphology needed to accurately determine design storms and release rates for maintaining natural channel equilibrium (and thus a design that best reflects a combination of practices, channel improvements, or other measures that minimize channel impact) have historically been outside the scope of engineering services for development projects (VDCR, n.d.). Thus, DCR provides guidance to ensure that in the absence of such an analysis, negative impacts to receiving channels can be minimized—including criteria for channel analysis, and discussion of generic solutions for situations where existing natural or man-made channels are inadequate to meet the Stream Channel Protection requirement (VDCR, n.d.).

Virginia Department of Conservation & Recreation. n.d. Technical Bulletin No. 1: Stream Channel Erosion Control Policy Guidance. Accessed at http://dcr.cache.vi.virginia.gov/stormwater_management/documents/tecbltn1.PDF on August 22, 2012.

Virginia Department of Conservation & Recreation. 2011. Virginia Stormwater Management Regulations. Effective November 2011. Accessed at http://dcr.cache.vi.virginia.gov/stormwater_management/documents/vaswmregs.pdf on July 10, 2012.

Virginia Department of Conservation & Recreation. 2011. Virginia Runoff Reduction Method Instructions and Documentation. Revised March 28, 2011. Accessed at http://leg5.state.va.us/reg_agent/frmView.aspx?Viewid=13631000587~1&typ=40&actno=000587&mime=application/pdf on July 11, 2012.

B.8. Washington

Washington has adopted a stringent channel protection (Flow Control) criterion: Stormwater discharges shall match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow (Washington DOE, 2012, Vol 1 p. 2-38). The pre-developed condition to be matched shall be a forested land cover unless:

- Reasonable, historic information is provided that indicates the site was prairie prior to settlement (modeled as "pasture" in the Western Washington Hydrology Model); or,
- The drainage area of the immediate stream and all subsequent downstream basins have had at least 40% total impervious area since 1985.

This standard requirement is waived for sites that will reliably infiltrate all the runoff from hard surfaces and converted vegetation areas.

Designers must use a continuous hydrologic simulation model (e.g. HSPF) to demonstrate compliance and for the purpose of designing flow control BMPs (Washington DOE, 2012, Vol 3 p. 2-1). As of 2004, hydrologic models such as TR-55 or P-8 that employ single event design storms are no longer allowed in Washington for design purposes.

Washington Department of Ecology. 2012. Stormwater Management Manual for Western Washington. Publication Number 12-10-030, effective August 2012. Accessed at https://fortress.wa.gov/ecy/publications/summarypages/1210030.html on August 22, 2012.

APPENDIX C: INTEGRATING LID CONCEPTS INTO VSWMM, DETAILS BY STATE

C.1. National Standards

C.1.1. The Energy Independence Security Act (ESIA). Section 438. Stormwater Runoff Requirements for Federal Development Projects

"Sec. 438. Storm Water Runoff Requirements for Federal Development Projects. The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow."

U.S. Environmental Protection Agency. 2011. Federal Stormwater Management Requirements: Energy Independence and Security Act of 2007 (EISA). Page updated August 16, 2011. Accessed at on July 12, 2012.

Option 1 in the EISA is to: Design, construct, and maintain stormwater management practices that infiltration, evapotranspiration, and/or reuse the precipitation from the 95th percentile rainfall event. Applies to any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet. Establishment of these requirements for Federal facilities is expected to have the effect of "mainstreaming" LID BMPs for non-federal facilities (Tetra Tech, Inc., 2008).

Technical guidance published by EPA in 2009, extracts below:

The purpose of this document is to provide technical guidance and background information to assist federal agencies in implementing EISA Section 438. Each agency or department is responsible for ensuring compliance with EISA Section 438. The document contains guidance on how compliance with Section 438 can be achieved, measured and evaluated. In addition, information detailing the rationale for the stormwater management approach contained herein has been included.

A new approach has evolved in recent years to eliminate or reduce the amount of water and pollutants that run off a site and ultimately are discharged into adjacent water bodies. The fundamental principle is to employ systems and practices that use or mimic natural processes to: 1) infiltrate and recharge, 2) evapotranspire, and/or 3) harvest and use precipitation near to where it falls to earth.

GI/LID practices include a wide variety of practices that utilize these mechanisms. These practices can be used at the site, neighborhood and watershed/regional scales, though the EPA guidance focuses on site-level practices as they are is most consistent with the terms used in Section 438.

Definition of the 95th percentile rainfall event: The 95th percentile rainfall event represents a precipitation amount which 95 percent of all rainfall events for the period of record do not exceed. In more technical terms, the 95th percentile rainfall event is defined as the measured precipitation depth accumulated over a 24-hour period for the period of record that ranks as the 95th percentile rainfall depth based on the range of all daily event occurrences during this period.

The 24-hour period is typically defined as 12:00:00 am to 11:59:59 pm. In general, at least a 20- 30 year period of rainfall record is recommended for such an analysis. This raw data is readily available and collected by most airports across the county. Small rainfall events that are 0.1 of an inch or less are excluded from the percentile analysis because this rainfall generally does not result in any measureable runoff due to absorption, interception and evaporation by permeable, impermeable and vegetated surfaces. Many stormwater modelers and hydrologists typically exclude rainfall events that are 0.1 inch or less from calculations of rainfall events of any storm from their modeling analyses of rainfall event frequencies. See, for example, the Center for Watershed Protection's Urban Subwatershed Restoration Manual 3 (available at www.cwp.org).

Option 1: Retain the 95th percentile event.

One approach to establishing the performance design objectives is to design, construct, and maintain stormwater management practices that manage rainfall onsite, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to the 95th percentile rainfall event to the maximum extent technically feasible (METF). This objective should be accomplished by the use of practices that infiltrate, evapotranspire and/or harvest and use rainwater… Because this approach necessitates the use of practices that generally preclude extended detention, it will also often address the issue of maintaining predevelopment temperatures.

Option 2: Site-specific hydrologic analysis

Another approach to establishing the performance design objective is to design, construct, and maintain stormwater management practices that preserve the pre-development runoff conditions following construction. Option 2 allows the designer to conduct a site-specific hydrologic analysis to determine the pre-development runoff conditions instead of using the estimated volume approach of Option 1. Under Option 2, the pre-development hydrology would be determined based on site-specific conditions and local meteorology by using continuous simulation modeling techniques, published data, studies, or other established tools.

Technical Infeasibility

For projects where technical infeasibility exists, the federal agency or department sponsoring the project should document and quantify that stormwater strategies, such as infiltration, evapotranspiration, and harvesting and use have been used to the METF, and that full employment of these types of controls are infeasible due to site constraints. A few examples of where site conditions may prevent the full employment of appropriate management techniques to the METF include a combination of:

- The conditions on the site preclude the use of infiltration practices due to the presence of shallow bedrock, contaminated soils, near surface ground water or other factors such as underground facilities or utilities.
- Soils that cannot be sufficiently amended to provide for the requisite infiltration rates,
- Retention and/or use of stormwater onsite or discharge of stormwater onsite via infiltration has a significant adverse effect on the site or the down gradient water balance of surface waters, ground waters or receiving watershed ecological processes.

Specific practices are not prescribed in the EISA or in the EPA guidance, but green infrastructure/LID practices and approaches are preferred, to be supplemented with conventional controls when site conditions dictate. Practices listed in the guidance include:

- Rain gardens, bioretention, and infiltration planters

- Porous pavements
- Vegetated swales and bioswales
- Green roofs
- Trees and tree boxes
- Pocket wetlands
- Reforestation/revegetation using native plants
- Protection and enhancement of riparian buffers and floodplains
- Rainwater harvesting for use (e.g., irrigation, HVAC make-up, non-potable indoor uses).

Instructions are provided in the guidance on calculating the 95th percentile precipitation event using local weather data (pages 22-24).

The guidance includes nine case studies in eight locations across the US, including one in Boston, Massachusetts. For the Boston case example, the 95th percentile storm was 1.55 inches, and the site imperviousness was 69% (rooftop 0.9 ac, pavement 1.5 ac, pervious 1.1 ac, total 3.5 ac). Using a simple, Direct Determination of Runoff Volume method, runoff from each land cover was estimated based on the following equation:

Runoff = Rainfall – Depression Storage – Infiltration Loss

Nearly an inch (0.98 inches) of runoff would require on-site management from the 95th percentile storm. In this case, a retrofit of 1.5 acres of parking lot was used to accommodate a paver block system retrofit, primarily dedicated for use as parking stalls.

U.S. Environmental Protection Agency. 2009. Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act). Report no. EPA 841-B-09-001, dated December 2009. Accessed at http://www.epa.gov/oaintrnt/documents/epa_swm_guidance.pdf on September 11, 2012.

C.2. Maine

Maine's Stormwater Management Law provides stormwater standards for projects located in organized areas that include one acre of more of disturbed area.

Under this law, a project qualifies for a stormwater permit by rule (PBR) if it results in “one or more acres of disturbed area and the following:

(1) Less than 20,000 square feet of impervious area and 5 acres of developed area in the direct watershed of a lake most at risk or urban impaired stream; and

(2) Less than one acre of impervious and five acres of developed area in any other watershed.”

Applicants for a stormwater PBR must submit the notification form, fee and other information for the Department’s review and approval. This information includes a location map, site plan, erosion and sedimentation control plan, and photographs of the area to be developed.

PBR must meet ***Basic Standards*** (4)(A) (which address erosion and sedimentation control, inspection and maintenance, and housekeeping)—essentially meeting the basic requirements of an NPDES Stormwater Construction general permit.

Projects above the PBR thresholds must meet ***General Standards*** in addition to the Basic Standards (4)(B), p. 4:

"To meet the general standards, a project's stormwater management system must include treatment measures that will mitigate for the increased frequency and duration of channel erosive flows due to runoff from smaller storms, provide for effective treatment of pollutants in stormwater, and mitigate potential temperature impacts. This must be achieved by using one or more of the following methods to control runoff from no less than 95% of the impervious area and no less than 80% of the developed area that is impervious or landscaped. Where treatment of 95% of the impervious area is not practicable, the department may allow treatment on as low as 90% of the impervious area if the applicant is able to demonstrate that treatment of a greater depth of runoff than specified in the standards will result in at least an equivalent amount of overall treatment for the impervious area.

The department may, on a case-by-case basis, consider alternate treatment measures to those described in this section. An alternate treatment measure must provide at least as much pollutant removal as the treatment measures listed below and, unless otherwise approved by the department, as much channel protection and temperature control.

If a project is not in an urban impaired stream watershed, the department may allow the portion of a project's impervious or developed acreage that must be treated to be reduced through mitigation by eliminating or reducing an off-site or on-site impervious stormwater source (see Section 6(B).

NOTE: The department strongly encourages applicants to incorporate low-impact development (LID) measures where practicable...".

Practices described in the Stormwater Management Rule include:

(a) Wetpond with detention above the permanent pool. A stormwater management system using detention to control runoff must detain, above a wetpond's permanent pool, a runoff volume equal to 1.0 inch times the subcatchment's impervious area plus 0.4 inch times the subcatchment's landscaped area…

(b) Filter. A detention structure using filters to control runoff must detain a runoff volume equal to 1.0 inch times the subcatchment's impervious area plus 0.4 inch times the subcatchment's developed area that is landscaped and discharge it solely through an underdrained vegetated soil filter having a single outlet with a diameter no greater than eight inches, or through a proprietary filter system approved by the department.

