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Compost Blankets for Erosion Control and Vegetation Establishment

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Research and Technology Transfer Section
MassDOT Office of Transportation Planning

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Project Champions - Stephanie Smoot and George Batchelor, MassDOT

16. Abstract
This research examined how and whether blanket applications of 1–3 inches of compost over bare soil can improve slope stabilization and whether such applications can aid in the establishment of native grasses and forbs, particularly for sloping roadside conditions on Massachusetts Dept. of Transportation (MassDOT) jurisdictional roadways. The research included a literature review, interviews with transportation engineers and other professionals with compost blanket and seeding expertise, and the evaluation of five MassDOT construction projects where compost blankets had been applied. Overall, the research found compost blankets to be highly effective at reducing erosion on slopes. The site evaluations, conducted two to three years after the application of compost and seed, found that erosion was limited to locations where concentrated flow occurred. Establishment of the native grasses and forbs seeded as part of the compost application was determined to be generally successful. This report includes recommendations for site preparation, particle size distribution of compost material, depth of compost with regard to slope steepness, specific cover crops to be included in the seed mix, recommended seeding dates, monitoring during seeding establishment, and mowing guidelines to improve establishment after seeding.

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Compost Blankets for Erosion Control and Vegetation Establishment

Final Report

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The Project Team would like to acknowledge the efforts of project champions Stephanie Smoot and George Batchelor for their helpful comments, suggestions, and consistent guidance throughout the project.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Massachusetts Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Executive Summary

This study of “Compost Blankets for Erosion Control and Vegetation Establishment” was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

A literature review was conducted to answer the primary research question: how do compost blankets affect slope stabilization and native grass and forb establishment along roadsides? The literature search was focused on U.S. states with similar rainfall and plant hardiness zones to the state of Massachusetts, with exceptions for specific research issues. Based on the literature reviewed, it was found that site preparation, compost blanket composition, compost blanket depths, seed mix, time of seeding, and management after seeding all affect slope stabilization, erosion control and native grass and forb establishment along roadsides.

Site preparation prior to compost and seed application has important effects on subsequent slope stabilization, erosion control and vegetation establishment. Improper site preparation can cause erosion, gullying, and seed-wash-out all resulting in an unsuccessful project. Compost particle size distribution is the most important characteristic affecting soil erosion with erosion decreasing with higher percentages of larger woody particles. The literature, however, was not conclusive on the effect of particle size distribution on seed germination.

Compost blanket depth directly relates to slope stabilization and soil erosion control. As the compost blanket depth increases, soil erosion is reduced. The compost blanket depth necessary to control soil erosion is influenced by the slope grade and the amount and intensity of rainfall the site receives. Compost blanket depths of 1–2” (2.5–5 cm) have been found to reduce soil erosion on slopes up to 2:1.

Compost blankets are far less effective at reducing soil erosion when they are exposed to concentrated surface water inflow. If concentrated surface water is expected to enter a compost blanket, additional erosion control measures should be used.

Importantly, no research was found that tested the factors affecting native grass and forb establishment when seeded in conjunction with a compost blanket.

Seed mixes should consist of a mixture of native grasses and forbs including a mixture of short-lived, quick-to-establish species and long-lived, slow-to-establish species. Native grasses/forbs can provide additional erosion control and habitat benefits that are not provided by standard roadside turfgrass.

Seeding timing has been shown to have significant effects on vegetation establishment, with native forbs preferring dormant-fall seeding and native warm-season grasses preferring spring seeding.

Regular inspection and maintenance of sites treated with compost blankets and native grass and forb seedings after installation is crucial to long-term success. In the first year, it is recommended that sites be checked for washout after significant rainfall events. Additionally, they should be checked periodically for the presence of invasive species, so that appropriate management actions can be taken, including hand weeding, or herbicide treatment. The most important maintenance activity for native grass and forb plantings is appropriately timed mowing.

An interview survey of general practices was conducted with MassDOT and other roadside/landscape officials and native vegetation experts from Northeastern, Midwestern, Southern and Western States. The interviews found that compost blankets are commonly used in roadside projects for slope stabilization and erosion control, often in conjunction with cool season turfgrasses. Interviews revealed the fact that compost was used less commonly in other states for warm season grass and forb establishment because of variable interest in the use of native species, lack of expertise with establishing warm season grasses and the time required for establishment. Interviews identify increasing awareness of the benefits of native species, including deeper roots for slope stabilization, support for biodiversity, including pollinators, and long-term reduced mowing opportunities.

Compost blankets 2–3” deep were found to successfully reduce soil erosion and help stabilize slopes. Pneumatic blowers are recommended for compost application to avoid soil compaction, however mechanical spreading with dozers or tractors is the most commonly employed compost blanket application method at present.

Interviews confirmed that native warm season grasses are well adapted to roadside conditions (sun, heat, drought). Warm season grasses were noted particularly for their erosion-control functionality, due to their dense, extensive root systems once they have become fully established (after two to five years). Interviews found that warm season grasses are used less commonly with compost treatments in other states, largely because of establishment challenges and variable interest in native plantings.

Native grass and forb mixes were reported to effectively stabilize slopes and reduce erosion on roadside slopes up to 3:1. Nurse crops are consistently recommended along with native grasses and forbs – species and species proportions in seed mixes should be tailored to match site environmental conditions.

A variety of seeding methods are currently practiced in conjunction with compost blankets including broadcast seeding underneath compost blankets, broadcast seeding on top of compost blankets, and mixing seed into compost then spreading the seed/compost mixture as a compost blanket. The consensus from interviewees is that seeds are best applied with a pneumatic blower, mixed with compost as a thin separate/top layer (0.5–1”) on top of a thicker base layer of compost has already been applied.

