Water Resources
Environmental Quality

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MEMORANDUM

To: Forrest Westall, Upper Neuse River Basin Association

From: S. Jay Zimmerman SJZ

Cc: Linda Culpepper, Tom Fransen, Rich Gannon and Trish D'Arconte, DWR

Date: March 10, 2017

Subject: Approval of Soil Improvements Nutrient Reduction Practice

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I received the proposal entitled "Design Specifications and Nutrient Accounting for Soil Improvements," dated February 3, 2017, for consideration as a nutrient reduction practice to support water quality restoration in the State of North Carolina. The Division acknowledges and thanks the Upper Neuse River Basin Association for serving as the proponent of this practice.

I understand that this nutrient reduction practice has been developed in consultation with independent subject matter experts and the Division's Nonpoint Source Planning Branch, was reviewed by the Nutrient Scientific Advisory Board on April 1, 2016, and received public comment from September 30, 2016 to October 30, 2016. All comments have been reconciled to the satisfaction of the Nonpoint Source Planning Branch, which has recommended this practice for approval.

I have also reviewed this proposal and find it to be satisfactory. Therefore, through the authorities delegated to me by the Governor of the State of North Carolina and provided by applicable legislation and nutrient strategy rules, I approve the use of this nutrient reduction practice for compliance with existing development stormwater rules according to the prerequisites, conditions and requirements described therein.

Design Specifications and Nutrient Accounting for Soil Improvements

Practice Description and Utility

Purpose: This chapter defines the practice of soil improvement, establishes design criteria and implementation specifications, and provides nutrient credit assignments used for compliance with Nutrient Management Strategy Rules.

Applicability: This practice provides nutrient reduction credits for existing, managed pervious areas (i.e., turfgrass or landscaped plants) associated with residential, commercial, industrial, institutional, and public open areas towards compliance with Existing Development rules. This practice may also be applicable to new development sites but would require approval by the local government permitting authority as well as the NCDEQ Division of Energy, Mineral and Land Resources Stormwater Permitting Program. Implementation of this practice must comply with existing local, state, and federal laws including tree preservation ordinances, buffer protection rules, and erosion and sediment control ordinances.

Method: Soils that have been disturbed by conventional site development (removal of topsoil, cutting, grading, filling, compacting) exhibit reduced soil porosity and precipitation storage capacity, yielding increased surface runoff. Soil improvement achieves runoff volume and related nutrient reductions by increasing the storage capacity of the soil and promoting infiltration, storage, and evapotranspiration. Soil improvements may include tillage or scarification with the addition of topsoil, or a combination of the two. Maintaining the post improvement conditions of the soil over a long term also requires pervious area nutrient management to establish and maintain healthy vegetation. This management will promote long-term, continued improvements of infiltration rates by establishing a healthy root structure and protecting surface soils from erosion, drying, and cracking. Verification of maintenance for continued credits is the responsibility of the local jurisdiction or applying entity.

This credit information supplements the statewide guidance found in Chapter 6 of NCDENR's Stormwater BMP Manual found here: http://deq.nc.gov/about/divisions/energy-mineral-land-resources/energy-mineral-land-permit-guidance/stormwater-bmp-manual.

Nutrient Credit Overview

Soil storage capacity and nutrient credits vary depending on the depth of soil that is improved. Relative to structural stormwater control measures, soil improvement is relatively cost effective and easy to maintain if the soil does not become recompacted. Soil improvement practices that are implemented to meet the nutrient reduction requirements of the Nutrient Management Strategy Stormwater Rules shall be credited using the methods described below. A **default option** and a **site-based monitoring** option are included to provide flexibility to practitioners applying for nutrient credits.

Under the default option, available volume reduction credit varies with site development age and improvement depth. For example, the default credit for new development,

provides runoff volume reductions from pervious areas ranging from 23 percent to 65 percent depending on the depth of the improvement. For an example site in Butner, NC, nitrogen reductions of 0.56 lb/ac/yr to 1.37 lb/ac/yr and phosphorus reductions of 0.16 lb/ac/yr to 0.38 lb/ac/yr have been estimated (actual reductions depend on the precipitation station selected in JFSAT and will vary from station to station.) Volume runoff reduction credit for older developments using the default option is assumed to incrementally decrease with the age of development. Sites using the site-based monitoring option as described below may be eligible for higher volume reduction credits. For this practice, the percent nutrient load reductions for nitrogen and phosphorus are equivalent to the volume reduction credit estimated using either the default or site-based monitoring option.
Relative Confidence in Credit Assignments
Soil improvement credit estimates are considered to have high confidence based on the well understood methods and conservative assumptions used to account for the degree of site variability with respect to pre- and post-improvement soil characteristics. The credit assignments for the default credit are estimated relatively conservatively, and higher credits require collection of monitoring data before and after soil improvement.

Design Criteria and Recommendations

Design criteria and recommendations for this practice are based on information found in the literature regarding best practices and consultation with local subject matter experts for this practice.

Prerequisites and Qualifying Conditions:

1. Option-specific prerequisites and requirements:
   a. The default credit (Option 1) may be awarded for soil improvement on Hydrologic Soil Group (HSG) B, C, or D soils, or soils classified as Urban. The default credit is not applicable to HSG A soils, which are assumed to have relatively high infiltration rates such that soil improvement would offer limited benefit. The default credit is limited to developed sites that are less than 30 years old because the assigned credit is based on site development age, and sites that are 30 years old and older are assumed to have good infiltration rates that would see no benefit from soil improvement.
   b. Practitioners may choose the site monitoring option (Option 2) for any site including those developed more than 30 years prior and those with soils mapped as HSG A, recognizing that development can impact soils for extended timeframes or impact soils with high native infiltration rates such that soils previously mapped as HSG A may have poor infiltration after development. Specific requirements for Option 2 include the following:
      i. Conduct post-improvement monitoring no earlier than three months after turfgrass has established or six months after non-turfgrass vegetation (i.e., shrubs and trees) have established.

ii. Conduct bulk density tests over the depth of improvement: depth-integrate results for each sampling location and spatially average them over the site to estimate the average change in porosity.
iii. Consult with a soil scientist and/or professional (e.g., hydrologist or soil conservation specialist, geotechnical engineer) experienced with measuring bulk density to develop the pre- and post-condition study plan. The study plan will need to describe the methods (including density of measurements) for the project.

2. Credits for this practice are not applicable for high use areas that would become re-compacted (e.g., sports fields, playgrounds, grassed parking lots, grassed fire lanes, walking paths).
3. Credits for this practice are not applicable for sites with greater than 10 percent slope.
4. To prevent injury to trees, tillage and application of topsoil shall not occur within the root zone of existing trees which may be approximated by the canopy drip line. Young trees that are failing to establish may benefit from careful soil improvement under the canopy drip line. Placement of mulch around trees is allowed. A certified arborist may be consulted for site specific concerns regarding compacted soil and tree health. Local tree ordinances must be followed.
5. Improvement depths greater than 13 inches are not eligible for further credit.
6. Improvement done to comply with the design criteria for another approved nutrient practice may not be awarded additional credit pursuant to the specifications of this practice.

Installation Requirements:

1. Treatment consists of tillage, or scarification of the soil surface followed by addition of topsoil, or a combination of the two. When combined, the treatment depth is cumulative for calculation of credits.
2. Minimum treatment depth is 3 inches for areas planting turfgrass or 6 inches for areas planting other non-turfgrass vegetation (i.e., landscaped plants or woody/perennial vegetation combined with turfgrass).
3. Before improvement, conduct nutrient testing on the soil to be improved and additional topsoil by an approved lab such as the N.C. Department of Agriculture and Consumer Services (NCDA&CS) soil testing laboratory. An explanation of the NCDA soil testing report is available online at http://www.ncagr.gov/agronomi/pdffiles/ustr.pdf.
4. The soil phosphorus index is a unitless measure of the amount of phosphorus available to plants in a soil. An explanation of the phosphorus index is available online at http://www.ncagr.gov/agronomi/pdffiles/ustr.pdf. To determine the appropriate amount of supplemental phosphorus fertilizer and prevent export of phosphorus from the site, the phosphorus index shall be analyzed over the depth of improvement before treatment. Soils with a phosphorus index greater than 50 do

not require supplemental phosphorus fertilizer. Topsoil brought onsite should have a phosphorus index of 50 or less. If compost is incorporated into the soil, then the nutrient analysis should also be factored into fertilizer requirements (refer to *Installation Recommendations* section). Compost shall not contain materials with high nutrient content such as plant food (i.e., fertilizer) or biosolids (i.e., the by-product of wastewater treatment).