(c) Infiltration. A stormwater management system using infiltration to control runoff must retain a runoff volume equal to 1.0 inch times the subcatchment's impervious area plus 0.4 inch times the subcatchment's developed area that is landscaped and infiltrate this volume into the ground. Pre-treatment of stormwater must occur prior to discharge to the infiltration area….

(d) Buffers. A stormwater management system using buffers to control runoff must meet the design and sizing requirements described in Appendix F.

Exceptions to the General Standards:

a. Pretreatment measures. A project that includes measures to pretreat runoff to a filter or infiltration system in a department-approved, flow-through sedimentation device may reduce the runoff volume to each treatment measure described in Section 4(B)(2)(b) and (c) by 25%.
b. Discharge to the ocean, great pond or a major river segment. A project discharging to the ocean, great pond or a major river segment and using a wetpond to meet the general standards is not required to incorporate treatment storage above the wetpond's permanent pool or to install an underdrain….
c. A linear portion of a project. For a linear portion of a project, runoff volume control may be reduced to no less than 75% of the volume from the impervious area and no less than 50% of the developed area that is impervious or landscaped, or the runoff volume to each treatment measure described in Section 4(B)(2) above may be reduced by 25%.
d. A utility corridor or portion of a utility corridor that meets specified criteria
e. Stormwater Management Law project including redevelopment of impervious area that was in existence as of November 16, 2005 (the effective date of Chapter 500 revisions)
f. Site Location of Development Law project including redevelopment. For a project requiring a Site Location of Development Law permit that includes redevelopment of existing impervious area that was in existence as of November 16, 2005 (the effective date of Chapter 500 revisions), redevelopment of that impervious area is required to meet the general standards to the extent practicable as determined by the department….

Phosphorus Standards apply only in lake watersheds.

A project disturbing one acre or more and resulting in any of the following is required to meet the phosphorus standards described in Section 4(C)(2) below.

(a) Lake most at risk watersheds. 20,000 square feet or more of impervious area, or 5 acres or more of developed area, in the direct watershed of a lake most at risk, except that an applicant with a project that includes less than three acres of impervious area and less than 5 acres of developed area may choose to meet the general standards rather than the phosphorus standards if the lake is not severely blooming. Severely blooming lakes are a subset of lakes most at risk as listed in Chapter 502.

(b) Any other lake watershed. One acre or more of impervious area, or 5 acres or more of developed area, in any other lake watershed, except that an applicant with a project that includes less than three acres of impervious area and less than 5 acres of developed area may choose to meet the general standards rather than the phosphorus standards.

(2) Description of phosphorus standards. An allowable per-acre phosphorus allocation for each lake most at risk will be determined by the department. The department's determination is based upon current water quality, potential for internal recycling of phosphorus, potential as a cold-water fishery, volume and flushing rate, and projected growth in the watershed. This allocation will be used to determine phosphorus allocations for a project unless the applicant proposes an alternative per-acre phosphorus allocation that is approved by the department. If the project is a road in a subdivision, only 50% of the parcel's allocation may be applied to the road unless phosphorus export from both the road and the lots is subject to this chapter, in which case the entire allocation for the parcel may be applied.

NOTE: For guidance in calculating per-acre phosphorus allocations and in determining if stormwater phosphorus export from a project meets or exceeds the parcel's allocation, see Volume II of the Maine Stormwater Management BMP Manual.

D. Urban impaired stream standard. If required, the urban impaired stream standard applies in addition to the basic standards, general standards and phosphorus standards described in Sections 4(A), (B) and (C).

(1) When the urban impaired stream standard must be met. If a project located within the direct watershed of urban impaired stream or stream segment listed in chapter 502 results in three acres or more of impervious area or 20 acres or more of developed area, requires review pursuant to the Site Law, or is a Site Law modification of any size as described in Section 16 of this chapter, the urban impaired stream standard must be met.

(2) Description of the urban impaired stream standard. A project in the direct watershed of an urban impaired stream must pay a compensation fee or mitigate project impacts by treating, reducing or eliminating an off-site or on-site pre-development impervious stormwater source as described in Section 6(A). Compensation fees must be paid to the department's compensation fund or to an organization authorized by the department pursuant to the Stormwater Management Law, 38 M.R.S.A. §420-D(11).

(3) Exception for a project including redevelopment. Redevelopment of an existing impervious area is not required to meet the urban impaired stream standard provided the department determines that the new use of the existing impervious area is not likely to increase stormwater impacts in the proposed project's stormwater runoff beyond the levels already present in the runoff from the existing impervious area.

E. Flooding standard. If required, the flooding standard applies in addition to the basic standards, general standards, phosphorus standards and urban impaired stream standards described in Sections 4(A), (B), and (C).

(1) When the flooding standard must be met. If a project results in three acres or more of impervious area or 20 acres or more of developed area, requires review pursuant to the Site Law, or is a modification of any size as described in Section 16 of this chapter, the flooding standard must be met. Stormwater management systems for these projects must detain, retain, or result in the infiltration of stormwater from 24-hour storms of the 2-year, 10-year, and 25-year frequencies such that the peak flows of stormwater from the project site do not exceed the peak flows of stormwater prior to undertaking the project.

(2) Waiver of the flooding standard. A project is eligible for a waiver from the flooding standard as follows.

(a) Discharge to the ocean, a great pond, or a major river segment. A waiver is available for a project in the watershed of the ocean, a great pond, or a major river segment provided the applicant demonstrates that the project conveys stormwater exclusively in sheet flow, in a manmade open channel, or in a piped system directly into one of these resources.

In addition, the department may allow a variance for other rivers, if the department determines that the increase in peak flow from the site will not significantly affect the peak flow of the receiving waters or result in unreasonable adverse impact on a wetland or waterbody.

(b) Insignificant increases in peak flow rates from a project site. When requesting a waiver for a project resulting in an insignificant increase in peak flow rates from a project site, the applicant shall demonstrate that insignificant increases in peak flow rates cannot be avoided by reasonable changes in project layout, density, and stormwater management design. The applicant shall also demonstrate that the proposed increases will not unreasonably increase the extent, frequency, or duration of flooding at downstream flow controls and conveyance structures or have an unreasonable adverse effect on protected natural resources. In making its determination to allow insignificant increases in peak flow rates, the department shall consider cumulative impacts. If additional information is required to make a determination concerning increased flow, the department may only consider an increase after the applicant agrees, pursuant to 38 M.R.S.A. §344-B(3)(B), that the review period may be extended as necessary by the department.

(3) Channel limits and runoff areas. The design of piped or open channel systems must be based on a 10-year, 24-hour storm without overloading or flooding beyond channel limits. In addition, the areas expected to be flooded by runoff from a 10-year or 25-year, 24-hour storm must be designated in the application, and no buildings or other similar facilities may be planned within such areas. This does not preclude the use of parking areas, recreation areas, or similar areas from use for detention of storms greater than the 10-year, 24-hour storm. Runoff from the project may not flood the primary access road to the project and public roads as a result of a 25-year, 24-hour storm.

NOTE: The municipality, the Maine Department of Transportation, or the Maine Turnpike Authority may require a project to meet additional design standards based on the 50-year or 100-year storm. The department recommends that any applicant proposing a project that may cause flooding of a primary access road or public road contact the appropriate entity.

In order to meet the standards in the Stormwater Management Law, Maine's Stormwater BMP manual encourages designers to (but does not mandate) using LID concepts first, and then to size and site other drainage control BMPs as appropriate to the site and assuming that only annual maintenance will be performed (Maine DEP, 2009, V1 Chapter 5). Other design considerations include:

- providing easily accessible, (and preferably visible) pre-treatment as a key feature of the design of all BMPs
- no bypasses (so that water back ups signal the need for maintenance)
- consideration of Maine's northern climate in designing BMPs (for instance, by designing infiltration systems assuming storage only and no exfiltration as could occur under winter condition, by avoiding the use of permeable pavers in areas where plows could hit and dislodge pavers, by separating infiltration BMPs from roads by at least 10 feet, and by designing in fencing to protect vegetation from vehicles plowing snow).
- Insuring ease of ongoing maintenance by designing BMPs for equipment access, ease and minimal cost of cleaning, easy access for evaluation and maintenance, and by providing a detailed and reasonable Operations & Maintenance plan including manpower and budget needs.

The LID design process described in Maine's manual is to:

- Minimize impervious areas
- Limit areas of site clearing and grading
- Minimize connected impervious surfaces
- Manage stormwater at the source, using LID techniques as much as possible.

LID techniques specifically included in the manual:

> Bioretention and raingardens, infiltration, filter strips/veg buffers, swales, porous pavement, rain barrels/cisterns, level spreader, rooftop greening. Rooftop greening is mentioned in a general description of LID techniques that are applicable in Maine, but no specific design details or cold climate implications are included for this particular practice (Maine DEP, 2009).

Maine's permit application forms for permit coverage under the Stormwater Management Law do not provide practice-specific worksheets for demonstrating compliance with treatment standards, or for indicating that minimum conditions are met for applying non-structural LID practices—however, buffers are included as one of the four groups of treatment practices allowed for use in meeting the General Standard. The manual and application form are both silent on the subject of credit systems for applying LID practices to proposed development projects.

Maine Department of Environmental Protection. 2005. Maine Stormwater Management Rules. 06-696 CMR, Chapter 500, effective November 16, 2005. Accessed at http://www.maine.gov/sos/cec/rules/06/096/096c500.doc on September 12, 2012.

Maine Department of Environmental Protection. 2009. Maine Stormwater Best Management Practices Manual. Accessed at http://www.maine.gov/dep/land/stormwater/stormwaterbmps/ on July 12, 2012.

Maine Department of Environmental Protection. 2010. Maine Stormwater Best Management Practices Manual Volume III: BMPs Technical Design Manual, Chapter 5, Vegetated Buffers. Revised June 2010. Accessed at http://www.maine.gov/dep/land/stormwater/stormwaterbmps/vol3/chapter5.pdf on October 2, 2012.

C.3. Massachusetts

Standard 2: Stormwater management systems shall be designed so that the post-development peak discharge rates do not exceed pre-development peak discharge rates. This Standard may be waived for discharges to land subject to coastal storm flowage as defined in 310 CMR 10.04.

Explanation: To prevent storm damage and downstream and off-site flooding, Standard 2 requires that the post-development peak discharge rate is equal to or less than the pre-development rate from the 2-year and the 10-year 24-hour storms. BMPs that slow runoff rates through storage and gradual release, such as LID techniques, extended dry detention basins, and wet basins, must be provided to meet Standard 2. Where an area is within the 100-year coastal flood plain or land subject to coastal storm flowage, the control of peak discharge rates is usually unnecessary and may be waived.

Standard 3: Loss of annual recharge to groundwater shall be eliminated or minimized through the use of environmentally sensitive site design, low impact development techniques, stormwater best management practices, and good operation and maintenance. At a minimum, the annual recharge from the post-development site shall approximate the annual recharge from pre-development conditions based on soil type. This Standard is met when the stormwater management system is designed to infiltrate the required recharge volume as determined in accordance with the Massachusetts Stormwater Handbook.

