North Carolina
Stormwater Control Measure Credit Document

Environmental Quality

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Acknowledgements

DEQ would like to thank the numerous people and organizations that directly contributed to this document, especially the following:

- Sarah Waickowski, NCSU Department of Biological and Agricultural Engineering, compiled and analyzed, and summarized the research data that forms the backbone of this document. She also adapted, ran, and summarized the results of the hydraulic models that were the basis for the under and oversizing credits.

- Dr. Bill Hunt, PE, NCSU Department of Biological and Agricultural Engineering, served as the lead advisor on data interpretation and decision-making.

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- The SCM Crediting Team stakeholders patiently and wisely advised DEQ and NCSU throughout the process of developing SCM credits. This team included the following people: Ben Brown, Jennifer Buzun, Ryan Eaves, Sally Hoyt, Steve Jadlocki, Josh Johnson, Mark Hortsman, Lisa Kirby, Brian Lipscomb, Alix Matos, Peter Raab, Scott Whalen and Sandra Wilbur.

Part A: Introductory Information

A-1. Purpose of this Document

The purpose of the North Carolina SCM Credit Document is to improve the clarity and consistency of the credits awarded for the Stormwater Control Measures (SCMs) throughout North Carolina. In the past, credits for SCMs have been listed in each individual chapter of the Stormwater Design Manual. The various SCM credits will now be listed together in this document in order to facilitate updates as new research becomes available and also to facilitate comparisons between different SCMs.

There are a variety of stormwater programs throughout the state, each with its own goals. The NPDES, Coastal Counties, Outstanding Resource Waters (ORW), High Quality Waters (HWQ) and Water Supply Watershed programs are based upon removing a certain level of Total Suspended Solids (TSS). TSS is the number one pollutant in the state and also acts as a surrogate for removal of other pollutants, such as phosphorus and heavy metals. The Nutrient Sensitive Waters (NSW) stormwater program is based on achieving low nutrient loadings throughout an entire site for new development and achieving reductions on existing development. All of the stormwater programs encourage runoff volume match from predevelopment to post-development conditions (sometimes called “Low Impact Development” or LID) as a voluntary supplement to the above goals.

In order to meet the requirements of the various stormwater programs, DEQ has produced a crediting scheme that answers each of the following questions for each SCM:

- Are basic TSS goals met?
- What is the “fate” of the stormwater after it enters the SCM?
- What is the concentration of TN and TP in the effluent from the SCM?

It should be noted that, for the “typical” development subject to a state stormwater program (other than NSW), this document will not change how development is regulated. Most designers will choose to implement one “Primary SCM” (what was formerly referred to as an “85% TSS removal SCM”) for each drainage area that is fully sized for the design storm. This document supports designers who wish to do the following:

- Oversize one SCM in exchange for undersizing another SCM,
- Meet NSW goals (note that this information will be loaded into the Nutrient Accounting),
- Meet runoff volume match goals (note that this information will be loaded into the Storm-EZ Tool), and
- Understand the basis for DEQ’s SCM Credits.

If you have any questions as you read this document, please do not hesitate to contact Annette Lucas at (919) 807-6381 or annette.lucas@ncdenr.gov.

A-2. SCM Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% Treated Runoff to Fates			$\text{EMC}_{\text{effluent}}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Bioretention per MDC	Primary	94	A	90	10	0.58	0.12
			B	71	29		
			C	36	64		
			D	14	86		
Bioretention per MDC but without IWS (retrofits and special cases only)	Primary	94	A	51	49	1.20	0.12
			B	20	80		
			C	11	89		
			D	9	91		
Bioretention with design variants per Hyper Tool	Primary	Tool Output	Tool Output			0.58 / 1.20	0.12
Infiltration per MDC	Primary	84	A	100	0	0	0
			B	100	0		
			C	100	0		
			D	100	0		
Permeable pavement (infiltration) per MDC	Primary	84	A	100	0	0	0
			B	100	0		
			C	100	0		
			D	NA	NA		
Permeable pavement (detention, unlined) per MDC	Primary	84	A	10	90	1.08	0.05
			B	5	95		
			C	0	100		
			D	0	100		
Permeable pavement (detention, lined) per MDC	Primary	84	A	0	100	1.08	0.05
			B	0	100		
			C	0	100		
			D	0	100		
Permeable pavement with design variants per the Hyper Tool	Primary	Tool Output	Tool Output			1.08	0.05
Wet Pond per MDC	Primary	84	A	25	75	1.22	0.15
			B	20	80		
			C	15	85		
			D	10	90		
Wet Pond per MDC with ≥ 5% covered by FWI per Fig. 1	Primary	84	A	25	75	0.85	0.09
			B	20	80		
			C	15	85		
			D	10	80		
Stormwater wetland per MDC	Primary	84	A	40	60	1.12	0.18
			B	35	65		
			C	30	70		
			D	25	75		

SCM	Role	% Annual Runoff Treated if 100% Sized	% of Treated Runoff to Each Fate			$EMC_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Sand Filter (open) per MDC	Primary	90	A	10	90	1.33	0.12
			B	5	95		
			C	0	100		
			D	0	100		
Sand Filter (closed) per MDC	Primary	90	A	0	100	1.33	0.12
			B	0	100		
			C	0	100		
			D	0	100		
Rainwater Harvesting per MDC	Primary	85	A	Custom based on water usage		Custom based on water usage	
			B				
			C				
			D				
Green Roof per MDC	Secondary	100	N/A	60	40	2.44	0.76
DIS per MDC	Secondary	90	A	65	35	2.44	0.76
			B	50	50		
			C	40	60		
			D	30	70		
LS-FS per MDC	Secondary	90	A	60	40	1.04	0.19
			B	40	60		
			C	25	75		
			D	15	85		
LS-FS with Virophos sand added to the filter strip	Secondary	90	A	60	40	0.87	0.10
			B	40	60		
			C	25	75		
			D	15	85		
Treatment swale with dry conditions	Secondary	90	A	25	75	1.10	0.14
			B	15	85		
			C	5	95		
			D	0	100		
Treatment swale with wet conditions	Secondary	90	A	40	60	0.82	0.11
			B	30	70		
			C	20	80		
			D	10	90		
Dry Pond per MDC	Secondary	84	A	10	90	1.65	0.66
			B	5	95		
			C	0	100		
			D	0	100		
StormFilter per MDC with PhosphoSorb media™	Primary	91	A	0	100	0.48	0.03
			B	0	100		
			C	0	100		
			D	0	100		
Silva Cell per MDC	Primary	94	A	90	10	0.58	0.12
			B	71	29		
			C	36	64		
			D	14	86		
Silva Cell per MDC but without IWS	Primary	94	A	51	49	1.20	0.12
			B	20	80		
			C	11	89		
			D	9	91		

A-3. Other SCM Benefits

SCM Type	Protection of Streambanks	Protection of Stream Temp.	Removal of Bacteria	% TN Removal[1]	% TP Removal[1]
Bioretention	Excellent	Good	Excellent	35-65[2]	45-60[2]
Infiltration	Excellent	Excellent	Excellent	84	84
Permeable Pavement (infiltration)	Excellent	Excellent	Excellent	84	84
Permeable Pavement (detention)	Fair	Good	Good	30	30
Wet Pond	Fair	Poor	Fair	30	30
Stormwater Wetland	Good	Fair	Good	44	40
Sand Filter	Poor	Fair	Good	35	45
Rainwater Harvesting	Excellent	Excellent	Good	Variable[3]	Variable[3]
Green Roof	Good	Good	Good	30	30
DIS	Good	Good	Good	30	35
LS-FS	Poor	Poor	Poor	30	35
Pollutant removal Swale (wet)	Fair	Fair	Poor	30	30
Pollutant removal Swale (dry)	Poor	Fair	Poor	10	10
Dry Pond	Poor	Poor	Poor	10	10
StormFilter	Poor	Fair	Fair	50	70

[1] Percentage TN and TP removal rates are offered in this table because they remain relevant in the areas subject to Neuse and Tar-Pamlico NSW Stormwater. Eventually, these areas will use the accounting tool and EMCs that apply to the Falls and Jordan Lake areas.

[2] Bioretention w/out IWS: 35% TN & 45% TP
Bioretention w/IWS: 60% TN & 60% TP in the Coastal Plain, 40% TN & 45% TP elsewhere

[3] Rainwater harvesting removal rates depend on the discharge point for the effluent.

A-4. Glossary

Design Variant	Modification to the design of an SCM (as required per the minimum design criteria) that results in a change in the performance of the SCM.
DIS	Disconnected Impervious Surface; the practice of directing stormwater runoff from built-upon areas to properly sized, sloped and vegetated pervious surfaces.
Effluent	Stormwater that is treated in an SCM and released as discharge to a drainage collection system or surface water.
EMC	Event Mean Concentration, the pollutant concentration of a composite of multiple samples collected during the course of a storm. The EMC accurately determines pollutant loads from a site and is most representative of average pollutant concentrations over an entire runoff event.
ET & I	Evapotranspiration and Infiltration; reduction of the volume of stormwater by either evaporation from the soil surface, transpiration from the leaves of the plants, or seepage into the soil, or a combination of these three.
FWI	Floating Wetland Island; may be made to a wet pond to improve its treatment performance. FWIs are typically large plastic mats that float half above and half below water
HSG	Hydrologic Soil Group; based on estimates of runoff potential. Soils are assigned to one of four groups (A, B, C and D) according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.
IWS	Internal Water Storage; a zone in an SCM where stormwater is retained in the media or aggregate after a storm event to encourage denitrification and infiltration. An IWS is created by adding an elbow in the underdrain piping at a 90º angle vertically perpendicular to the horizontal underdrain.
LS-FS	Level Spreader-Filter Strip; a poured concrete linear lip constructed with a uniform slope of close to zero percent that spreads flow over a grassed area located immediately downslope. The length of the LS is based on the discharge rate of the stormwater that is directed to it. The vegetation and soils in the FS remove pollutants primarily via filtration and infiltration.

MDC	Minimum Design Criteria; the requirements set forth in state rules for siting, site preparation, design and construction, and post-construction monitoring and evaluation necessary for SCMs to comply with State water quality standards
Percent sizing	The amount by which an SCM is under or oversized with respect to the required storm depth (1.5" in Coastal Counties, 1" elsewhere). In other words, a 100% sized SCM treats the runoff resulting from the 1.5" storm in a Coastal County and the runoff from a 1.0" storm elsewhere. For example, an SCM outside of Coastal Counties that is sized to treat the runoff from the 0.8-inch storm is 80% sized. An SCM within a Coastal County that is sized to treat the 2.0-inch storm is 133% sized.
Primary SCM	An SCM that can stand alone to treat stormwater on a high-density project when it is designed per the MDC to treat the design storm. Primary SCMs include wet ponds, stormwater wetlands, infiltration systems, sand filters, bioretention cells, permeable pavement, green roofs, rainwater harvesting, and approved new stormwater technologies.
Secondary SCM	An SCM that does not achieve the annual reduction of Total Suspended Solids (TSS) of a "Primary SCM" but can be used in a treatment train with a Primary SCM or other Secondary SCMs to provide pre-treatment, hydraulic benefits or a portion of the required TSS removal.
SCM	Stormwater Control Measure; a permanent structural device that is designed, constructed, and maintained to remove pollutants from stormwater runoff by promoting settling or filtration or mimic the natural hydrologic cycle by promoting infiltration, evapo-transpiration, post-filtration discharge, reuse of stormwater, or a combination thereof.
Required storm depth	This is the depth of storm that is required to be treated per the 15A NCAC 02H .1000 Section, which can be summarized as 1.5" in Coastal Counties and 1.0" elsewhere.
TSS	Total Suspended Solids, which includes all particles suspended in water which will not pass through a filter. Nonpoint sources of total suspended solids include erosion from construction sites.
Virophos	A soil amendment that increases the ability of a soil to remove phosphorus.
VRA	Vegetated Receiving Area; the grassed area that receives flow in either a Disconnected Impervious Surface (DIS) or a Level Spreader-Filter Strip (LS-FS)

Part B: Technical Foundation for Credits

Applicants may select from a number of goals when designing the SCMs for a new project. The decision about which goal to design toward will depend on the stormwater requirements that apply to the project as well as the preferences of the project's owner. Each column of the SCM Crediting Table provides the information needed to support one or more of the potential goals that a designer may use.

Design Goal	Relevant Columns of SCM Crediting Table	Where the Goal May be Applied
Runoff Treatment (new development)	Blue	Any new development except for NSW areas.
Runoff Volume Match (new development)	Green	Any new development project throughout the entire state.
NSW Nutrient Export Compliance (new development)	Green and Tan	NSW areas
Retrofits	Variable	NSW areas and elsewhere

Runoff treatment is met by treating the volume of stormwater runoff generated from all of the built-upon area of a project at build-out during a storm of the required storm depth in one or more primary SCMs or a combination of Primary and Secondary SCMs that provides equal or better treatment.

Runoff volume match is met by designing the project such that the annual runoff volume after development is not more than ten percent higher than the annual runoff volume of runoff before development, except in areas subject to SA waters, where runoff volume match means that the annual runoff volume after development is not more than five percent higher than the annual runoff volume before development.

NSW nutrient export compliance is met by designing the project such that the nutrient loading rates in pounds/acre/year do not exceed the rates allowed in the applicable NSW program.

For **retrofits**, the goal is to make an improvement relative to the baseline. The goal is often based on reducing nutrients (and thus the green and tan columns will be used) but retrofits may also seek to provide a level of runoff treatment or runoff volume match depending on the reasons for which they are implemented.

B.1. Primary vs. Secondary SCMs

In the past, 85% TSS removal has been used as a standard. DEQ is no longer using that standard because it is not reflective of the actual field performance of SCMs. Most SCMs do not remove 85% of TSS, especially at lower concentrations of TSS in the influent.

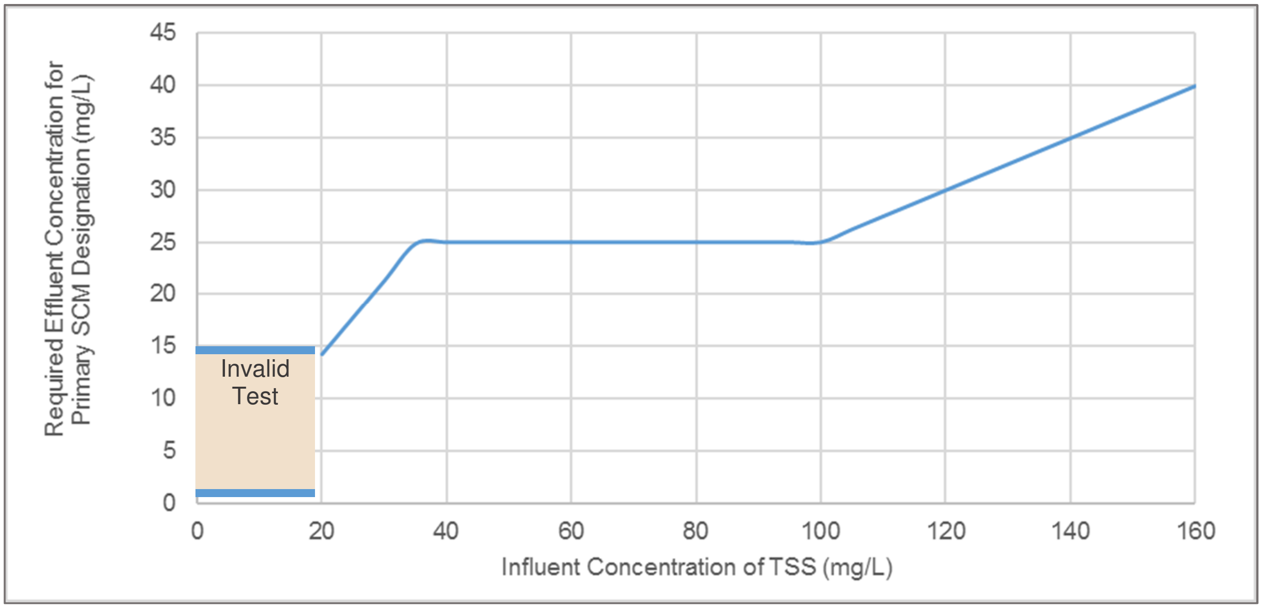
SCMs are designated as either primary or secondary based on their demonstrated performance at TSS removal in research studies. With stakeholder input, DEQ developed the table and graph below to characterize the performance that is required of primary SCMs. In addition to the table below, primary SCMs shall be capable of treating the design storm (1.5 inches in Coastal Counties and 1 inch in the remainder of the state).

Median Influent EMC	Applicable Performance Standard[1,2]
< 20 mg/L	Invalid test
20 – 35 mg/L	≥ 29% removal
35 – 100 mg/L	≤ 25 mg/L
100 mg/L	≥ 75% removal

[1] The median effluent EMC requirements may also be considered on a total load basis for SCMs that reduce runoff volume. Divide the performance standard by [100% – (% of runoff reduced)] to determine the corresponding load-based standards.

[2] Primary SCMs comply with the above standards as demonstrated through research studies. Proposed new stormwater technologies shall be held to this same standard.

Figure B-1: Required Performance Standard for Primary SCMs



Based on applying the above criteria to the available research results, the SCMs were designated as follows:

List & Uses	Primary SCMs	Secondary SCMs
List	- Bioretention Cell - Infiltration System - Permeable Pavement - Wet Pond[1] - Stormwater Wetland[1] - Sand Filter - Rainwater Harvesting	- Green Roof - Disconnected Impervious Surface - Level Spreader-Filter Strip - Pollutant removal Swale - Dry Pond
Uses	- As a stand-alone SCM to treat a new development site (when 100% sized). - As a retrofit.	- In series with a primary SCM to reduce the volume of runoff and thus reduce the size of the primary SCM. - In series with a primary SCM to provide pretreatment. - In series with a primary SCM as a hydraulic device to slowly "feed" the stormwater runoff to the primary SCM, to reduce the size of the primary SCM. - In series with another secondary SCM to treat the design storm in a manner that meets or exceeds performance standard. - As a retrofit.

[1] The research data on wet ponds and stormwater wetlands actually indicate that only about 50% of those studied meet the performance standard shown in the figure above. However, DEQ is retaining these as Primary SCMs due to their history as being considered stand-alone SCMs and their capacity to manage peak flows.

[2] The research data on level spreader-filter strips actually indicate that they do meet the performance standard shown in the figure above. However, DEQ is retaining LS-FS as a Secondary SCM for the present because the research sites were sized 50-300 times larger than the MDC for this SCM require.

For more information, see Part G: Summary of TSS Removal Data.