5. When applying topsoil, the in-situ soil shall be scarified prior to application. Topsoil may originate from the development site and be stockpiled before application or brought in from offsite.
6. Phosphorus and potassium fertilizer and lime/sulfur shall be tilled-in or mixed with the topsoil at the rates recommended by the soil testing laboratory. Vegetation type is specified at the time the soil sample is submitted to the soil testing laboratory. The agronomist evaluates the soil test results for the plant to be grown. An area with many different types of plants may require additional consultation with the agronomist providing the report.
7. This practice requires establishment and maintenance of healthy vegetation to stabilize soil and maintain the benefits of this practice. Plant-based mulches are also allowed around woody shrubs and trees. After soil improvement, establish region-appropriate turfgrass or low-maintenance plants such as perennials, woody shrubs or trees. High-maintenance turfgrass or other vegetation is discouraged. Recommendations for low maintenance turfgrass vary by region and are provided online at http://www.turffiles.ncsu.edu/Files/Documents/Publications/2008/carolina_lawns.pdf
8. Avoid damage to trees. If treatment area borders tree root zones, monitor tree health. Replace trees inadvertently killed by treatment.
9. Local governments may require additional or more stringent requirements as part of their approval of this practice.

Installation Recommendations:

1. Treatment may include the addition of compost to improve the nutrient and organic matter content of the soil.
2. The nutrient and organic matter content of the compost needs to be considered along with the soil nutrient content. The US Composting Council recommends purchasing certified compost from a supplier that provides a Seal of Testing Assurance (STA) that includes analysis of pH, nutrient content, organic matter content, and other properties of the compost. If the compost does not come with a nutrient and organic content analysis, send a sample to the NCDA&CS waste laboratory.
3. If an STA report is not provided, analyses may be conducted at the NCDA&CS waste laboratory.
4. County Cooperative Extension and/or professional (e.g., hydrologist or soil conservation specialist) may be consulted to determine the volume of compost to achieve approximately 5 percent to 10 percent of organic matter (by dry weight) in the amended soil while minimizing nutrient levels. Incorporate compost into the

entire tilled depth. The higher range of percent compost (10 percent) is more appropriate for plants other than turfgrass.

Alternatively, the following equation may be used to estimate the volume of compost needed for a specific depth of soil improvement over a 1000 sq. ft. area to achieve the target percent organic matter (by dry weight) . The equation estimates the volume of compost needed based on the dry weight percent organic matter associated with the compost and soil:

Compost (cuyd)/1000s.f. improvement area = $9.35*D*[(\%OM_T - \%OM_S)/(\%OM_C - \%OM_T)]$

Assuming
soil bulk density = 2000lb/cuyd dry weight
compost bulk density = 660lb/cuyd dry weight
Where
D is the improvement depth (inches),
$\%OM_T$ is the target percent organic matter after soil improvement,
$\%OM_S$ is the percent organic matter of the soil before improvement, and
$\%OM_C$ is the percent organic matter of the compost

5. For best results compost should be tilled to a minimum depth of 3 to 6 inches for turfgrass and landscape plants, respectively.
6. Compost shall be tilled-in with the topsoil and fertilizer and lime/sulfur prior to application at the rates recommended by the soil testing laboratory.
7. Topsoil should have a minimum of 5 percent organic matter. Topsoil that is removed prior to construction for post-construction application should be tested and amended if it has been stored for a length of time.

Operation and Maintenance Requirements:

1. Protect surface soils from erosion, drying, and cracking by establishing and maintaining healthy vegetation. Maintain at least 75 percent vegetative cover (tree/shrub canopy included). Planting of trees and shrubs should occur doing the dormant season beginning in the late fall through winter. Apply annual application of mulch to landscape bedding areas or around trees, as applicable post-treatment.
2. Protect soils from re-compaction: do not allow driving or parking of vehicles and use methods to exclude treatment areas from use as trails. Periodic vehicle based mowing and maintenance is allowed.
3. To reduce/prevent the need for future fertilization, practitioners may mulch grass clippings in place and may mulch leaf litter from deciduous plants in landscaped areas rather than removing it.

4. Conduct soil tests every three years to determine fertilization requirements for phosphorus and potassium. Unless re-compaction occurs, this practice does not involve a maintenance schedule beyond the continued maintenance of healthy vegetation. Phosphorus and potassium fertilizer and lime/sulfur application shall be applied at rates recommended by the soil testing laboratory.
5. Nitrogen fertilizer shall be applied at rates required for healthy plant growth. Consult with County Cooperative Extension for guidance on selecting appropriate fertilizer and applying it at appropriate times and intervals. For various species of turfgrass, these rates are provided online at http://www.turffiles.ncsu.edu/Files/Documents/Publications/2008/carolina_lawns.pdf.
6. The following practices shall be followed when the area is fertilized to prevent nutrient export from the area:
    a. Fertilizer shall be kept off or removed from impervious surfaces in the vicinity of the improved area such as sidewalks, driveways, patios, and roads. Removal of fertilizer, if needed, shall be accomplished either by the use of specialized application equipment and/or removal by blower, broom, etc.
7. Fertilizer shall not be applied before moderate or heavy rain.
8. Per the Buffer Rule, fertilizer shall not be applied within 50 feet of an intermittent steams, perennial streams and perennial waterbodies, with the exception of an initial application for plant establishment.

Verification Requirements:
Each local government or entity applying for nutrient credits is responsible for verifying that soil improvement practices continue to be maintained as a justification for continued crediting. The verification procedures may be established by the local government or applying entity in coordination with their existing programs and protocols. The size of the jurisdiction, number of practices installed, and staffing resources will likely dictate the type of program. The program shall include some form of maintenance agreement, and credits shall be renewed at least every 5 years. During credit renewal, jurisdictions shall confirm that each practice is being maintained per the agreement. Confirmation and renewal may be based on site inspections, notification and documentation submitted by mail, or other similar means acceptable to the Division, to ensure that the site is being maintained and credit renewal is appropriate. These verification requirements may be relaxed in the future once the practice has been implemented and more information is available regarding the success and persistence of maintenance at the site level. The Division will revisit these requirements at the request of the local government(s) implementing these practices, or of its own accord based on the compilation of maintenance and verification information from multiple local governments.

Example Soil Improvement Operation and Maintenance Agreement

Soil improvement practices must be maintained according to the following operation and maintenance items as described in the **Design Specifications and Nutrient Accounting for Soil Improvements** practice standard:

Maintenance Activities	**Guidance and Frequency**
Maintain at least 75% vegetative cover	As needed, aerate and reseed turfgrass to maintain cover Replant dead trees and plants. Planting of trees should occur during dormant season beginning in late fall through winter. Fertilize as specified below.
Mulch	Apply post treatment and annually to landscape bedding or around trees
Mowing	As needed. To reduce/prevent the need for future fertilization, practitioners may mulch grass clippings in place and may mulch leaf litter from deciduous plants in landscaped areas rather than removing it.
Prevent Re-compaction of Soil	Do not allow driving or parking of vehicles and use methods to exclude treatment areas from use as trails. Periodic vehicle based mowing and maintenance is allowed.
Fertilizer Application Rate	Conduct soil tests every three years to determine fertilization requirements for phosphorus and potassium. Apply nitrogen fertilizer at rates required for healthy plant growth. Consult with County Cooperative Extension for guidance on selecting appropriate fertilizer and applying it at appropriate times and intervals for various plants. For various species of turfgrass, refer to http://www.turffiles.ncsu.edu/Files/Documents/Publications/2008/carolina_lawns.pdf.
Prevent fertilizer runoff	Fertilizer shall be kept off or removed from impervious surfaces in the vicinity of the improved area such as sidewalks, driveways, patios, and roads. Removal of fertilizer, if needed, shall be accomplished either by the use of specialized application equipment and/or removal by blower, broom, etc. Fertilizer shall not be applied before moderate or heavy rain. Per the Buffer Rule, fertilizer shall not be applied within 50 feet of an intermittent steams, perennial streams and perennial waterbodies, with the exception of an initial application for plant establishment.

______________________________ ____________________

Landowner Signature Date

Printed Name and Property Address:

For sites that are deemed noncompliant, the land owner would need to rectify site conditions, reestablish healthy vegetation, and reapply for crediting with a signed maintenance agreement.

Nutrient Credit Estimation and Relative Confidence

A. Nutrient Load Reduction Credit Method Summary

This section summarizes the nutrient credits awarded towards compliance with Jordan and Falls rules. Credit is assigned for the footprint of the area that is improved.

This practice credits soil improvement over a minimum depth of 3 inches to 6 inches depending on the plant type, with credits increasing as the depth of improvement increases up to 13 inches. For non-grass plants which have deeper rooting depths, a minimum depth of improvement of 6 inches is required. Improvements that exceed the minimum depth will have a greater impact on runoff and will result in a larger credit. Combinations of tillage plus compost and addition of topsoil are allowed to estimate the total depth of improvement.

Two options are available for estimating runoff volume reductions and associated nutrient reduction credits. Option 1 provides a default credit and assumes a net change in effective porosity of 5 percent resulting from soil improvement. Recommendations from subject matter experts and literature were used to set the credits based on site development age based on an assumption that after 30 years the naturally occurring processes in the soil would reduce compaction to near pre-development conditions and that soil improvement at older sites would not warrant the same amount of credit as younger sites. Once set, the credit does not change over time (assuming that re-compaction does not occur as specified in the design criteria on pages 2-4 for this practice).

Option 2 requires pre- and post-improvement site-based monitoring to demonstrate that additional runoff volume reductions are warranted beyond the default credit assumed for Option 1. Site age is not explicitly accounted for in Option 2 because the site-based monitoring data inherently reflect this site characteristic.