Explanation: The intent of this standard is to ensure that the infiltration volume of precipitation into the ground under post-development conditions is at least as much as the infiltration volume under pre-development conditions. Standard 3 requires the restoration of recharge, using infiltration measures and careful site design. Through judicious use of low impact development techniques and other approaches that minimize impervious surfaces and mimic natural conditions, new developments can approximate pre-development recharge for most storms.

The NRCS classifies soils into four hydrologic groups, A thru D, indicative of the minimum infiltration obtained for a soil after prolonged wetting. Group A soils have the lowest runoff potential and the highest infiltration rates, while Group D soils have the highest runoff potential and the lowest infiltration rates. The required recharge volume, the stormwater volume that must be infiltrated, shall be determined using existing site conditions and the infiltration rates set forth below.

Hydrologic Group Volume to Recharge (x Total Impervious Area)	
Hydrologic Group	**Volume to Recharge x Total Impervious Area**
A	0.60 inches of runoff
B	0.35 inches of runoff
C	0.25 inches of runoff
D	0.10 inches of runoff

For each NRCS Hydrologic Group on the site, the required recharge volume equals the recharge volume set forth above multiplied by the total area within that NRCS Hydrologic Group that is impervious. Infiltration of these volumes must be accomplished using appropriate BMPs. The following BMPs may be used to infiltrate stormwater in compliance with Standard 3: dry wells; infiltration basins; infiltration trenches; subsurface structures; leaching catch basins; exfiltrating bioretention areas; and porous pavement. Some proprietary BMPs can also be used to infiltrate stormwater in compliance with Standard 3. Proponents can reduce the volume of stormwater that they are required to recharge by using the LID Site Design Credit.

Standard 4: Stormwater management systems shall be designed to remove 80% of the average annual post-construction load of Total Suspended Solids (TSS). This standard is met when:

(a) Suitable practices for source control and pollution prevention are identified in a long-term pollution prevention plan, and thereafter are implemented and maintained;
(b) Structural stormwater best management practices are sized to capture the required water quality volume as determined in accordance with the Massachusetts Stormwater Handbook; and
(c) Pretreatment is provided in accordance with the Massachusetts Stormwater Handbook.

Explanation:

This standard applies after the site is stabilized. Since removal efficiency may vary with each storm, 80% TSS removal is not required for each storm. It is the average removal over the year that is required to meet the standard. The required water quality volume, the runoff volume requiring TSS treatment, is calculated as follows:

The required water quality volume equals 1.0 inch of runoff times the total impervious area of the post-development project site for a discharge

- from a land use with a higher potential pollutant load;
- within an area with a rapid infiltration rate (greater than 2.4 inches per hour);
- within a Zone II or Interim Wellhead Protection Area;
- near or to the following critical areas:
  - Outstanding Resource Waters,
  - Special Resource Waters,

- bathing beaches,
- shellfish growing areas,
- cold-water fisheries.

The required water quality volume equals 0.5 inches of runoff times the total impervious area of the post-development site for all other discharges.

V1 ch1 p. 4: Environmentally Sensitive Site Design and Low Impact Development Techniques

The Wetlands Regulations, 310 CMR 10.04, and the Water Quality Certification Regulations, 314 CMR 9.02, define environmentally sensitive site design to mean design that incorporates low impact development techniques to prevent the generation of stormwater and non-point source pollution by reducing impervious surfaces, disconnecting flow paths, treating stormwater at its source, maximizing open space, minimizing disturbance, protecting natural features and processes, and/or enhancing wildlife habitat. The Wetlands Regulations, 310 CMR 10.04, and the Water Quality Certification Regulations, 314 CMR 9.02, define low impact development (LID) techniques to mean innovative stormwater management systems that are modeled after natural hydrologic features. Low impact development techniques manage rainfall at the source using uniformly distributed decentralized micro-scale controls. Low impact development techniques use small cost-effective landscape features located at the lot level.

Proponents of projects subject to the Stormwater Management Standards must consider environmentally sensitive site design and low impact development techniques to manage stormwater. Proponents shall consider decentralized systems that involve the placement of a number of small treatment and infiltration devices located close to the various impervious surfaces that generate stormwater runoff in place of a centralized system comprised of closed pipes that direct all the drainage from the entire site into one large dry detention basin.

MassDEP has established an "LID Site Design Credit" to encourage developers to incorporate LID techniques in their projects. In exchange for directing runoff from roads and driveways to vegetated open areas, preserving open space with a conservation restriction, or directing rooftop runoff to landscaped or undisturbed areas, MassDEP allows developers to reduce or eliminate the traditional BMPs used to treat and infiltrate stormwater.

Incorporating environmentally sensitive design that uses the land to filter and recharge the water back into the ground and that reduces the amount of paved areas is a critical first step in creating sustainable development. Inspired by EEA's Smart Growth Toolkit, MassDEP believes that the LID Site Design Credit protects our natural resources, encourages cluster development, and reduces the environmental impacts of growth. By using this credit, *proponents can reduce the volume of stormwater subject to Standard 3 - the Recharge Standard, and Standard 4 - the Water Quality Standard.*

There are three LID Site Design Credits available to designers:

Environmentally Sensitive Development

Disconnected Rooftop Runoff

Disconnected Non-Rooftop Runoff

The details regarding the conditions under which each credit can be claimed are described fully in Volume 3, Chapter 1 (page 42) of the Massachusetts Stormwater Handbook (2008), reproduced below.

Credit 1: Environmentally Sensitive Development

This credit is given for environmentally sensitive site design techniques that "cluster development" or reduce development scale, to leave a significant amount of the site undisturbed in its natural state. If a site is designed, constructed, operated and maintained in accordance with the requirements of this credit, a project proponent need not develop and implement additional structural stormwater BMPs to meet Standards 3 and 4.

The Required Recharge Volume and the Required Water Quality Volume requirements are completely met without the use of structural practices in certain low density (less than 1 dwelling unit per acre) or cluster residential developments when the following conditions are met:

- The total impervious cover footprint must be less than 15 % of the base lot area. Because alterations are limited in these areas under the Wetlands Protection Act Regulations, 310 CMR 10.00, the following wetland resource areas may not be included in the base lot area used for purposes of determining compliance with this requirement: any vegetated wetlands (Bordering Vegetated Wetland (BVW), Isolated Vegetated Wetland (IVW), Salt Marsh); Land Under Water and Waterways; Land Under Ocean; Bank; Coastal Bank; or 5,000 square feet or 10% of the Riverfront Area, whichever is greater.
- No alteration may occur in any coastal wetland resource areas other than Land Subject to Coastal Storm Flowage.
- No alteration may occur in BVW or IVW.
- A minimum of 25% of the site must be protected as a natural conservation area. To qualify as a natural conservation area, an EEA Conservation Restriction must be placed on the protected area. Information on adopting conservation restrictions is available via the web at: http://www.mass.gov/envir/dcs/restrictions/default.htm. Because alterations are limited in these areas under the Wetlands Protection Act Regulations, 310 CMR 10.00, the Natural Conservation Area must not include the following wetland resource areas: any vegetated wetlands (BVW, IVW, Salt Marsh); Land Under Water and Waterways; Land Under Ocean; Bank; Coastal Bank; or more than 5000 square feet or 10% of the Riverfront Area, whichever is greater.
- Stream buffers must be incorporated into the design of any areas adjacent to perennial and intermittent streams on the site. A stream buffer is the inner 50 feet of the buffer zone adjacent to the bank. At a minimum, no work, including any alteration for stormwater management, may be proposed in the 50-foot-wide area in the buffer zone along any wetland resource area. The proposed project shall not include any impervious surfaces in the 50-foot-wide area in the buffer zone along any wetland resource area.
- The amount of impervious surface shall not exceed 40% of the area of the buffer zone between 50 and 100 feet from any resource area or the amount of existing impervious surface, whichever is greater.
- No work may be proposed in a buffer zone that:
  - Borders an Outstanding Resource Water,

- Contains estimated wildlife habitat which is identified on the most recent Estimated Habitat Map of State-listed Rare Wetlands Wildlife prepared by the Natural Heritage and Endangered Species Program,
- Contains slopes greater than 15% prior to any work
- Rooftop runoff must be disconnected in accordance with the requirements applicable to Credit 2.
- Qualifying pervious areas are used to convey runoff from roads and driveways instead of curb and gutter systems.

Credit 2: Rooftop Runoff Directed to Qualifying Areas

This credit is available when rooftop runoff is directed to a qualifying pervious area where it can either infiltrate into the soil or flow over it with sufficient time and reduced velocity to allow for filtering. Qualifying pervious areas are flat locations, where the discharge is directed via sheet flow and not as a point source discharge. Dry water quality swales are not “qualifying pervious areas” for purposes of this credit. The credit may be obtained by grading the site to induce sheet flow over specially designed flat vegetated areas that can treat and infiltrate rooftop runoff.

If rooftop runoff is adequately directed to a qualifying pervious area, the rooftop area can be deducted from total impervious area, therefore reducing the Required Water Quality Volume and the size of the structural BMPs used to meet the TSS removal requirement of Standard 4. As more fully set forth below, redirected rooftop runoff can also be used to meet the recharge requirement as a non-structural practice.

[calculation information removed]

Credit No 3: Roadway, Driveway or Parking Lot Runoff Directed to Qualifying Area

Credit is given for practices that direct runoff from impervious roads, driveways, and parking lots to pervious areas where plants provide filtration (through sheet flow) and the ground provides exfiltration. This credit can be obtained by grading the site to promote overland vegetative filtering. This credit is available for paved driveways, roads, and parking lots associated with all land uses, except for high-intensity parking lots that generate 1,000 or more vehicle trips per day or runoff not segregated from LUHPPL.

Disconnected impervious areas can be subtracted from the site impervious area when computing the Required Water Quality Volume. In addition, disconnected impervious surfaces can be used to reduce the Required Recharge Volume as determined by calculating the Required Recharge Volume: Rv using the "Static" Method and the Recharge Area Requiring Treatment: Rea using the Percent Area Approach. See example for Credit 2 - disconnection of rooftop runoff.

SEE ALSO, UPDATED TSS REMOVAL EFFICIENCY TABLE BY BMP

SEE ALSO, BMPS FOR COLD WATER FISHERIES IN STANDARD 6

Massachusetts Department of Environmental Protection. 2008. Massachusetts Stormwater Handbook Volume 1: Overview of Massachusetts Stormwater Standards. Effective February, 2008. Accessed at http://www.mass.gov/dep/water/laws/policies.htm#storm on September 12, 2012.

Massachusetts Department of Environmental Protection. 2008. Massachusetts Stormwater Handbook Volume 3: Documenting Compliance with the Massachusetts Stormwater Management Standards. Effective February, 2008. Accessed at http://www.mass.gov/dep/water/laws/policies.htm#storm on September 17, 2012.

Massachusetts Department of Environmental Protection. 2008. Checklist for Stormwater Report. Form last updated April, 2008. Accessed at http://www.mass.gov/dep/water/laws/swcheck.pdf on September 28, 2012.