This study researched five MassDOT highway projects that have incorporated compost blankets and native seeding, and that have been completed within the past five years (Conway, Deerfield, Longmeadow, Danvers, Waltham). These sites were evaluated for effectiveness of compost blankets in stabilizing slopes and whether they aided in the establishment of the seeded native grass and forb vegetation.

Site evaluations conducted in this research found that 1–2.5” compost blankets—when vegetated with native grasses and forbs can effectively stabilize steep roadsides with up to 2:1 slopes, after the seeded vegetation was established. Compost blankets likely increased soil cation exchange capacity, organic matter content, and macronutrient levels at the four sites where compost was determined to have been applied. While this in turn likely increased the establishment of the seeded native species, it also likely increased the establishment of non-seeded species that colonized the sites.

Frequent mowing of naive grass and forb plantings according to a cool season turf schedule was observed to decrease native grass and forb ground cover. Instead, mowing of established native grasses and forbs should be done according to a warm-season grass mowing regime—with only one annual, or biannual mowing after establishment.

Post-seeding maintenance activities such as reseeding bare ground and spot application of herbicide was found to increase desirable vegetation established and reduce the presence of exotic species. Also, the surrounding land use matrix was observed to affect native grass and forb establishment and site colonization by invasive species. In general, sites surrounded by land less affected by human impact face lower rates of invasive species colonization and increased establishment of desired species.

In summary, the five case studies from this research project illustrate the capacity of 1–2.5” compost blankets to reduce erosion, stabilize slopes, and aid the establishment of native grasses and forbs. These five case studies alone are not sufficient to draw more specific conclusions regarding the optimum compost blanket depth within the 1–2.5” range for both erosion control and native grass and forb establishment. This would require more controlled and replicable experimentation. Additionally, the optimum depth is likely to change based on such site characteristics as slope and moisture regime.

Recommendations for compost blanket application and native grass and forb establishment were developed based on the literature review, interviews, and site observations conducted specifically for this research project. The recommendations include specifications/guidelines for: site preparation, compost composition and application, and seeding application, post-seeding monitoring and management and evaluation.

Regarding future research, recommendations include the use of alternatives as part of standard MassDOT project specifications, implemented as part of selected construction contracts, and monitored/observed by MassDOT staff or subject experts. In this way selected MassDOT projects could have an explicit experimental component. This would require keeping detailed notes and data on the project.

A more ambitious research program would be to design specific experimental treatments, following rigorous experimental design protocols including randomized/replicated alternative treatments. For these experiments, scientists would be needed for experimental design, observation of field work, record keeping and monitoring, and evaluation and assessment of results. This could include building MassDOT-staff expertise in the area of native species horticulture and ecology. Having a qualified staff person with available time to monitor project construction and to perform systematic observations on results and outcomes of native plantings associated with compost applications (and other roadside project-related topics) could provide opportunities to research alternative practices and materials that are beyond the scope of this project to address, but with the potential to lead to improved project success.

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List of Acronyms

Acronym	Expansion
AASHTO	American Association of State Highway Testing Officials
BMP	Best Management Practices
CEC	Cation Exchange Capacity
DOT	Department of Transportation
FHWA	Federal Highway Administration
MassDOT	Massachusetts Department of Transportation
PLS	Pure Live Seed
PVC	Polyvinyl Chloride
ROSAP	National Transportation Library’s Repository and Open Science Access Portal
SPR	State Planning and Research funds
TRID	Transportation Research International Documentation

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1.0 Introduction

1.1 Overview

This study of Compost Blankets for Erosion Control and Vegetation Establishment was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

The research conducted for this project was organized as three distinct research tasks (Literature Review, General Practices Interview Survey, and Case Study Site Visits and Evaluations). The results from the three research tasks were integrated as recommended "Best Practices and Specifications." Each of these research components are described as follows.

1.2 Literature Review

Interest in compost blankets has increased over the last few decades for their erosion control potential, and many state's Department of Transportation have been documented using them. Several years ago, the Massachusetts Department of Transportation (MassDOT) began using compost blankets in conjunction with seeding on certain transportation projects. The goal of this project is to investigate the potential and actual performance of compost blankets with regards to stabilizing slopes, controlling erosion, and establishing native grass and forb vegetation in roadside locations. MassDOT is increasingly using native grasses and forbs as an alternative to conventional cool-season grasses for general roadside use, as well as for roadside slopes that are less likely to be mowed.

A literature review was conducted to answer the primary research question: How does the use of compost blankets affect slope stabilization and native grass and forb establishment along roadsides?

Secondary research questions were created that help answer the primary inquiry. These secondary questions are:

- How does site preparation of newly graded roadsides prior to compost and seed application affect soil erosion and native grass and forb establishment?
- How do the physical and chemical characteristics of compost used for compost blankets affect soil erosion and native grass and forb establishment?
- How do compost blanket application methods such as timing, depth, and application equipment affect soil erosion and native grass and forb establishment?

- How do various site characteristics such as slope grade, slope length, and annual rainfall affect soil erosion and native grass and forb establishment in a compost blanket?
- How are native grass and forb seed mixes designed, and how does the ratio of different plant groups and species affect vegetation establishment?
- How do seeding application methods such as seeding timing, application rates, and planting depth affect native grass and forb establishment?
- What are the recommendations for compost blanket and native grass and forb maintenance post application/seeding, and how do these affect soil stabilization and native grass and forb establishment?

Much of the reviewed literature comes from outside of New England (New England constituting Massachusetts, Rhode Island, Connecticut, New Hampshire, Vermont, and Maine) and therefore some of the "native" species described in the examined studies may not actually be native to New England.

For the purposes of this study, a species here considered native to New England if naturally occurring wild populations of the species are present in one or more New England states. If naturally occurring wild populations of a species are not present in any of the New England States, then that species is considered exotic to New England. A plant's Latin binomial will either be followed with a superscript N if it is native to New England (*Elymus virginicus*^{N}) or a superscript E if it is exotic to New England (*Lolium perenne*^{E}). If a study references a plant at species level and multiple subspecies exist, superscript N+E will be used when some of the subspecies are considered native to New England and others are considered exotic to New England.