<u>Option 1: Default Credit</u>

Option 1 crediting is based on the age of the development at the time of soil improvement, with lower credits assigned for older developments. Site development age is used as a surrogate indicator of pre-improvement infiltration rates to assign the volume reduction credit for this practice in the absence of monitoring data. Runoff volume reduction credits are assigned in perpetuity based on the age of the site at the time of soil improvement, with no credit assumed for developments that are 30 years or older. Site age is a surrogate for the pre-improvement condition of the site, and it was assumed that the available credit based on site age decreases linearly to 0 at 30 years old. Once this credit is established, using either Option 1 or Option 2, it does not decline as the site ages. For example, the default credit option provides greater volume reduction for a newly developed site (23 percent) compared to a site that is 5 years old (19 percent) if the depth of soil improvement is 3-inches (see Table 1). These credits will remain in perpetuity if the design criteria are followed.

Soil improvement is measured in terms of an improved soil's ability to store more runoff (and thus reduce the runoff volume) compared to its prior post-development condition. For this option, it is assumed that soil improvement results in a 5 percent increase in porosity. The nutrient reduction credit is based on the annual volume of surface runoff that can be stored in the increased pore space, assuming stored runoff has similar nutrient concentrations to that which runs off, and those stored nutrients will be made unavailable to waterbodies through natural soil functions. A greater nutrient reduction credit is provided with deeper soil improvement because the assumed increase in soil porosity of 5 percent extends over a greater volume of soil.

Runoff volume reduction percentages for this practice are listed for several improvement depths and increments of site development age (Table 1). Practitioners may further interpolate between site age as needed. Multiply the runoff reduction percent by the area's pre-treatment nutrient export mass to get the mass of nutrient reduction (See Section C for an example calculation).

Table 1. Soil Improvement Option 1: Perpetual Annual Percent Runoff Volume Reduction Amounts Varied By Site Development Age[1] and Improvement Depth

Depth of Improvement (in)	Annual Runoff Reduction (%)						
	New Development	Site Development Age					
		5 year	10 year	15 year	20 year	25 year	30 year
3	23	19	15	12	8	4	0
4	30	25	20	15	10	5	0
5	35	29	23	18	12	6	0
6	40	33	27	20	13	7	0
7	45	38	30	23	15	8	0
8	49	41	33	25	16	8	0
9	53	44	35	27	18	9	0
10	57	47	38	28	19	9	0
11	60	50	40	30	20	10	0
12	63	52	42	31	21	10	0
13	65	54	44	33	22	11	0

[1]Site development age is used to assign the volume reduction credit for this practice in the absence of monitoring data. Once this credit is established, it does not decline as the site ages.

<u>Option 2: Site-based Monitoring Estimate</u>

This approach involves measuring bulk density in the field before and after soil improvement. Bulk density is defined as the mass of dry soil solid divided by the volume of soil.

The bulk density measurement would be used along with an assumed particle density of 2.65 g/cm^3 for mineral soils to estimate the volume of macro pores as a percentage for the pre- and post- improvement condition. The net change in porosity would be used along with the improvement depth to calculate the additional volume available to store runoff after soil improvement using the following equations:

- Porosity (%) = 100 * [1 - (bulk density / 2.65 g/cm^3)]
- Net change in Porosity% = Porosity%$_{post}$ – Porosity%$_{pre}$
- Storage depth (inches) = (Change in porosity%/100) * improved soil depth in inches
- Use the storage depth with Table 2 to look up the annual runoff reduction percent; also shown in Figure 1.
- Multiply the runoff reduction percent by the area's pre-treatment nutrient export mass to get the mass of nutrient reduction.

Table 2. Annual Runoff Reductions[1] Corresponding to Precipitation Storage Depths in Improved Soil

Storage Depth (in)	Annual Runoff Reduction (%)	Storage Depth (in)	Annual Runoff Reduction (%)	Storage Depth (in)	Annual Runoff Reduction (%)
0.1	15.8	1.1	82.9	2.1	96.1
0.2	29.6	1.2	85.4	2.2	96.4
0.3	40.6	1.3	87.2	2.3	96.7
0.4	49.4	1.4	88.7	2.4	97.0
0.5	56.6	1.5	90.3	2.5	97.2
0.6	62.7	1.6	91.9	2.6	97.5
0.7	68.0	1.7	93.2	2.7	97.8
0.8	72.7	1.8	94.1	2.8	98.2
0.9	76.9	1.9	94.9	2.9	98.6
1.0	80.1	2.0	95.5	3.0	99.0

[1] The annual runoff reduction is based on the frequency of storms observed at RDU Airport from 1980 to 2013 that are less than the storage depth resulting from the soil improvement. Depths greater than the storage depth are assumed to generate runoff from the site. Annual runoff reductions are slightly greater than the observed frequency of a given storm size because improvements mitigate a portion of the precipitation depth for storms larger than the storage depth in addition to fully mitigating the depth of storms equal to or less than the storage depth.

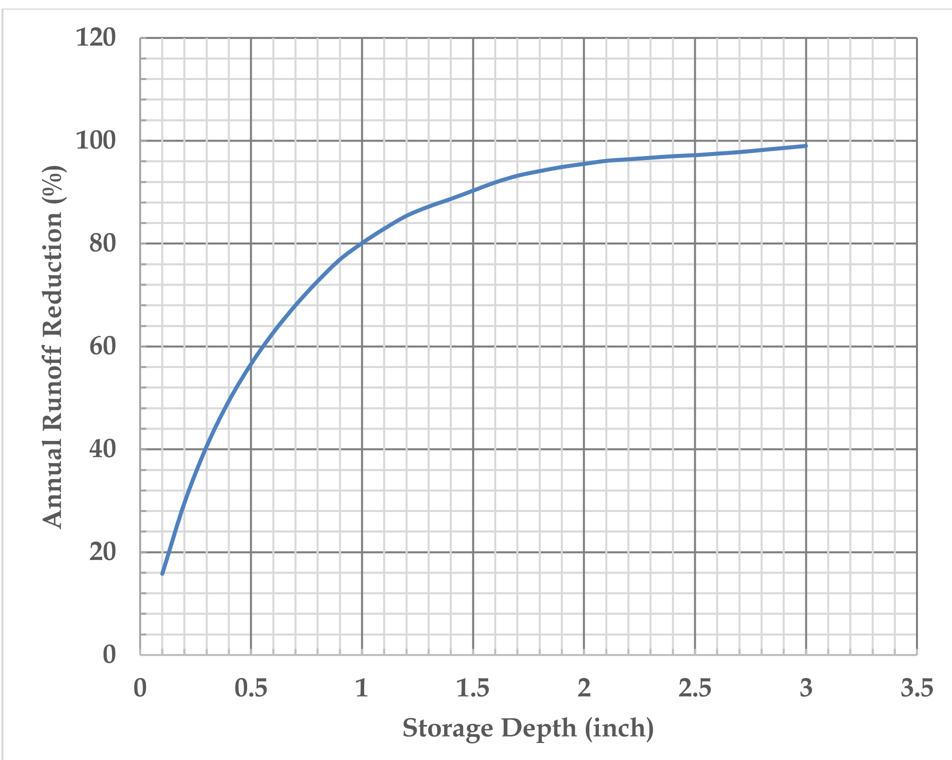

Figure 1. Annual Runoff Reductions Corresponding to Precipitation Storage Depths in Improved Soil

B. Reductions Obtained with Practice

The range of reductions in annual runoff volume, nutrient loading rates, and nutrient load reductions associated with soil improvement depends on whether or not the default credit (Option 1) or site-based monitoring credit (Option 2) is assumed. For the default credit, the range also depends on the age of the site development.

The practitioner also needs an estimate of the nutrient loading rates from the pervious area prior to soil improvement to apply the percent load reduction and estimate the nutrient credits (i.e., the load reduced). To estimate the nutrient loads from the site before soil improvement, and the resulting load reduction credit, practitioners may use the latest version of the Jordan Falls Stormwater Accounting Tool (JFSAT) or a subsequent Division-approved tool. JFSAT accounts for precipitation and geologic province in the estimate of nutrient loads from various land uses.

The ranges listed in Table 3 are estimated using the default crediting option (Option 1) at a new development site, and older sites would receive less credit under the default option. The ranges assume a managed pervious area in the Piedmont physiographic region near the Butner, NC weather station. Pre-improvement nutrient loading rates are 1.41 lb-N/ac/yr and 0.39 lb-P/ac/yr based on the JFSAT.

Table 3. Example Annual Nutrient Reductions for Soil Improvement Assuming the Default Credit on a New Development Site

Depth of Improvement (inches)	Annual Runoff Volume, Nitrogen Load, and Phosphorus Load Reductions (%)	Annual TN Credit (Load Reduction) (lbs/ac/yr)	Annual TP Credit (Load Reduction) (lbs/ac/yr)
3	23	0.32	0.11
5	35	0.49	0.17
8	49	0.69	0.24
13	65	0.92	0.32

Additional credits may be calculated for sites with pre- and post-improvement monitoring data (Option 2). Table 4 provides examples of annual volume reductions that would be achieved with various levels of net change in macro porosity, using the same land use nutrient loading and rainfall information as above. These examples are used to illustrate the potential credits associated with a range of net changes in porosity that could be obtained using Option 2.