C.4. Minnesota

In Minnesota, the state's Pollution Control Agency administers the MS4, construction, and industrial stormwater permitting programs. Under the construction program, when a project replaces vegetation or other pervious surfaces with one or more acres of cumulative impervious surface, one-half inch of runoff from the new impervious surface must be treated by one of the following methods:

- wet sedimentation basin
- infiltration/filtration
- regional ponds
- combination of practices
- alternative method, pending MPCA approval (MPCA, 2009)

Permits for construction sites near specially-protected and impaired waters require additional controls, conditions, or an individual permit:

- Sites that discharge near waters with qualities that warrant extra protection (special waters) must use additional best management practices and enhanced runoff controls.
- Sites that discharge near an "impaired water," impaired for phosphorous, turbidity, dissolved oxygen, and biotic impairment, must meet special conditions.

Minnesota's Stormwater Manual uses an "integrated stormwater management" approach to regulating stormwater runoff (MN Stormwater Steering Committee, 2008). "Integrated stormwater management is simply thinking about all of the factors that somehow affect precipitation as it moves from the land surface to an eventual receiving water. It is the process of accounting for all of these factors (e.g. rate, volume, quality, ground water impact) in a logical process so that inadvertent mistakes are not made that could eventually harm a resource. The treatment train approach to runoff management mimics the sequence as the stormwater manager looks at the runoff problem and determines how best to address it, starting with the most basic of questions and increasing in complexity only if needed, since simple methods of management are often the most practical."

Volume reduction practices included in the manual:

- Low impact development/better site design/sustainable development
- Infiltration practices
- Trench or basin
- Perforated sub-surface pipes, tanks and storage systems

- Disconnected imperviousness
- Pervious (porous) pavement
- Bioretention (rain gardens)
- Vegetated swales
- Wetland/pond storage
- Vegetated drainage corridor
- Recessed road/parking drainage
- Rain barrel/cistern
- Rooftop (green roof)
- Vegetated swale
- Filter strips/buffers

The manual includes a chapter on "Better Site Design", and lists 12 practices that, when applied early in the design process, reduce impervious cover, conserve natural areas, and use pervious areas to more effectively treat stormwater runoff.

The state does allow some better site design techniques to be worked into a program for stormwater credit which reduces the water quality volume that must be treated at a site (Chapter 11 of the manual):

- Natural Area Conservation
- Site Reforestation or Prairie Restoration
- Drainage to Stream or Shoreline Buffers
- Surface Impervious Cover Disconnection
- Rooftop Disconnection
- Use of Grass Channels

Formulas for computing water quality volumes and related credits are based on the requirements contained in the MPCA Construction General Permit (CGP). The approach used is to subtract the credit volume from the water quality volume (Vwq); the volume of a permanent pool (Vpp) in a stormwater pond or wetland is not adjusted. Other options that could be considered include applying credits to Vpp, or proportional application of a credit to both Vpp and Vwq. In Minnesota, decisions on how/whether to apply credits rest with local implementing authorities—not with the state. The table below summarizes how the credits could be applied by local authorities:

Table 11.1 Summary of Stormwater Credits Function

Stormwater Credit	Adjusted Water Quality Volume	Channel Protection & Overbank Storms
Natural Area Conservation	Subtract CA from site IC when	Adjust CN for CA to woods in good condtion

	computing V_{WQ}	
Site Reforestation or Prairie Restoration	Subtract ½ RA from site IC when computing V_{WQ}	Adjust CN for RA to woods or prairie in fair condition
Stream and Shoreline Buffers	Subtract ADB from site IC when computing V_{WQ}	Adjust CD for ADB to woods in good condition
Surface Impervious Cover Disconnection	Subtract DIA from site IC when computing V_{WQ}	Adjust CN for DIA to grass in good condition Adjust Tc
Rooftop Disconnection	Subtract DRA from site IC when computing V_{WQ}	Adjust CN for DIA to grass in good condition Adjust Tc
Grass Channels	Subtract GA from site IC when computing V_{WQ}	Adjust Tc

Note: Unless otherwise noted, all units below measured in acres
CA – Combined area of all natural areas conserved at site
RA – Total area of site reforestation or prairie restoration
ADB – Total area draining to buffer with appropriate flow path distance
DIA – Total area of surface impervious cover that can be effectively disconnected
DRA – Aggregate rooftop area that can be effectively disconnected
GA – total non-roadway area draining to swale (rooftop, yard, and driveway)
CN – Runoff curve number for area (units: dimensionless) (see Ch. 8 and App. B)
Tc – Time of concentration (units: time)

In 2009, the Minnesota Legislature allocated funds to "develop performance standards, design standards or other tools to enable and promote the implementation of low impact development and other stormwater management techniques." (Minnesota Statutes 2009, section 115.03, subdivision 5c). Minnesota's Minimal Impact Design Standards (MIDS), when complete, will represent the next generation of stormwater management – and the intent is to implement LID as the primary method for new development in Minnesota.

The MIDS contain three main elements:

- A higher clean water performance goal for new development and redevelopment that will provide enhanced protection for Minnesota's water resources.
    - For new, nonlinear developments that create more than one acre of new impervious surface on sites without restrictions, stormwater runoff volumes will be controlled and the post-construction runoff volume shall be retained on site for 1.1 inches of runoff from impervious surfaces statewide.
    - Performance goals are also under development for redevelopment and linear projects.
- New modeling methods and credit calculations that will standardize the use of a range of "innovative" structural and nonstructural stormwater techniques.
- A credits system and ordinance package that will allow for increased flexibility and a streamlined approach to regulatory programs for developers and communities.

As part of the MIDS development effort, a review was completed of existing credit methodology systems that are used in other jurisdictions to assess runoff impacts, evaluate credit methodology systems, and recommend a credit methodology system approach that will allow the user to evaluate runoff impacts (Barr Engineering Company, 2011). Fifteen credit methodology systems were originally screened:

- City of Seattle
- Georgia

- Florida
- Kitsap County, Washington
- Maryland
- Massachusetts
- Minnesota
- New Hampshire
- New Jersey
- Pennsylvania
- Purdue University
- Rhode Island
- Stearns County, Minnesota
- Ventura County, California
- Virginia

The fifteen systems were evaluated based on how well they met common goals (such as pollutant loading, water quality volume/stormwater runoff volume, channel protection volume) and how well the met criteria in Minnesota's MIDS legislation (such as native hydrology mimicry, LID promotion, pollutant loading estimation, BMP treatment train inclusion, etc.). Based on this screening, six systems were chosen for more detailed evaluation of their credit methodology system features (like quality of documentation, scientific foundations for calculations and performance standards, and pros and cons). Six systems were screened in detail (Florida, Kitsap County, Pennsylvania, Purdue, Stearns County, and Virginia). The MIDS Work Group decided that the credit tracking system/calculator should:

- provide an incentive for incorporating low impact development (LID) techniques onto a site
- determine the stormwater volume control required on the site
- determine TP and TSS removal
- provide volume and pollutant removal credit for BMPs in parallel and in series
- focus on pollutant removals for sites with Hydrologic Soil Group D soils
- not replace existing models, such as HydroCAD, for calculating and showing conformance to stormwater peak runoff rate requirements

The Virginia credit tracking calculator was chosen as performing most of these functions, and was adapted to Minnesota's needs in the creation of a draft MIDS calculator.

A list of 32 structural and non-structural BMPs was developed by the MIDS subcommittee; each practice was defined and then grouped by volume and pollutant reduction processes (Barr Engineering Company, 2011). Based on an extensive literature search of credit methodologies used by organizations and peer-reviewed research, each practice's applicability to MIDS and the pros and cons for each individual BMP were summarized. Three alternative scenarios were offered to the MIDS Work Group for quantifying stormwater runoff volume and pollution reduction:

- Quantifying reductions based on literature-reported values
- Quantifying reduction amounts of individual BMPs based on devised relationships between BMP parameters and volume reduction
- Allowing currently accepted hydrologic models to quantify the runoff reductions of proposed on-site BMPs.

The MIDS workgroup also has a Trees team – http://www.urbanforestryinstitute.com/uploads/

Minnesota Stormwater Steering Committee. 2008. The Minnesota Stormwater Manual. Effective November 2005.; version 2 effective January 2008. Accessed at http://www.pca.state.mn.us/publications/wq-strm9-01.pdf on July 12, 2012.

Minnesota Pollution Control Agency. 2009. Construction Stormwater Permit Overview. Document ID wq-strm2-05, February 2009. Accessed at http://www.pca.state.mn.us/index.php/view-document.html?gid=7386 on September 17, 2012.

Minnesota Pollution Control Agency. 2012. Minimal Impact Design Standards (MIDS): Enhancing stormwater management in Minnesota. Web page last updated September 6, 2012. Accessed at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/stormwater-minimal-impact-design-standards-mids.html on September 28, 2012.

Barr Engineering Company. 2011. MIDS Subtask 2.1(1): Review Methods, Models and Spreadsheets Used to Track Runoff Reduction on Development Sites and Recommend Integrated System of MID Credits that Account for Both Runoff and Pollution Reduction. Memorandum to the MIDS Work Group dated June 12, 2011. Accessed at http://www.pca.state.mn.us/index.php/view-document.html?gid=15517 on July 11, 2012.

Barr Engineering Company. 2011. MIDS Subtask 2.2(1): Recommend Credits for MIDS Practices. Memorandum to the MIDS Work Group dated June 30, 2011. Accessed at http://www.pca.state.mn.us/index.php/view-document.html?gid=15662 on July 11, 2012.

C.5. New Hampshire

NHDES construction program CGP applies to projects with over one acre of disturbance. Alteration of Terrain (AoT permit) applies if a construction project (or other alteration like a gravel pit, mining operation, etc.) will create over 100,000 square feet (2.3 acres) of disturbance (NHDES, 2008 vol 1). The AoT rules specify requirements for permanent methods of protecting water quality – including treatment of the water quality volume (WQv of 1 inch), groundwater recharge, channel protection (2-year, 24-hour storm), and peak runoff rate control (10-year or 50-year, 24-hour storms if appropriate). While the New Hampshire Stormwater Manual (2008) places a strong emphasis on LID development planning and related structural measures, there do not appear to be any in-rule requirements for using LID practices, nor are there incentives for, or well-defined methods for including, these practices in development plans or permitting applications.

New Hampshire's stormwater manual:

- Uses Effective Impervious Cover (10%)
- Undisturbed Cover (65%) (1065 is the surrogate for pollutant loading analysis to meet the proposed anti-degradation requirements)
- Encourage non-structural site planning (LID) measures:
    - Minimize Disturbed Areas
    - Maintain Natural Buffers

- Minimize Impervious Cover
- Disconnect Impervious Cover
- Minimize Soil Compaction
- Use Alternative Pavement

- Encourage impervious surface disconnection for rooftop and non-rooftop runoff

LID structural practices included in NH's manual:

Bioretention System (rain garden), pervious pavement (filtering), treatment swale, vegetated buffer, Infiltration Trench (Including Drip Edge), green roof, rainbarrel/cistern.

New Hampshire Department of Environmental Services. 2008. New Hampshire Stormwater Manual, Volume 1, Stormwater and Antidegradation. Revision 1.0, December 2008. Accessed at http://des.nh.gov/organization/commissioner/pip/publications/wd/documents/wd-08-20a.pdf on July 12, 2012.

New Hampshire Department of Environmental Services. 2008. New Hampshire Stormwater Manual, Volume 2, Post-Construction Best Management Practices Selection and Design. Revision 1.0, December 2008. Accessed at http://des.nh.gov/organization/commissioner/pip/publications/wd/documents/wd-08-20b.pdf on July 12, 2012.