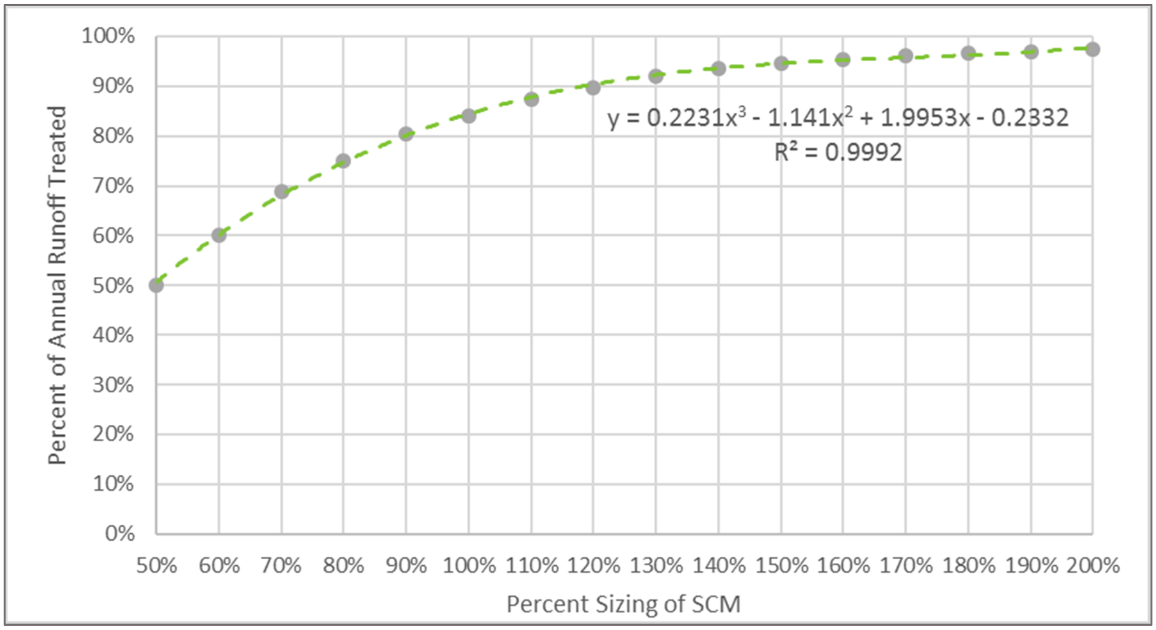
B.2. Annual Runoff Treated Based on Percent Sizing

A SCM that is 100-percent sized treats the majority of the annual runoff from their contributing drainage area. However, a certain percentage of the runoff resulting from larger storm events is released as untreated stormwater. The percentage of annual runoff treated by a 100-percent sized SCM varies based on the treatment mechanisms of the device as well as the retention time. See the table below for DEQ's estimations.

SCMs (designed per the MDC unless otherwise specified)	% of annual runoff treated if 100% sized	How the percent of annual runoff treated was estimated
Bioretention Bioretention without IWS	94%	This is the output of NCSU's HyPerTool for a bioretention cell that is 100% sized and designed per the MDC.
Infiltration Permeable Pavement (infiltration or detention) Wet Ponds Wetlands Dry Ponds	84%	These SCMS are assumed to have a 60-hour average drawdown time. NCSU researchers ran a model with 20 years of rainfall data through 60-hour detention time devices to determine that, on the average, 84 percent of annual runoff if these SCMs are sized to treat the design storm.
Bioretention (variations from MDC) Permeable Pavement (variations from MDC)	Variable	Use the appropriate NCSU accounting tool to enter the sizing and its impact on runoff fates: Bioretention HyPerTool and the PermPave HyPerMod.
Sand Filter (open or closed)	90%	Sand Filters are assumed to have a 12-hour average drawdown time. NCSU researchers ran a model with 20 years of rainfall data through 12-hour detention time devices to determine that, on the average, 91 percent of annual runoff will be treated for Sand Filters that are sized to treat 0.75 times the design storm (note that the MDC require only 75% sizing because of the short detention times of these two devices).
LS-FS DIS	90%	These SCMs are designed per the 0.75 in/hr drawdown time rather than a storm depth. NCSU has run a model based on 20 years of rainfall data showing that, on the average, 90 percent of annual runoff will be treated.
Green Roofs	100%	The drainage area of a green roof is the green roof itself; all storms will rain directly on the green roof.
Rainwater Harvesting	85%	Per the MDC, a 100-percent sized rainwater harvesting system is sized based on treating 85% of the annual runoff volume from the area that drains to it based on the results of the Rainwater Harvester.
Pollutant removal Swale (wet or dry) StormFilters	90%	May not be under or oversized for variable credit at this time.

Determining the performance for under and oversized SCMs is based on hydraulic modeling using 20 years of historic rainfall data. For infiltration, permeable pavement, wet ponds, stormwater wetlands and dry ponds, the estimated draw down time is 60 hours. More detailed information can be found in Part F: Technical Justifications and References. Figure B-2 below shows how the percent of annual runoff treated changes with the percent sizing of these SCMs. **Note that all of this information is programmed into the SNAP Tool.**

Figure B-2: Sizing versus Annual Runoff Treated for Infiltration, Wet Ponds, Stormwater Wetlands and Dry Ponds



The performance of the other SCMs relative to sizing was determined as explained below.

SCMs	How Sizing Affects Crediting
Sand Filters	Have own performance/sizing curve because, unlike the other SCMs, they are estimated to have 12-hour detention times and are only sized for 0.75 times the design storm. More detail can be found C-6 and Part F: Technical Justification and References.
Bioretention and Rainwater Harvesting	Credit should be determined with the appropriate NCSU Modeling Tool.
DIS and LS-FS	Not allowed to be undersized due to concerns about erosion. Oversized DIS and LS-FS are estimated to treat 90 percent of the annual runoff but are credited with a higher percentage of ET&I. See C-9 and C-10.
Permeable Pavement, Green Roofs, Pollutant Removal Swales and StormFilters	Permeable pavement, green roofs, pollutant removal swales and StormFilters may not be under or oversized for various reasons explained in the designated section of Part C.

B.3. Fates of Treated Runoff

After determining the percent of total annual runoff treated based on percent sizing, the second step is to partition the treated runoff into two more categories: ET&I and Effluent. For infiltration systems, wet ponds, stormwater wetlands, dry ponds and sand filters, DEQ and NCSU-BAE estimate that the percentage of ET&I remains constant regardless of how much the device is under or oversized.

The figure at the right shows how an infiltration system (as an example) is credited for under and oversizing. Note that regardless of how large or small the device it, the treated runoff is 100% ET&I and 0% Effluent.

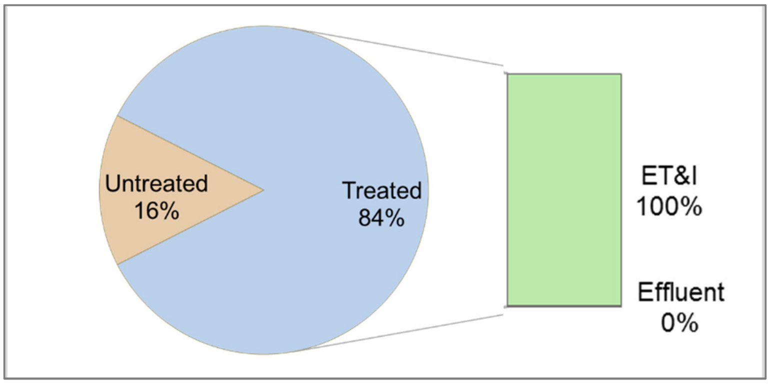
Infiltration systems, infiltrating permeable pavement, wet ponds, stormwater wetlands, dry ponds and sand filters, shall have their fates partitioned in the same way with respect to sizing.

Bioretention cells and rainwater harvesting shall have their fates partitioned with the appropriate NCSU modeling tool.

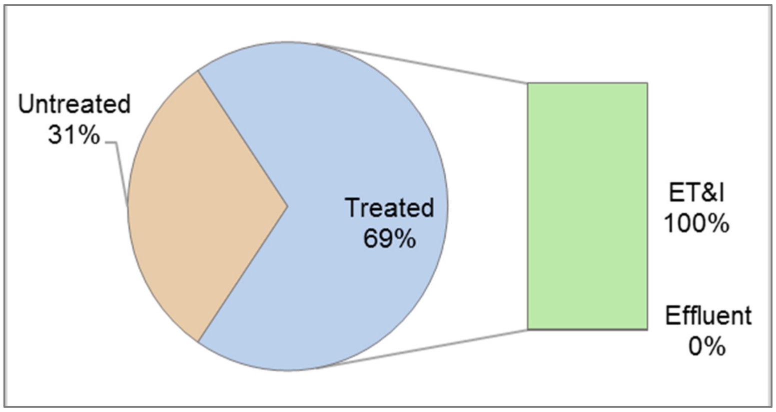
The treated runoff fates for pollutant removal swales and StormFilter shall be as stated in the crediting table because under and oversizing is not allowed.

Figure B-3: Sizing versus Runoff Fates for Infiltration Systems

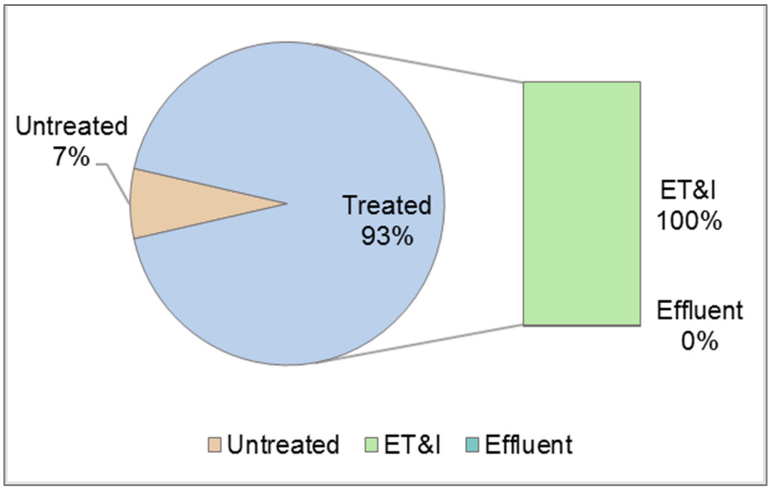
a. 100% sized



b. 70% sized



c. 130% sized

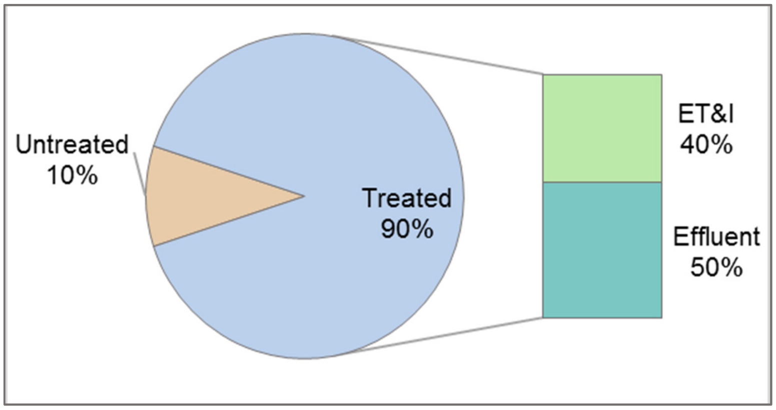


The fates of treated runoff for LS-FS and DIS are handled in an almost opposite manner than the infiltration system above. Regardless of how much these devices are oversized (note that undersizing an LS-FS or DIS is not allowed), LS-FS and DIS are estimated to treat 90 percent of the annual runoff. However, the percentage of ET&I increases as the vegetated receiving areas of these devices increases. Stormwater "lost" from SCMs as ET&I results in a commensurate level of nutrient load reduction.

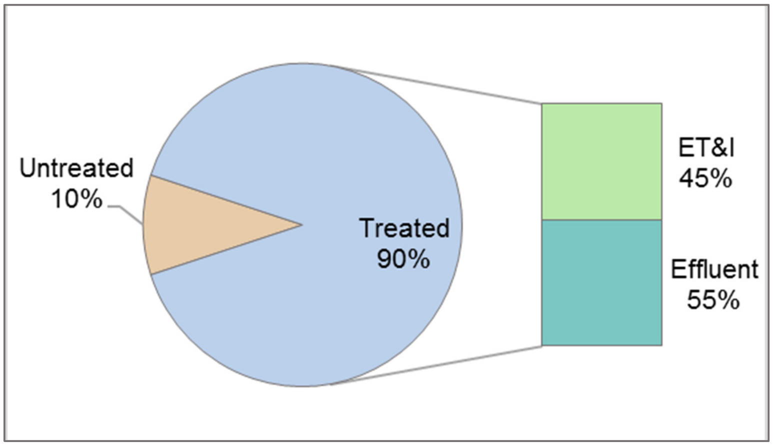
See C-9 Disconnected Impervious Surface and C-10 Level Spreader-Filter Strip for more detailed information.

Figure B-4: Sizing versus Runoff Fates for DIS installed in HSG C

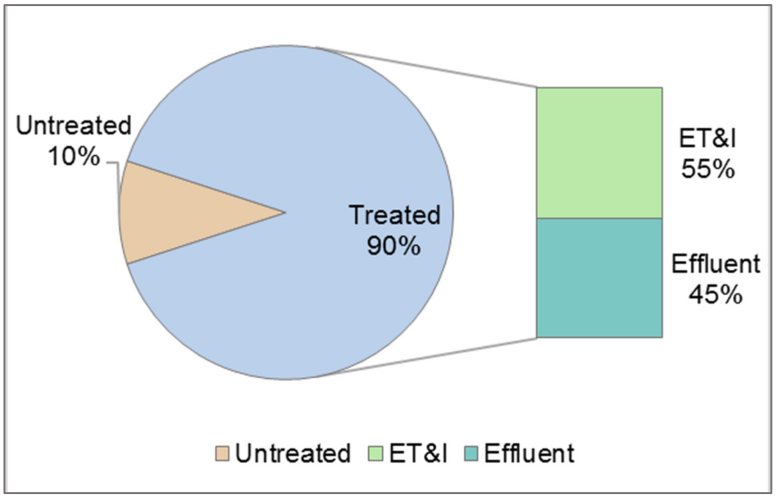
a. 100% sized



b. 200% sized



c. 400% sized



B.4. EMC Methodology

For all SCMs, only paired influent and effluent data from sites located in North Carolina or other states with similar ecoregions were included in the evaluations. When possible, only published or submitted journal articles were used to determine the EMCs, and studies where the monitored SCM designs met the MDCs. For sand filters, green roofs, and dry ponds data were retrieved from the International Stormwater BMP Database. For all of the data, a QA/QC was performed. The EMCs reflect the average of the median or average EMCs from the sites.

A summary of the number and locations of studies for each SCM is provided below. Further details regarding the data and calculations for each SCM type are provided in the associated sections and in Part F: Technical Justification and References.

SCM	# of NC Studies	# & locations of out of state studies
Bioretention	10	0
Permeable pavement	7	OH (1)
Wet pond and FWI	8	0
Stormwater wetland	10	0
Sand filters	0	FL (3), MD (1), NH (1), and VA (1)
Rainwater Harvesting	5	0
Green Roof	2	CT (1), Auckland, NZ (3)
DIS	4	0
LS-FS	6	0
Pollutant removal swale	8	0
Dry pond	3	VA (2)
StormFilter	2	1 (OR)

Part C: Credit for each SCM

C.1. Infiltration System

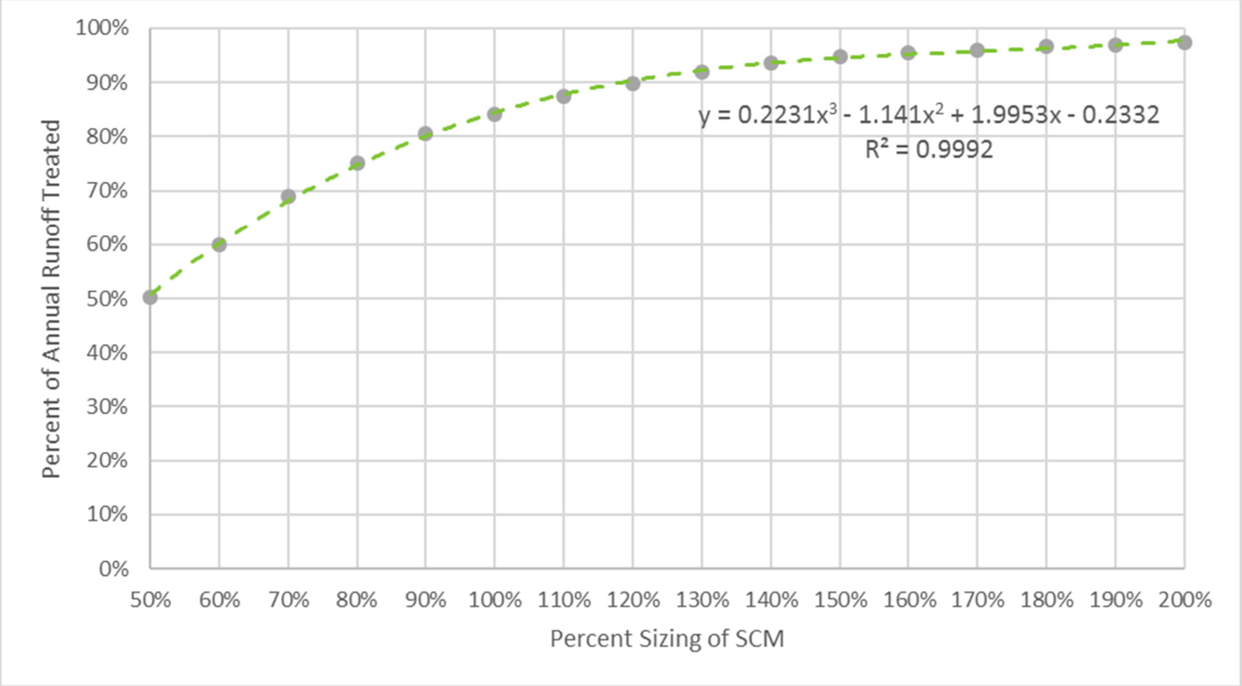
Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% Treated Runoff to Fates			EMC$_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Infiltration per MDC	Primary	84	A	100	0	0	0
			B	100	0		
			C	100	0		
			D	100	0		

Annual Runoff Treated Based on Percent Sizing

Based on modeling done by NCSU using 20 years of rainfall data, a device designed for the design storm (1 inch or 1.5 inches on the Coast) and a 60-hour drawdown time will treat 84 percent of the total annual runoff volume. Figure C-1 below shows how the percent of annual runoff treated changes depending on the percent sizing of the infiltration system.

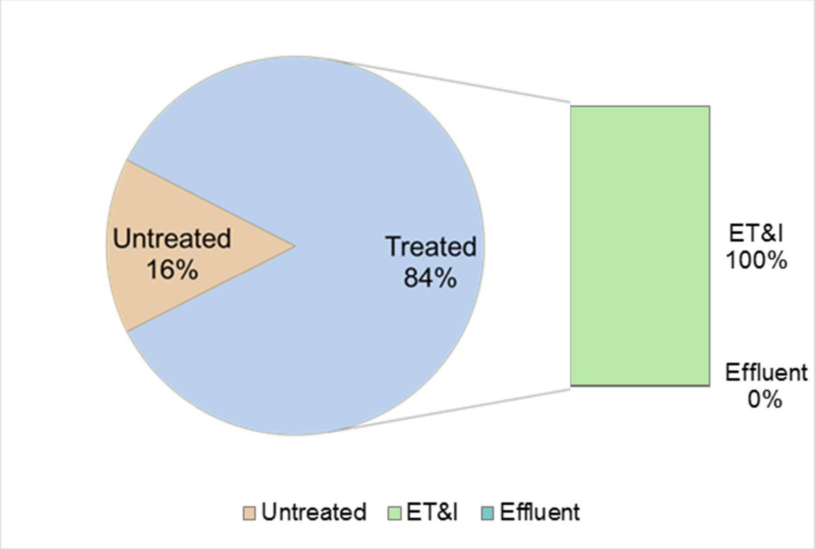
Figure C-1: Sizing versus Annual Runoff Treated for Infiltration



Fates of Treated Runoff

Because the MDC require that infiltration systems infiltrate the entire design storm, 100% of treated runoff is allocated to ET&I. Figure C-2 below shows how the percent of annual runoff treated increases with the percent sizing of the infiltration system.

Figure C-2: Runoff Fates for a 100% Sized Infiltration System



Design Variants

There are no approved design variants for infiltration systems. However, rule language allows the applicant to propose design variants for any SCM and provide technical justification based on engineering calculations and the results of research studies showing that the proposed design is equally or more protective of water quality than the current MDC for the SCM and that it shall function in perpetuity.