Table 4. Example Annual Reduction in Runoff for Soil Improvement Using Site-Based Monitoring Option

Depth of Improvement (inches)	Net Change in Porosity (%)	Storage Depth (inches)	Annual Runoff Reduction (%)	Annual TN Credit (Load Reduction) (lbs/ac/yr)	Annual TP Credit (Load Reduction) (lbs/ac/yr)
3	10	0.3	40	0.56	0.16
5	10	0.5	56	0.79	0.22
8	10	0.8	72	1.02	0.28
13	10	1.3	87	1.23	0.34
3	15	0.45	53	0.75	0.21
5	15	0.75	70	0.99	0.27
8	15	1.2	85	1.20	0.33
13	15	1.95	95	1.34	0.37
3	20	0.6	62	0.87	0.24
5	20	1.0	80	1.13	0.31
8	20	1.6	92	1.30	0.36
13	20	2.6	97	1.37	0.38

C. Soil Improvement Example Calculation

The following is an example of how to represent the nutrient load reduction credits for soil improvement in the JFSAT for a site in Butner, NC using a combination of tillage plus compost and addition of topsoil. The effective depth of the tillage equipment is 6 inches and an additional 2 inches of topsoil is overlaid for a total improvement depth of 8 inches. The managed pervious area to be improved is 10 acres (435,600 s.f.). The site is ten years old and pre- and post-improvement monitoring data indicate that the soil improvements resulted in a 10 percent increase in porosity, on average, across the 10 acres.

Because this is a site-based monitoring credit (Option 2), the age of the site development is not factored into the credit estimate. To estimate the nutrient load reductions from this scenario using the JFSAT, take the following steps:

<u>Data Entry</u>

1. Enter the necessary information into JFSAT to estimate the pre-improvement nutrient loads
    - On the *Project Info* page enter 435,600 s.f. of development area, select the Piedmont physiographic region and the Butner precipitation location.
    - On the *Watershed Characteristics* page enter 435,600 s.f. of *pervious area* (e.g., turfgrass) in the *Pre-Development* and *Post-Development* columns.

2. From Table 3, on page 11 of this document, select the appropriate volume reduction from the site-based monitoring option for an improvement depth of 8 inches and a measured increase in porosity of 10 percent (72 percent volume reduction).
3. Calculate the overflow volume percent as 100 percent minus the percent volume reduction. For this example the overflow volume percent is 100 - 72 = 28 percent. Use a treated volume percent of zero. [For this practice, no additional treatment beyond the volume reduction is credited.]
4. On the *BMP Characteristics* page, select the *Other Custom BMP* as the type of BMP.
5. Enter the *Overflow %* and *% Treated* for the soil improvement (the percent volume reduction is not entered but rather is calculated by JFSAT).
    - The percent volume reduction for the practice based on the design specifications is 72 percent.
    - The *% Treated* should be entered as *0* for any soil improvement project.
    - The Overflow % is calculated as 100 % minus % Volume Reduction, or 28 percent for this example.
6. Leave the nutrient EMC values blank since there is no treated runoff from this practice.
7. In the rows under the *Area Treated by BMP* on the *BMP Characteristics* tab, enter the area of managed pervious that is being improved (435,600 s.f.)

<u>Interpreting Results</u>

On the *Overall Summary* page, the *Total Nitrogen* & *Phosphorus Loading* (lbs/yr) should show the following values:

- *Pre-Development Conditions*
    - *Total Nitrogen Loading (lbs/yr)* = 14.1
    - *Total Phosphorus Loading (lbs/yr)* = 3.91
- *Post-Development Conditions w/BMPs*
    - *Total Nitrogen Loading (lbs/yr)* = 3.94
    - *Total Phosphorus Loading (lbs/yr)* = 1.09

These values are information that the tool outputs in pounds per year. The user completes the remaining steps by hand to calculate the credits (reductions in loading):

8. Compute the nutrient reductions in pounds per year, which would be used towards compliance with the Nutrient Management Strategy:
    - Compute the reduction in loading rates
        - Nitrogen -> 14.1-3.94=10.16 lbs/yr
        - Phosphorus -> 3.91-1.09= 2.82 lbs/yr

D. Tier Assignment and Basis

Soil improvement has been designated Tier II based on the fact that volume reduction practices have been approved by NCDEQ for volume reductions, and the data used to estimate the annual volume reductions were obtained from the National Oceanic Atmospheric Administration (NOAA). Tier II measures receive the currently established credit at the time of installation for their functioning lifetime. Any credit refinements based on additional research would apply only to installations done subsequent to those refinements.

To evaluate relative confidence in the measure's estimated reduction, Division staff considered a range of factors outlined in the document "*DWR Approval Process for Alternative Nutrient Load-Reducing Measures.*"

1. Supporting Research

Based on the well-understood processes and conservative assumptions used to establish the default credit, there is a relatively high confidence in the crediting estimate methods for these practices.

<u>Data Scope</u>
The methods used to estimate the improvement in the storage capacity of the soil are based on the change in porosity of the soil before and after improvement. For the site-based monitoring option, practitioners are required to conduct bulk density tests on site to calculate the change in porosity. For the default credit, a change in porosity of 5 percent over the improvement depth is assumed based on research conducted by Barret Kays (1979). Since Kays' thesis was published, several researchers have documented the impacts of site development on soil characteristics, the reductions in runoff associated with soil improvements, and the design criteria needed to sustain this practice. This literature provides the basis of the credit and the design criteria.

The second key source of data used to develop the volume reduction credits for this practice is 60-minute precipitation data collected by NOAA at the Raleigh-Durham International Airport from 1980 to 2013. Storm sizes generated from this time series were compared to the size of the design storms that could be stored following soil improvement. For each storm size, estimates of the volume reduced and volume of runoff were estimated and then translated into annual values. For each design storm size, the average annual runoff reduction was computed for the 1980 to 2013 period to generate the values listed in Table 6.

These precipitation-based estimates of annual runoff reduction are lower, and thus more conservative, than values produced by modeling done for comparative purposes using the Water Quality Capture Optimization and Statistic Model developed by the Urban Watersheds Research

Institute. This is likely because 1) the precipitation analysis assumes that all of the precipitation reaches the improved area instantaneously and 2) the precipitation analysis does not account for hydrologic losses due to evaporation or transpiration. While the precipitation-based analysis does not account for antecedent soil moisture conditions, its overall more conservative credit estimates relative to a more comprehensive model are very defensible.

A critical assumption of this crediting method is that the improved soil is not re-compacted in the future and that healthy vegetation is established and maintained. In order to receive this credit, the design criteria for soil improvement must be followed.

Applicability

This analysis is based on precipitation data collected in the Piedmont of NC at Raleigh-Durham International Airport (RDU), and thus this crediting is directly applicable to the Jordan and Falls watersheds. The other key factors, soil improvement depth and site age, are site specific, making this credit method fully applicable and thus uncertainty based on applicability negligible.

Data Quality

The quality of data, fundamental concepts, and conservative assumptions used in the analysis result in a high degree of confidence in the annual volume reductions and the associated nutrient credits. The soils data used for this assessment was primarily collected in North Carolina by subject matter experts at North Carolina State University. Additional studies have been published by other researchers including the U.S. Geological Survey. These studies have been documented in several university theses and peer reviewed journals and are considered high quality sources of information. The weather data was collected by the National Oceanic Atmospheric Administration (NOAA) and is reviewed and managed according to NOAA Information Quality Guidelines.

In addition to the high quality of these data sources, the assumption that soil improvement will result in additional storage capacity by increasing the porosity is rooted in a fundamental understanding of soil science and well documented in the literature. Uncertainty in the net effects of soil improvement comes from the variability in pre- and post-improvement soil characteristics within and among sites. To deal with this uncertainty, the default credit assumes a relatively small increase in storage volume of 5 percent over the improvement depth. Practitioners seeking higher credits may use the site-based monitoring option.

2. Measure Design & Operation Specification

Confidence in sustained load reductions is reasonably high given that the design criteria for soil improvement are straight-forward and are aimed at maintaining post-improvement conditions over the long term. Because this is a new practice and maintenance practices may vary from site to site, the nutrient credits were set conservatively.

3. Load Reduction Estimation Methods
Soil improvement is a simple practice, and the volume reduction and associated nutrient loading reduction assumptions used in the Jordan/Falls Tool are known and straightforward, so the practice and the credit method are well matched and do not introduce a lot of uncertainties.

Co-Benefits

In the case of soil improvement, additional benefits may include further reducing other pollutants including Total Suspended Solids (TSS) and pathogens. Because of the reductions of runoff volume associated with soil improvement, the practice may also alleviate drainage issues and reduce flooding.

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Supporting Technical Information

This supporting technical information is provided for the soil improvement nutrient crediting document and includes a summary of literature and a description of the precipitation analysis that was conducted to establish the volume reduction credits associated with a change in soil storage capacity.