New Hampshire Department of Environmental Services. 2008. Innovative Land Use Planning Techniques: A Handbook for Sustainable Development. Revised October 2008. Accessed at http://des.nh.gov/organization/divisions/water/wmb/repp/documents/ilupt_complete_handbook.pdf on July 9, 2012.

New Hampshire Department of Environmental Services. 2009. New Hampshire Code of Administrative Rules, Chapter Env-Wq 1500 Alteration of Terrain. Effective January 1, 2009. Accessed at http://des.nh.gov/organization/commissioner/legal/rules/documents/env-wq1500.pdf on September 17, 2012.

C.6. New Jersey

The standards within New Jersey's state-level Stormwater Management Rules (N.J.A.C. 7:8) related to new development and construction are primarily administered locally, with most application review and permitting activity occurring at municipal or county government offices. The state stormwater management rules and the Stormwater BMP Manual (2004) are tightly integrated, in that the Rules specify that non-structural practices must be used to the maximum extent practicable in meeting stormwater standards for any new major development, while the Manual provides guidance in how to meet the in-rule requirements.

7:8-5.2(a) Stormwater management measures for major development shall be developed to meet the erosion control, groundwater recharge, stormwater runoff quantity, and stormwater runoff quality standards at N.J.A.C. 7:8-5.4 and 5.5. To the maximum extent practicable, these standards shall be met by incorporating nonstructural stormwater management strategies at N.J.A.C. 7:8-5.3 into the design. If these measures alone are not sufficient to meet these standards, structural stormwater management measures at N.J.A.C. 7:8-5.7 necessary to meet these standards shall be incorporated into the design.

7:8-5.3 To the maximum extent practicable, the standards in N.J.A.C. 7:8-5.4 and 5.5 shall be met by incorporating nonstructural stormwater management strategies at N.J.A.C. 7:8-5.3 into the design. The person submitting an application for review shall identify the nonstructural strategies incorporated into the design of the project. If the applicant contends that it is not feasible for engineering, environmental, or safety reasons to incorporate any nonstructural stormwater management strategies identified in (b) below into the design of a particular project, the applicant shall identify the strategy and provide a basis for the contention.:

(b) Nonstructural stormwater management strategies incorporated into site design shall:

- Protect areas that provide water quality benefits or areas particularly susceptible to erosion and sediment loss.
- Minimize impervious surfaces and break up or disconnect the flow of runoff over impervious surfaces.
- Maximize the protection of natural drainage features and vegetation.
- Minimize the decrease in the time of concentration from pre-construction to post-construction.
- Minimize land disturbance including clearing and grading.
- Minimize soil compaction.
- Provide low-maintenance landscaping that encourages retention and planting of native vegetation and minimizes the use of lawns, fertilizers and pesticides.
- Provide vegetated open-channel conveyance systems discharging into and through stable vegetated areas.
- Provide other source controls to prevent or minimize the use or exposure of pollutants at the site in order to prevent or minimize the release of those pollutants into stormwater runoff.

7:8-5.4(a)(2) Groundwater Recharge: For new major development, the design engineer shall, either: (a) Demonstrate through hydrologic and hydraulic analysis that the site and its stormwater management measures maintain 100 percent of the average annual pre-construction groundwater recharge volume for the site; or (b) Demonstrate through hydrologic and hydraulic analysis that the increase of stormwater runoff volume from pre-construction to post-construction for the 2-year storm is infiltrated. (The groundwater recharge standard does not apply within “urban redevelopment areas”, to stormwater from areas of high pollutant loading, or to industrial stormwater exposed to "source material.")

7:8-5.4(a)(3) Water Quantity: In order to control stormwater runoff quantity impacts, the design engineer shall, using the assumptions and factors for stormwater runoff calculations at N.J.A.C. 7:8-5.6, complete one of the following:

i. Demonstrate through hydrologic and hydraulic analysis that for stormwater leaving the site, post-construction runoff hydrographs for the two, 10 and 100-year storm events do not exceed, at any point in time, the pre-construction runoff hydrographs for the same storm events;

ii. Demonstrate through hydrologic and hydraulic analysis that there is no increase, as compared to the pre-construction condition, in the peak runoff rates of stormwater leaving the site for the two, 10 and 100-year storm events and that the increased volume or change in timing of stormwater runoff will not increase flood damage at or downstream of the site. This analysis shall include the analysis of impacts of existing land uses and projected land uses assuming full development under existing zoning and land use ordinances in the drainage area;

iii. Design stormwater management measures so that the post-construction peak runoff rates for the two, 10 and 100-year storm events are 50, 75 and 80 percent, respectively, of the pre-construction peak runoff rates. The percentages apply only to the post-construction stormwater runoff that is attributable to the portion of the site on which the proposed development or project is to be constructed.

7:8-5.5(a) Stormwater runoff quality standards: Stormwater management measures shall be designed to reduce the post-construction load of total suspended solids (TSS) in stormwater runoff generated from the water quality design storm by 80 percent of the anticipated load from the developed site, expressed as an annual average. Stormwater management measures shall only be required for water quality control if an additional one-quarter acre of impervious surface is being proposed on a development site. The requirement to reduce TSS does not apply to any stormwater runoff in a discharge regulated under a numeric effluent limitation for TSS imposed under the New Jersey Pollutant Discharge Elimination System (NJPDES) rules, N.J.A.C. 7:14A, or in a discharge specifically exempt under a NJPDES permit from this requirement. The water quality design storm is 1.25 inches of rainfall in two hours. Water quality calculations shall take into account the distribution of rain from the water quality design storm...The calculation of the volume of runoff may take into account the implementation of non-structural and structural stormwater management measures. [This section of the Stormwater Management Rules also contains substantial details on calculating compliance, and a table of TSS removal rates by BMP, which are not reproduced here.]

The NJDEP has developed a Nonstructural Strategies Point System to allow planners, designers, and regulators in determining that the strategies have been used to the “maximum extent practicable” at a major development as required by the Rules (NJDEP, 2006). The New Jersey NSPS is a Microsoft Excel-based computer spreadsheet program that can be used to demonstrate that sufficient nonstructural stormwater management measures have been incorporated into the design of a major land development project to the meet the maximum extent practicable requirement for nonstructural strategies in the Stormwater Management Rules. The NSPS assigns points based upon the existing and proposed conditions at the development site. A specific percentage of existing or pre-developed points must be achieved under proposed or post-developed conditions in order to demonstrate compliance through the NSPS. If the NSPS demonstrates that sufficient nonstructural stormwater management measures have been utilized at a major development, no further proof of compliance with the maximum extent practicable requirement is required. However, if the NSPS fails to demonstrate such compliance, the applicant will instead be required to demonstrate compliance through other and/or additional means—including, for instance, the Low Impact Development (LID) Checklist contained in Appendix A of the New Jersey Stormwater Best Management Practices Manual, which includes a rigorous alternatives analysis for each measure.

New Jersey Administrative Code, Title 7, Chapter 8. Stormwater Management. R.2004 d.48 and d.61, effective February 2, 2004. last amended April 19, 2010. Accessed at http://www.nj.gov/dep/rules/rules/njac7_8.pdf on July 11, 2012.

New Jersey Department of Environmental Protection. 2004. New Jersey Stormwater Best Management Practices Manual. Dated February 2004, revised September 2009. Accessed at http://www.njstormwater.org/bmp_manual2.htm on September 17, 2012.

New Jersey Department of Environmental Protection. 2006. New Jersey Nonstructural Stormwater Management Strategies Point System (NSPS) User's Guide. Last updated January 31, 2006. Accessed at http://www.njstormwater.org/pdf/nsps_userguide2006013.pdf on September 17, 2012.

C.7. New York

New York's stormwater regulations apply to new development and redevelopment projects that result in a land disturbance of one acre or greater, including projects less than one acre if they are part of a larger common plan of development or sale or if controlling such activities in a particular watershed is required by the Department (New York SPDES Permit No GP-0-10-001). The standards are applied statewide and are administered by NYDEC. The Notice of Intent form includes questions regarding requirements for the development of a SWPPP that includes Water Quality and Quantity Control components (Post-Construction Stormwater Management Practices, question 27 on the NOI). There is a question about the application of the Unified Stormwater Sizing Criteria for the site (question 31) that includes WQv, CPv, overbank flood, and extreme storm standards—but there is no space on the NOI to document compliance with the runoff reduction volume (RRv) standard (which is described below).

Chapter 4 of New York's Stormwater Management Design Manual (2010) presents a unified approach for sizing green infrastructure for runoff reduction and structural practices to meet pollutant removal goals, reduce channel erosion, prevent overbank flooding, and help control extreme floods. For a summary, please consult Table 4.1 below. The remaining sections describe the sizing criteria in detail and present guidance on how to properly compute and apply the required reduction and storage volumes.

New York State's Stormwater Management Design Manual, Chapter 5 describes planning and design of green infrastructure practices acceptable for runoff reduction. Planning practices described for preserving and conserving natural features include:

- Preservation of Undisturbed Areas.
- Preservation of Buffers
- Reduction of Clearing and Grading
- Locating Development in Less Sensitive Areas
- Open Space Design
- Soil Restoration

Table 4.1 New York Stormwater Sizing Criteria

Water Quality Volume (WQv)	90% Rule: WQv(acre-feet) = [(P)(Rv)(A)] /12 Rv = 0.05+0.009(I) I = Impervious Cover (Percent) Minimum Rv = 0.2 if WQv > RRv
Runoff Reduction Volume(RRv)	RRv (acre-feet)= Reduction of the total WQv by application of green infrastructure techniques and SMPs to replicate pre-development hydrology. The minimum required RRv

	is defined as the Specified Reduction Factor (S), provided objective technical justification is documented.
Channel Protection Volume (Cp_v)	**Default Criterion:** Cp_v(acre-feet)= 24 hour extended detention of post-developed 1-year, 24-hour storm event; remaining after runoff reduction. Where site conditions allow, Runoff reduction of total CPv , is encouraged **Option for Sites Larger than 50 Acres:** Distributed Runoff Control - geomorphic assessment to determine the bankfull channel characteristics and thresholds for channel stability and bedload movement.
Overbank Flood (Q_p)	Q_p(cfs)=Control the peak discharge from the 10-year storm to 10-year predevelopment rates.
Extreme Storm (Q_f)	Q_f(cfs)=Control the peak discharge from the 100-year storm to 100-year predevelopment rates. Safely pass the 100-year storm event.
Alternative method (WQv):	Design, construct, and maintain systems sized to capture, reduce, reuse, treat, and manage rainfall on-site, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to the 95th percentile rainfall event, computed by an acceptable continuous simulation model.

Planning practices described for reducing impervious cover include:

- Roadway Reduction
- Sidewalk Reduction
- Driveway Reduction
- Cul-de-sac Reduction
- Building Footprint Reduction
- Parking Reduction

Green infrastructure techniques for runoff reduction included in the manual:

- Conservation of Natural Areas
- Sheetflow to Riparian Buffers or Filter Strips
- Vegetated Swale
- Tree Planting / Tree Pit
- Disconnection of Rooftop Runoff
- Stream Daylighting
- Rain Gardens
- Green Roofs
- Stormwater Planters
- Rain Barrels and Cisterns

- Porous Pavement

A subset of these practices are potentially allowed for re-development projects:

- Rain gardens
- Cisterns
- Green roofs
- Stormwater planters
- Permeable paving (including modular block)
- Select proprietary products (hydrodynamic practices, etc.)