EMCs

EMCs are not relevant to infiltration systems because a correctly designed infiltration system will infiltrate the entire design storm. Runoff that exceeds the capacity of the infiltration system is considered “untreated.”

C.2. Bioretention Cell

Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% Treated Runoff to Fates			$\text{EMC}_{\text{effluent}}$ (mg/L)	
			HSG	**ET&I**	**Effluent**	**TN**	**TP**
Bioretention per MDC	Primary	94	A	90	10	0.58	0.12
			B	71	29		
			C	36	64		
			D	14	86		
Bioretention per MDC but without IWS (only retrofits and special cases)	Primary	94	A	51	49	1.20	0.12
			B	20	80		
			C	11	89		
			D	9	91		
Bioretention with design variants per HyPerTool	Primary	Tool Output	Tool Output			0.58 / 1.20*	0.12

* NOTE: The TN EMC for bioretention cells with design variants shall be based on whether the bioretention cell has an IWS (in which case the Effluent EMC shall be 0.58 mg/L) or not (in which case the effluent EMC shall be 1.20 mg/L)

Annual Runoff Treated Based on Percent Sizing

The portioning of annual runoff between treated and untreated in the table was estimated using NCSU's Bioretention HyPerTool, which provides options for selecting 50%, 75%, 100%, 150% and 200% sizing. To determine the annual runoff treated for bioretention cells that do not fall into these exact percentages, the user should interpolate between the two relevant sizes. HyPerTool is a Microsoft Excel spreadsheet model that references a database of hundreds of DRAINMOD simulations to allow for custom analysis and design of bioretention cells. More information on the Bioretention HyPerTool may be found in Part F: Overview of NCSU Models.

Under or oversizing a bioretention cell affects the percentage of annual runoff treated. However, it is not considered to change the TN or TP EMCs of the effluent.

To account for the uncertainty associated with this modeling based approach, the user should select a factor of safety of 10 percent when applying the Bioretention HyPerTool.

Fates of Treated Runoff

NCSU's HyPerTool also partitions the Treated Runoff into ET&I versus Effluent. The percentage of total annual runoff treated and the partitioning of treated runoff between ET&I and Effluent should be done through the use of NCSU's HyPerTool as well.

Design Variants

The three design variants listed below are options provided in the Bioretention HyPerTool. If a designer wishes to use one of the following design variants, the effect on Treated Runoff fates should be estimated using the Bioretention HyPerTool.

Design Variant	Where it is allowed	Effects on Performance
Exclude the internal water storage (IWS) zone	On retrofits or new development where the IWS poses a threat to the SCM or the site	Reduces % annual runoff treated. Reduces % of ET&I. No effect on TN & TP EMCs.
Reduce the ponding depth from 12 to 9 inches (while retaining the same design volume)	Retrofit or new development	Increases % annual runoff treated. Increases % ET&I. No effect on TN & TP EMCs.
Increase the soil media depth from 3 to 4 feet in B, C and D soils.	Retrofit or new development	Increases % annual runoff treated Increases % ET&I. No effect on TN & TP EMCs.

EMCs

Data from 10 NCSU monitored bioretention cells in: Charlotte, Graham, Knightdale, Louisburg, Nashville, and Rocky Mount, NC were used to determine the EMCs. For each site, average or mean pollutant effluent concentrations were calculated. For bioretention cells designed per the MDC, only sites with IWS were used to determine the TN EMC. For bioretention cells designed without IWS, only sites without IWS were included to calculate the TN EMC. Because IWS lacks treatment mechanisms for TP, the average of all effluent concentrations was used to determine the EMC (Hunt et al., 2012).

Site	Location	Resource
Hal Marshall	Charlotte, NC	Hunt et al. (2008)
Graham North	Graham, NC	Passeport et al. (2009)
Graham South	Graham, NC	Passeport et al. (2009)
Louisburg 1	Louisburg, NC	Sharkey (2005)
Louisburg 2	Louisburg, NC	Sharkey (2005)
Mango Creek Large	Knightdale, NC	Luell et al. (2011)
Mango Creek Small	Knightdale, NC	Luell et al. (2011)

Nashville Deep	Nashville, NC	Brown and Hunt (2011a)
Nashville Shallow	Nashville, NC	Brown and Hunt (2011a)
Rocky Mount	Rocky Mount, NC	Brown and Hunt (2011b)

C.3. Wet Pond

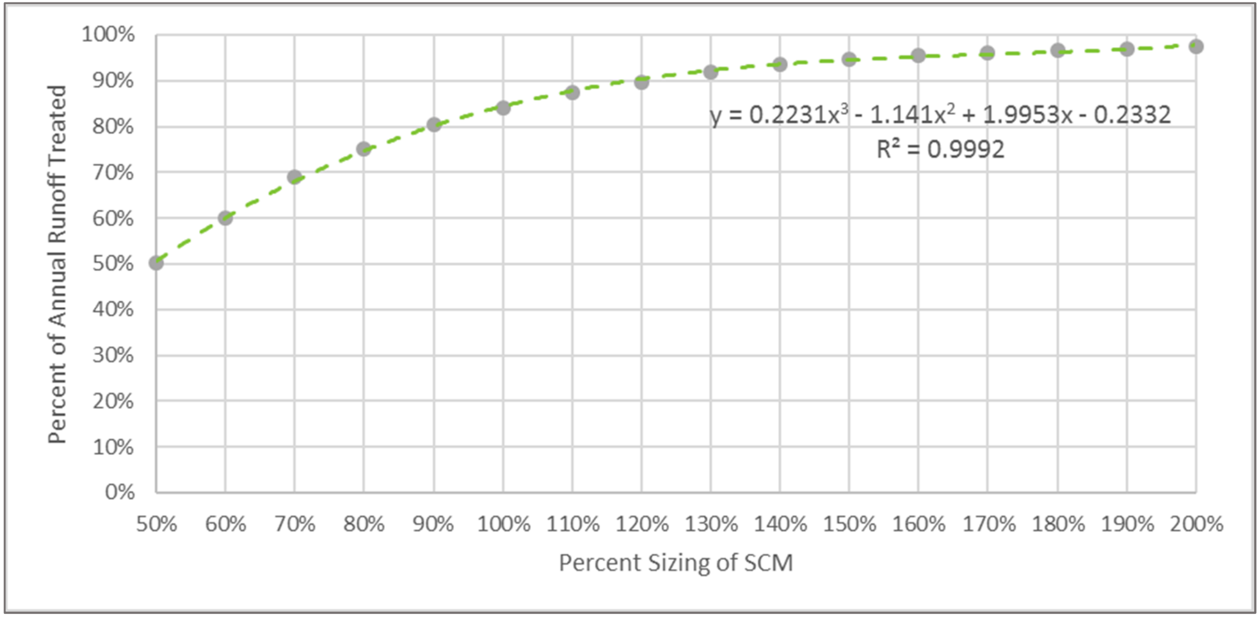
Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% Treated Runoff to Fates			EMC$_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Wet Pond per MDC	Primary	84	A	25	75	1.22	0.15
			B	20	80		
			C	15	85		
			D	10	90		
Wet Pond per MDC with ≥ 5% covered by FWI per Fig. 1	Primary	84	A	25	75	0.85	0.09
			B	20	80		
			C	15	85		
			D	10	80		

Annual Runoff Treated Based on Percent Sizing

Based on modeling done by NCSU using 20 years of rainfall data, a device designed for the design storm (1 inch or 1.5 inches on the Coast) and a 60-hour drawdown time will treat 84 percent of the total annual runoff volume. Figure C- below shows how the percent of annual runoff treated increases with the percent sizing of the wet pond.

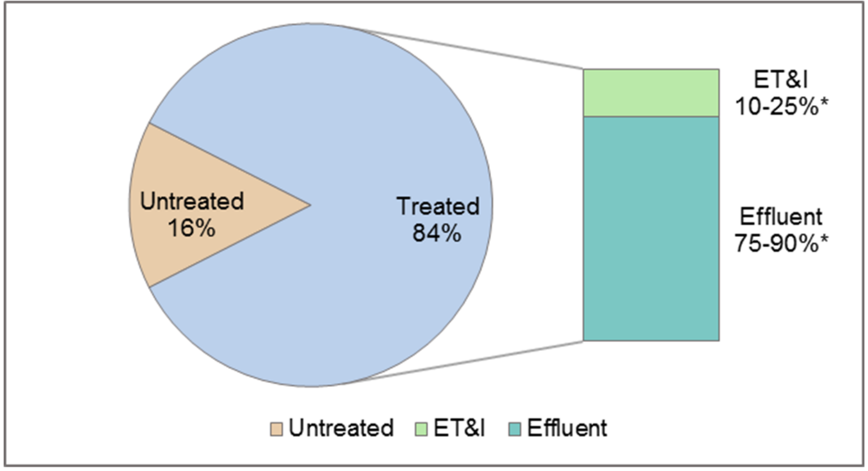
Figure C-3: Size versus Annual Runoff Treated for a Wet Pond



Fates of Treated Runoff

The ratio of ET&I to Effluent in the Treated Runoff is estimated to remain constant regardless of whether the pond is under or oversized. The allocation of treated runoff between ET&I and Effluent varies based on HSG. Figure C- below shows runoff fates for a 100% sized wet pond.

Figure C-4: Runoff Fates for a 100% Sized Wet Pond



* NOTE: The percentages of ET&I and Effluent vary based on HSG.

Design Variants

There is one approved design variant for wet ponds; adding a floating wetland island (FWI). A FWI is an addition that may be made to a wet pond to improve its treatment performance. FWIs are typically large plastic mats that float half above and half below water. Wetland plants, such as rushes, sedges, hibiscus, lizard's tail and pickerelweed, are planted in the mesh and grow by taking up nutrients from the stormwater pond. The plants grow very quickly – nearly to maturity within the first growing season. The roots dangle into the water about three feet (depending upon species), providing flow resistance and filtration of pollutants from the water column.

Design Variant	Where it is Allowed	Effect on Performance
Cover at least 5% of the surface area of the pond with a FWI	Retrofit or new development	Negligible effect on % annual runoff treated. Negligible effect on % ET&I. Reduces TN and TP EMCs.

EMCs

Data from eight wet ponds located in: Charlotte, Durham, Fayetteville and High Point, NC were used to develop the EMCs for constructed stormwater wetlands. With the exception of the Wilmington wetland, the sites were monitored by NCSU. Average pollutant effluent concentrations from each site were calculated, and the average of the mean concentrations was used to determine the EMCs.

Project Name	Location	Reference
Bingham Wet Pond	Fayetteville	Baird, J. B. (2014).
Davis Pond	High Point	Hathaway, J. M., Hunt, W. F., Smith, J. T., & Johnson, A. (2007b).
Hillandale	Durham	Borden, R., Dorn, J., Stillman, J., & Liehr, S. (1998)
Museum	Durham	Borden, R., Dorn, J., Stillman, J., & Liehr, S. (1998)
Piedmont Pond	High Point	Hathaway, J. M., Hunt, W. F., Smith, J. T., & Johnson, A. (2007d)
Pierson	Charlotte	Hathaway, J. M., Hunt, W. F., Smith, J. T., & Johnson, A. (2007d)
Raeford	Fayetteville	Baird, J. B. (2014)
Shade Valley	Charlotte	Hathaway, J. M., Hunt, W. F., Smith, J. T., & Johnson, A. (2007d)

C.4. Stormwater Wetland

Credit Table

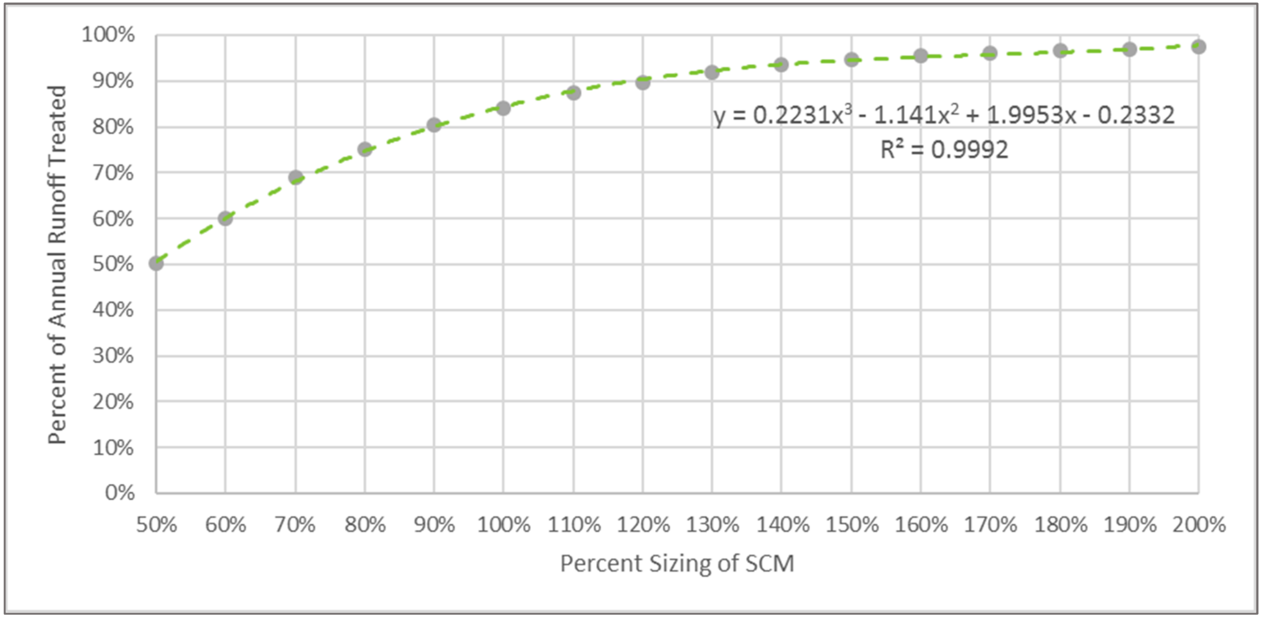
SCM	Role	% Annual Runoff	% Treated Runoff to Fates			$EMC_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP

		Treated if 100% Sized					
Stormwater wetland per MDC	Primary	84	A	40	60	1.12	0.18
			B	35	65		
			C	30	70		
			D	25	75		

Annual Runoff Treated Based on Percent Sizing

Based on modeling done by NCSU using 20 years of rainfall data, a device designed for the design storm (1 inch or 1.5 inches on the Coast) and a 60-hour drawdown time will treat 84 percent of the total annual runoff volume. Figure C- below shows how the percent of annual runoff treated increases with the percent sizing of the stormwater wetland.

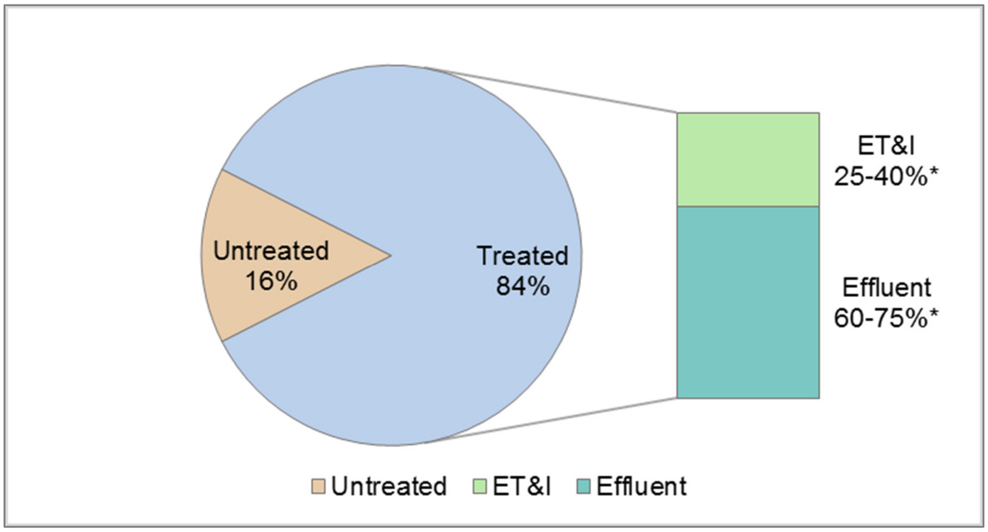
Figure C-5: Size versus Annual Runoff Treated for a Stormwater Wetland



Fates of Treated Runoff

The ratio of ET&I to Effluent in the Treated Runoff is estimated to remain constant regardless of whether the stormwater wetland is under or oversized. The allocation of treated runoff between ET&I and Effluent varies based on HSG. **Figure C-** below shows runoff fates for a 100% sized wet pond.

Figure C-6: Runoff Fates for a 100% Sized Stormwater Wetland



* NOTE: The percentages of ET&I and Effluent vary based on HSG.

Design Variants

There are no approved design variants for stormwater wetlands. However, rule language allows the applicant to propose design variants for any SCM and provide technical justification based on engineering calculations and the results of research studies showing that the proposed design is equally or more protective of water quality than the current MDC for the SCM and that it shall function in perpetuity.

EMCs

Data from 10 stormwater wetlands located in: Asheville, Charlotte, Edenton, Mooresville, New Bern, Raleigh, Riverbend, and Wilmington, NC were used to develop the EMCs for constructed stormwater wetlands. With the exception of the Wilmington wetland, the sites were monitored by NCSU. Average pollutant effluent concentrations from each site were calculated, and the average of the mean concentrations was used to determine the EMCs. Note for site Dye Branch, only data collected from the first wetland in the series of three was used for the calculations.

Site	Location	Resource
Bruns Ave	Charlotte, NC	Johnson (2006)
Cent. Campus MS	Raleigh, NC	Line et al. (2008)

Dye Branch	Mooresville, NC	Hathaway and Hunt (2010)
Edwards Branch	Charlotte, NC	Hathaway et al. (2007a)
Edenton Hospital	Edenton, NC	Bass (2000)
Simmons Base	New Bern, NC	Merriman (2015)
Simmons Event	New Bern, NC	Merriman (2015)
Riverbend	Riverbend, NC	Lenhart and Hunt (2011)
Riverbend LSM	Riverbend, NC	Merriman and Hunt (2014); Merriman (2015)
UNCA	Asheville, NC	Line et al. (2008)
JEL Wade	Wilmington, NC	Mallin et al. (2012)

C.5. Permeable Pavement

Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% Treated Runoff to Fates			EMC$_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Permeable pavement (infiltration) per MDC	Primary	84	A	100	0	0	0
			B	100	0		
			C	100	0		
			D	NA	NA		
Permeable pavement (detention, unlined) per MDC	Primary	84	A	10	90	1.08	0.05
			B	5	95		
			C	0	100		
			D	0	100		
Permeable pavement (detention, lined) per MDC	Primary	84	A	0	100	1.08	0.05
			B	0	100		
			C	0	100		
			D	0	100		
Permeable pavement with design variants per the HyPerMod	Primary	Tool Output	Tool Output			1.08	0.05

Built-upon Area Credit for Infiltrating Pavement

Infiltrating permeable pavement that is designed per the MDC may be considered as 100% pervious for the following purposes:

a. On new projects: As a tool to keep a project below the BUA threshold for high density or to reduce the volume of the SCM that is treating the balance of the project.