As a final note, many species that are marked as native to New England do not occur throughout the entire region. Many such species are confined by habitat or temperature to specific areas within the New England Region. Therefore prior to identifying/selecting a species as native for use in a MassDOT planting, search the Native Plant Trust's GoBotany website (https://gobotany.nativeplanttrust.org/search/?q=baptisia+tinctoria) to determine if the species being considered is native to the area it is to be used.

1.3 General Practices Interview Survey

About five years ago, the Massachusetts Department of Transportation (MassDOT) began using compost blankets seeded with native grasses and forbs on select highway projects to stabilize slopes and establish native vegetation. Compost blankets are a relatively new practice employed by MassDOT, and more research is required to determine the degree to which the compost blanket and native seeding specification is successful in achieving the goal of stabilizing slopes and allowing for successful establishment of seeded native grasses and forbs along roadways.

This report presents the results of interviews conducted with DOT roadside/landscape experts from Northeastern US states and other states with climatic conditions similar to Massachusetts, with follow-up interviews with other DOT officials and interviews with recommended experts and academic researchers added. A total of 17 interviews were conducted.

Interview questions were developed by the research team and approved by the Project Champion. Suggested interview subjects were requested, and received, from the Project Champion. In the course of the interviews, the research team was referred to other DOT experts by interviewees in many cases based on knowledge that these subjects had more direct experience with roadside compost use and/or experience with roadside establishment of native grasses and forbs. Likewise, additional private-sector interview experts were recommended from the native plant seed industry and landscape contracting industry.

The interview findings are organized according to the main stages/topics involved in the use of compost blankets for erosion control/slope stabilization and to aid in the establishment of native grasses and forbs.

1.4 Case Study Site Visits and Evaluations

This research component reports on an evaluation of five specific completed MassDOT projects that used compost blankets and native grass and forb seed on sloped roadsides to determine how well they performed to stabilize slopes, reduce erosion and aid in the establishment of native grasses and forbs - and to use this evaluation to recommend changes to improve current MassDOT specifications.

This study examines five MassDOT projects as case studies. The five case study sites examined are: Longmeadow, Route 5; Deerfield, Interstate Route 91; Conway, Route 116; Waltham, Interstate Route 95; and Danvers, Route 1. The sites are distributed across the state and were chosen for sharing the presence of moderate to steep slopes, application of compost blankets, native grass and forb seeding, and similar seeding dates. Detailed satellite maps (Google Earth) and site maps for each project show the surrounding land use context within which each project is located.

Field work including site visits, soil testing, and vegetation analysis was conducted in May and Aug. 2019. Site visits were conducted to visually inspect for signs of erosion and slope stabilization. Soil testing was carried out to physically and chemically describe each site’s soils, including the compost layer. Vegetation analysis was conducted to determine the vegetative community composition and density and compare species present to those that were intentionally seeded.

1.5 Summary of Recommendations

The findings of the Literature Review, General Practices Interview Survey, and Case Study Site Visits and Site Evaluations were integrated into the Recommendations. These recommendations are referenced in the text to the respective source(s): (LR = Literature Review, I = General Practices Interview Survey, and SE = Case Study Site Visits and evaluations). Often, these recommendations are presented with acceptable alternatives in the case that they are not feasible to adopt within the context of current MassDOT policy and practice.

2.0 Research Methodology

2.1 Literature Review

The scope of this literature review is to review the available literature on parameters affecting the effectiveness of compost blankets to stabilize slopes, reduce soil erosion and to support establishment of native grasses and forbs on roadside projects. Literature sources used include the following literature sources: peer reviewed journal articles, conference papers, final reports, books, and academic theses. The time period of sources considered was open to any publication date. In interpreting how the literature applies to the research questions, several premises were applied.

1. That compost blankets will be used as a tool on recently regraded roadsides, following the completion of construction activities including earthwork/regrading.
2. These roadsides may be surfaced with regraded topsoil from the site or with imported topsoil.
3. Both regraded topsoil and imported topsoil can have different chemical and structural properties compared with the site's native, undisturbed soil *(1)*
4. The composition (organic content, C:N ratio, pH, nutrient profile) and depth of the compost blanket will affect vegetation establishment.
5. Geography/Climate: Along with varying altered soil characteristics, climatic factors such as temperature and precipitation become the dominant uniform factors affecting vegetation establishment from seed along Massachusetts roadsides. Precipitation is also one of the dominant forces affecting slope stability and causing soil erosion in Massachusetts. Therefore, this literature review is limited to research carried out in states with similar plant hardiness zones and yearly precipitation totals as those found in Massachusetts. Specifically, states must share a minimum of two USDA Plant Hardiness zones with the Commonwealth of Massachusetts and must receive average annual precipitation within +/- 15" of average annual precipitation for the State of Massachusetts. Table 2.1 summarizes the states that meet these criteria.
    a. One exception was made for a pair of studies conducted by in Wisconsin, outside of this review's geographic range *(2, 3)*. These two studies provide information on the mechanism of compost blanket erosion control under concentrated surface water inflow conditions. None of the studies found within this review's geographic range investigated this. Additionally, this exception is justified because this review's geographic range is based on the effect precipitation has on compost blanket erosion control, and the combined effect of precipitation and temperature on plant establishment. Since this study examined simulated concentrated surface water inflow conditions and did not involve vegetation establishment, the results are applicable to the Northeastern region.