New York State Department of Environmental Conservation. 2010. SPDES General Permit for Stormwater Discharges From Construction Activity, Permit No. GP-0-10-001. Effective January 29, 2010; expires January 28, 2015. Accessed at http://www.dec.ny.gov/docs/water_pdf/noipgr10.pdf on September 17, 2012.

New York State Department of Environmental Conservation. n.d. Notice of Intent, Stormwater Discharges Associated with Construction Activity Under State Pollutant Discharge Elimination System (SPDES) General Permit # GP-0-10-001. Accessed at http://www.dec.ny.gov/docs/water_pdf/noipgr10.pdf on September 17, 2012.

New York State Department of Environmental Conservation. 2010. New York State Stormwater Management Design Manual. Revised August 2010. Accessed at http://www.dec.ny.gov/docs/water_pdf/swdm2010entire.pdf on July 12, 2012.

C.8. Pennsylvania

Pennsylvania's post-construction stormwater management requirements apply to earth disturbance activities that disturb equal to or greater than one acre, or any earth disturbance as part of a larger common plan of development or sale that involves equal to or greater than one (1) acre (025 PA Code, Chapter 102). These activities are permitted through the Pennsylvania DEP (or soil conservation districts, if DEP has delegated to them). A single application for coverage under the *General (PAG-02) or Individual NPDES Permits for Stormwater Discharges Associated with Construction Activities* covers both construction-phase erosion and sediment control plans and post-construction stormwater management plans and requirements.

Runoff Volume Control Standards (combined WQv and Channel Protection)

- "Do not increase the post-development total runoff volume for all storms equal to or less than the 2-year/24-hour event" (Volume Control Guideline 1, Pennsylvania DEP, 2006).
- For new impervious surfaces on projects less than 1 acre, "Stormwater facilities shall be sized to capture at least the first two inches (2") of runoff from all contributing impervious surfaces. At least the first one inch (1.0") of runoff from new impervious surfaces shall be permanently removed from the runoff flow — i.e. it shall not be released into the surface Waters of this Commonwealth. Removal options include reuse, evaporation, transpiration, and infiltration" (Volume Control Guideline 2, Pennsylvania DEP, 2006).

The recommended control guideline for peak rate control is:

- "Do not increase the peak rate of discharge for the 1-year through 100-year events (at minimum); as necessary, provide additional peak rate control as required by applicable and approved Act 167 plans" (Pennsylvania DEP, 2006).

The recommended control guideline for total water quality control is:

- "Achieve an 85 percent reduction in post-development particulate associated pollutant load (as represented by Total Suspended Solids), an 85 percent reduction in post-development total phosphorus loads, and a 50 percent reduction in post-development solute loads (as represented by NO3-N), all based on post-development land use" (Pennsylvania DEP, 2006).

State standards do recognize that the runoff volume control standards may require modification before they are applied to so-called "Special Management Areas", such as highways and roads, redevelopment, contaminated or brownfield sites, sites located in public water supply protection areas, and so on. A chapter in the BMP manual discusses these special situations in more detail, and projects proposed in these areas often require an Individual NPDES Stormwater Construction Permit (Pennsylvania DEP, 2006).

Applicants are required, within the NOI process, to supply analysis "demonstrating that the PCSM BMPs will meet the volume reduction and water quality requirements specified in an applicable Department approved and current Act 167 stormwater management watershed plan; or manage the net change for storms up to and including the 2-year/24-hour storm event when compared to preconstruction runoff volume and water quality" (025 PA Code, § 102.8(g)(2)). Analysis is also required to demonstrate "that the PCSM BMPs will meet the rate requirements specified in an applicable Department approved and current Act 167 stormwater management watershed plan; or manage the net change in peak rate for the 2-, 10-, 50-, and 100-year/24-hour storm events in a manner not to exceed preconstruction rates" (025 PA Code, § 102.8(g)(3)).

The NOI and permit application form provides explicit direction and associated worksheets to utilize non-structural BMPs first (see Worksheet 3, Page 9 of the NOI form). Non-structural BMP credits are allowed for three types of "protected areas" (areas of protected sensitive/special value features, riparian forest buffer, and minimum disturbance/reduced grading), where these areas are subtracted from the total site area to result in a reduced "stormwater management area" where runoff volume, peak control, and water quality standards must be met. Volume Credits are allowed for several practices (minimum soil compaction, protecting existing trees, disconnecting roof leaders to vegetated areas, and disconnecting non-roof impervious to vegetated areas), where proportional volume reductions, as well as proportional reductions in peak rates for flood protection and channel protection, are subtracted from the total stormwater volumes that are required to be managed on the site. The change in runoff volume for the two-year storm event is summarized on Worksheet 4. On Worksheet 5, the non-structural credits from Worksheet 3 are subtracted from the required stormwater control volume calculated on Worksheet 4, leaving a volume that must be managed using structural practices. (Credits can only be used for up to 25% of the required volume.) A wide range of BMPs are allowed to be implemented, including many LID structural practices:

- Pervious Pavement with Infiltration Bed
- Infiltration Basin
- Subsurface Infiltration Bed
- Infiltration Trench
- Rain Garden/Bioretention
- Dry Well / Seepage Pit
- Constructed Filter

- Vegetated Swale
- Vegetated Filter Strip
- Infiltration Berm & Retentive Grading
- Vegetated Roof
- Runoff Capture & Reuse
- Constructed Wetland
- Wet Pond/Retention Basin
- Dry Extended Detention Basin
- Water Quality Filters & Hydrodynamic Devices
- Riparian Buffer Restoration
- Landscape Restoration
- Soil Amendment & Restoration
- Level Spreader
- Special Detention Areas - Parking Lot, Rooftop

Further guidance on siting and designing each of these BMPs is provided in the Pennsylvania Stormwater BMP Manual (Pennsylvania DEP, 2006).

Pennsylvania Department of Environmental Protection. 2006. Pennsylvania Stormwater BMP Manual. Document No. 363-0300-002, Effective December 30, 2006. Accessed at http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-68851/363-0300-002.pdf on September 18, 2012.

Pennsylvania Code, Title 25, Part I, Subpart C, Article II, Chapter 102. Erosion and Sediment Control. Amended August 20, 2010, effective November 19, 2010. Accessed at http://www.pacode.com/secure/data/025/chapter102/chap102toc.html on September 18, 2012.

Pennsylvania Department of Environmental Protection. 2010. PAG-02 Stormwater Discharges Associated with Construction Activities, NOI for Coverage under General or Individual Permit. Document no. 3930-PM-WM0035, created November 18, 2010. Accessed at http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-9432 on September 18, 2012.

C.9. Rhode Island

Rhode Island's Department of Environmental Management adopted a new *Stormwater Design and Installation Standards Manual* in January 2011, and filed new regulations that require the use of the new Manual for all DEM Office of Water Resources permitting programs. All applicable development proposals under any OWR program (including any development disturbing one acre or more) must now include a Stormwater Management Plan for review by the Department of Environmental Management.

The Fresh Water Wetlands (FWW), Water Quality Certification (WQC), Underground Injection Control (UIC), and the Rhode Island Pollutant Discharge Elimination System (RIPDES) Programs all require the use of the new RI Storm Water Manual. Municipal officials may also use this manual to support local storm water management programs by incorporating or referencing the manual into local ordinances. Most municipalities and large operators of stormwater systems (e.g., Rhode Island Department of Transportation - RIDOT) are regulated under the Rhode Island Pollutant Discharge Elimination System (RIPDES) Municipal Separate Storm Sewer System (MS4) program and are required by their MS4 permits to have applicants who apply for local permits adhere to this manual.

The key components of a Storm Water Management Plan are:

- Application Forms (DEM Permitting Program Specific Application and a completed Stormwater Design and Installation Standards Manual Appendix A checklist).
- A Stormwater Site Planning, Analysis, and Design Report.
- A Construction Phase Erosion and Sediment Control Plan if the development project will disturb less than 1 acre of land, or a Storm Water Pollution Prevention Plan (SWPPP) if the development project will disturb greater than or equal to 1 acre of land.
- An Operation and Maintenance Plan which addresses operations and maintenance (O&M) of the proposed Best Management Practices (BMPs) after construction is completed and the site is in use. The Plan must address the stormwater management system and structural stormwater controls as well as pollution prevention and source controls.

Applicants must submit a completed application checklist with the program-specific application. Rhode Island's *Stormwater Design and Installation Standards Manual* Appendix A is a Stormwater Management Checklist—a guide for engineers and designers to refer to during all stages of a project to ensure that they are meeting all applicable requirements (Rhode Island DEM and CRC, 2011). The checklist includes stormwater site planning, analysis and design (and includes a substantial LID Site Planning and Design Checklist); best management practices identification; ESC and SWPPPs; and Operation & Maintenance and Pollution Prevention Plans.

Rhode Island's recently revised *Stormwater Design and Installation Standards Manual* incorporates LID as the "industry standard" for development, representing a fundamental shift in how subdivisions and commercial projects are planned and designed. Under the revised manual, the five minimum stormwater management standards are:

- Minimum Standard 1: LID Site Planning and Design Strategies
    - "LID site planning and design strategies must be used to the maximum extent practicable in order to reduce the generation of the water runoff volume for both new and redevelopment projects. All development proposals must include a completed Stormwater Management Plan checklist (Appendix A) and Stormwater Management Plan for review by the approving agency that shows compliance with this standard".
- Minimum Standard 2: Groundwater Recharge
    - "Stormwater must be recharged within the same subwatershed to maintain baseflow at pre-development recharge levels to the maximum extent practicable in accordance with the requirements and exemptions described in Section 3.3.2….Maintaining pre-development groundwater recharge conditions may also be used to reduce the volume requirements dictated by other sizing criteria (i.e., water quality, channel protection, and overbank flood control) and the overall size and cost of stormwater treatment practices."
- Minimum Standard 3: Water Quality
    - "Stormwater runoff must be treated before discharge. The amount that must be treated from each rainfall event is known as the required water quality volume (WQv) and is the portion of runoff containing the majority of the pollutants."

- The water quality (WQv) is equivalent to the runoff associated with the first 1.2 inches of rainfall over the impervious surface (which is assumed to equal 1" of runoff) and shall be determined according to the following equation: WQv = (1") (I) / 12 (Manual 3.3.3 p. 3-13)
- The water quality volume requirement may be waived or reduced by applying disconnection-based LID practices (Manual 4.6.1 p. 4-10)

- Minimum Standard 4: Conveyance and Natural Channel Protection
  - “Open drainage and pipe conveyance systems must be designed to provide adequate passage for flows leading to, from, and through stormwater management facilities for at least the peak flow from the 10-year, 24-hour Type III design storm event.
  - Protection for natural channels downstream must be supplied by providing 24-hour extended detention of the one-year, 24-hour Type III design storm event runoff volume.
  - If a stormwater discharge is proposed in a watershed draining to a cold-water fishery, additional restrictions apply for surface detention practices based on the distance from the discharge point to streams (and any contiguous natural or vegetated wetlands) as described in Section 3.3.4.”
    - Section 3.3.4 states “If a stormwater discharge is proposed within 200 feet of streams and any contiguous natural or vegetated wetlands in watersheds draining to cold-water fisheries, surface detention practices are prohibited (underground detention or infiltration practices will be required). Discharges beyond 200 feet shall be designed to discharge up to the CPv through an underdrained gravel trench outlet…”
  - Credits for LID Site Planning and Design Strategies <u>do not</u> appear to be applied to this standard, except that the CPv criterion is waived for “projects when the post-development peak discharge from the facility without attenuation is less than 2 cfs for the 1-year, 24-hour Type III design storm event” (Section 3.3.4, page 3-18).
- Minimum Standard 5: Overbank Flood Protection
  - “Downstream overbank flood protection must be provided by attenuating the post-development peak discharge rate to the pre-development levels for the 10-year and 100-year, 24-hour Type III design storm events.”