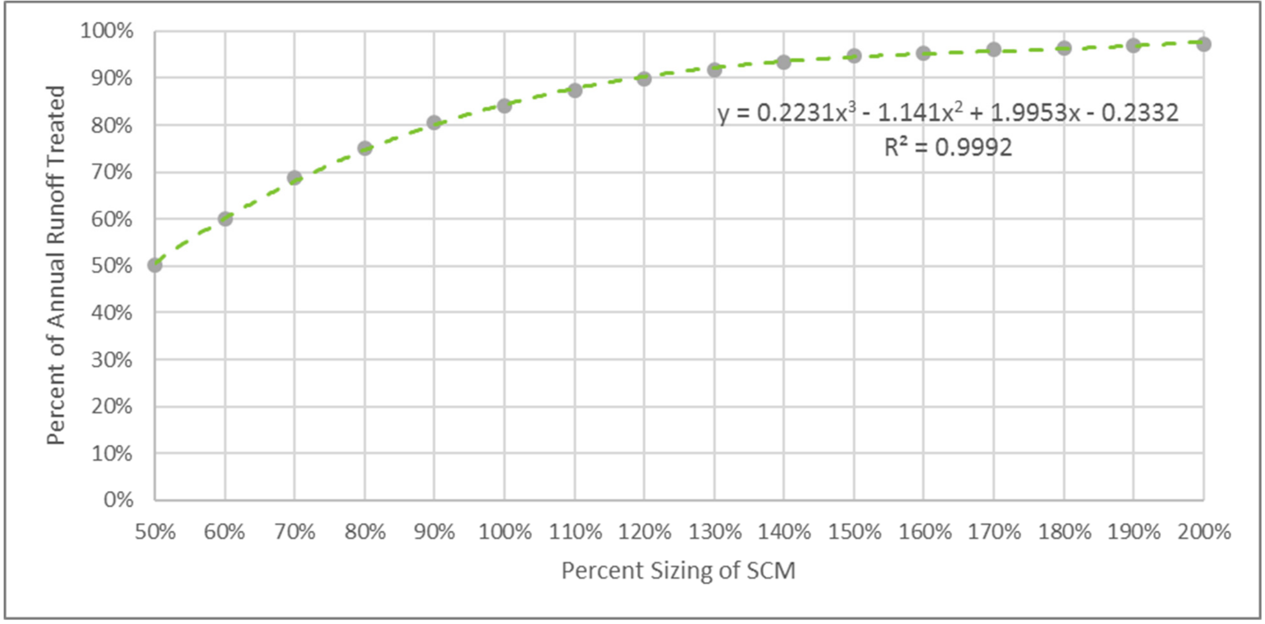
b. On existing projects: As a tool to add a driveway, parking area, road, patio or other paved area while still adhering to a BUA restriction imposed by development covenants, SCM design or permit conditions.

The BUA credit for infiltrating permeable pavement cannot be used to create an exemption from the permit requirements in 15A NCAC 02H .1019(2)(c) [Coastal Stormwater Requirements], because the permeable pavement must be reviewed to determine whether it meets the MDC.

Annual Runoff Treated Based on Percent Sizing

Based on modeling done by NCSU using 20 years of rainfall data, a device designed for the design storm (1 inch or 1.5 inches on the Coast) and a 60-hour drawdown time will treat 84 percent of the total annual runoff volume. Figure C- below shows how the percent of annual runoff treated changes depending upon the percent sizing of the permeable pavement system.

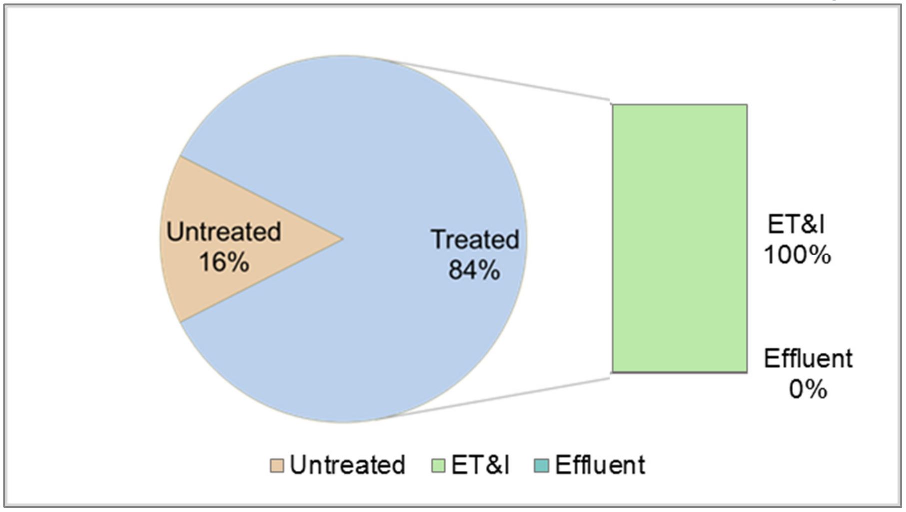
Figure C-7: Sizing versus Annual Runoff Treated for Permeable Pavement



Fates of Treated Runoff

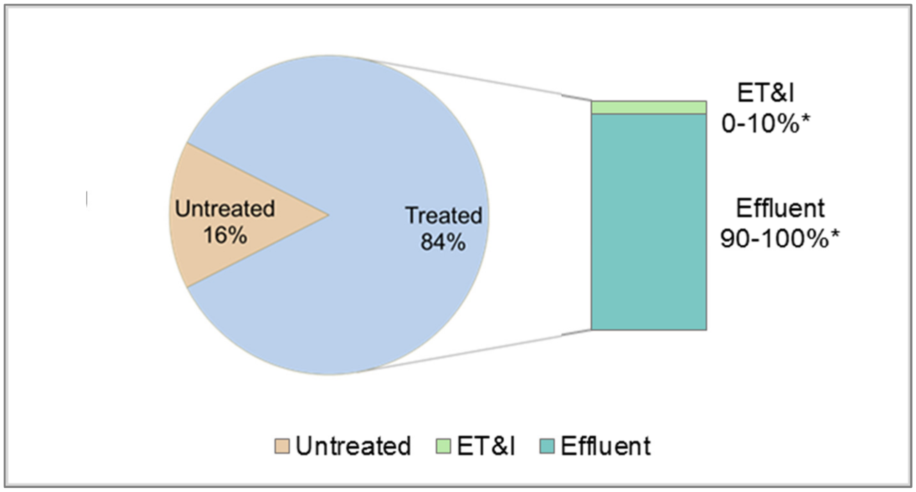
Because the MDC require that infiltration pavement systems infiltrate the entire design storm, 100% of treated runoff is allocated to ET&I. Figure C- below shows how the percent of annual runoff treated increases with the percent sizing of the permeable pavement system.

Figure C-8: Runoff Fates for a 100% Sized Permeable Pavement (Infiltration)



Permeable pavement systems that are designed for detention have all or nearly all of the treated runoff released as effluent. An unlined permeable pavement system installed in an A or B soil will infiltrate 10 or 5 percent of the design storm, respectively. This is illustrated in the figure below.

Figure C-9: Runoff Fates for a 100% Sized Permeable Pavement (Detention)



* Note: The partitioning between ET&I and Effluent depends on the soil type and whether a liner is used.

Design Variants

Design variants to permeable pavement designs should be analyzed using the PermPave HyPerMod. The design variants that are available and their effects on the treatment outcomes are summarized in the table below. **To account for the uncertainty associated with this modeling based approach, the user should select a factor of safety of 10 percent when applying the PermPave HyPerMod.**

Design Variant	Where it is allowed	Effect on Performance
Exclude the internal water storage (IWS) zone	Retrofit or new development	Reduces % annual runoff treated. Reduces % of ET&I. Increases TN & TP EMCs.
Vary the IWS depth	Retrofit or new development	**A deeper IWS depth**: Increases % annual runoff treated. Increases % of ET&I. No effect on TN & TP EMCs.
Vary the profile depth (the combined depth of the pavement and aggregate)	Retrofit or new development	**A deeper profile depth**: Increases % annual runoff treated. Increases % ET&I. Has no effect on TN & TP EMCs.
Vary the run-on ratio (the amount of additional runoff to the permeable pavement.	Retrofit or new development	**A larger run-on ratio**: Reduces % annual runoff treated. Reduces % ET&I. Has no effect on TN & TP EMCs.

EMCs

Eight NCSU permeable pavement studies were used to determine the EMCs. The sites were located in: Durham, Fayetteville, Goldsboro, and Kinston, NC, and Willoughby Hills, OH. The data from Willoughby Hills were included because monitoring did not occur during the winter season. Average pollutant effluent concentrations from each site were calculated, and the average of the mean concentrations was used to determine the EMCs.

Site	Location	Resource
Fayetteville	Fayetteville, NC	Smolek (2016)
Goldsboro	Goldsboro, NC	Bean et al. (2007)
Kinston GP	Kinston, NC	Collins et al. (2010); Collins (2007)
Kinston PC	Kinston, NC	Collins et al. (2010); Collins (2007)
Kinston PICP1	Kinston, NC	Collins et al. (2010); Collins (2007)
Kinston PICP2	Kinston, NC	Collins et al. (2010); Collins (2007)
Piney Wood	Durham, NC	Smolek (2016)
OhioLgOut	Willoughby Hills, OH	Winston et al. (2016)

C.6. Sand Filters

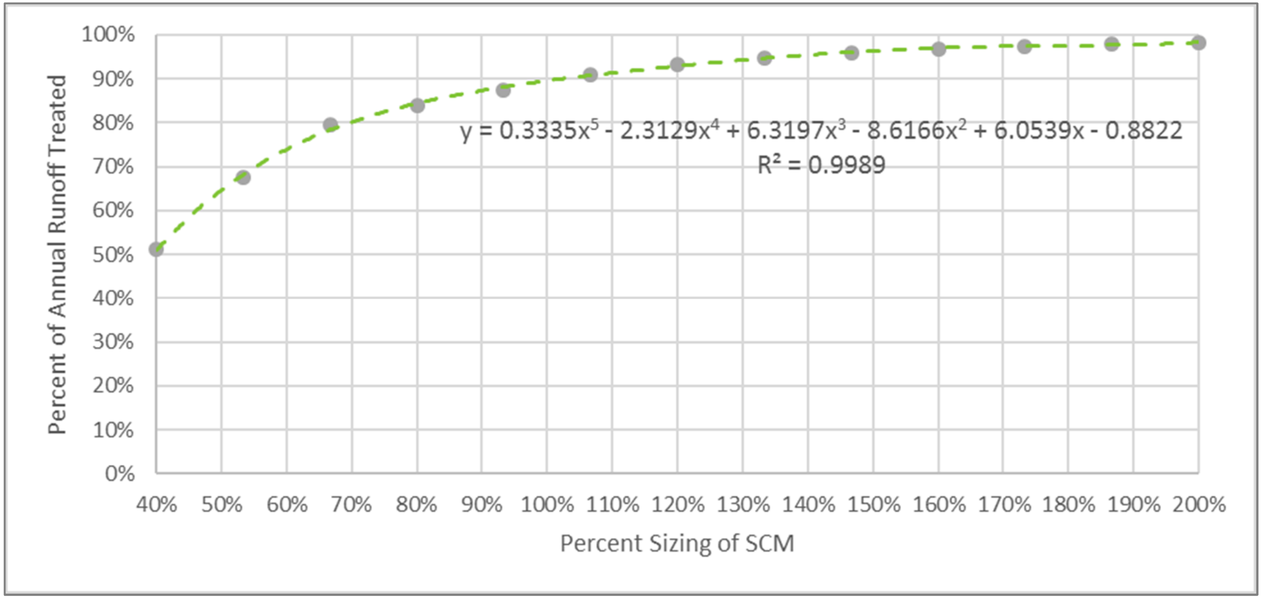
Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% of Treated Runoff to Each Fate			EMC$_{\text{effluent}}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Sand Filter (open) per MDC	Primary	91	A	10	90	1.33	0.12
			B	5	95		
			C	0	100		
			D	0	100		
Sand Filter (closed) per MDC	Primary	91	A	0	100	1.33	0.12
			B	0	100		
			C	0	100		
			D	0	100		

Annual Runoff Treated Based on Percent Sizing

Based on modeling done by NCSU using 20 years of rainfall data, a device designed for the design storm (1 inch or 1.5 inches on the Coast) and a 12-hour drawdown time will treat 91 percent of the total annual runoff volume. Per the MDC, sand filters are only required to be sized for the 0.75 times the design storm because they have such rapid draw down times that allow stormwater to be treated throughout the duration of the storm, which increases their capacity. Figure C- below shows how the percent of annual runoff treated increases with the percent sizing of the sand filter.

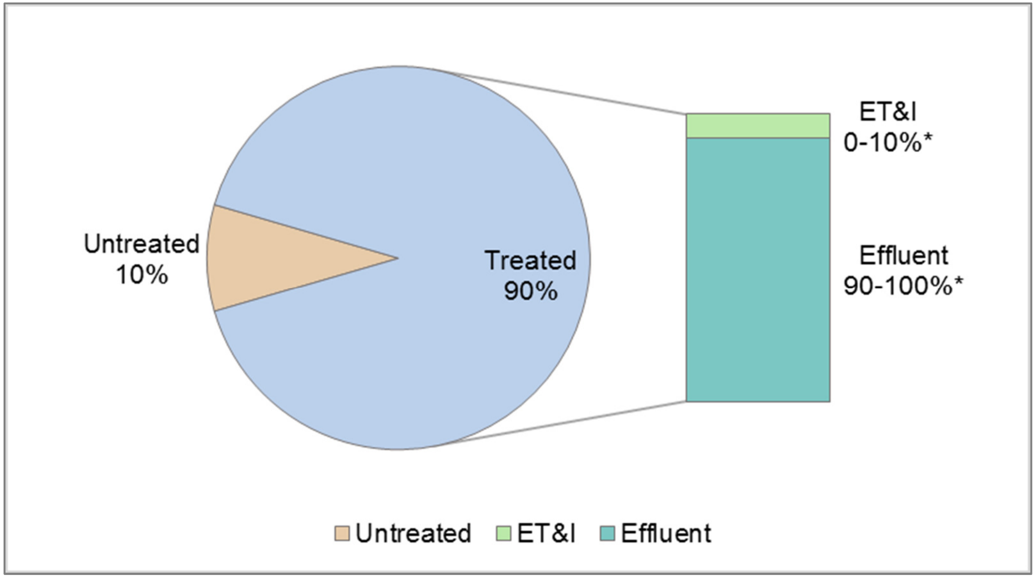
Figure C-10: Size versus Annual Runoff Treated for a Sand Filter



Fates of Treated Runoff

The partitioning of treated runoff between ET&I and Effluent is based on recent research conducted by NCSU-BAE at two North Carolina sites. Figure C-3 below shows runoff fates for a 100% sized wet pond.

Figure C-3: Runoff Fates for a 100% Sized Sand Filter



* NOTE: The percentages of ET&I and Effluent vary based on whether the sand filter is closed or open and the soil type for open sand filters.

Design Variants

There are no approved design variants for sand filters. However, rule language allows the applicant to propose design variants for any SCM and provide technical justification based on engineering calculations and the results of research studies showing that the proposed design is equally or more protective of water quality than the current MDC for the SCM and that it shall function in perpetuity.

EMCs

Due to a lack of published data, six studies from the International Stormwater BMP Database were used to determine the EMCs for sand filters. These studies were conducted in Orlando and Tallahassee, FL, North Potomac, MD, Durham, NH, and Alexandria, VA**.** Median pollutant effluent concentrations from each site were calculated, and the average of the median concentrations was used to determine the EMCs.

Site	Location	Resource
Hal Marshall	Charlotte, NC	Wright Water Engineers, Inc. et al. (2016)
Clear Lake	Orlando, FL	Wright Water Engineers, Inc. et al. (2016)
Appleyard	Tallahassee, FL	Wright Water Engineers, Inc. et al. (2016)
Megginnis	Tallahassee, FL	Wright Water Engineers, Inc. et al. (2016)
Willow Oaks 1	North Potomac, MD	Wright Water Engineers, Inc. et al. (2016)
Univ. of NH	Durham, NH	Wright Water Engineers, Inc. et al. (2016)
Airpark	Alexandria, VA	Wright Water Engineers, Inc. et al. (2016)

C.7. Rainwater Harvesting

Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% of Treated Runoff to Each Fate			EMC$_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Rainwater Harvesting per MDC	Primary	85	A B C D	Custom based on water usage		Custom based on water usage	

Annual Runoff Treated Based on Percent Sizing

A rainwater harvesting system is considered to be a primary SCM when it is designed such that water demand, passive discharge or a combination of the two is provided for 85% of the total annual runoff volume as demonstrated through water balance calculations. Rainwater harvesting may also be designed as a secondary SCM if it does not meet this goal but instead is used to slowly release a smaller fraction of the annual runoff volume to a primary SCM.

Designers will use the NCSU Rainwater Harvester model to determine the annual runoff treated based on the system’s size, rainfall data for the location where it will be installed, its drainage area, and withdrawals from the cistern for use and/or drawdown.

Fates of Treated Runoff and EMCs

The fates of treated runoff depend upon how the cistern water is used or discharged. For example, if cistern water is used as graywater, then the entire volume of treated runoff will be considered as ET&I (removed from the system). On the other hand, if the water is discharged to a land use or another SCM, then the treated effluent from the rainwater harvesting system will take on the fates and EMCs of the location or device to which its effluent is discharged.

Design Variants

There are no approved design variants for rainwater harvesting systems. However, rule language allows the applicant to propose design variants for any SCM and provide technical justification based on engineering calculations and the results of research studies showing that the proposed design is equally or more protective of water quality than the current MDC for the SCM and that it shall function in perpetuity.

EMCs

Five NCSU monitored rainwater harvesting tanks were used to determine the EMCs. All five sites were located in Raleigh, NC. Median pollutant effluent concentrations from each site were calculated, and the average of the median concentrations was used to determine the EMCs. The water usage will determine which EMCs are used.

Site	Location	Resource
Fire Station 24	Raleigh, NC	Debusk (2013); Debusk and Hunt (2014)
Fire Station 28	Raleigh, NC	Debusk (2013); Debusk and Hunt (2014)
Fire Station 6	Raleigh, NC	Debusk (2013); Debusk and Hunt (2014)
Fire Station 8	Raleigh, NC	Debusk (2013); Debusk and Hunt (2014)
Whole Foods	Raleigh, NC	Wilson (2013); Wilson et al. (2014)

C.8. Green Roof

Credit Table

SCM	Role	% Annual Runoff Treated when sized for Design Storm	% of Treated Runoff to Each Fate			EMC$_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Green Roof per MDC	Secondary	100	N/A	60	40	2.44	0.76

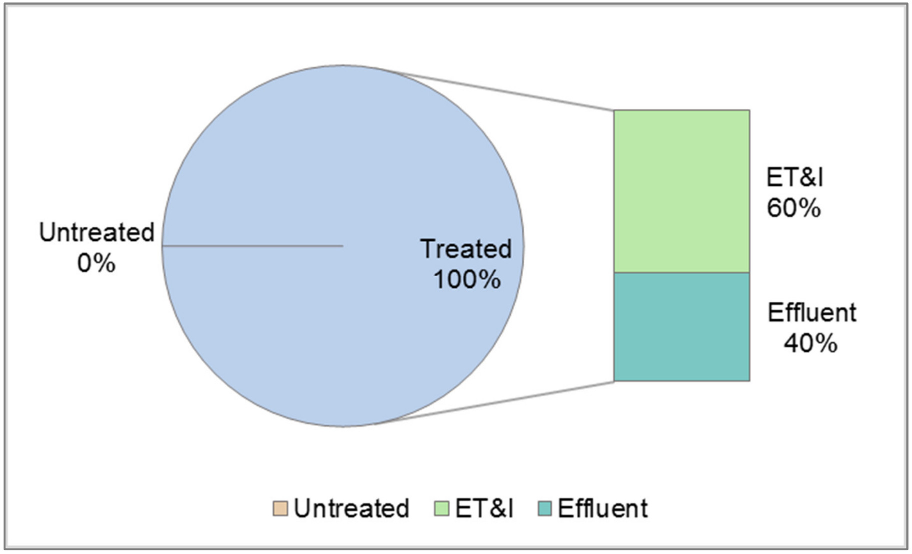
Annual Runoff Treated Based on Percent Sizing

Since a green roof receives all of the rain that falls upon it, it is considered to treat 100 percent of the annual runoff. Currently, there is not an approved method for under or oversizing a green roof.