Table 2.1: Geographic area of interest

State	Precipitation *	3b **	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b	9a
Massachusetts	47.68” (121.11 cm)				5a	5b	6a	6b	7a	7b			
Alabama	58.27” (148.01 cm)								7a	7b	8a	8b	9a
Arkansas	50.57” (128.45 cm)							6b	7a	7b	8a		
Connecticut	50.34” (127.86 cm)					5b	6a	6b	7a				
Delaware	45.68” (116.03 cm)								7a	7b			
Georgia	50.66” (128.68 cm)						6a	6b	7a	7b	8a	8b	9a
Illinois	39.23” (99.64 cm)				5a	5b	6a	6b	7a				
Indiana	41.72” (105.97 cm)					5b	6a	6b					
Iowa	34.03” (86.44 cm)			4b	5a	5b	6a						
Kentucky	48.90” (124.21 cm)						6a	6b	7a				
Maine	42.21” (107.21 cm)	3b	4a	4b	5a	5b	6a						
Maryland	44.54” (113.13 cm)					5b	6a	6b	7a	7b	8a		
Michigan	32.79” (83.29 cm)		4a	4b	5a	5b	6a	6b					
Missouri	42.15” (107.06 cm)					5b	6a	6b	7a	7b			
New Hampshire	43.41” (110.26 cm)	3b	4a	4b	5a	5b	6a						
New Jersey	47.08” (119.58 cm)						6a	6b	7a	7b			
New York	41.80” (106.17 cm)	3b	4a	4b	5a	5b	6a	6b	7a	7b			
North Carolina	50.34” (127.86 cm)					5b	6a	6b	7a	7b	8a	8b	
Ohio	39.09” (99.29 cm)					5b	6a	6b					
Oklahoma	36.51” (92.74 cm)						6a	6b	7a	7b	8a		
Pennsylvania	42.87” (108.89 cm)				5a	5b	6a	6b	7a	7b			
Rhode Island	47.94” (121.77 cm)					5b	6a	6b	7a				
South Carolina	49.78” (126.44 cm)								7a	7b	8a	8b	9a
Tennessee	54.18” (137.62 cm)					5b	6a	6b	7a	7b	8a		
Vermont	42.73” (108.53 cm)	3b	4a	4b	5a	5b							
Virginia	44.30” (112.52 cm)				5a	5b	6a	6b	7a	7b	8a		
Washington	38.44” (97.64 cm)		4a	4b	5a	5b	6a	6b	7a	7b	8a	8n	9a
West Virginia	45.16” (114.71 cm)				5a	5b	6a	6b	7a				

*Average annual precipitation between 1971 and 2000 *(4)*. Annual Precipitation within 15” of Massachusetts = 32.68–62.68”

**USDA Plant Hardiness Zones by state as of 2012 *(5)*.

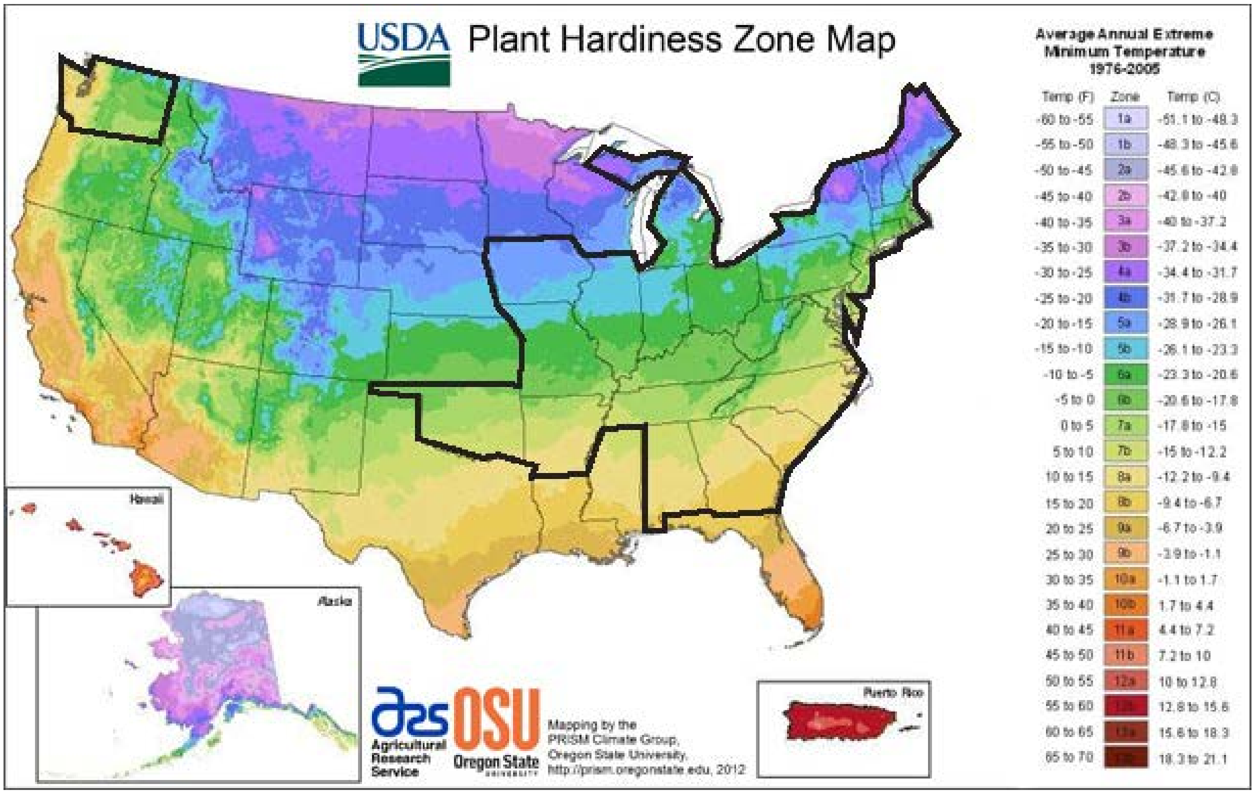

Figure 2.1: Geographic area of interest

The Transportation Research International Documentation (TRID) database (combines TRIS and ITRD databases), Google Scholar, National Transportation Library Repository and Open Science Access Portal, Academic Search Premier, AGRICOLA, and GreenFILE databases were used in the literature search.