Development of the nutrient credit document for this practice included input from representatives from the following organizations:

- North Carolina Department of Environmental Quality Division of Water Resources: Rich Gannon, John Huisman, Trish D'Arconte, and Amin Davis, PWD
- North Carolina State University Department of Soil Science: Deanna Osmond, Ph D; Richard McLaughlin, Ph D; and Josh Heitman, Ph D
- North Carolina State University Biological & Agricultural Engineering Stormwater Engineering Group: Andrew Anderson, PE; Erin Carey, MS; and Bill Hunt, Ph D, PE
- NC Farm Bureau: Anne Coan and Keith Larrick
- Upper Neuse River Basin Association: Forrest Westall, PE
- Cardno: Alix Matos, PE
- The Center for Watershed Protection, Inc.: Neely Law, Ph D

<u>Option 1 Crediting:</u>

This option recognizes that development can significantly reduce the porosity and storage capacity of soil due to removal of top soil, grading, and compaction. Practitioners implementing soil improvement as a volume reduction practice for new or existing development have the option of assuming the default volume reduction credit for their site if the design criteria are met.

The literature and corresponding field studies indicate that over a period of 30 to 50 years after development, the physical, biological, and chemical reactions occurring in the soil result in conditions similar to pre-development conditions. Credits remain constant after improvement and are not further reduced as the site continues to age because natural processes in the soil will continue to improve the storage capacity.

This credit depends on the age of the development at the time of implementation and the depth of soil improvement. The method proposed by Kays (2010) was used to estimate the increase in storage volume associated with soil improvement at new development sites based on a change in porosity. Kays' data (1979) suggest that soil amendment can achieve an effective porosity up to 15 percent to 35 percent of the volume of amended soil. To provide a general and conservative estimate for this practice, a net change in effective porosity of 5 percent was assumed for the default credit.

Table 4 shows the volume reductions for a one-acre site associated with different improvement depths which may be achieved with tillage and incorporation of compost and/or scarification of the surface and addition of topsoil. The mean depth of improvement is used along with an assumed net increase in effective porosity of 5 percent to calculate the volume of stormwater and the precipitation depth that can be stored following improvement. Subsequent infiltration and evapotranspiration of the stored water from the soil results in an annual runoff reduction from the pervious area. The storm depth that can be stored is compared against Figure 4 to look up the annual runoff reduction percent.

Table 4. Option 1: Annual Volume Stored and Reduction in Runoff Associated with Soil Improvement over 1 acre of Pervious Area

Depth of Improvement (inches)	Volume of additional water stored per storm (ft^3/ac)[1]	Storm depth that can be stored (in)[2]	Annual Runoff Reduction (percent)[3]
3	544.5	0.15	23
4	726.0	0.20	30
5	907.5	0.25	35
6	1,089	0.30	40
7	1,270	0.35	45
8	1,452	0.40	49
9	1,634	0.45	53
10	1,815	0.50	57
11	1,996	0.55	60
12	2,178	0.60	63
13	2,359	0.65	65

[1] The volume stored for each acre of improved soil is calculated as
Depth of improvement (in) * 1 ft/12 in * 43,560 ft^2 / acre * Net change in effective porosity (5 percent) / 100 percent.
[2] The storm depth that can be stored over an acre of amended soil is calculated as
Volume stored (ft^3) * 1 acre/43,560 ft^2 * 12 in/ft.
[3] The annual runoff reduction is based on the frequency of storms observed at RDU Airport from 1980 to 2013 that are less than the storage depth resulting from the soil improvement. Depths greater than the storage depth are assumed to generate runoff from the site.

The review group worked through several technical issues in a series of meetings and conference calls. The following questions and answers serve to document these issues and memorialize the progress that has been made on this practice with respect to specific issues:

1. **For the default option, why are hydrologic soil group (HSG) B soils eligible for credit? Don't HSG B soils have sufficient infiltration rates already?**
   Based on input from the Subject Matter Experts and several published studies summarized below, the designated HSGs are not representative of site conditions following conventional development that typically results in a

compacted clay surface layer that prevents infiltration of moderate to large precipitation events.

2. **Shouldn't site monitoring be used to verify compacted soils for credit eligibility?**
   The goal of the default credit is to provide an option where no site monitoring is needed. To be eligible for this "default credit," the site would have to be developed less than 30 years ago, and the resulting credit is relatively small. For the site-based monitoring option, pre and post site monitoring is needed to estimate the net change in porosity and storage capacity. There have been some cases where even a soil designated as HSG A has been altered such that infiltration is not adequate. To allow for credits associated with improvements on these soils, the site-based monitoring option is applicable to all HSGs.
3. **For the default calculation, won't there be cases where the existing, un-amended soil could infiltrate small rainfalls completely, albeit over a greater soil depth than a less porous soil?** Yes, this is why the credit increases the deeper you improve, and why a very small net increase in porosity (5 percent) is assumed to account for the degree of porosity that was already present before the improvement. The credit method accounts for the rainfall that could already be stored on pre-improved soils, and only offers credit for the assumed 5 percent increase in porosity.
4. **Why is the crediting method based on measuring bulk density rather than infiltration rates? Isn't measurement of infiltration rates a more direct measurement of the effects of soil amendment? Did you consider modeling options that have been discussed in the literature?**
   We discussed measuring infiltration rates with the Subject Matter Experts and evaluated using either double ring infiltrometers or Cornell Sprinkler infiltrometers. The Subject Matter Experts indicated that the bulk density test was a more direct measurement of porosity. We also discussed modeling options that assume different HSGs or curve numbers for the pre- and post-improvement condition, but the Subject Matter Experts did not feel these models would be accurate at the site level, particularly given the issues with mapped HSGs compared to conditions that are common after site development.
5. **Is there some way to check the plausibility of the default credits?**
   The results of the default method were compared site results measured in North Carolina (Brown 2012), and the results were conservative at both monitoring sites (default credit predicted a percent volume reduction that was 9 percent to 32 percent lower than what was observed at the monitoring sites).
6. **Why doesn't the 30-year credit attenuation apply to existing development sites the same way it does for new development sites?**
   The time varied credit applies to both new development and existing development sites, but only when the default credit is assumed. The literature

indicates that after 30 to 50 years, the natural biogeochemical processes will restore the soils back to their near, pre disturbed condition. Once soils are improved through this practice, site conditions will continue to improve over time due to these natural processes. For the default credit, it is assumed that the worst case condition in terms of porosity occurs on a new development site where these natural processes have not had a chance to affect the soils. Therefore, the full credit only applies to a new development site when the default credit is sought. For existing development, it is not known how much of the natural restoration has actually occurred, so the default credit is incrementally reduced based on site age. For the site-based monitoring credit, the pre and post conditions are measured, so site age does not need to be accounted for: it is already accounted for in the site data. As things are only expected to improve over time due natural processes, unless the site is recompacted, porosity and storage capacity should actually improve over time.

Summary of Literature

Nineteen monitoring and modeling studies were used to support the crediting recommendation for this practice. Most of the site-based monitoring studies to evaluate soil amendments had a short duration of 1 to 2 months, and most of the studies focused on only 1 or 2 storm events, with the exception of Kays (1979), Brown (2012), and Carmen (2015). Each study was also limited in the parameters that were monitored, and none reported changes in nutrient loads or concentrations across varying designs. For these reasons, the crediting methodology is based on the change in soil porosity and storage capacity and a comparison to historical precipitation data.

- In 1979 Barrett Kays published his dissertation titled "Relationship of Soil Morphology, Soil Disturbance and Infiltration to Stormwater Runoff in the Suburban North Carolina Piedmont." Kays conducted research on the effects of soil disturbance at urban sites located in the Piedmont of NC and compared these sites and their infiltration rates to undisturbed forest and pasture sites. The urban development resulted in loss of porosity and reduced infiltration rates compared to the forest and pasture sites. Measurements of infiltration rates at the sites indicated that the rates assumed for Hydrologic Soil Groups (HSG) generally underestimated the infiltration rates for all of the sites studied. Infiltration rates measured at the sites were compared to historical rainfall records to estimate the percent increase in surface runoff associated with soil compaction.