Fates of Treated Runoff

Based on research conducted in North Carolina and in New Zealand (where the climate is very similar to North Carolina), a green roof designed in accordance with the MDC will bring about 60 percent ET&I and 40 percent effluent. Figure C-4 below shows runoff fates for a 100% sized green roof.

Figure C-4: Runoff Fates for a Green Roof



Design Variants

There are no approved design variants for green roofs. However, rule language allows the applicant to propose design variants for any SCM and provide technical justification based on engineering calculations and the results of research studies showing that the proposed design is equally or more protective of water quality than the current MDC for the SCM and that it shall function in perpetuity.

EMCs

Data from two NCSU monitored green roofs, one published study, and three studies from the International Stormwater BMP Database were used to determine the EMCs for green roofs. These studies were conducted in Goldsboro, NC, Storrs, CT, and Auckland, NZ**.** Data from the Auckland sites were included because of the similar annual rainfall patterns between North Carolina and New Zealand (NIWA, 2016; State Climate Office of North Carolina, 2016). Median pollutant effluent concentrations from each site were calculated, and the average of the median concentrations was used to determine the EMCs.

Site	Location	Resource
NCGR	Goldsboro, NC	Moran (2004); Hathaway et al. (2008)
WCCGR	Goldsboro, NC	Moran (2004); Hathaway et al. (2008)
Storrs GR	Storrs, CT	Gregoire and Clausen (2011)
Tamaki 100 mm	Auckland, NZ	Wright Water Engineers, Inc. (2016); Fassman et al. (2013)
Tamaki 150 mm	Auckland, NZ	Wright Water Engineers, Inc. (2016); Fassman et al. (2013)
WCC	Auckland, NZ	Wright Water Engineers, Inc. (2016); Fassman et al. (2013)

C.9. Disconnected Impervious Surface

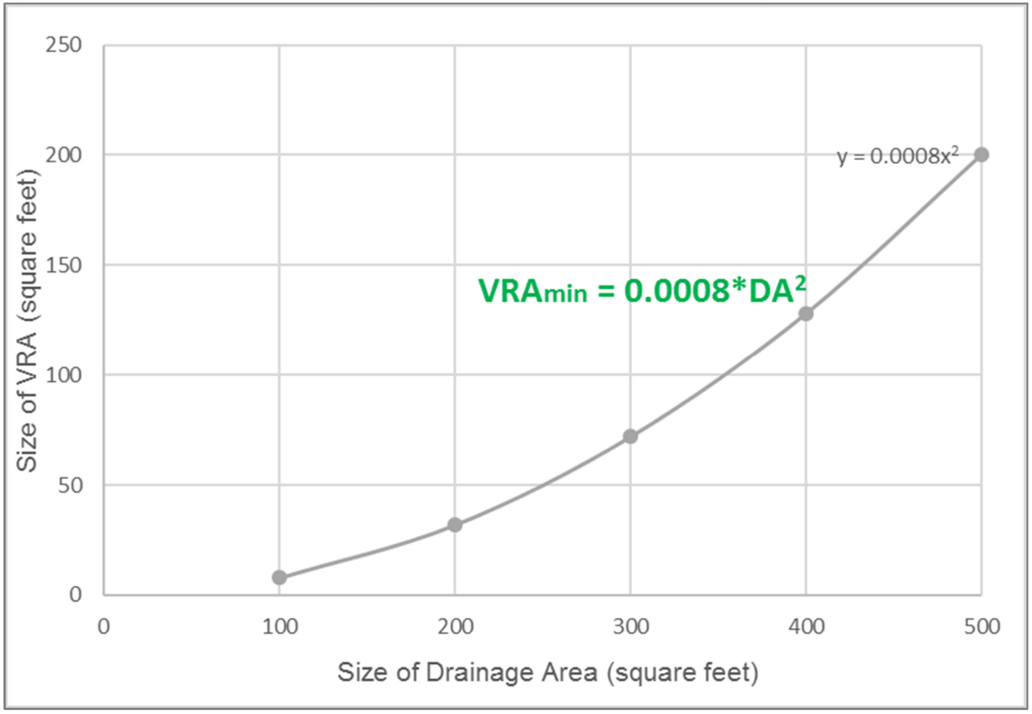
Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% of Treated Runoff to Each Fate			$EMC_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
DIS per MDC	Secondary	90	A	65	35	2.44	0.76
			B	50	50		
			C	40	60		
			D	30	70		

Annual Runoff Treated Based on Percent Sizing

Based on modeling done by NCSU using 20 years of rainfall data, a DIS designed for the 0.75 inch per hour storm intensity will treat 90 percent of the total annual runoff volume. A DIS may not be sized for less than the 0.75 inch per hour storm intensity due to the risk of erosion, which can cause the practice to become a source rather than a sink for TSS. The figure below shows the minimum sizing required for a DIS with respect to the area of rooftop from which is receives runoff. The maximum area that may drain to a single vegetated receiving area is 500 square feet of roof.

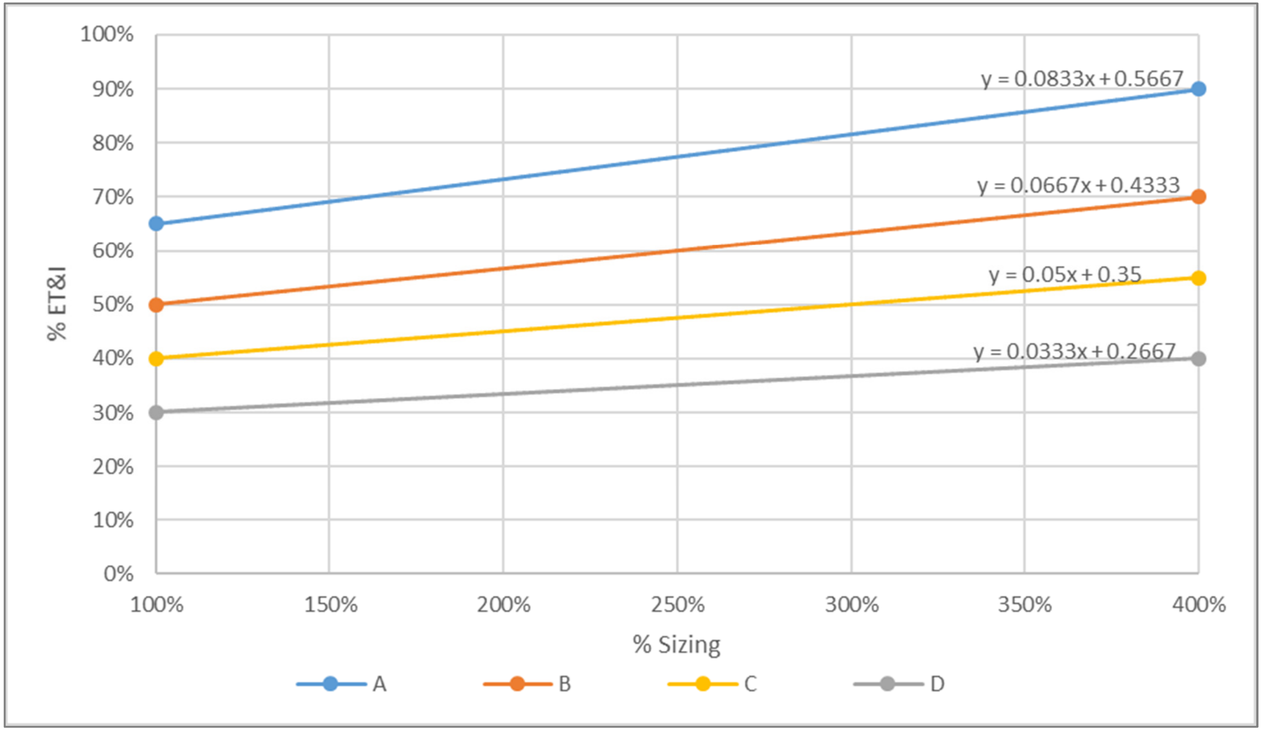
Figure C-5: Minimum Sizing for the Vegetated Receiving Area (VRA) of a DIS



Fates of Treated Runoff

Oversizing an DIS that is designed to treat the entire 0.75 inch per hour storm from the drainage area will result in an increased fraction of the Treated Runoff being allocated to ET&I. The figure below shows runoff fates for 100 percent sized and oversized DIS systems. The percentage oversized would be determined based on the ratio between the area of the VRA required and the area of the VRA provided.

Figure C-6: Percent ET&I for DIS Based on VRA Size



Design Variants

There are no approved design variants for DIS. However, rule language allows the applicant to propose design variants for any SCM and provide technical justification based on engineering calculations and the results of research studies showing that the proposed design is equally or more protective of water quality than the current MDC for the SCM and that it shall function in perpetuity.

EMCs

Data from four NCSU monitored DIS sites in Wilmington, NC were used to determine the EMCs. Median pollutant effluent concentrations from each site were calculated, and the average of the median concentrations was used to determine the EMCs.

Site	Location	Resource
6810E	Wilmington, NC	Taguchi et al. (2016)
6810W	Wilmington, NC	Taguchi et al. (2016)
6926E	Wilmington, NC	Taguchi et al. (2016)
6926W	Wilmington, NC	Taguchi et al. (2016)

C.10. Level Spreader – Filter Strips

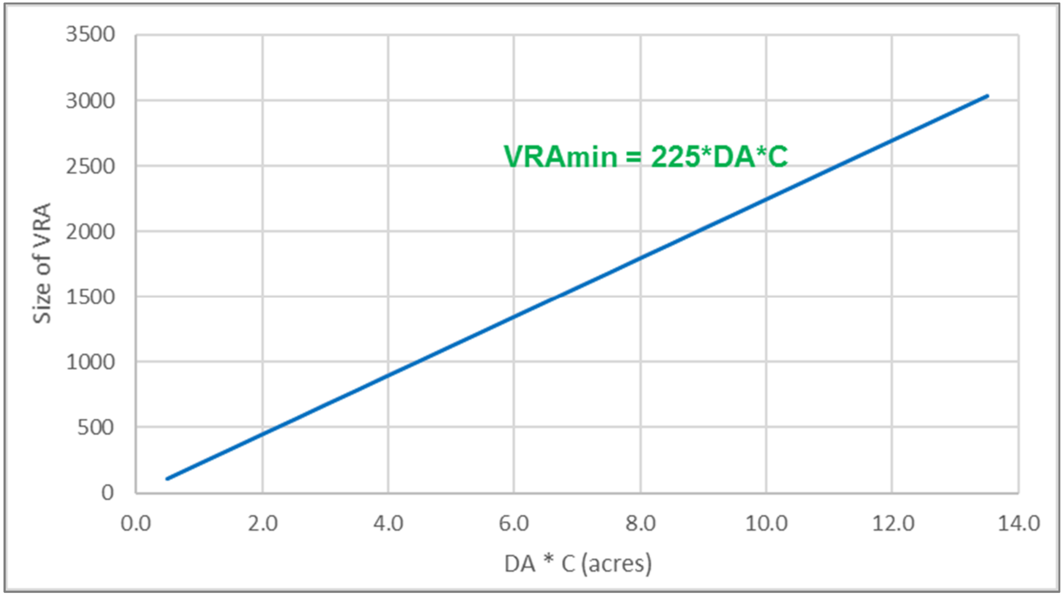
Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% of Treated Runoff to Each Fate			EMC$_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
LS-FS per MDC	Secondary	90	A	60	40	1.04	0.19
			B	40	60		
			C	25	75		
			D	15	85		
LS-FS with Virophos sand added to the filter strip	Secondary	90	A	60	40	0.87	0.10
			B	40	60		
			C	25	75		
			D	15	85		

Annual Runoff Treated Based on Percent Sizing

Based on modeling done by NCSU using 20 years of rainfall data, a device designed for the 0.75 inch per hour storm intensity will treat 90 percent of the total annual runoff volume. An LS-FS may not be sized for less than the 0.75 inch per hour storm intensity due to the risk of erosion, which can cause the practice to become a source rather than a sink for TSS. **Figure C-7** below shows runoff fates for a 100% sized LS-FS.

Figure C-7: Minimum Sizing for the Vegetated Receiving Area (VRA) of an LS-FS



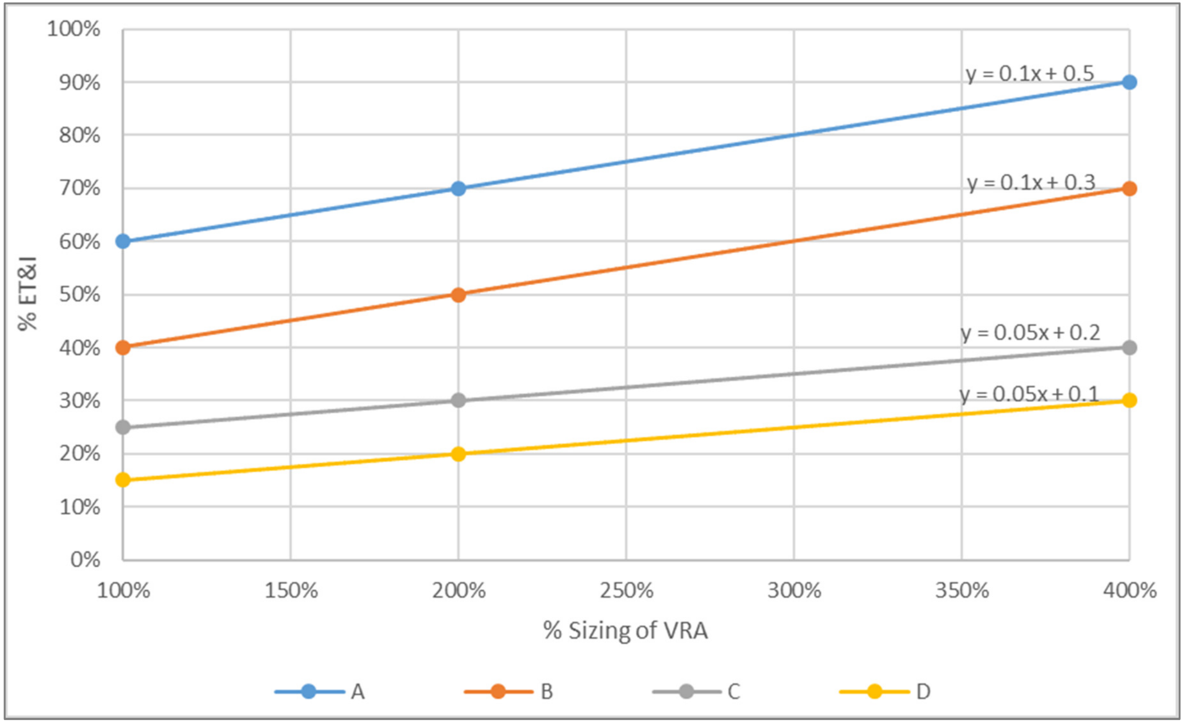
In most cases, an LS-FS will be equipped with a flow splitting device (this is usually required per the MDC). If the LS-FS is installed as a retrofit, then the designer can design the flow splitting device to direct only a portion of the flow during the 0.75 inch per hour storm to the LS-FS. To design a LS-FS to capture only a portion of the flow from a large drainage area, a designer would work backward from the area that is available for the LS-FS installation. Using that information, the designer would calculate the flow rate that corresponds to the available VRA and design the flow splitting device to bypass larger storm events. The designer would determine the size of the drainage area that would be credited for nutrient removal by working backward from the equation:

$$DA_{credited} = \frac{VRA_{available}}{(225*C)}$$

Fates of Treated Runoff

Oversizing an LS-FS is designed to treat the entire 0.75 inch per hour storm from the drainage area will result in an increased fraction of the Treated Runoff being allocated to ET&I. Figure C-8 below shows runoff fates for 100 percent sized and oversized LS-FSs.

Figure C-8: Percent ET&I for LS-FS Based on VRA Size



Design Variants

Three design variants are currently available for LS-FS as summarized in the table below.

Design Variant	Where it is Allowed	Effect on Results
Reducing the width of the filter strip (but it may not be reduced below 15 feet)	Retrofit only	Does not affect the credit in any way; but does provide flexibility in the geometry of the LS-FS that may be needed for retrofits.
Amending the filter strip with Virophos.	Retrofit or new development	Reduces the EMCs for TN and TP.

On retrofit projects, designers may have the option of reducing the 30-foot width of the VRA (required by LS-FS MDC 8) to 15 feet. However, the designer will need to extend the length of the level spreader such that the following equation still holds:

$$VRA_{min} = 225 * DA * C$$

A second design variant to LS-FS that is allowed on either retrofits or new development is amending the soil in the VRA with ViroPhos sand. This design variant does not alter the percentages of annual runoff treated or the percent ET&I. However, it does significantly reduce the TN and TP EMCs.

EMCs

Data from six NCSU monitored level spreader-filter strips in Apex, Louisburg, and Wilson, NC were used to determine the EMCs. Median pollutant effluent concentrations from each site were calculated, and the average of the median concentrations was used to determine the EMCs.

Site	Location	Resource
Apex 25	Apex, NC	Winston et al. (2011)
Apex 50	Apex, NC	Winston et al. (2011)
Louisburg 25	Louisburg, NC	Winston et al. (2011)
Louisburg 50	Louisburg, NC	Winston et al. (2011)
Wilson Small Unamended	Wilson, NC	Knight et al. (2013)
Wilson Small Amended	Wilson, NC	Knight et al. (2013)
Wilson Large Unamended	Wilson, NC	Knight et al. (2013)
Wilson Large Amended	Wilson, NC	Knight et al. (2013)

C.11. Pollutant Removal Swale

Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% of Treated Runoff to Each Fate			EMC$_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Pollutant removal swale with dry conditions	Secondary	90	A	25	75	1.10	0.14
			B	15	85		
			C	5	95		
			D	0	100		
Pollutant removal swale with wet conditions	Secondary	90	A	40	60	0.82	0.11
			B	30	70		
			C	20	80		
			D	10	90		

Annual Runoff Treated Based on Percent Sizing

Based on modeling done by NCSU using 20 years of rainfall data, a pollutant removal swale designed for the 0.75 inch per hour storm intensity will treat 90 percent of the total annual runoff volume. The partitioning of treated runoff between ET&I and Effluent is based on recent research conducted by NCSU-BAE at two North Carolina sites. A pollutant removal swale may not be sized for less than the 0.75 inch per hour storm intensity due to the risk of erosion, which can cause the practice to become a source rather than a sink for TSS. North Carolina has not yet developed oversizing standards for pollutant removal swales because they are not frequently selected SCMs.

Design Variants

There are no approved design variants for pollutant removal swales. However, rule language allows the applicant to propose design variants for any SCM and provide technical justification based on engineering calculations and the results of research studies showing that the proposed design is equally or more protective of water quality than the current MDC for the SCM and that it shall function in perpetuity.