TRID was chosen because it is a premier database specific to transportation research, combining records from the Transportation Research Information Services Database and the Organization for Economic Cooperation and Development's Joint Transport Research Centre's International Transport Research Documentation Database. Google Scholar was chosen for its breadth of material, searching various types of publications across many different disciplines. TRID and Google Scholar are the two search engines specifically recommended by the Transportation Research Board (TRB) for the purpose of transportation literature searches *(6)*.

As comprehensive as TRID and Google Scholar are, however, it must be acknowledged that not all relevant material may be found in these two databases. In order to be more thorough, this research conducted a review of the National Transportation Library's Repository and Open Science Access Portal (ROSAP), Academic Search Premier, AGRICOLA, and GreenFILE. ROSAP was chosen because it is a transportation-specific database, collects transportation related resources and emphasizes USDOT, state DOTs, and other transportation organizations publications. Academic Search Premier examines 4,600 journals across a range of disciplines, helping to locate relevant research outside of transportation related fields. AGRICOLA was added because it searches the USDA's National Agricultural

Library, and the agricultural field has long been interested in the uses of compost and the reduction of soil erosion. Lastly, the study included GreenFILE, a database collecting research on all the ways humans impact the environment.

Database searches were conducted using keywords chosen based on the research questions and informed by preliminary database searches to test if keywords appeared to generate relevant results. The keywords were assigned as either primary keywords or secondary keywords . The primary keywords used were "compost blanket," compost, and "compost application." The secondary keywords used were "erosion control", "soil erosion," "slope stabilization", stabilization, roadside, highway, "right-of-way," revegetation, vegetation, "native plants," "native grasses," "native forbs," and wildflowers.

All databases were first searched with primary keywords. If this search returned over 500 results, secondary keywords were combined with primary keywords to narrow the results to below 500 results. After primary keyword combinations were exhausted, secondary keywords were searched in varying combinations. As before, keyword combinations that generated over 500 results were modified to reduce the number of search results to below 500. A database search was considered exhausted and searching stopped after five consecutive searches with varying keyword combinations yielded no new, relevant citations.

After completing the primary and secondary keyword searches above, the abstract or summary of each result was reviewed to determine relevance. Relevant results were imported into Refworks, a bibliographic citation manager, for later analysis and synthesis after the literature search was completed.

2.2 General Practices Interview Survey

The interview questions below were developed in consultation with the MassDOT Project Champions. The list of interviewees was initially suggested by George Bachelor, and subsequently expanded to include all of the New England states, and included additional interviewees that were suggested by the initial interviews. Summary notes on each interview were written and consulted to draft findings.

2.2.1. Interview Questions

<u>Do you use compost blankets/compost topsoil for slope stabilization?</u>

- [If yes]
    - For what types of application do you use the blankets?
    - What methods are used for application?
    - For example, what thickness?
    - Do you till into the subsoil, or prepare subsoil in any way?
    - What successes and challenges have you encountered? Like erosion? And how did you respond to these challenges?

    - What are key factors for success of the application?
    - Do you have specifications that you could share?

- [If no]
    - What methods do you use for stabilization?
    - What successes and challenges have you encountered?
    - What are key factors for success of the application?

<u>What type of seeding do you use for steep slope establishment?</u>

- Cool season grasses?
- Warm season grasses?
- Cover or nurse crops?
- Native forbs?
- What types of soils in your experience are optimal for establishment of native grasses and forbs?
- What types of slope stabilization have you used in conjunction with native grass and forb seeding?
- Have you applied native seeding in areas where you have used compost blankets/compost topsoil, and if so,
    - How are the seeds applied? (mixed? Under compost? Over compost?)
    - how did that work?
- What factors of slope stabilization contribute to the success of establishing native grasses and/or forbs?
- Do you have specific requirements for the dates of seeding?
- How/when do you evaluate seeding success?
- What kinds of maintenance do you do after seeding?
- Do you have specifications that you could share?

<u>We are interviewing DOT's in New England, as well as other states, and recommended experts – is there anyone you could recommend that we interview?"</u>

2.2.2. Interview Subjects

<u>Northeast DOT Experts</u>

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2.3 Case Study Site Visits and Evaluations

2.3.1. Site Selection

MassDOT provided a list of candidate roadside project sites that used compost blankets in conjunction with native grass and forb seeding to establish vegetation and control erosion along roadsides. A total of five project sites and a sixth alternate site were selected as field research sites based on several shared key characteristics: year of planting was between 2015 and 2017, all used compost blankets (depths varying 1–2.5”), all had significant slope conditions, and all were planted with native grass and forb seed mixes. Longmeadow, Deerfield, and Conway were each planted with Restoration Mix Item 764.5 (see Appendix for seed mix specs). The Danvers site was divided up into three different planting areas (see Appendix for Danvers Planting Plan) and each was planted with a different seed mix. These seed mixes were Restoration Mix Item 764.5 (modified from the version used at Deerfield and Conway), Infiltration Basin/Swale Mix Item 765.457, and Wildflower Mix Item 765.71. Waltham received a custom seed mix designed by the contractor titled “3rd Avenue Slope.” See Appendix 7.1 for seed mix specifications.

The Westwood site was ultimately rejected due to the absence of any signs of compost at the site and an inability to independently confirm from DOT personnel involved in the project installation that compost was indeed applied as indicated in the construction documents. The remaining five sites used in this report are Longmeadow, Deerfield, Conway, Waltham, and Danvers and their characteristics are summarized in Table 2.2.