  Kays (1979) reports a relationship between saturated hydraulic conductivity and volume of macro pores for Cecil Soils in Charlotte, NC (Figure 2). His data suggests that agricultural and urban activities significantly affect infiltration rates compared to native forest conditions (64 percent reduction to 98 percent reduction in infiltration rates). Kays (1979) indicates that HSG underestimates the infiltration rates of forest soils and restored soils because they were primarily based on studies conducted at agricultural sites with disturbed soils. He suggests measuring infiltration rates on site to determine infiltration rates. In the event that monitoring data cannot be collected, he suggests the following approach to determine an estimate of storage volume associated with soil amendment and the amount of time needed to infiltrate the water volume stored in the soil (Kays 2010):

- Identify the underlying HSG from the County Soil Survey
- Assume the infiltration rate is the midrange reported for the HSG
- Determine the depth of soil to be amended and assume an effective porosity representative of the volume of amended soil
- Assume that porosity results in a storage volume of stormwater that will infiltrate into the soil at the assumed infiltration rate

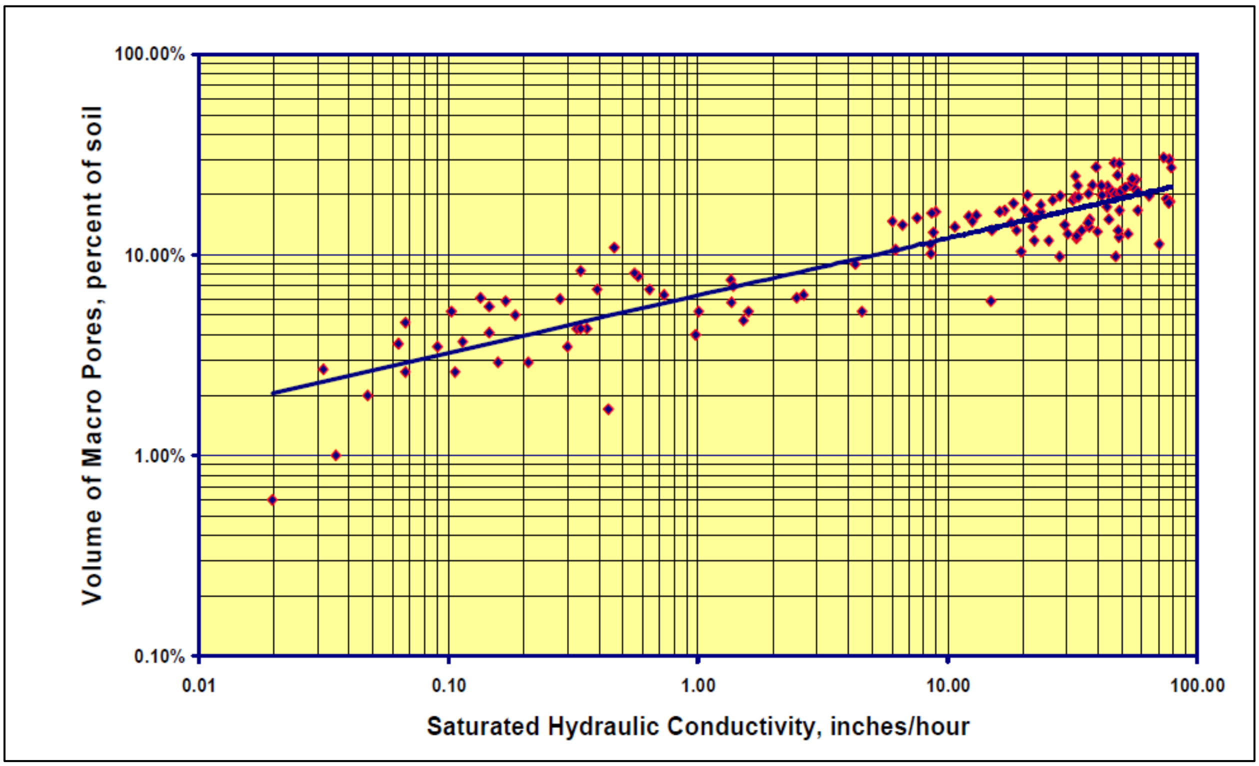


Figure 2. Relationship between Macro Pores and Saturated Hydraulic Conductivity (from Kays 1979)

Kays recommends physical, chemical, and biological amendments incorporated into soil amendment practices. The types of tillage equipment and effective tillage depths are provided in Figure 3 (from Kays 2010). The reductions in storm runoff volumes from a site in Charlotte amended to an effective depth of 9 inches resulted in significant runoff volume reductions. The 2-year storm generated no runoff and the 100-year storm only generated 25 percent runoff from the 8.5 inch storm (Figure 4 (from Kays 2010)).

Types	Blade Diameter Inches	Shank Height Inches	Effective Tillage Depth[a] Inches
Disks	16 – 24[b]		4 – 6
Rotary Tillers	12 – 18[c]		6 – 10
Chisel Plows		20 – 30	8 – 18
Subsoilers		20 – 30	12 – 18
V-Rippers		20 – 30	16 – 20

[a] Effective tillage depth depends upon equipment model, horse power, soil texture, soil moisture, and number of tillage passes. Chisel plows typically have an effective depth of 8 to 12 inches, some can achieve 18 inches. Chisel plows, subsoilers, and rippers all require about 30 Hp per shank to achieve deep effective tillage.
[b] Agricultural disks are commonly 16 to 20 inch diameter.
[c] Large rotary tillers are typical have 12 to 16 inch tines.
***Based upon experience and recommendations of Dr. George Naderman, NCSU.

Figure 3. Types of Tillage Equipment and Effective Tillage Depths (from Kays 2010) [Note the design criteria for this practice assumes that chisel plows, subsoilers, and v-rippers each achieve an effective depth not more than 13 inches.]

Rainstorm Frequency	Rainstorm Amount inches	Runoff Amount inches	Runoff Percent
2 Year	3.75	0.00	0.00
5 Year	4.75	0.08	1.67
10 Year	5.70	0.56	10.47
25 Year	6.40	0.92	15.51
50 Year	7.20	1.28	21.61
100 Year	8.50	1.94	25.46

Figure 4. Runoff Reductions Following Soil Amendment at a Site in Greensboro, NC (from Kays 2010)

- Two studies addressed the effects of site development age on rates of infiltration:
    - Legg et al. (1995) report that physical, chemical, and biological processes will develop pore space and macro pores over time in the soil matrix, and that in increase in pore space results in increased infiltration rates. They also summarize other studies that indicate that lawns with healthy turf coverage are capable of infiltrating light and moderate intensity rain events. Five age classes of lawns were tested in Wisconsin using a rainfall simulator to quantify the effect of lawn age on infiltration rates. The youngest lawns (1 to 3 years) had the lowest infiltration rates (1.1 cm/hr) and the highest bulk densities (1.6 g/cm^3), and the oldest lawns (65 to 70 years) had the highest infiltration rates (5.4 cm/hr) and the lowest bulk densities (1.2 g/cm^3).
    - Hamilton and Waddington (1999) report that construction activities affect soil properties and effect hydrologic characteristics of developed areas. They studied 15 residential lawns in Pennsylvania and collected data on lawn age, lawn quality (visual ranking) and maintenance levels (homeowner survey), infiltration rates (using a double ring infiltrometer), and soil characteristics. The youngest lawns (2 years) had the lowest infiltration rates; the oldest lawns built on disturbed soils (29 and 30 years old) had infiltration rates approaching the undisturbed site (8.5 cm/hr, 9.8 cm/hr, and 10.0 cm/hr, respectively). Site construction practices were also associated with infiltration rates with excavated sites showing lower infiltration rates compared to filled sites.
- Spence et al (2012) conducted a study of residential lawns in the Piedmont area in Cary, NC. This study compared runoff volumes and concentrations of total nitrogen and total phosphorus from high maintenance lawns (aerated, fertilized at 80 percent of recommended rates, and irrigated daily as needed) and low maintenance lawns (fertilized at 64 percent of recommended rates, not aerated or irrigated). The lawns were approximately 35 years old and were comprised of a mix of turf grass and forested areas. Soil bulk density was similar to undisturbed soils for the low maintenance and high maintenance lawns. Given the dry period over which the study was conducted (2007 – 2008), the well-structured soils of the older development, and the degree of canopy cover at the study locations, runoff was minimal from these sites (less than 1 percent of total precipitation). The high maintenance lawn was irrigated daily, but the runoff volume was approximately half that of the low maintenance lawn which was not irrigated. Mean total nitrogen concentrations of 5.67 mg/L and 5.64 were measured for low and high maintenance lawns, respectively. The high maintenance lawns had more variable total phosphorus concentrations (0.28 – 2.43 mg/L) compared to the low maintenance lawns (0.34 – 1.9 mg/L),had a lower mean concentration, and a higher observed maximum. Neither the total nitrogen nor total

phosphorus concentrations were statistically different between the low maintenance and high maintenance lawns. Given that the runoff concentrations were not statistically different, but the runoff volumes differed by a factor of two, the nutrient loading from the low maintenance lawn was approximately twice that of the high maintenance lawn during this study period.

- Bierman et al. (2010) conducted a 3-year study in MN on sites with silt loam and moderate slopes (5 percent) to help promote runoff. The sites did not receive fertilizer treatment, but greater phosphorus concentrations in runoff were higher at sites with poor turf health. Other studies from the Midwest also suggest that well-maintained lawns may have phosphorus losses that are 86-91 percent lower than low maintenance lawns (Kussow 2004).
- Raciti et al (2008) conducted a site-based experiment in the MD Piedmont to determine major mechanisms for nitrogen processing by turf grass, Results demonstrate that turf grass can be a net sink for atmospheric nitrogen.
- Raciti et al (2011) evaluated the mass-balance for nitrogen in turf grass areas representative of suburban lawns. They found that 77 percent of nitrogen input (from fertilizer and atmospheric deposition) was sequestered in the soil and that 13 percent was lost as leachate.
- One study compared the effect of tillage practices (shallow till, ST, 15 cm and deep till, DT, 30 cm) on compacted soils (control, C) in the Piedmont, Coastal and Mountain regions in NC (Brown 2012). Results from the Piedmont site are summarized. Soil physical characteristics were compared for a 20 yr home with an established lawn, a 50 yr pine forest, and an ungrazed meadow
    - Infiltration at the C plots were 6 percent or less. Infiltration significantly improved for both ST and DT compared to C plots where ST ranged from 31-72 percent and DT infiltration ranged from 30-72 percent.
    - Runoff volume reduced by 96 percent or greater for DT plots compared to C plots for all 12 storm events; and reduced at least 83 percent runoff volume for the ST plots
    - 7 of the 12 storm events exported significantly less sediment. Overall, ST and DT produced 6-10 times less sediment compared to the control, respectively
    - Vegetation coverage and slope were additional design variants attributed to the reduction in runoff and water quality
- One study was conducted in Raleigh NC and studied the impacts of tillage practice on percent volume reductions (Haynes et al 2013); this study monitored four sampling events:
    - For deep tillage (20 – 30 cm), the percent volume reduction (as a percentage of precipitation) was reported as 98 percent;
    - For core aeration (1-2 cm) the percent volume reduction was 73.6 percent; the highly compacted nature of the soils at the study area resulted in poor