There are six other Minimum Standards described in the Manual, relating to special situations, pollution prevention, and long-term operation and maintenance:

- Minimum Standard 6: Redevelopment and Infill Projects
- Minimum Standard 7: Pollution Prevention
- Minimum Standard 8: Land Uses with Higher Potential Pollutant Loads
- Minimum Standard 9: Illicit Discharges
- Minimum Standard 10: Construction Erosion and Sedimentation Control
- Minimum Standard 11: Stormwater Management System Operation and Maintenance

“LID site planning and design strategies must be formally documented according to the Stormwater Management checklist included in Appendix A using the LID strategies described below. Site planning and design should be done in unison with the design and layout of stormwater and wastewater infrastructure in attaining management and land use goals. The LID site planning and design objectives can be split into three main categories:

1. Avoid the Impacts – Preserve, and where possible restore, natural features;
2. Reduce the Impacts – Reduce impervious cover; and
3. Manage the Impacts at the Source – Design site specific runoff reduction, treatment, and source controls” (Rhode Island DEM and CRC, 2011)

Techniques listed for managing impacts at source in LID chapter include:

- “disconnecting” any necessary impervious surfaces
- implementing small-scale, “natural system”-based BMPs close to the source (bioretention, swales, infiltration, and filter strips)
- Stream/Wetland Restoration
- Reforestation
- Source Control

The LID Stormwater Credit is available “when rooftop, roadway, driveway, or parking lot runoff is directed to a qualifying pervious area where it can either infiltrate into the soil or flow over it with sufficient time and reduced velocity to allow for adequate filtering. Qualifying pervious areas are generally flat locations, where the discharge is directed via sheet flow and not as a point source discharge. The credit may be obtained by grading the site to induce sheet flow over specially designed, gently sloped vegetated areas that can treat and infiltrate the runoff. This credit is available for impervious cover associated with all land uses, except for runoff from a LUHPPL. If runoff from impervious areas is adequately directed to a QPA, the area can be deducted from total impervious area, therefore reducing the required WQv and the size of the structural BMPs used to meet the removal requirement of Standard 3…Redirected runoff can also be used to meet the recharge requirement as a non-structural practice” (Manual Section 4.6.1, page 4-10).

LID BMPs specifically included in the manual:

- Infiltration Trenches/Chambers/Dry Wells
- Permeable Paving. The standard details do include guidance for design to avoid frost heaving, and maintenance that includes plowing/cold climate considerations (see section 5.4).
- Bioretention (including tree box filters)
- Green roofs (extensive and intensive). This manual does contain good standard details, schematic sketches, feasibility criteria, and maintenance needs/requirements (see section 5.6), but does not provide any information regarding cold climate design considerations.
- Open channels (dry swale, wet swale)

Rhode Island Department of Environmental Management, Office of Water Resources. 2003. Regulations for The Rhode Island Pollutant Discharge Elimination System. Amended: February 5, 2003; Effective: February 25, 2003. Accessed at http://www.dem.ri.gov/pubs/regs/regs/water/ripdes03.pdf on September 18, 2012.

Rhode Island Department of Environmental Management and Coastal Resources Management Council. 2011. Rhode Island Stormwater Design and Installation Standards Manual. Revised December 2010, effective January 1, 2011. Accessed at http://www.dem.ri.gov/pubs/regs/regs/water/swmanual.pdf on July 9, 2012.

Rhode Island Department of Environmental Management. 2011. Coordinated Stormwater Permitting. Web page last updated August 29, 2011. Accessed at http://www.dem.ri.gov/programs/benviron/water/permits/swcoord/index.htm on September 18, 2012.

Rhode Island Department of Environmental Management. N.d. Stormwater Management Plan Guide. Accessed at http://www.dem.ri.gov/programs/benviron/water/permits/swcoord/pdf/swmpguid.pdf on September 18, 2012.

Rhode Island Department of Environmental Management. 2011. Rhode Island Community LID Site Planning and Design Guidance Document. Revised March 2011. Accessed at http://www.dem.ri.gov/programs/bpoladm/suswshed/pdfs/lidplan.pdf on July 9, 2012.

C.10. Vermont (VTrans)

Practices identified in this review that are recommended for inclusion in the list of available tools for addressing VTrans stormwater management objectives include:

Group of BMPs	Specific Practice Examples
Infiltration Practices	Infiltration berms
	Pervious pavement systems
Bioretention Practice Variations	Micro-bioretention (rain gardens)
	Media Filter Drains and Embankment Media Filter
	Compost Amended Vegetated Filter Strips
Filter System Practices	Micro-filter systems, including:
	Gutter filters
	OhioDOT “Exfiltration Trench”
	VTrans “Micro-pool Filter”
	Minnesota DOT “Permeable Ditch Blocks”
Open Channels	Bioswale
Non-structural Practices	Vegetated Buffers and Filter Strips

Detailed evaluations, sketch drawings, and pros/cons are included in the report for each listed practice. See Section B.6 for this report’s discussion of a Modified Runoff Curve Number method to facilitate LID BMPs receiving credit for reductions in CPv, etc.

Comprehensive Environmental, Inc. 2012. Stormwater Practices Research Project, Final Report. Report prepared for the Vermont Agency of Transportation, dated April 24, 2012. Accessed at http://www.aot.state.vt.us/progdev/Sections/M&R%20Info/Research%20Projects%20-%20Completed/VTrans%20Stormwater%20Research%20Final%20Report2012.pdf on July 9, 2012.

APPENDIX D: MAINTENANCE PLANS, DETAILS BY STATE

D.1. California

Like other stormwater programs in the greater San Francisco area, the Alameda Countywide Clean Water Program (ACCWP, http://www.cleanwaterprogram.org/) has been active in developing information on meeting the San Francisco Regional Water Quality Control Board's MS4 C.3 permit measure, which extended stormwater practices to new development and redevelopment projects in 2001. For LID, ACCWP has addressed one of the thornier issues related to both structural and non-structural BMPs—maintenance. The following templates have been developed and are applicable to any stormwater program.

- How to Use the Templates
  http://www.cleanwaterprogram.org/uploads/6.0%20Template%20Intro%20FINAL.pdf
- Vegetated Swale Maintenance Plan Template
  http://www.cleanwaterprogram.org/uploads/6.1%20Veg%20Swale%20template%20FINAL.doc
- Vegetated Buffer Strip Maintenance Plan Template
  http://www.cleanwaterprogram.org/uploads/6.2%20Buffer%20Strip%20template%20FINAL.doc
- Tree Well Filter Maintenance Plan Template
  http://www.cleanwaterprogram.org/uploads/6.3%20Tree%20well%20filter%20template%20FINAL.doc
- Media Filter Maintenance Plan Template
  http://www.cleanwaterprogram.org/uploads/6.4%20media%20filter%20template%20FINAL.doc
- Flow-Through Planter Maintenance Plan Template
  http://www.cleanwaterprogram.org/uploads/6.5%20flo-thru%20plntr%20template%20FINAL.doc
- Bioretention Area Maintenance Plan Template
  http://www.cleanwaterprogram.org/uploads/6.6%20Bioretention%20Area%20template%20FINAL.doc
- Infiltration Trench Maintenance Plan Template
  http://www.cleanwaterprogram.org/uploads/6.7%20Infiltration%20Trench%20template%20FINAL.doc
- Extended Detention Basin Maintenance Plan Template
  http://www.cleanwaterprogram.org/uploads/6.8%20Detention%20Plan%20template%20FINAL.doc

Tetra Tech, Inc. 2008. State and Local Policies Encouraging or Requiring Low Impact Development in California. Prepared for the Ocean Protection Council of California, revised January 2008. Accessed at http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20080229/06_LID/0802COPC_06_EX1%20Tetra%20Tech%20LID%20Final%20Report.pdf on July 10, 2012.

D.2. Connecticut

Inspection & Maintenance/O&M:

> Stormwater management plans should describe the procedures, including routine and non-routine maintenance, that are necessary to maintain treatment practices, including vegetation, in good and effective operating conditions. Detailed inspection and maintenance requirements/tasks include; Inspection and maintenance schedules; Parties legally responsible for maintenance (name, address, and telephone number); Provisions for financing of operation and maintenance activities; As-built plans of completed structures; Letter of compliance from the designer; post-construction documentation to demonstrate; compliance with maintenance activities. (Connecticut DEP, 2004, p. 9-7)

Connecticut Department of Environmental Protection. 2004. Connecticut Stormwater Quality Manual. Accessed at http://www.ct.gov/dep/cwp/view.asp?a=2721&q=325704 on July 10, 2012.

D.3. Delaware

Draft guidance states that each stormwater management system shall have an Operations and Maintenance Plan detailing each component of the system (Delaware DNREC, 2011). The turn over process of the stormwater management system is incorporated with the construction completion process and the termination of the National Pollutant Discharge Elimination System construction permit. The system owner, as designated on the approved Sediment and Stormwater Plan owner's certification, is responsible for performing maintenance items as listed in the Operations and Maintenance Plan, or as guided in maintenance review reports submitted to the owner by DNREC or a delegated local agency.

Operation and Maintenance (O&M) Plan Elements (extract from Delaware DNREC, 2011):

> An Operation and Maintenance Plan is submitted with the initial designed set of plans for approval. Prior to project construction completion, a revised O&M Plan including post construction verification documentation is reviewed and accepted by the Department or Delegated Agency to ensure that any revisions during construction have been included on the final O&M Plan. The Department or Delegated Agency must verify that the owner is represented on the owner's certification on the O&M Plan, or at a minimum, a maintenance obligation form. The owner is responsible for maintenance reviews of the stormwater management system at the frequency stated on the O&M Plan. A submitted O&M Plan shall include all stormwater facilities listed on the Operation and Maintenance Checklist.

Minimum Maintenance Guidelines (extract from Delaware DNREC, 2011):

> The maintenance of the stormwater management system and all associated easements shall run with the land and be binding upon the landowner and any successors in interest, ensuring proper function. Proper function shall minimally include:
>
> - Mowed access path to the stormwater management system including all inlets and outlets
> - Access in order for both routine and non-routine maintenance to occur (including areas within easements)
> - No excessive sediment deposition
> - Well stabilized slopes that are not contributing sediment to the stormwater management system

- No scour in swales or other vegetated areas
- Trash racks, inlets, outlets, and low flow orifices (where applicable) clear of trash, debris, and sediment
- No woody vegetation impeding the performance of any structural component of the stormwater management system
- Additional maintenance items to ensure longevity of all structural components as required by the local delegated agency on the regular maintenance review
- Other references for maintenance are available at Appendix 5.01.1 Standard Guidelines for Operation and Maintenance of Stormwater BMPs.