Table 2.2: Study site characteristics

Site Name	MassDOT Project #	Date of Visits	Reported Slope*	Measured Slope**	Planting Date	Solar Aspect
Longmeadow, Rte. 5	605886	5/16/19, 8/7/19	4:1	5:1, 7:1	8/2015	NW
Deerfield, I-91	603478	5/16/19, 8/8/19	3:1, 2:1	50:1, 3:1	11/2016	N, E, NW
Conway, Rte. 116	606705	5/17/19, 8/7/19	3:1	5:2, 3:1	2015	S, SE
Waltham, I-95	permit	5/23/19, 8/6/19	-	7:2	2016	W
Danvers. Rte. 1	608131	5/23/19, 8/6/19	2:1	5:2, 4:1	11/2017	Predominantly S

*Reported slope provided by MassDOT for the project.
**Measured slope found and measured during site visits to the project. Sites that lacked a uniform slope were measured in two places and recorded separately.

2.3.2. Soil Sampling and Analysis

In May 2019, soil and erosion inspection and testing were carried out at each of the five field research sites selected. Mid-spring was chosen for these site inspections because the vegetation was low and without a closed canopy, thus aiding in the observation/assessment of signs of erosion on the sites. The Longmeadow and Deerfield sites were visited on May 16, 2019. The Conway site was visited on May 17, 2019. The Waltham and Danvers sites were visited on May 23, 2019. Soil and erosion inspection were conducted according to the following procedure.

1) A field sketch was made to show each site’s characteristics and landmarks. A visual survey of the site determined existing landscape variability. If significantly variable, the site was separated into sample areas. Selected slopes were measured using a string/line level and tape measure to determine broad slope categories (e.g., 3:1, 2:1, 1:1) and included on the field sketch. Photos were taken to show site characteristics and features.
2) Two soil samples were collected from each field site; locations were noted on the field sketch. One sample was collected from a typical/representative location including only the organic/compost layer and soil 2” to 3” below the compost (this location was flagged). The other sample was an aggregate of 12 soil samples collected from the entire site at a depth of six to eight inches using a soil probe. All 12 probe samples at each site were placed in a bucket. Within the bucket, clods, stones, roots, and debris were removed, and the probe samples were mixed. From the mix a single cup of soil was gathered for laboratory analysis.
3) The soil samples were taken to the Bayer lab at UMass Amherst where they were spread out and air-dried. After drying they were placed in a new zip-locked bag labeled with the sample ID#.
4) Samples were then taken to the UMass Amherst Soil Testing Lab for analysis.
    a. Routine soil test

b. Organic matter
c. Particle size analysis
d. Distribution Curve
e. Total Soil Carbon and Nitrogen (the UMass Soil Lab was unable to perform the C:N analysis due to an equipment problem, therefore the University of Maine completed this test.

5) At each site a soil profile was exposed by digging an 18” deep hole. The Longmeadow, Conway, and Danvers sites contained a hardpan or rock layer within the top 18” of soil that the shovel could not penetrate. In these instances, the soil profile down to the depth of the limiting layer was exposed. Soil profiles were then photographed and described using field analysis/description for soil texture and color. These soil pit locations were flagged.
6) Soil temperature and air temperature were recorded for each sample site using a Wet Sensor.
7) Aspect of the slope was recorded.
8) Soil conductivity was tested.
9) Bulk density was tested using the on-site sand cone method at the site. The excavated soil was brought back to UMass for weighing and drying. The procedure followed is described in the following specifications:
http://www.state.in.us/indot/files/Earthworks_Chapter_11.pdf
https://www.dot.ny.gov/divisions/engineering/technical-services/technical-services-repository/GTM-9b.pdf
10) Erosion inspection: Each site was traversed on paths perpendicular with the slope, starting at the top of the slope. The paths were repeated at intervals of approximately 20’ to cover the entire site. Any visual evidence of current or past erosion was photographed and flagged with survey flags. Soil samples were collected and analyzed from the site, as described above, including locations of significant erosion when present, and were noted for specific vegetation analysis during the vegetation assessment phase of this research. Also noted were deposits of eroded material at the base of the slope.

2.3.3. Vegetation Sampling

In Aug. 2019, vegetation sampling was carried out at each of the five field research sites. This sampling was scheduled during late-growing-season to observe near-fully grown vegetation, with flowering and/or seedhead maturation. The late-season sampling allowed for reliable species identification when diagnostic features are present. The Waltham and Danvers sites were visited on Aug. 6, 2019. The Conway site was visited on Aug. 7, 2019. The Longmeadow and Deerfield sites were visited on Aug. 8, 2019.

A 1 m^2 PVC frame equipped with a 10 cm grid of fishing-lines in perpendicular directions was used for the sampling (Figure 2.2). This 1 m^2 frame, with 100, 10 cm x 10 cm squares defined by the fishing line, allowed for accurate estimates of percentage cover for the upper/canopy layer, as well as the groundcover layer, by species. Quadrat locations were determined by the Field Botanist to represent the typical range of vegetative conditions present. GPS coordinates for each quadrat site were recorded. The number of quadrats measured at each site ranged from 4 to 17 quadrats. The number of quadrats deemed necessary to accurately reflect the vegetative community at a site was determined in the field by the field botanist after taking into consideration the site's size, vegetative diversity, and the distribution of vegetative diversity across the site. At each site, one of the quadrats was sampled at the location of the soil pit dug/flagged during the May site visits.

Figure 2.2: 1 m^2 vegetation sampling grid

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3.0 Results

3.1 Literature Review

3.1.1. Site Preparation Prior to Compost and Seed Application

Proper site preparation prior to compost and seed application is a critical component to the successful control of erosion and establishment of native grass and forb communities. Topsoil sourcing, soil surface tracking, fertilization, and pre-planting weed management have important implications affecting the performance of roadsides following the completion of construction activities *(7-16)*.