EMCs

Data from eight pollutant removal swales located in: Duplin County, Johnston County, Knightdale, Sampson County, and Wilson, NC were used to develop the EMCs for swales with dry and wet conditions. Median pollutant effluent concentrations from each site were calculated, and the average of the median concentrations was used to determine the EMCs for swales with dry conditions. Note data from the Mango Creek Retrofitted site was include in the calculations for swales with dry conditions because there were no significant differences between the EMCs pre and post-retrofit. Due to the lack of data, a ratio (wet conditions to dry conditions) of median site effluents for swales located in Johnston, Duplin, and Sampson counties was applied to the EMCs established for pollutant removal swales with dry conditions to determine the EMCs for swales with wet conditions.

Site	Location	Resource
I40 A	Johnston County, NC	Winston et al. (2012)
I40 B	Johnston County, NC	Winston et al. (2012)
I40 C	Sampson County, NC	Winston et al. (2012)
I40 D	Duplin County, NC	Winston et al. (2012)
Mango Creek	Knightdale, NC	Luell (2001)
Mango Creek Swale	Knightdale, NC	Powell (2015)
Mango Creek Retrofitted	Knightdale, NC	Powell (2015)
Wilson	Wilson, NC	Powell (2015)

C.12. Dry Pond

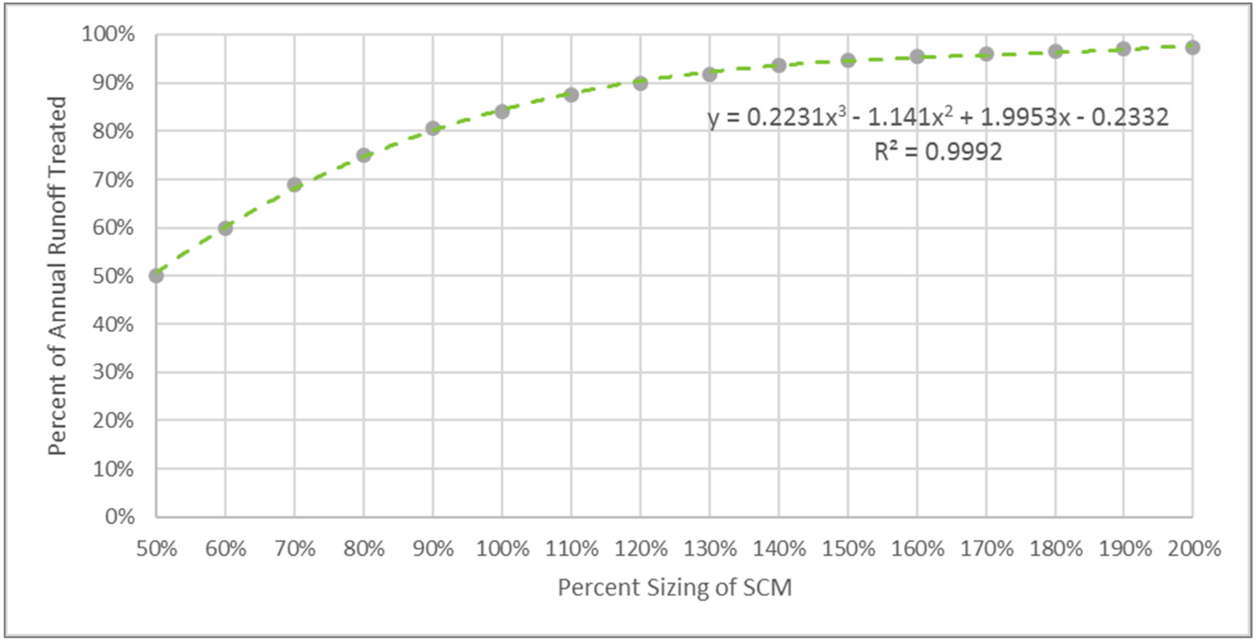
Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% of Treated Runoff to Each Fate			EMC$_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Dry Pond per MDC	Secondary	84	A	10	90	1.65	0.66
			B	5	95		
			C	0	100		
			D	0	100		

Annual Runoff Treated Based on Percent Sizing

Based on modeling done by NCSU using 20 years of rainfall data, a device designed for the design storm (1 inch or 1.5 inches on the Coast) and a 60-hour drawdown time will treat 84 percent of the total annual runoff volume. Figure C-9 below shows how the percent of annual runoff treated increases with the percent sizing of the dry pond.

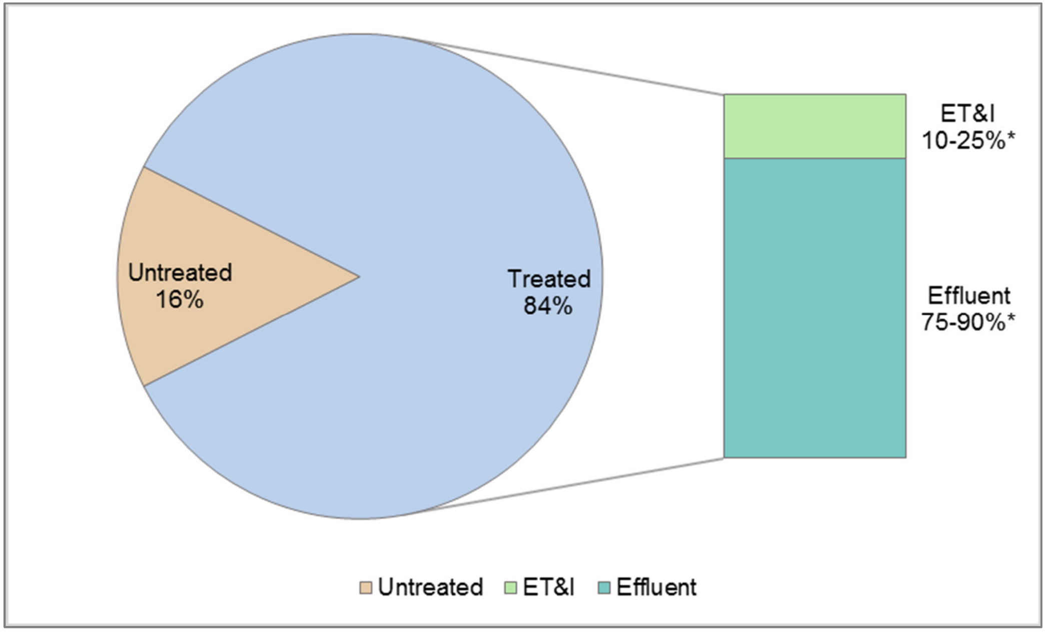
Figure C-9: Size versus Annual Runoff Treated for a Dry Pond



Fates of Treated Runoff

The ratio of ET&I to Effluent in the Treated Runoff is estimated to remain constant regardless of whether the pond is under or oversized. The allocation of treated runoff between ET&I and Effluent varies based on HSG. Figure C-10 below shows runoff fates for a 100% sized dry pond.

Figure C-10: Runoff Fates for a 100% Sized Dry Pond



* NOTE: The percentages of ET&I and Effluent vary based on HSG.

Design Variants

There are no approved design variants for dry ponds. However, rule language allows the applicant to propose design variants for any SCM and provide technical justification based on engineering calculations and the results of research studies showing that the proposed design is equally or more protective of water quality than the current MDC for the SCM and that it shall function in perpetuity.

EMCs

Data from two NCSU monitored dry ponds and three studies from the International Stormwater BMP Database were used to determine the EMCs for dry ponds. These studies were conducted in Charlottesville, VA and Charlotte and Durham, NC. Median pollutant effluent concentrations from each site were calculated, and the average of the median concentrations was used to determine the EMCs.

Site	Location	Resource
Morehead	Charlotte, NC	Hathaway et al. (2007)
University	Charlotte, NC	Hathaway et al. (2007)
Greenville	Greenville, NC	Wright Water Engineers, Inc. (2016)
Hillsdale	***Charlottesville, VA***	***Wright Water Engineers, Inc. (2016)***

Part D: Credit for each New Stormwater Technology

D.1. StormFilter

Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% of Treated Runoff to Each Fate			EMC$_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
StormFilter per MDC with PhosphoSorb media^{TM}	Primary	91	A	0	100	0.48	0.03
			B	0	100		
			C	0	100		
			D	0	100		

Annual Runoff Treated Based on Percent Sizing

Based on modeling done by NCSU using 20 years of rainfall data, a device designed for the design storm (1 inch or 1.5 inches on the Coast) and a 12-hour drawdown time will treat 91 percent of the total annual runoff volume. Per the MDC, the required water quality volume retained upstream of the StormFilter shall be 0.75 times the design storm because it has such a rapid draw down time that allows stormwater to be treated throughout the duration of the storm. Per the requirements of the New Stormwater Technology (NEST) Program, the approval is for the configuration in which the device is tested. All StormFilter testing sited were equipped with 100 percent sized devices; therefore, the approval of this StormFilter requires 100-percent sizing be provided.

Design Variants

There are no approved design variants for StormFilters. Any design variants would be required to be approved through the NEST program.

EMCs

Data from two monitored sites in North Carolina and one monitored site in Oregon were used to determine the EMCs for StormFilters. These studies were conducted in Mooresville, NC, Dare Co., NC and Clackamas County, OR. Median pollutant effluent concentrations from each site were calculated, and the average of the median concentrations was used to determine the EMCs.

Site	Location	Resource
Mitchell Community College	Mooresville, NC	Contech Engineered Solutions et al (2012)
Currituck Gas House	Dare Co., NC	Contech Engineered Solutions et al (2007)
Lolo Pass Road	Zigzag, OR	Contech Engineered Solutions et al (2014)

D.2. Silva Cell Suspended Pavement with Bioretention

Credit Table

SCM	Role	% Annual Runoff Treated if 100% Sized	% Treated Runoff to Fates			EMC$_{effluent}$ (mg/L)	
			HSG	ET&I	Effluent	TN	TP
Silva Cell per MDC	Primary	94	A	90	10	0.58	0.12
			B	71	29		
			C	36	64		
			D	14	86		
Silva Cell per MDC but without IWS	Primary	94	A	51	49	1.20	0.12
			B	20	80		
			C	11	89		
			D	9	91		

Annual Runoff Treated Based on Percent Sizing

The portioning of annual runoff between treated and untreated in the table was estimated using NCSU's Bioretention HyPerTool, which provides options for selecting 50%, 75%, 100%, 150% and 200% sizing. To determine the annual runoff treated for bioretention cells that do not fall into these exact percentages, the user should interpolate between the two relevant sizes. HyPerTool is a Microsoft Excel spreadsheet model that references a database of hundreds of DRAINMOD simulations to allow for custom analysis and design of bioretention cells. More information on the Bioretention HyPerTool may be found in Part F: Overview of NCSU Models.

Under or oversizing a bioretention cell affects the percentage of annual runoff treated. However, it is not considered to change the TN or TP EMCs of the effluent.

> To account for the uncertainty associated with this modeling based approach, the user should select a factor of safety of 10 percent when applying the Bioretention HyPerTool.

Fates of Treated Runoff

NCSU's HyPerTool also partitions the Treated Runoff into ET&I versus Effluent. The percentage of total annual runoff treated and the partitioning of treated runoff between ET&I and Effluent should be done through the use of NCSU's HyPerTool as well. The HyPerTool was originally developed for traditional bioretention, but has been used to successfully model Silva Cell systems with bioretention as well.

EMCs

Data from 10 NCSU monitored bioretention cells in: Charlotte, Graham, Knightdale, Louisburg, Nashville, and Rocky Mount, NC were used to determine the EMCs. This dataset was supplemented with two NCSU field monitored Silva Cell sites in Wilmington, NC. EMCs for the

Silva Cell sites were lower than the mean reported for the other NC bioretention sites. However, because the Silva Cell system uses bioretention, EMCs for the Silva Cell system follow the EMCs used for typical bioretention. See Bioretention C-2 for additional explanation of EMC determinations.

Site	Location	Resource
Hal Marshall	Charlotte, NC	Hunt et al. (2008)
Graham North	Graham, NC	Passeport et al. (2009)
Graham South	Graham, NC	Passeport et al. (2009)
Louisburg 1	Louisburg, NC	Sharkey (2005)
Louisburg 2	Louisburg, NC	Sharkey (2005)
Mango Creek Large	Knightdale, NC	Luell et al. (2011)
Mango Creek Small	Knightdale, NC	Luell et al. (2011)
Nashville Deep	Nashville, NC	Brown and Hunt (2011a)
Nashville Shallow	Nashville, NC	Brown and Hunt (2011a)
Rocky Mount	Rocky Mount, NC	Brown and Hunt (2011b)
Orange Street	Wilmington, NC	Page et al., 2015
Ann Street	Wilmington, NC	Page et al., 2015

Part E: Overview of NCSU Modeling and Accounting Tools

Bioretention Hydrologic Performance Tool (HyPerTool)

The Bioretention HyPerTool was developed by North Carolina State University and is available for download at https://stormwater.bae.ncsu.edu/resources/. The model simulates the hydrologic performance of bioretention cells with various design configurations by using historical rainfall data, drainage area, underlying hydrologic soil group, media depth depth, and depth of the internal water storage zone. Outputs from the model include the runoff volume fates (infiltration/evaporation, effluent, and surface runoff or overflow) and annual pollutant loads removed by the SCM. Data from field studies in Boone and Durham, NC as well as Perkins Township and Willoughby Hills, OH were used to develop the model.

The Bioretention HyPerTool was developed using DRAINMOD, which is a long-term, continuous simulation agricultural drainage model that is readily adaptable to simulate water movement through bioretention practices. Many of the DRAINMOD inputs correspond directly to bioretention cell design specifications and its output can be applied to assess the hydrologic performance of bioretention cells (Brown et al 2011). DRAINMOD's application for bioretention cells is fully described in Brown et al 2011a and Winston 2016.

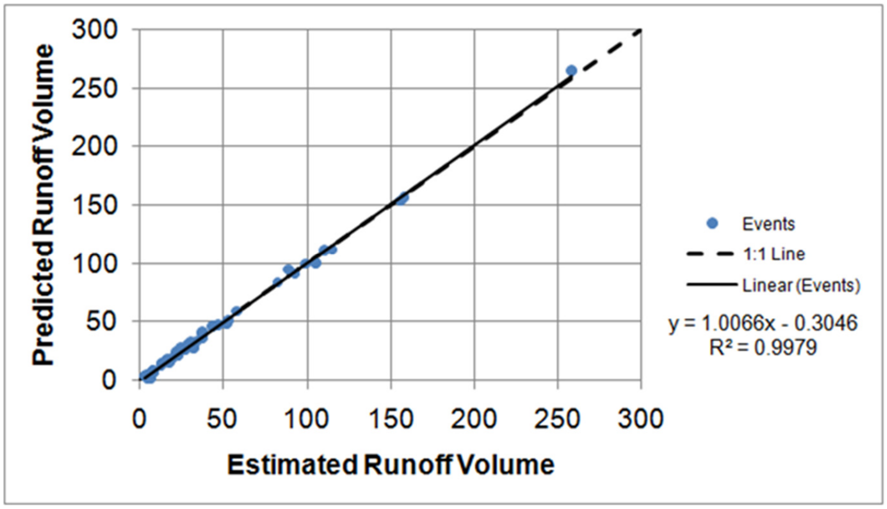
The DRAINMOD application for bioretention was based on field-based monitoring of bioretention facilities in Rocky Mount and Nashville, North Carolina. Long-term simulations using DRAINMOD were conducted to calibrate model input parameters with a specific focus on bioretention design specifications currently presented in the NCDENR Stormwater BMP Manual (NCDENR 2009). Each of the 432 DRAINMOD simulations are based on sixty years of historical, hourly rainfall and daily temperature records from the Raleigh-Durham International and Wilmington airports. The factors that varied between the simulations were surface storage depth, surface storage volume relative to the design event, underlying soil type, media depth, and drainage configuration. The effects of over-sizing and under-sizing the bioretention surface storage volume was also evaluated based on five additional variations of surface storage volume relative to the design capacity.

NCSU collected detailed hydrologic data from two bioretention field sites over a 24-month monitoring and calibration period. The eight bioretention cells were located in Nashville, NC representing a Piedmont/Coastal site and Rocky Mount, NC (Upper Coastal Plain). The Nashville site was conventionally drained, while the Rocky Mount bioretention cells had IWS. Variable media depths, media types, drainage configurations, underlying soils, and surface storage volumes were also manipulated (see Brown 2011a et al, Brown et al. 2011b, Brown et al. 2011c, and Brown et al 2013 for details) but differed between the two sites. The results of the field studies were used to calibrate and validate DRAINMOD. For both the calibration and validation time periods, the modeled stormwater volume of exfiltration and evapotranspiration was within 1 and 5 percent of the predicted volume for the underlying soil type sand and sandy clay loam cells, respectively.

Existing bioretention specifications at Rocky Mount and Nashville were altered to analyze the overall impact of different design specifications on the model and the implications for design recommendations. Long-term simulations were also conducted based on 60 years of historical hourly rainfall and daily temperature records as described above. These studies provide data that extend the applicability of this practice across the NC Piedmont and Upper Coastal Plain. The application of the drainage results can also reasonably be extended to Coastal Plain systems which may lie above predominately sandy soils as the underlying soil types studied in the Upper Coastal Plain cells in the Rocky Mount study were sandy clay loam and sand. Three underdrain configurations associated with these cells were assessed, adding more robust calibration data to the DRAINMOD simulations. The two cells studied in Nashville, NC contained soil cores classified as sandy-loam, loamy-sand, sandy-clay-loam, and clay-loam. The presence of clay in these underlying soils suggested extrapolation of DRAINMOD and HyPer Tool to the Piedmont and Mountain regions could be possible, where more clay is typically found than in the Coastal Plain.

The results of the field data were used to calibrate and validate DRAINMOD. Overall, the maximum error between the predicted and calculated runoff volume (using the SCS CN method) from each set of cells during the validation period was less than 10 percent of the total water budget. For this reason, the HyPer Tool incorporates an option for the user to apply a Factor of Safety of 10 percent. Model statistics demonstrate the strong agreement between simulated and observed water depth, (i.e., the predictive capabilities of the model (see Figures 1 and 2, taken from Brown et al 2011)). Consistent with the data, nutrient credits that are calculated using the procedures established in this document require that the factor of safety of 10 percent be assumed when running the HyPer Tool. **Figure E-1** show the predicted versus observed runoff volume at the Nashville bioretention cell.

Figure E-1:
Predicted Versus Observed Runoff Volume at the Nashville Bioretention Cell



Brown, R. a., Skaggs, R.W., Hunt, W.F., 2013. *Calibration and validation of DRAINMOD to model bioretention hydrology*. J. Hydrol. 486, 430–442. Peer-review publication of Brown et al 2011. Description of DRAINMOD application for bioretention practices.

Rainwater Harvester Model

The Rainwater Harvester model was developed by North Carolina State University and is available for download at https://stormwater.bae.ncsu.edu/resources/. The model simulates the hydrologic performance rainwater harvesting tanks or cisterns by using historical daily or hourly rainfall data, roof characteristics (drainage area, slope, and surface), cistern and overflow volumes, and detailed water usage information (Jones and Hunt, 2010; Debusk, 2013). Outputs from the model include: total runoff volume captured, average drawdown time, annual water usage, overflow frequency, annual pollutant loads removed by the system, and cost savings. Data from field studies in Craven County, Kinston, and Raleigh, NC were used to develop the model.

Location	Cistern Size (gal)	Contributing area (sf)	Normal annual rainfall	Water use
Craven County, NC	2,998	1,798	54	Irrigation
Raleigh, NC	1,400	2,196	46	Toilet flushing
Kinston, NC	5,199	4,370	50	Vehicle washing

DeBusk, K. M. (2013). Rainwater harvesting: Integrating water conservation and stormwater management. (Unpublished Doctoral). North Carolina State University, Raleigh, NC.