Standard guidelines are included for O&M of (Delaware DNREC, 2011):

- Wet Pond
- Dry Extended Detention (Dry Pond)
- Infiltration Basins
- Sand Filter
- Filter Strip
- Biofiltration Swales
- Bioretention Facilities
- Infiltration Trench

Maintenance checklists are provided for (Delaware DNREC, 2011):

- Detention Practices
- Dry Detention Practices
- Infiltration
- Bioretention Practices
- Underground Detention Practices

Delaware DNREC. 2011. Delaware Sediment and Stormwater Program Technical Document Article 5, Maintenance of Permanent Stormwater Management Systems. Draft document, revised April 2011. Accessed at http://www.dnrec.delaware.gov/swc/Drainage/Documents/Sediment%20and%20Stormwater%20Program/Technical%20Document/Article%205.%20Maintenance%20of%20Permanent%20SWM%20Systems/Article%205.%20Maintenance%20of%20Permanent%20SWM%20Systems.pdf on July 11, 2012.

D.4. New Hampshire

Stormwater System Operation and Maintenance Plan:

> "It is essential for all stormwater management systems to be carefully planned and to undergo routine inspection and maintenance in order to operate at the designed efficiency. To more easily track the operation and maintenance activities, including the activity schedule, the person(s) responsible, and the maintenance activity records, it is recommended (and sometimes required) that a stormwater management plan is developed and implemented. If a plan is being developed under a specific permit, check with the permit program to see if additional plan elements are required. At a minimum, the Stormwater System Operation and Maintenance Plan should include the following elements:
>
> - The names of the responsible parties who will implement the Plan,
> - The frequency of inspections,
> - And inspection checklist to be used during each inspection,
> - And inspection and maintenance log to document each activity,
> - A plan showing the locations of all the stormwater practices described in the plan."

New Hampshire Department of Environmental Services. 2008. New Hampshire Stormwater Manual, Volume 1, Stormwater and Antidegradation. Revision 1.0, December 2008. Accessed at http://des.nh.gov/organization/commissioner/pip/publications/wd/documents/wd-08-20a.pdf on July 12, 2012.

Inspection and Maintenance (I&M) Manual:

> "The AoT regulations (Env-Wq 1500) require the long term maintenance of stormwater practices, and stipulate the establishment of a mechanism to provide for ongoing inspections and maintenance. Such a mechanism includes the preparation of an Inspection and Maintenance (I&M) Manual. This manual must include, at a minimum, the following:
>
> 1. The names of the responsible parties who will implement the required reporting, inspection, and maintenance activities identified in the I&M manual;
> 2. The frequency of inspections;
> 3. An inspection checklist to be used during each inspection;
> 4. An inspection and maintenance log to document each inspection and maintenance activity;
> 5. A deicing log to track the amount and type of deicing materials applied to the site;
> 6. A plan showing the locations of all the stormwater practices described in the I&M manual; and
> 7. Actions to be taken if any invasive species begin to grow in the stormwater management practices.
>
> All record keeping required by the I&M manual shall be maintained by the responsible parties, and any transfer of responsibility for I&M activities or transfer in ownership shall be documented to the DES in writing."

New Hampshire Department of Environmental Services. 2008. New Hampshire Stormwater Manual, Volume 2, Post-Construction Best Management Practices Selection and Design. Revision 1.0, December 2008. Accessed at http://des.nh.gov/organization/commissioner/pip/publications/wd/documents/wd-08-20b.pdf on July 12, 2012.

D.5. New Jersey

Inspection & Maintenance/O&M: (7:8-5.8 Maintenance requirements)

> Stormwater plan shall include a maintenance plan for the stormwater management measures, including preventative and corrective maintenance to be performed to maintain the function of the stormwater management measure, including repairs or replacement to the structure; removal of sediment, debris, or trash. Municipalities may require the posting of a performance or maintenance guarantee in accordance with N.J.S.A. 40:55D-53 (New Jersey DEP, 2009)

New Jersey Department of Environmental Protection. 2009. Stormwater Best Management Practices Manual. Manual dated April 2004, Revised September 2009. Accessed at http://www.njstormwater.org/bmp_manual2.htm on July 10, 2012.

D.6. New York

“The responsibility for implementation of long term operation and maintenance of a post-construction stormwater management practice shall be vested with a responsible party by means of a legally binding and enforceable mechanism such as a maintenance agreement, deed covenant or other legal measure. This mechanism shall protect the practice from neglect, adverse alteration and/or unauthorized removal. The mechanism and Operation and Maintenance (O&M) plan must be included in the SWPPP.

At a minimum, the O&M plan must address each of the following:

1. An owner of a post-construction stormwater management practice, including the runoff reduction practices and SMPs included in this Design Manual, shall erect or post, in the immediate vicinity of the stormwater management practice, a conspicuous and legible sign of not less than 18 inches by 24 inches (or 10"X12" for footprints smaller than 400 sf) bearing information identifying the practice
2. Identification of the entity that will be responsible for long term operation and maintenance of the stormwater management practices.
3. Identification of the mechanism(s) that will be used to ensure long term operation and maintenance of the stormwater management practices (Deed covenant, easements/rights-of-way, executed maintenance agreement, etc.). Include a copy of such mechanism.
4. A copy of the schematics of the practice, with the measurements of design specifications clearly defined.
5. A list of maintenance requirements (already defined in this Design Manual and the additional site specific requirements), proper frequency, and a maintenance log for tracking and observation.”

Appendix G of the manual includes maintenance inspection checklists for:

- Stormwater Pond/Wetland
- Infiltration Trench
- Sand/Organic Filter
- Bioretention
- Open Channel

New York State Department of Environmental Conservation. 2010. New York State Stormwater Management Design Manual. Revised August 2010. Accessed at http://www.dec.ny.gov/docs/water_pdf/swdm2010entire.pdf on July 12, 2012.

D.7. North Carolina

Each BMP design practice chapter in NC's Stormwater BMP Manual has a discussion of common maintenance issues, followed by a description of sample operation and maintenance provisions. Sample operation and maintenance agreements are also included for each class of BMP, including:

- Level Spreader & Veg. Filter Strip
- Stormwater Wetland
- Wet Detention Basin
- Sand Filter
- Bioretention
- Grassed Swale
- Restored Riparian Buffer
- Infiltration Devices
- Dry Detention Basin
- Permeable Pavement
- Rooftop Runoff Management
- Proprietary Systems

North Carolina Department of Environment and Natural Resources. 2007. DWQ Stormwater BMP Manual & BMP Forms. Effective July 2007, revised September 1, 2010. Accessed at http://portal.ncdenr.org/web/wq/ws/su/bmp-manual/ on July 12, 2012.

D.8. Pennsylvania

Post-construction stormwater management plans are required as of November 19, 2010. Long-term maintenance and monitoring are part of that plan. Key components:

- The permittee or co-permittee responsible for long-term operation and maintenance of PCSM BMPs
- BMPs must be recorded in land records and access must be provided for long-term operation; responsibility for operation and maintenance of the PCSM BMP is a covenant that runs with the land that is binding upon and enforceable by subsequent grantees
- O&M responsibility may be transferred to a conservation district, nonprofit organization, municipality, authority, private corporation or other person

Pennsylvania Administrative Code, Title 25, Part I, Subpart C, Article II, Chapter 102. Erosion and Sediment Control and Stormwater Management. Adopted August 20, 2010, effective November 19, 2010, 40 Pa.B. 4861. Accessed at http://www.pacode.com/secure/data/025/chapter102/chap102toc.html on July 11, 2012.

D.9. Rhode Island

Appendix A checklist: All systems must have a stormwater management system operation and maintenance plan that includes:

- Name, address, and phone number of responsible parties for maintenance
- 8 ½ x 11 inch plan depicting the locations of all BMPs requiring O&M
- Description of annual maintenance tasks
- Description of applicable easements
- Description of funding source
- Minimum vegetative cover requirements
- Access and safety issues

Appendix E of the manual contains more guidance on the details of each of these plan elements (Rhode Island DEM and CRC, 2010). Detailed information on maintenance and guidance, as well as maintenance checklists, are provided for:

- Stormwater Basins and WVTSs
- Infiltration facilities
- Permeable pavement
- Filters (sand, bioretention)
- Open channels

Rhode Island Department of Environmental Management and Coastal Resources Management Council. 2010. Rhode Island Stormwater Design and Installation Standards Manual. Revised December 2010. Accessed at http://www.dem.ri.gov/pubs/regs/regs/water/swmanual.pdf on July 9, 2012.

D.10. Washington

Inspection & Maintenance/O&M:

> Permittees must require an operation and maintenance manual that is consistent with the provisions in Volume V of the Stormwater Management Manual for Western Washington (2005) for all proposed stormwater facilities and BMPs. The party (or parties) responsible for maintenance and operation shall be identified in the operation and maintenance manual. For private facilities approved by the Permittee, a copy of the manual shall be retained onsite or within reasonable access to the site, and shall be transferred with the property to the new owner. For public facilities, a copy of the manual shall be retained in the appropriate department. A log of maintenance activity that indicates what actions were taken shall be kept and be available for inspection by the local government (Washington State Dept. of Ecology, 2005, Appendix 1, page 27; requirement is unchanged in new permit effective August 2012).

Washington State Department of Ecology, Water Quality Program. 2005. Stormwater Management Manual for Western Washington. Publication No. 05-10-33, revised February 2005. Accessed at http://www.ecy.wa.gov/programs/wq/stormwater/manual.html on July 10, 2012.

Washington State Department of Ecology, Water Quality Program. 2010. Phase I: Municipal Stormwater NPDES and State Waste Discharge General Permit. Issued January 17, 2007; modified September 1, 2010. Accessed at http://www.ecy.wa.gov/programs/wq/stormwater/municipal/phaseIpermit/MODIFIEDpermitDOCS/PhaseIStormwaterGeneralPermit.pdf on July 10, 2012.

Washington State Department of Ecology, Water Quality Program. 2012. Draft Phase I: Municipal Stormwater NPDES and State Waste Discharge General Permit. Issued January 17, 2007; modified September 1, 2010. Accessed at http://www.ecy.wa.gov/programs/wq/stormwater/municipal/MUNIdocs/PhaseIdraft.pdf on July 10, 2012.

D.11. West Virginia

Inspection & Maintenance/O&M:

- Maintenance agreement and maintenance plan required for all approved stormwater management practices. Verification of maintenance must be provided by property owners (West Virginia DEP, 2009, Permit part C.b.5.a.ii.C).
- The MS4 is required to inspect stormwater BMPs at least once every five years (West Virginia DEP, 2009, Permit part C.b.5.a.ii.E).

West Virginia Department of Environmental Protection. 2009. General National Pollution Discharge Elimination System Water Pollution Control Permit, Stormwater Discharges from small Municipal Separate Storm Sewer Systems, effective: July 22, 2009. Accessed at http://www.dep.wv.gov/WWE/Programs/stormwater/MS4/permits/Documents/WV%20MS4%20permit%20FINAL%20%282%29%204-26-12.pdf on September 28, 2012.