  - penetration by the aerator; the authors indicate that a heavier aerator would be required to result in proper penetration
  - For native, compacted soils the percent volume reduction was 83.2 percent.
  - The authors hypothesized that the aeration process compacted the soil which is why the native, compacted soil had a higher volume reduction than the soil that was poorly aerated to a depth of 1 to 2 cm.
  - The authors found that establishment of "vigorous vegetation" was critical to the success of the soil amendment
- Two studies were conducted in Wisconsin (Balousek 2003, Olsen et al 2013).
  - Balousek (2003) directly measured runoff volumes from plots with simulated rainfall, looking at two methods of infiltration + compost addition; this study monitored one sampling event at a site with silt loam and silty clay loam soils:
  - Deep tillage to 90 cm at 1.5 meter spacing resulted in percent volume reduction of 54 percent
  - Following deep tillage (as stated above) with chisel plowing with twisted shanks to 30 cm resulted in percent volume reduction of 71 percent
  - Following deep tillage and chisel plowing (as stated above) with incorporation of compost resulted in percent volume reduction of 98 percent
  - Olson et al. 2013 conducted a study at three locations in Minneapolis, WI with urban soils characterized as loam and clay loam soils to evaluate the effect of soil amendment to increase infiltration rates. Each site had a control, a till only, and a till + compost plot. Hydraulic conductivities, bulk densities, and soil strength data were collected at each site. Using Green-Ampt infiltration modelling, compost plot runoff volume was 17 percent of control, and till-only was 33 percent of control runoff volume. No annualized or long-term runoff reduction calculations were attempted. These involved a range of design storms (2-year, 1-hour to 100-yr, 1-hour).
  - Study areas were parks or open fields; turf health and density varied from site to site;
  - Tillage included: "Deep-tillage was conducted by using a subsoiler with two-foot long tines. This machine used larger rubber tires to minimize soil compaction. Ripping was paced at 0.30 m intervals to approximately a 0.55-0.60 m depth. The tree spading machine was used to comingle the soil to a depth of 0.40-0.45 m. 70 mm of compost was added to the soil surface. The compost was produced locally using yard-waste as the feedstock material. The treatment plots were then smoothed with a Harley Rake. The plots were dormant seeded and fenced off from the surrounding area
  - Temporal variations were observed (e.g., effects of freeze/thaw; spring Ksat different from summer Ksat, etc.)
  - Tillage plus composting was an effective treatment at all three sites, but tillage alone was not effective at two sites (i.e., proposed that tillage

destroys macro pore structures in soils); the site where tillage alone was effective was at relatively new construction
    - Neither bulk density not soil strength were good surrogates for Ksat
- One study was conducted in Alabama (Pitt 2002); this study monitored multiple sites over the course of one month and measured the effects of soil type and compaction on infiltration rates, but did not study the effects of soil amendment. Non compacted soils generally had infiltration rates that were an order of magnitude greater than compacted soils.
- Two studies were conducted in Washington State:
    - Kolsti et al (1995) collected monitoring data during 1 to 2 storms over a period of 3 months. Soils at the study sites were comprised of 74 to 81 percent sand and gravel. Percent volume reductions were measured for controls (with tillage) and variants (tillage plus compost) and ranged from 25 percent to 46 percent. Given the low percentage of clays and high percentage of sand and gravel, these data are not directly applicable to the Piedmont, but they do provide supporting evidence that soil amendment can achieve volume reductions. For this study, the permeability of the native soils likely reduced the additional volume reductions compared to monitoring data collected at sites with more clays and silts.
    - Pitt et al. (1999) conducted a six month study where he monitored the impacts of soils amended with two types of compost on infiltration rates and nutrient concentrations. Nutrient data were not presented for individual sites, but rather as averages for all sites. On average, amendment with compost increased the nutrient concentrations at each site, indicating that selection of amendment material is important to manage nutrient loading from soil amended sites.
- Weindorf et al (2006): Seven soils with compost amendments in Dallas, TX were studied with a range of compost depths. Infiltration rate was more strongly affected by soil texture, soil mineralogy, and climatic effects than by the addition of compost.
- Faucette et al. (2004) found that nutrients were exported from most compost-treated research plots (tested poultry residue, wastewater treatment, yard waste organics, biosolids compost, food compost) when compared to mulch or soil-only plots. Link to article: http://www.jswconline.org/content/59/4/154.short
- Virginia DEQ has a compost/tilling spec which goes through the specific design criteria, installation, and maintenance. There is no nutrient credit given, but C and D type soils that receive a compost amendment are given additional volume reduction credits ranging from 30 percent to 50 percent depending on the BMP that the soil is amended for. Source: http://chesapeakestormwater.net/wp-content/uploads/downloads/2014/05/VA_BMP_Spec_No_4_SOIL_AMENDMENT_FINAL_Draft_v2-0_01012013.pdf
- Woltemade (2010) provides data from a study illustrating the effect of soil disturbance on infiltration rates. For example, local disturbances can be a greater influence on infiltration rates than differences between soil series, at least within a single HSG. Further, lawns built before 2000 (approximately ten years prior to

the study) had far higher infiltration rates (measured using a double-ring infiltrometer) than those built after.

- Methods to measure this affect can vary substantially in the estimate of runoff generated. For example, using the CN method based on measured infiltration rates, it resulted in more residential urban lawn runoff than if you just chose a CN based on the native HSG assuming no compaction. (For instance, he showed the 2.5 inch rain event had a 35 percent higher runoff volume than the same neighborhood assuming undisturbed ("by-the-table").
- Residential development can lead to soil compaction that reduces the infiltration capacity of lawns by 80 to 99 percent. On undisturbed soils, using the HSG associated with the soil type is fairly accurate, but for disturbed soils, site specific field tests are needed to understand infiltration rates due to a combination of factors affecting infiltration. Woltemade (2010) recommends site specific measurements using a double ring infiltrometer to reduce error associated with lateral flow (horizontal flow). With this method, the actual field infiltration rate is approximately 10 percent lower than that measured by the double ring infiltrometer.
- In addition to site development age, the quality of the lawn also affected the measured infiltration rate for similar HSG B soils. While the differences in the mean were not statistically significant, lawns with good vegetative cover infiltrated 7.1 cm/hr while lawns with fair vegetative cover infiltrated at a rate of 5.5 cm/hr. Increasing the amount of vegetative cover will likely further increase the infiltration rates associated with soil amendment.

- Carmen (2015) conducted a 21-month study of eight filter strips at existing residential lawns in Durham.
  - Two filter strips (FSs) were installed per house; one per house was tilled (to a depth of 6 to 8 inches (15 to 20 cm)), composted with 1 inch of plant-based compost, limed, and seeded with a local turf seed blend; filter strips were established for three months prior to monitoring
  - Studied effects of slope of lawn, length of run over lawn, and proportion of contributing roof area to receiving lawn area (loading ratio).
  - Loading ratio was the strongest predictor of volume reduction, which ranged from 57 to 99 percent
  - Indicates that lawns that may be a good infiltration-based stormwater control measure and studied the effects of routing runoff from impervious areas onto lawns
  - Little to no linear correlation between volume reduction and infiltration rate, slope, or flow distance; loading ratio showed an r^2 of 0.52
  - Soil amendment did increase infiltration rate and reduce runoff volumes but not consistently, and may do so at the expense of nutrient removal—but results were inconclusive with this particular study).
    - Two sites had no change in runoff depth (control vs. till/amend)
    - Two sites showed improvement.