Jones, M. P., & Hunt, W. F. (2010). Performance of rainwater harvesting systems in the southeastern United States. Resources, Conservation and Recycling, 54(10), 623-629. doi: http://dx.doi.org/10.1016/j.resconrec.2009.11.002

Permeable Pavement Hydrologic Performance Model (PermPave HyPerMod)

The PermPave HyPerMod tool was developed by North Carolina State University and is available for download at https://stormwater.bae.ncsu.edu/resources/. The model simulates the hydrologic performance of permeable pavement with various design configurations by using historical rainfall data, underlying hydrologic soil group, permeable pavement profile depth (pavement and aggregate), depth of the internal water storage zone, and run-on ratio (Smolek, 2016). Outputs from the model include the runoff volume fates (infiltration/evaporation, effluent, and surface runoff or overflow) and annual pollutant loads removed by the SCM. Data from field studies in Boone and Durham, NC as well as Perkins Township and Willoughby Hills, OH were used to develop the model.

Location	Pavement Type	DA (sf)	Percent Imperviousness	Pavement Infiltrative Surface Area (sf)
Boone, NC	PICP	NA	NA	775
Durham, NC	PICP	164	100%	538
Perkins Township, OH	PC	23,025	81%	4,844
Willoughby Hills[a], OH	PICP	9,580	100%	2,207
Willoughby Hills[b], OH	PICP	3,444	100%	484

[a] Site: Willoughby Hills Large
[b] Site: Willoughby Hills Small

Smolek, A. P. (2016). Monitoring and modeling the performance of ultra-urban stormwater control measures in North Carolina and Ohio. (Unpublished Doctoral). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/11020

Part F: Technical Justifications and References

Credits for Under and Oversizing SCMs

The percent of annual runoff volume treated by SCMs (indicated on the graphs that appear in B.2 and in each of the SCM explanations in Part C) was based on the prior work of Smolek et al. (2015). The detention-based SCMs received runoff from a hypothetical 15-acre watershed with a curve number of 98. Following the currents MDCs, the SCMs were designed with a 1-foot ponding depth and storm depths as a percentage (10 to 200%) of the water quality storm depth (1 or 1.5 inches). Drawdown orifice sizes were then determined for the SCMs such that that the drawdown depth at the end of 12, 60, or 72 hours was 0.50 inches (+/- 0.03 inches). This drawdown depth was used by Smolek et al. (2015) because outflow at this depth was negligible.

The drawdown orifice dimensions and SCM surface area were then evaluated with 20 years of rainfall data (07/01/96 to 07/01/16) from the State Climate Office of North Carolina for stations at the Asheville, Raleigh-Durham, and Wilmington airports to identify the percent of annual runoff volume treated by the SCMs sized as a percentage of the water quality storm event. These values were then evaluated with 20 years of rainfall data from the State Climate Office of North Carolina for stations at the Asheville, Raleigh-Durham, and Wilmington airports to identify the percent of annual runoff volume treated by SCMs sized from 10 to 200% of the sized with storm depths as a percentage of the water quality storm depth. The model also accounted for the hourly antecedent moisture conditions. The average of the annual percent overflow volumes for each SCM size, rainfall location, and drawdown period was calculated and plotted to create regression equations that will be used in regulatory tools.

Sand filters differed from the other SCMs in that they are estimated to have a 12-hour draw down time. However, the MDC for sand filters requires that they be sized for only 0.75 times the design storm. The 12-hr drawdown period results for over/under-sized SCMs were found as percentages of 1 or 1.5 inches rather than 0.75 inches and then this was corrected by normalizing the results by 0.75. Similar to the nutrient concentrations, a QA/QC of the models was performed. This included verifying the rainfall data, equations, and descriptive statistics were correct. Twenty years of QA/QC rainfall data were available for modeling.

NOAA (National Oceanic Atmospheric Administration). 2016. *Precipitation data for the Raleigh-Durham International Airport (RDU),* acquired from the NOAA online data portal. 15-minute precipitation data from 1980 to 2013 collected by NOAA at RDU were used to generate a precipitation time series for this period.

Smolek, A. P. (2016). *Monitoring and modeling the performance of ultra-urban stormwater control measures in North Carolina and Ohio.* (Unpublished Doctoral). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/11020

Temperature and Bacteria

For **temperature protection**, it appears from literature that infiltration is the main process for reducing thermal loads. For **bacterial reductions**, it appears from literature infiltration, sun exposure, dry conditions (for wetlands and wet ponds: increased hydraulic retention time) are the main processes for reducing bacteria (Hathaway et al., 2009; Hathaway et al., 2011; Price et al., 2013; Mallin et al., 2002; Struck et al., 2008; Mallin et al., 2012).

Winston, R., Lauffer, M., Narayanaswamy, K., McDaniel, A., Lipscomb, B., Nice, A., & Hunt, W. (2015). Comparing bridge deck runoff and stormwater control measure quality in North Carolina. *Journal of Environmental Engineering, 141*(1), 04014045. doi:10.1061/(ASCE)EE.1943-7870.0000864

Buren, M., Watt, W., Marsalek, J., & Anderson, B. (2000). Thermal balance of on-stream storm-water management pond. *Journal of Environmental Engineering, 126*(6), 509-517. doi:6(509)

Hathaway, J. M., Hunt, W. F., Graves, A. K., Bass, K. L., & Caldwell, A. (2011). Exploring fecal indicator bacteria in a constructed stormwater wetland. *Water Science and Technology: A Journal of the International Association on Water Pollution Research, 63*(11), 2707. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/22049768

Hathaway, J., Hunt, W., & Jadlocki, S. (2009). Indicator bacteria removal in storm-water best management practices in Charlotte, North Carolina. *Journal of Environmental Engineering, 135*(12), 1275-1285. doi:10.1061/(ASCE)EE.1943-7870.0000107

Jones, M., & Hunt, W. (2009). Bioretention impact on runoff temperature in trout sensitive waters. *Journal of Environmental Engineering, 135*(8), 577-585. doi:10.1061/(ASCE)EE.1943-7870.0000022

Jones, M., & Hunt, W. (2010). Effect of storm-water wetlands and wet ponds on runoff temperature in trout sensitive waters. *Journal of Irrigation and Drainage Engineering, 136*(9), 656-661. doi:10.1061/(ASCE)IR.1943-4774.0000227

Lieb, D., & Carline, R. (2000). Effects of urban runoff from a detention pond on water quality, temperature and caged *Gammarus minus* (Say) (Amphipoda) in a headwater stream. *Hydrobiologia, 441*(1), 107-116. doi:1017550321076

Mallin, M. A., Ensign, S. H., Wheeler, T. L., & Mayes, D. B. (2002). Pollutant removal efficacy of three wet detention ponds. *Journal of Environmental Quality, 31*(2), 654-660. doi:10.2134/jeq2002.0654

Mallin, M. A., McAuliffe, J. A., McIver, M. R., Mayes, D., & Hanson, M. A. (2012). High pollutant removal efficacy of a large constructed wetland leads to receiving stream improvements. *Journal of Environmental Quality, 41*(6), 2046-2055. doi:10.2134/jeq2012.0025.

Price, W. D., Burchell II, M. R., Hunt, W. F., & Chescheir, G. M. (2013). Long-term study of dune infiltration systems to treat coastal stormwater runoff for fecal bacteria. *Ecological Engineering, 52*, 1-11. doi://dx.doi.org/10.1016/j.ecoleng.2012.12.008

Struck, S. D., Selvakumar, A., & Borst, M. (2008). Prediction of effluent quality from retention ponds and constructed wetlands for managing bacterial stressors in storm-water runoff. *Journal of Irrigation and Drainage Engineering, 134*(5), 567-578. doi:5(567)

Wardynski, B., Winston, R., & Hunt, W. (2013). Internal water storage enhances exfiltration and thermal load reduction from permeable pavement in the North Carolina mountains. *Journal of Environmental Engineering, 139*(2), 187-195. doi:10.1061/(ASCE)EE.1943-7870.0000626

Winston, R., Hunt, W., & Lord, W. (2011). Thermal mitigation of urban storm water by level spreader–vegetative filter strips. *Journal of Environmental Engineering, 137*(8), 707-716. doi:10.1061/(ASCE)EE.1943-7870.0000367

Bioretention

Dr. Ryan Winston and Andrew Anderson provided raw data from former graduate students for the following sites: Mango Creek Small, Mango Creek Large, Nashville Shallow, and Nashville Deep. These data were summarized and published by Winston et al. (2015). Additionally, raw data from Sharkey (2006) were used for the Louisberg 1 and 2 sites. Data for sites: Graham North, Graham South, Rocky Mount (Sandy clay loam, SCL), and Hal Marshall were retrieved from published journal articles (Passport et al., 2009; Brown and Hunt, 2011; Hunt et al., 2008). The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file, and the descriptive statistics were consistent with published materials.

Brown, R.A., Hunt, W.F., 2011b. *Underdrain Configuration to Enhance Bioretention Exfiltration to Reduce Pollutant Loads. Journal of Environmental Engineering, 137*(11), 1082-1091. doi:10.1061/(ASCE)EE.1943-7870.0000437. Two bioretention cells in Rocky Mount, North Carolina, were monitored for two year-long periods to measure the impact of varying IWS zone depths over sandier underlying soils. This research builds on previous findings of underdrain configuration at Piedmont sites in North Carolina. The increased hydraulic retention time in the sandy clay loam media resulted in lower outflow concentrations. For events monitored with drainage from the SCL cell, efficiency ratios of all the nitrogen species and TSS exceeded 0.5.

Brown, R.A., Hunt, W.F., 2011c. *Impacts of Media Depth on Effluent Water Quality and Hydrologic Performance of Undersized Bioretention Cells. Journal of Irrigation and Drainage Engineering, 137*(3), 132-143. doi:10.1061/(ASCE)IR.1943-4774.0000167 Two sets of loamy-sand-filled bioretention cells of two media depths (0.6 m and 0.9 m), located in Nashville, North Carolina, were monitored from March 2008 to March 2009 to examine the impact of media depth on their performance with respect to hydrology and water quality. Estimated annual pollutant load reduction for total nitrogen, total phosphorus, and total suspended solids were 21, 10, and 71percent for the 0.6-m media cells and 19, 44, and 82 percent for the 0.9-m media cells, respectively. Design specifications and local nutrient sources attributed to the results of this study.

Hunt, W.F, A. R. Jarrett, J. T. Smith, and L. J. Sharkey. 2006. *Evaluating Bioretention Hydrology and Nutrient Removal at Three Field Sites in North Carolina.* Journal of Irrigation and Drainage Engineering, 132:600-608. Three bioretention cells with varying media types and drainage configurations were evaluated for pollutant removal capabilities. Total nitrogen reductions averaged 40 percent by mass. Selection of media with a low phosphorus index improved phosphorus reductions relative to cells with a higher phosphorus index.

Hunt, W., Smith, J., Jadlocki, S., Hathaway, J., & Eubanks, P. (2008). Pollutant removal and peak flow mitigation by a bioretention cell in urban charlotte, N.C. *Journal of Environmental Engineering, 134*(5), 403-408. doi:10.1061/(ASCE)0733-9372(2008)134:5(403)

Hunt, W., Davis, A., & Traver, R. (2012). Meeting hydrologic and water quality goals through targeted bioretention design. *Journal of Environmental Engineering, 138*(6), 698-707. doi:10.1061/(ASCE)EE.1943-7870.0000504

Line, D.E. and W.F. Hunt. 2009. *Performance of a Bioretention Area and a Level Spreader-Grass Filter Strip at Two Highway Sites in North Carolina*. Journal of Irrigation and Drainage Engineering, 135(2): 217-224. One LS-VFS and a bioretention area along the North Carolina highway system were evaluated for pollutant and volume reduction. The LS-VFS was found to have 49 percent total volume reduction over the 13 storm events monitored.

Liu, J., Sample, D.J., Bell, C., Guan, Y. (2014). *Review and research needs of bioretention used for the treatment of urban stormwater.* Water 2014, 6, 1069-1099. This review paper summarizes data from 11 bioretention field studies for water quality performance. It includes discussion of Total Nitrogen (TN) and Total Phosphorus (TP) for systems with and without IWS. The studied BMPs varied in location, media composition and depth, surface area and ponding depth.

Luell, S. K. (2011). *Evaluating the impact of bioretention cell size and swale design in treating highway bridge deck runoff.* (Unpublished Master's). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/6921

Luell, S. K., Hunt, W. F., & Winston, R. J. (2011). Evaluation of undersized bioretention stormwater control measures for treatment of highway bridge deck runoff. *Water Science & Technology, 64*(4) doi:10.2166/wst.2011.736

Passeport, E., Hunt, W., Line, D., Smith, R., & Brown, R. (2009). Field study of the ability of two pollutant removal bioretention cells to reduce storm-water runoff pollution. *Journal of Irrigation and Drainage Engineering, 135*(4), 505-510. doi:10.1061/(ASCE)IR.1943-4774.0000006

Sharkey, L. J. (2006). *The performance of bioretention areas in North Carolina: A study of water quality, water quantity, and soil media.* (Unpublished Master's). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/2062

Winston, R. J. 2016. *Resilience of Green Infrastructure under Extreme Conditions.* PhD dissertation, North Carolina State University. Department of Biological and Agricultural Engineering. Raleigh, NC. This study validated the application of DRAINMOD as a tool to predict bioretention water balance to low-conductivity, clayey underlying soils.

Permeable Pavement

Raw data from Smolek (2016) were used for the Piney Wood and Fayetteville sites. Journal articles regarding these data have been submitted for publication. Data for sites: Kinston GP, Kinston PC, Kinston PICP1, Kinston PICP2, Goldsboro PICP, and Ohio Lg Out were retrieved from published journal articles (Collins et al., 2007; Bean et al., 2007; Winston et al., 2016). TP data from the Kinston sites were not included in the analyses because the data were unreliable. The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file, and the descriptive statistics were consistent with published materials.

Bean, Z.E., Hunt, W.F., & Bidelspach, A.D. (2007). Evaluation of four permeable pavement sites in eastern North Carolina for runoff reduction and water quality impacts. *Journal of Irrigation and Drainage Engineering, 133*(6), 583-592. doi:10.1061/(ASCE)0733-9437(2007)133:6(583)

Collins, K. A. (2007). *A field evaluation of four types of permeable pavement with respect to water quality improvement and flood control.* (Unpublished Master's). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/2227

Collins, K., Hunt, W., & Hathaway, J. (2010). Side-by-side comparison of nitrogen species removal for four types of permeable pavement and standard asphalt in eastern North Carolina. *Journal of Hydrologic Engineering, 15*(6), 512-521. doi:10.1061/(ASCE)HE.1943-5584.0000139

Smolek, A. P. (2016). *Monitoring and modeling the performance of ultra-urban stormwater control measures in North Carolina and Ohio.* (Unpublished Doctoral). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/11020

Winston, R. J., Davidson-Bennett, K. M., Buccier, K. M., & Hunt, W. F. (2016). Seasonal variability in stormwater quality treatment of permeable pavements situated over heavy clay and in a cold climate. *Water Air Soil Pollution, 227*(5) doi:10.1007/s11270-016-2839-6

Wet Pond and Floating Wetland Islands

Dr. Ryan Winston and Andrew Anderson provided raw data for the following sites: Shade Valley, Pierson, Hillandale, Hillandale Islands, Museum, and Museum Islands. However, TSS concentrations for Hillandale and Hillandale Islands sites were retrieved from Winston et al. (2015) due to a QA/QC issue. The raw data were summarized and published by Winston et al. (2015). Additionally, raw data from Baird (2015) were used for the Bingham and Raeford sites. Data for sites Davis and Piedmont Pond were retrieved from a published journal article (Borden et al., 1998). The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file, and the descriptive statistics were consistent with published materials.

Baird, J. B. (2014). *Evaluating the hydrologic and water quality performance of infiltrating wet retention ponds.* (Unpublished Master's). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/9996

Borden, R., Dorn, J., Stillman, J., & Liehr, S. (1998). Effect of in-lake water quality on pollutant removal in two ponds. *Journal of Environmental Engineering, 124*(8), 737-743. doi:10.1061/(ASCE)0733-9372(1998)124:8(737)

Hathaway, J. M., Hunt, W. F., Smith, J. T., & Johnson, A. (2007b). *Pierson pond final monitoring report*. Raleigh, NC: North Carolina State University. https://stormwater.bae.ncsu.edu/resources/

Hathaway, J. M., Hunt, W. F., Smith, J. T., & Johnson, A. (2007d). *Shade valley pond final monitoring report*. Raleigh, NC: North Carolina State University. https://stormwater.bae.ncsu.edu/resources/

Winston, R. J., Hunt, W. F., Kennedy, S. G., Merriman, L. S., Chandler, J., & Brown, D. (2013). Evaluation of floating treatment wetlands as retrofits to existing stormwater retention ponds. *Ecological Engineering, 54*, 254-265. doi:http://dx.doi.org/10.1016/j.ecoleng.2013.01.023

Stormwater Wetlands

Dr. Ryan Winston and Andrew Anderson provided raw data for the following sites: Bruns Ave, Centennial Campus MS, Dye Branch, UNCA, and Edwards Branch. These raw data were summarized and published by Winston et al. (2015). Additionally, raw data from Bass (2000) and Merriman (2015) were used for the Edenton Hospital, Simmons Base, and Simmons Event sites. Data for sites Riverbend, JEL Wetland, and Riverbend LSM were retrieved from published journal articles (Lenhart and Hunt, 2011; Merriman and Hunt, 2014; Mallin et al., 2012). The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file, and the descriptive statistics were consistent with published materials.

Bass, K. L. (2000). *Evaluation of A small in-stream constructed wetland in North Carolina's coastal plain.* (Unpublished Master's). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/1737

Caldwell, P. V., Vepraskas, M. J., Skaggs, R. W., & Gregory, J. D. (2007). Simulating the water budgets of natural carolina bay wetlands. Wetlands, 27(4), 1112-1123. doi:10.1672/0277-5212(2007)27[1112:STWBON]2.0.CO;2

Hathaway, J. M., Hunt, W. F., & Johnson, A. (2007a). *Edwards branch wetland final monitoring report.* Raleigh, NC: North Carolina State University.

Hathaway, J., & Hunt, W. (2010). Evaluation of storm-water wetlands in series in piedmont North Carolina. *Journal of Environmental Engineering, 136*(1), 140-146. doi:10.1061/(ASCE)EE.1943-7870.0000130

Johnson, J. L. (2006). *Evaluation of stormwater wetland and wet pond forebay design and stormwater wetland pollutant removal efficiency.* (Unpublished Master's). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/1590

Lenhart, H., & Hunt, W. (2011). Evaluating four storm-water performance metrics with a North Carolina coastal plain storm-water wetland. *Journal of Environmental Engineering, 137*(2), 155-162. doi:10.1061/(ASCE)EE.1943-7870.0000307

Line, D. E., Jennings, G. D., Shaffer, M. B., Calabria, J., & Hunt, W. F. (2008). Evaluating the effectiveness of two stormwater wetlands in North Carolina. *American Society of Agricultural and Biological Engineers, 51*(2), 521-528.

Mallin, M. A., McAuliffe, J. A., McIver, M. R., Mayes, D., & Hanson, M. A. (2012). High pollutant removal efficacy of a large constructed wetland leads to receiving stream improvements. *Journal of Environmental Quality, 41*(6), 2046-2055. doi:10.2134/jeq2012.0025.

Merriman, L. S. (2015). *Assessing the design and maintenance effects on ecosystem services provided by regional-scale green stormwater infrastructure.* (Unpublished Doctoral). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/10687

Merriman, L., & Hunt, W. (2014). Maintenance versus maturation: Constructed storm-water Wetland's fifth-year water quality and hydrologic assessment. *Journal of Environmental Engineering, 140*(10), 05014003. doi:10.1061/(ASCE)EE.1943-7870.0000861

Sand Filters

These data were retrieved from the International Stormwater BMP Database. The data were selected using a media filter BMP type. The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file.