3.1.2. Topsoil and Weed Seed Management

After typical roadside construction is finished, topsoil is re-applied and the roadside graded. Sometimes this topsoil originates from the same roadside site, having been removed and stockpiled/re-spread during construction activities. Other times topsoil is imported from off-site. Either way, it is highly important that all used topsoil be free of excessive amounts of weed propagules.

There is agreement in the literature that topsoil used in any revegetation effort should be tested to determine the amount and composition of weed propagules present *(7-9)*. A recent Illinois DOT report *(8)* recommends that when possible, topsoil from the site should be stockpiled and re-spread to prevent the inadvertent addition of weed species that were not previously present. If topsoil must be imported, Busby *(8)* recommends testing topsoil for the presence of noxious weeds prior to application to the site

The *Manual for the Effective Establishment of Native Grasses on Roadsides in New England (7)* recommends testing to quantify the composition and amount of weed propagules present in topsoil so that an appropriate weed management plan can be developed and implemented prior to seeding. Barton et al. *(9)* go a step further and recommends that imported topsoil should be free of noxious, invasive, and other weed seed. A West Virginia study tested the effect of topsoil, subsoil, ProGanics, and Biotic Earth Black seeding mediums on the successful establishment of desired vegetation from seed *(10)*. The topsoil used in the study was considered highly contaminated with weed seed, and 90 days after seeding had 3% desired vegetative cover and 96% undesired (weed) vegetative cover. Meanwhile the subsoil, ProGanics, and BioticEarth Black treatments all achieved greater than 70% desired vegetative cover. This study illustrates the detrimental effect that weed infested topsoil has on desirable vegetation establishment. Hilvers et al. *(10)* recommends using weed-free topsoil, or developing an appropriate weed management strategy.

No specific testing protocols were recommended *(7-10)*, however two types of testing protocols are used, seedling emergence and seed separation. Each protocol type has its strength and weaknesses. Seedling emergence protocols have been shown to germinate 81% to 100% of viable seeds from soil samples *(17)*. While seedling emergence protocols require less human labor to complete, the amount of time required to get results is much longer than seed separation protocols, taking up to 6 weeks. Seed separation protocols generally recover a smaller percentage of the total viable seed present compared to seedling emergence protocols. One study testing three different seed separation protocols achieved seed recovery rates between 61% and 75% of the total viable seed per sample *(18)*. The upside of seed separation protocols is that it takes less time to get results. In the aforementioned study the longest of the seed separation protocols took 30 minutes to complete. It should be mentioned that additional time would be required if species identification of seed present in soil samples is required.

Although it is assumed that compost blankets will be used on roadside construction projects that involve regrading, there is sometimes a period of time between regrading and seeding that is sufficiently long to allow opportunistic vegetation to establish (four to six weeks, depending on the season and growing conditions). Should the regraded roadside become populated with a mixture of vegetation, weed management with herbicides may be necessary prior to seeding in order to establish the desired new native grass and forb community.

The *Manual for Effective Establishment of Native Grasses and Forbs in New England (7)* recommends starting on-site weed management a year in advance of planting to allow sufficient time for such management practices to reduce the site's weed seed bank and initial weed pressure when desirable seed is planted. Although initiating on-site weed management far in advance of seeding may not always be feasible with many MassDOT construction projects, there is evidence that single interventions (see below) undertaken close to the seed planting date are still beneficial to native grass and forb establishment *(11)*.

A study in West Virginia tested how different weed management interventions prior to seeding affected the long-term establishment of desired native grasses and forbs *(11)*. At each of three highway sites, four treatments were tested: no disturbance, mowing to 0.8–1" (2–3 cm) two weeks prior to seeding, tilling two weeks prior to seeding, or glyphosate application two weeks prior to seeding. All sites were then hand-broadcast-seeded with a native grass and forb mixture at a rate of 19 lbs. pure live seed (PLS)/ac (21 kg PLS/ha). At three years' post-seeding, only the tilling and herbicide treatments had a significantly greater percentage of native vegetative cover than the control and no disturbance treatments at all three sites. The mowing treatment only resulted in a significantly greater percentage of native vegetative cover at one site. *(11)*. Single interventions close to the planting date may be a useful management tool when opportunistic plants colonize regraded roadsides prior to seeding. While vegetation management on the site to be planted is necessary, it is also necessary to look beyond the planting site at potential nearby sources of weed seed.

The presence of invasive species on land adjacent to a roadside vegetation project may impede the success of the planting project if not addressed. The *Manual for Effective Establishment of Native Grasses on Roadsides in New England (7)* recommends working with cooperative extension or DOT agents specializing in invasive species control to develop and implement an invasive species management plan on land adjacent to the site one year in advance of planting. If not addressed, it is likely that these invasive species will spread to the site and outcompete the native grasses and forbs.

On regraded roadsides, it is preferable to stockpile and re-spread topsoil from onsite rather than import topsoil from off-site. If topsoil is imported, it should be tested for weed propagules present to avoid introducing invasive species and other weeds not currently present on the site. The reviewed literature does not describe or recommend a specific test for weed propagules *(7-10)*. If weeds are already present on the roadside prior to seeding native grasses and forbs, then weed management should begin prior to seeding. Tilling and glyphosate application to roadsides two weeks prior to seeding are recommended on roadsides with existing weed populations *(7, 11)*. Additionally, invasive species management should be conducted on land adjacent to the site to prevent later colonization of the roadside *(7)*.

3.1.3. Fertilization

According to the literature, less fertilizer is necessary for seeding native grasses and forbs into topsoil than used for non-native turf establishment *(8, 11, 12)*. Recent work by the Illinois DOT recommends limiting fertilizer application in areas to be seeded with native warm-season grasses and forbs in order to achieve soil nutrient concentrations of 4–20 lbs. total N/ac (4.5–22 kg total N/ha), 1–15 ppm P, and 100–150 ppm K *(8)*. Miller recommends a similar restraint in fertilizing, advising that soil should never be amended with greater than 30 lbs. N/ac (34 kg N/ha) where warm-season grasses are to be planted and warning that additional N may enhance weed growth *(12)*. These recommendations appear to be supported by work done in West Virginia, which tested the effect of pre-planting fertilization on the percentage of native grass and forb vegetative cover and found no significant difference compared to the un-fertilized controls three years after planting *(11)*.