- Inconclusive results from this study are likely due to the age of the development (~ 50 years old) where the soil structure was already likely healthy
- The following table shows how the Carmen study has been incorporated into the BMP manual draft chapter:

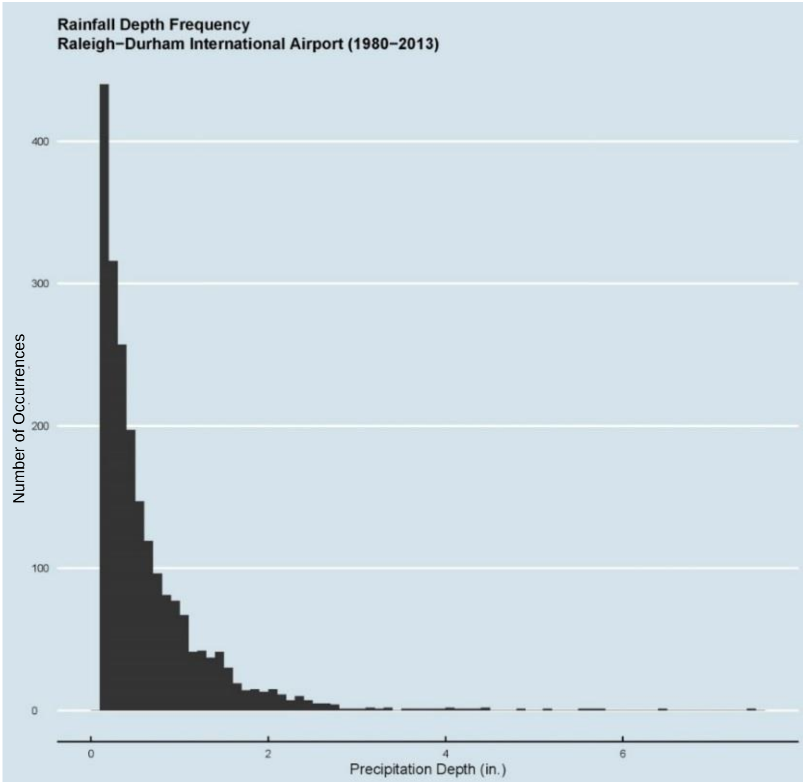
	Type 1 DIS		**Type 2 DIS**		**Type 3 DIS**
Disconnected Roof: Vegetated Area Size	**6′ x 12′**		**12′ x 24′**		**12′ x 24′ & site BUA < 24%**
Disconnected Paved Area: Vegetated Area Size	**10′ width**		**15′ width**		**15′ width & BUA < 24%**
Hydrologic soil group	A/B	C/D	A/B	C/D	A/B only
Runoff reduction credit	45%	30%	65%	50%	100%
TSS reduction credit	45%	30%	65%	50%	85%
TN reduction credit	30%	30%	30%	30%	30%
TP reduction credit	35%	35%	35%	35%	35%

- Additional consideration for the practice of soil amendment needs to consider existing soil phosphorus content (P-index) and how the soil amendment will affect how much phosphorus the soil will retain. The P-index is going to be an important factor to consider for the effect of soil amendment on a P credit. Furthermore, crediting will need to be associated with maintenance procedures like grass clipping, fertilization, compaction, etc. that affects the mobility or source contributions of P. For example, liming to reduce the acidity of soils makes soil-bound P available for plant uptake. However, this can have some stormwater consequences if done on soils with a high background P-index. Iyamuremye and Dick (1996) provide information on the phosphorus and liming complex.

Estimation of Runoff Reduction

To estimate the runoff reduction associated with volume reduction practices, Extension Associates at the North Carolina State University Department of Biological and Agricultural Engineering analyzed 60-minute precipitation data collected by the National Oceanic and Atmospheric Administration (NOAA) at the Raleigh-Durham International Airport from 1980 to 2013 to generate a precipitation time series for this period. Separate storms were identified by 6-hour periods during which no rainfall occurred. The frequencies and cumulative distributions for storm depths are shown in Figure 5. These observed storms were then compared to the depth of water that could be stored in amended soil to estimate the amount of water that would runoff off during each storm. Annual totals for precipitation, storage (subject to infiltration and evapotranspiration), and runoff were calculated for each year during the period of record, and these values were then used to estimate average annual runoff reductions associated with infiltration of specific storm depths (Figure 6).

These precipitation-based estimates of annual runoff reduction are lower, and thus more conservative, than values produced by modeling done for comparative purposes using the Water Quality Capture Optimization and Statistic Model developed by the Urban Watersheds Research Institute. This is likely because 1) the precipitation analysis assumes that all of the precipitation reaches the improved area instantaneously and 2) the precipitation analysis does not account for hydrologic losses due to evaporation or transpiration. While the precipitation-based analysis does not account for antecedent soil moisture conditions, its overall more conservative credit estimates relative to a more comprehensive model are very defensible.



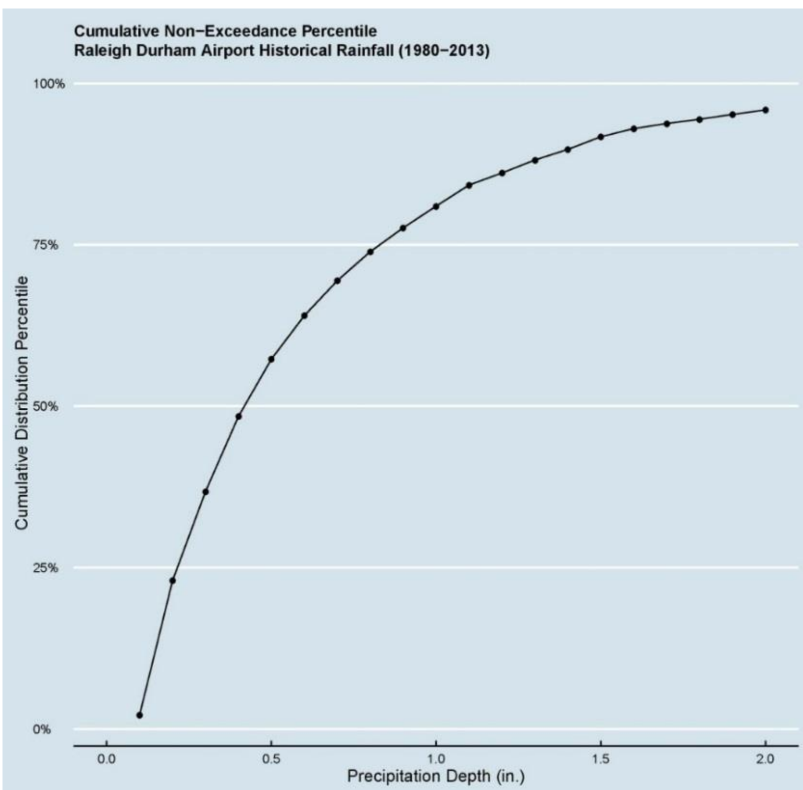


Figure 5. Rainfall Depth Frequencies and Cumulative Distribution for Storms Observed at RDU Airport from 1980 to 2013. (Data Source: NCDC)

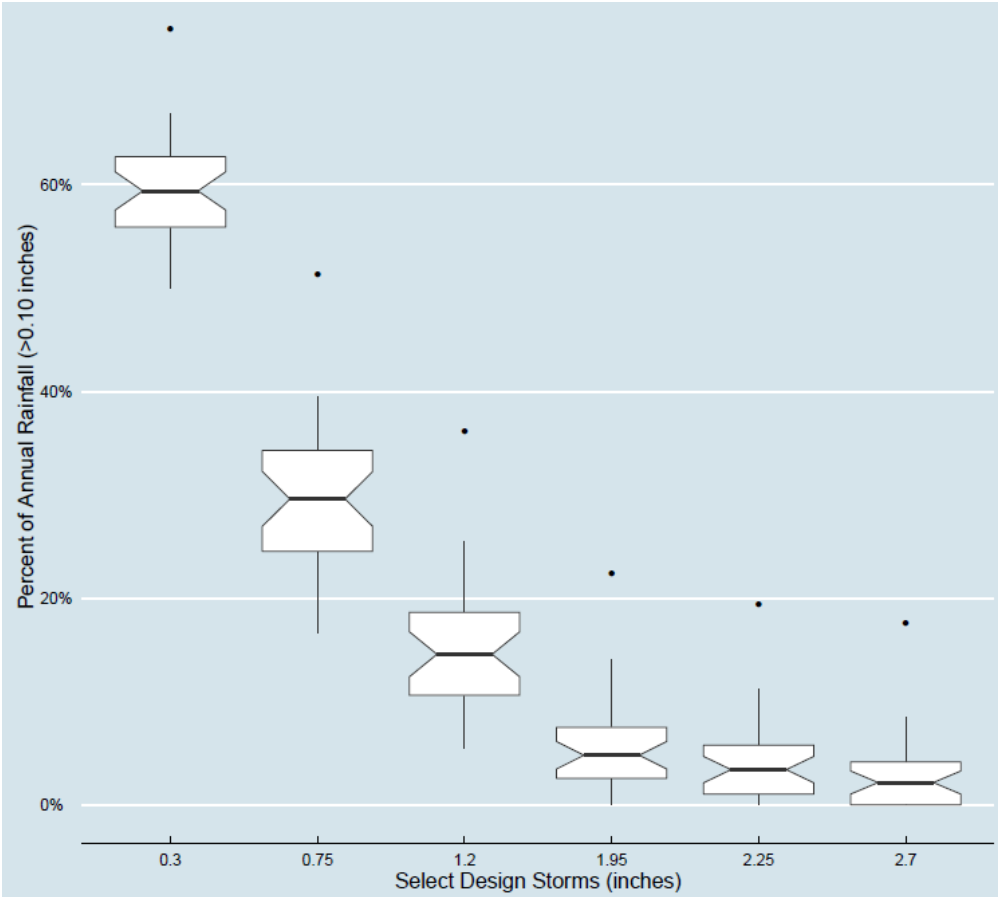


Figure 6. Percent Reduction in Annual Runoff Volume for Design Storms Associated with Stored Precipitation in Amended Soils