Wright Water Engineers, Inc., Geosyntec Consultants for the Water Environment Research Foundation (WERF), American Society of Civil Engineers (ASCE)/Environmental and Water Resources Institute (EWRI), American Public Works Association (APWA), Federal Highway Administration (FHWA), & U.S. Environmental Protection Agency (EPA). (2016). International Stormwater BMP Database. Retrieved from http://www.bmpdatabase.org/retrieveBMPs.asp

Rainwater Harvesting

Raw data from Debusk (2013) and Wilson (2013) were used for the following sites: Fire Station 24, Fire Station 28, Fire Station 6, Fire Station 8, and Whole Foods. The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file, and the descriptive statistics were consistent with published materials.

DeBusk, K. M. (2013). *Rainwater harvesting: Integrating water conservation and stormwater management.* (Unpublished Doctoral). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/8855

DeBusk, K. M., & Hunt, W. F. (2014). Impact of rainwater harvesting systems on nutrient and sediment concentrations in roof runoff. *Water Science & Technology: Water Supply, 14*(2), 220-229.

Jones, M. P., & Hunt, W. F. (2010). Performance of rainwater harvesting systems in the southeastern United States. *Resources, Conservation and Recycling, 54*(10), 623-629. doi:http://dx.doi.org/10.1016/j.resconrec.2009.11.002

Wilson, C. E. (2013). *A comparison of runoff quality and quantity from an innovative underground low impact development and a conventional development.* (Unpublished Master's). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/8679

Wilson, C. E., Hunt, W. F., Winston, R. J., & Smith, P. (2014). Assessment of a rainwater harvesting system for pollutant mitigation at a commercial location in Raleigh, NC, USA. *Water Science & Technology: Water Supply, 14*(2), 283-290.

Green Roofs

Raw data from Moran (2004) were used for the WCCGR and NCGR sites. Data for WCC, Tamaki 150 mm, and Tamaki 100 mm sites were retrieved from the International Stormwater BMP Database. Data for the Storrs site were obtained from a published journal article (Gregoire and Clausen, 2011). The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file, and the descriptive statistics were consistent with published materials.

Fassman, E. A., Voyde, S. R., & Hong, Y. S. (2013). *Extensive green (living) roofs for stormwater mitigation part 2: Performance monitoring.* (No. TR2010/018). Auckland, NZ: Auckland UniServices.

Gregoire, B. G., & Clausen, J. C. (2011). Effect of a modular extensive green roof on stormwater runoff and water quality. *Ecological Engineering, 37*(6), 963-969. doi:http://dx.doi.org/10.1016/j.ecoleng.2011.02.004

Hathaway, A. M., Hunt, W. F., & Jennings, G. D. (2008). A field study of green roof hydrologic and water quality performance. *American Society of Agricultural and Biological Engineers, 51*(1), 37-44.

Moran, A. M. (2004). *A North Carolina field study to evaluate greenroof runoff quantity, runoff quality, and plant growth.* (Unpublished Master's). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/803

NIWA. (2016). Climate summaries. Retrieved from https://www.niwa.co.nz/education-and-training/schools/resources/climate/summary

State Climate Office of North Carolina. (2016). 1971-2000 climate normals. Retrieved from http://climate.ncsu.edu/cronos/normals.php

DIS

Raw data for sites: 6810E, 6810W, 6926E, and 6926 W were provided by Vinicius Taguchi. The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file. A journal article regarding these data has been submitted for publication. It is important to note Dr. Bill Hunt and Sarah Waickowski decided the average TN and TP concentrations from the data were not conservative and chose to use the current rooftop concentrations in the crediting document instead.

Carmen, N.B., Hunt, W.F., and Anderson, A.R. 2013. *Evaluating Residential Disconnected Downspouts as Stormwater Control Measures*. 6th International Low Impact Development Conference. August 19-22, 2013. St. Paul, MN. (Extended Abstract)

Hunt, W.F., J.M. Hathaway, R.J. Winston, and S.J. Jadlocki. 2010. *Runoff Volume Reduction by a Level Spreader - Vegetated Filter Strip System in Suburban Charlotte, NC*. Journal of Hydrologic Engineering, 15(6): 399-503. One LS-VFS system with a 19.4 meter level spreader and 900 m^2 vegetated filter strip was monitored over a 14-month period with 23 monitored storm events. Receiving runoff from a 2.15 acre water shed only produced outflow from the LS-VFS system in three storm events that were all greater than 1.6 inches. Total volume reduction over the monitoring period was 85 percent.

Knight, E.M.P, W.F. Hunt, and R.J. Winston. *Side-by-side evaluation of four level spreader–vegetated filter strips and a swale in eastern North Carolina*. 2013. Journal of Soil and Water Conservation. Two LS-VFS pairs and a swale in eastern North Carolina were evaluated for pollutant concentrations (N, P, and, TSS) and hydrologic performance. Two of the LS-VFSs were amended with sand and a phosphorus sorptive aggregate. Length of LS-VFS system was also evaluated. Runoff volumes were reduced by 36–59 percent. The systems consistently reduced the nitrogen and particulate pollution, while all systems increased total phosphorus.

Line, D.E. and W.F. Hunt. 2009. *Performance of a Bioretention Area and a Level Spreader-Grass Filter Strip at Two Highway Sites in North Carolina*. Journal of Irrigation and Drainage Engineering, 135(2): 217-224. One LS-VFS and a bioretention area along the North Carolina highway system were evaluated for pollutant and volume reduction. The LS-VFS was found to have 49 percent total volume reduction over the 13 storm events monitored.

Taguchi, V., Hunt, W. F., & Carey, E. S. (2016). *Windward Oaks downspout disconnection.* Raleigh, NC: North Carolina State University.

Winston, R.J., W.F. Hunt, D.L. Osmond; W.G. Lord; and M.D. Woodward. 2011. *Field Evaluation of Four Level Spreader–Vegetative Filter Strips to Improve Urban Storm-Water Quality*. Journal of Irrigation and Drainage Engineering 137(3):170-182. Two level spreader-vegetated filter strip pairs were tested in Louisburg and Apex, NC. The LS-VFS systems reliably removed particulate pollution from all locations. Runoff volumes were reduced by 40-50 percent. A minimum width of 25 feet appeared sufficient to achieve most observed benefits.

Level Spreader- Filter Strips

Dr. Ryan Winston and Andrew Anderson provided raw data from former graduate students for the following sites: Apex 25, Apex 50, Louisberg 25, and Louisberg 50. These raw data were summarized and published by Winston et al. (2015). Due to QA/QC issues, a combination of raw and published data from Knight et al. (2013) and Knight (2013) were used for the following sites: Wilson Small Amended, Wilson Large Amended, Wilson Small Unamended, and Wilson Large Unamended. The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file, and the descriptive statistics were consistent with published materials.

Study	DA (acres)	% Imp	Runoff Coeff (C)	Design Flow (cfs)	LS Length (ft)	VRA Width (ft)	Ratio of VRA to DA	Percent Volume Reduction
Line and Hunt, 2009	0.86	49%	0.57	0.49	24	56	49	49%
Hunt et al., 2010	2.15	45%	0.54	1.16	63.5	158	55	85%
Winston, 2011	0.49	73%	0.75	0.37	13	25	35	48%
Winston, 2011	0.49	73%	0.75	0.37	13	51	35	41%
Knight et al, 2013	0.27	56%	0.62	0.17	26	20	155	36%
Knight et al, 2013	0.36	56%	0.62	0.22	66	20	296	59%
Knight et al, 2013	0.38	56%	0.62	0.24	26	20	110	42%
Knight et al, 2013	0.57	56%	0.62	0.35	66	20	187	57%

Hunt, W.F., J.M. Hathaway, R.J. Winston, and S.J. Jadlocki. 2010. *Runoff Volume Reduction by a Level Spreader - Vegetated Filter Strip System in Suburban Charlotte, NC*. Journal of Hydrologic Engineering, 15(6): 399-503. One LS-VFS system with a 19.4-meter level spreader and 900 m^2 vegetated filter strip was monitored over a 14-month period with 23 monitored storm events. Receiving runoff from a 2.15-acre water shed only produced outflow from the LS-VFS system in three storm events that were all greater than 1.6 inches. Total volume reduction over the monitoring period was 85 percent.

Knight, E.M.P, W.F. Hunt, and R.J. Winston. 2013. *Side-by-side evaluation of four level spreader–vegetated filter strips and a swale in eastern North Carolina*. *Journal of Soil and Water Conservation, 68*(1), 60-72. doi:10.2489/jswc.68.1.60. Two LS-VFS pairs and a swale in eastern North Carolina were evaluated for pollutant concentrations (N, P, and, TSS) and hydrologic performance. Two of the LS-VFSs were amended with sand and a phosphorus sorptive aggregate. Length of LS-VFS system was also evaluated. Runoff volumes were reduced by 36–59 percent. The systems consistently reduced the nitrogen and particulate pollution, while all systems increased total phosphorus.

Line, D.E. and W.F. Hunt. 2009. *Performance of a Bioretention Area and a Level Spreader-Grass Filter Strip at Two Highway Sites in North Carolina*. Journal of Irrigation and Drainage Engineering, 135(2): 217-224. One LS-VFS and a bioretention area along the North Carolina highway system were evaluated for pollutant and volume reduction. The LS-VFS was found to have 49 percent total volume reduction over the 13 storm events monitored.

Winston, R.J., W.F. Hunt, D.L. Osmond; W.G. Lord; and M.D. Woodward. 2011. *Field Evaluation of Four Level Spreader–Vegetative Filter Strips to Improve Urban Storm-Water Quality*. *Journal of Irrigation and Drainage Engineering, 137*(3), 170-182. doi:10.1061/(ASCE)IR.1943-4774.0000173. Two level spreader-vegetated filter strip pairs were tested in Louisburg and Apex, NC. The LS-VFS systems reliably removed particulate pollution from all locations. Runoff volumes were reduced by 40-50 percent. A minimum width of 25 feet appeared sufficient to achieve most observed benefits.

Pollutant Removal Swales

Dr. Ryan Winston and Andrew Anderson provided raw data for the following sites: I-40 A, I-40 B, I-40 C, and I-40 D. These raw data were summarized and published by Winston et al. (2015). Additionally, raw data from Luell (2011) and Powell (2015) were used for sites Mango Creek, Mango Creek Swale, and Mango Creek Retrofitted Swale. Event mean concentrations for the I-40 Swale and I-40 Retrofitted Swale were not included because of continuous ponding at the sites during the monitoring period. Data for the Wilson site were retrieved from a published journal article (Knight et al., 2013). The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file, and the descriptive statistics were consistent with published materials.

Luell, S. K. (2011). *Evaluating the impact of bioretention cell size and swale design in treating highway bridge deck runoff.* (Unpublished Master's). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/6921

Powell, J. T. (2015). *Evaluating the hydrologic and water quality benefits associated with retrofitting vegetated swales with check dams.* (Unpublished Master's). North Carolina State University, Raleigh, NC. http://www.lib.ncsu.edu/resolver/1840.16/10675

Winston, R., Hunt, W., Kennedy, S., Wright, J., & Lauffer, M. (2012). Field evaluation of storm-water control measures for highway runoff treatment. *Journal of Environmental Engineering, 138*(1), 101-111. doi:10.1061/(ASCE)EE.1943-7870.0000454

Dry Ponds

These data were retrieved from the International Stormwater BMP Database. The data were selected using a detention basin BMP type where the description included “surface grass-lined basin that empties out after a storm.” The QA/QC consisted of verifying all of the data were transcribed and calculated correctly in the Excel file.

Hathaway, J. M., Hunt, W. F., & Johnson, A. (2007c). *Morehead place dry detention basin final monitoring report.* Raleigh, NC: North Carolina State University.

Hathaway, J. M., Hunt, W. F., & Johnson, A. (2007e). *University executive park dry detention basin final monitoring report.* Raleigh, NC: North Carolina State University.

Wright Water Engineers, Inc., Geosyntec Consultants for the Water Environment Research Foundation (WERF), American Society of Civil Engineers (ASCE)/Environmental and Water Resources Institute (EWRI), American Public Works Association (APWA), Federal Highway Administration (FHWA), & U.S. Environmental Protection Agency (EPA). (2016). International Stormwater BMP Database. Retrieved from http://www.bmpdatabase.org/retrieveBMPs.asp

StormFilter

CONTECH Engineered Solutions Inc. 2014. The Stormwater Management StormFilter® with PhosphoSorb® Media Performance Evaluation Study: Lolo Pass Road, Zigzag, Oregon.

CONTECH Engineered Solutions Inc. 2012. North Carolina Department of Environment and Natural Resources Division of Water Quality Preliminary Evaluation Period Program Field Evaluation: The Stormwater Management StormFilter®: Treatment System.

CONTECH Construction Products Inc. 2010. Removal of Phosphorus from Urban Runoff Using the Stormwater Management StormFilter® with PhosphoSorb™ Media.

CONTECH Stormwater Solutions Inc. 2008. Design Guidelines: Design Methodologies for Projects in the State of North Carolina.

CONTECH Stormwater Solutions Inc. 2015. StormFilter® Inspection and Maintenance Procedures.

Part G: Summary of TSS Data for SCMs

Bioretention (6 pass, 0 fail):

Location	Site Name	Mean Influent (mg/L)	Mean Effluent (mg/L)	Removal Efficiency	Pass or Fail?
Charlotte	Hal Marshall	49.50	20.00	60%	Pass
Knightdale	Mango Creek Small	49.48	25.66	48%	Pass
Knightdale	Mango Creek Large	47.96	20.38	58%	Pass
Nashville	Nashville Deep	35.38	7.70	78%	Pass
Nashville	Nashville Shallow	35.35	12.23	65%	Pass
Rocky Mount	Rocky Mount	40.60	16.90	58%	Pass

Sand Filters (3 pass, 1 fail, 1 invalid):

Location	Site Name	Mean Influent (mg/L)	Mean Effluent (mg/L)	Removal Efficiency	Pass or Fail?
Alexandria, VA	Airpark	47.00	14.00	70.21%	Pass
Tallahassee, FL	Appleyard	182.59	50.00	72.62%	Fail
Tallahassee, FL	Megginnis	105.18	4.87	95.37%	Pass
Durham, NH	Univ. of NH	45.26	19.20	57.58%	Pass
North Potomac, MD	Willow Oaks 1	14.00	5.00	64.29%	Invalid

Permeable Pavement (2 pass, 1 fail, 1 invalid):

Location	Site Name	Mean Influent (mg/L)	Mean Effluent (mg/L)	Removal Efficiency	Pass or Fail?
Fayetteville	Fayetteville	106.20	10.97	90%	Pass
Goldsboro	Goldsboro PICP	12.00	8.00	33%	Invalid
Durham	Piney Wood	703.17	14.74	98%	Pass
Willoughby Hills, OH	Ohio Lg Out	26.00	159.00	-512%	Fail

Wet Pond (4 pass, 4 fail):

Location	Site Name	Mean Influent (mg/L)	Mean Effluent (mg/L)	Removal Efficiency	Pass or Fail?
Fayetteville	Bingham Wet Pond	55.88	12.06	78%	Pass
High Point	Davis Pond	97.00	39.00	60%	Fail
Durham	Hillandale	354.00	30.00	92%	Pass
Durham	Museum	225.67	24.47	89%	Pass
High Point	Piedmont Pond	61.00	49.00	20%	Fail
Charlotte	Pierson	127.00	56.07	56%	Fail
Fayetteville	Raeford	51.93	21.93	58%	Pass
Charlotte	Shade Valley	109.18	40.29	63%	Fail

Stormwater Wetland (4 pass, 5 fail, 2 invalid):

Location	Site Name	Mean Influent (mg/L)	Mean Effluent (mg/L)	Removal Efficiency	Pass or Fail?
Charlotte	Bruns Ave	70.63	24.20	66%	Pass
Raleigh	Cent. Campus MS	33.00	32.80	1%	Fail
Mooresville	Dye Branch	76.80	12.30	84%	Pass
Charlotte	Edwards Branch	29.38	25.06	15%	Fail
Edenton	Edenton Hospital	34.14	26.71	22%	Fail
Wilmington	JEL Wetland	12.50	4.10	67%	Invalid
Riverbend	Riverbend	31.20	40.50	-30%	Fail
Riverbend	Riverbend LSM	9.89	8.37	15%	Invalid
New Bern	Simmons Base	36.89	80.19	-117%	Fail
New Bern	Simmons Event	71.88	7.34	90%	Pass
Asheville	UNCA	341.36	55.36	84%	Pass

Level Spreader-Filter Strips (7 pass, 1 fail):

Location	Site Name	Mean Influent (mg/L)	Mean Effluent (mg/L)	Removal Efficiency	Pass or Fail?
Apex	Apex 25	64.00	37.00	42%	Fail
Apex	Apex 50	64.00	25.00	61%	Pass
Louisburg	Louisburg 25	41.50	17.00	59%	Pass
Louisburg	Louisburg 50	41.00	10.00	76%	Pass
Wilson	Wilson Small Amended	33.00	5.00	85%	Pass
Wilson	Wilson Small Unamended	33.00	8.00	76%	Pass
Wilson	Wilson Large Amended	33.00	5.00	85%	Pass
Wilson	Wilson Large Unamended	33.00	8.00	76%	Pass

Pollutant Removal Swale (4 pass, 0 fail, 3 invalid):

Location	Site Name	Mean Influent (mg/L)	Mean Effluent (mg/L)	Removal Efficiency	Pass or Fail?
Johnston County	I40 A	9.00	16.00	-78%	Invalid
Johnston County	I40 B	15.50	21.00	-35%	Invalid
Duplin County	I40 D	9.00	47.00	-422%	Invalid
Knightdale	Mango Creek	55.00	30.00	45%	Pass
Knightdale	Mango Creek Retrofitted Swale	52.00	15.00	71%	Pass
Knightdale	Mango Creek Swale	47.00	26.00	45%	Pass
Wilson	Wilson	33.00	10.00	70%	Pass

Green Roof (3 invalid):

Location	Site Name	Mean Influent (mg/L)	Mean Effluent (mg/L)	Removal Efficiency	Pass or Fail?
Auckland, NZ	Tamaki 100 mm	4.00	5.40	-35.00%	Invalid
Auckland, NZ	Tamaki 150 mm	4.00	8.00	-100.00%	Invalid
Auckland, NZ	WCC	1.80	2.80	-55.56%	Invalid

Rainwater Harvesting (5 invalid):

Location	Site Name	Mean Influent (mg/L)	Mean Effluent (mg/L)	Removal Efficiency	Pass or Fail?
Raleigh	Fire Station 24	5.19	3.45	33.62%	Invalid
Raleigh	Fire Station 28	5.35	4.58	14.41%	Invalid
Raleigh	Fire Station 6	4.20	3.48	17.20%	Invalid
Raleigh	Fire Station 8	5.18	7.76	-49.99%	Invalid
Raleigh	Whole Foods	5.44	1.81	66.63%	Invalid

Dry Pond (1 pass, 0 fail, 3 invalid):

Location	Site Name	Mean Influent (mg/L)	Mean Effluent (mg/L)	Removal Efficiency	Pass or Fail?
Greenville, NC	Greenville	98.50	28.00	71.57%	Pass
Charlottesville, VA	Hillsdale	16.17	20.27	71.57%	Invalid
Charlotte	Morehead	12.00	5.00	-25.36%	Invalid
Charlotte	University	12.00	7.00	58.33%	Invalid