The literature does not address pre-planting fertilizer recommendations for seeding native grasses and forbs in conjunction with compost blankets. Compost contains substantial macro-nutrients that are held in a stable, organic form and are released slowly over time *(19)*. Multiple studies have measured high macronutrient concentrations in composts derived from a wide spectrum of organic source materials *(13-15)*. Compost blankets have been shown to result in increased N, P, K, organic C, Mg, and Zn concentrations in the top 3.0” (7.5 cm) of the soil profile up to two years after application *(13)*. Therefore, it seems likely that if a compost blanket is to be applied to a native grass and forb planting site, additional pre-planting fertilization is unnecessary, and may support weeds

The above recommendations and findings indicate that little to no fertilizer is necessary on roadsides where compost blankets are applied, and native grasses and forbs are planted. This plant community can thrive on very low soil nutrient levels, and it is likely that the nutrient requirements of these plants will be met by nutrients contained within compost blankets even on very nutrient-poor sites.

3.1.4. Physical Soil Preparation

Prior to the spreading of stockpiled or imported topsoil, it is important that the underlying re-graded soil surface be scarified to reduce sheering and slippage *(8, 16)*. Soil scarification is especially important when re-grading sloped roadsides. Busby *(8)* recommends ripping subsoil prior to topsoil application and reports that the Kentucky Transportation Cabinet advises against any topsoil application on slopes greater than 3:1. The American Association of State Highway and Transportation Organization (AASHTO) recommends that prior to compost blanket installation on any site, the soil surface should be scarified and on sloped sites, a bulldozer should be moved up and down the slope, so that the resulting cuts and ridges are parallel with the contour of the slope *(16)*. Such tracking should always be done prior to compost blanket application. Additionally, if the compost blanket is to be seeded, ASHTO recommends removal of large debris greater than 2" in diameter prior to compost blanket installation *(16)*.

3.1.5. Physical and Chemical Properties of Compost

Compost is defined by the Environmental Protection Agency (EPA) as "the product of controlled biological decomposition of organic matter through the generation of heat and stabilized to the point that it is beneficial to plant growth" *(19)*. However, within this definition different composts can differ widely in their physical and chemical properties. Specifically, differences in pH, particle size, organic matter source, nutrient content, maturity, C:N ratio, and other properties of compost may affect the effectiveness of compost blankets in controlling erosion and establishing native grasses and forbs.

pH

The pH of composts is an important factor affecting plant growth, as macro and micronutrients differ in their bioavailability depending on the pH. In general, the widest number of plant nutrients are more easily available for plant uptake when pH is between 6.5 and 7.5. AASHTO guidelines recommend a broader range of compost pH between 5.0 and 8.5 when compost blankets are to be used in conjunction with seeding *(16)*. Compost outside of this range may limit nutrient availability to the detriment of vegetation establishment.

Some plant groups are more tolerant of acid or alkaline conditions than others. For example, cool season turf grasses prefer a pH of 6.0 to 6.5, while warm-season grasses, and native forbs tolerate pH between 4.5 and 6.0 *(9)*. There may be an opportunity to give native grasses and forbs a competitive edge over other undesirable vegetation such as cool season turf grasses by specifying compost with a pH between 4.5 and 6.0. However due to the lack of literature found that investigates effect of compost blanket pH on native grass and forb establishment, a stronger or more specific recommendation cannot currently be given.

Particle Size

Many compost blanket studies discussed in this literature review test mulch blankets or compost-mulch blends in addition to compost blankets. Mulch is an organic material, often chipped or ground, that has not undergone the controlled decomposition process necessary to become compost. Mulches often tend to have a coarser particle size distribution than composts, but this is not universally true.

The particle size distribution is the physical property referenced to describe compost coarseness. Compost particle size affects both the erosion control and seed germination capacity of compost blankets. AASHTO compost blanket guidelines for both vegetated and unvegetated uses specify the following compost particles size distributions as a percentage of compost passing through a specific mesh size on a dry weight basis: 100% passing through a

3” (7.6 cm) sieve, 90–100% passing through a 1” (2.5 cm) sieve, 65–100% passing through a 0.75” (1.9 cm) sieve, 0–75% passing through a 0.25” (0.6 cm) sieve, and a maximum particle length of 6” (15 cm) *(16)*. AASHTO stresses the importance of the coarse woody fraction of compost when compost blankets are used for slope stabilization and erosion control. It is consistently recommended that coarser compost should be used to improve erosion control in areas receiving high annual precipitation, however both the EPA and AASHTO caution that increasing the particle size may hinder vegetation establishment *(16, 19)*.

Results from several studies support the above guidelines. A field study in Illinois compared 1” (2.5 cm) deep compost blankets, mulch blankets, and 1:1 compost to mulch blankets on a 10% slope (10:1). under natural rainfall conditions *(20)*. While all three blankets met AASHTO particle size guidelines, the mulch blanket was the coarsest, the 1:1 compost-mulch blanket second most coarse, and the compost blanket the least coarse (Table 3.1). The 1:1 compost-mulch blanket was the most effective at reducing sediment loss during rain events, often losing half as much as the compost blanket. The compost blanket was the least effective treatment of the three. Additionally, when the same three treatments were tested at varying slopes between 4% and 16% grade under simulated rainfall conditions, the efficacy of the 1:1 compost to mulch blanket in reducing total solid loss increased compared to the compost blanket as the slope increased *(20)*.

Faucette et al. *(21)* tested the effect of particle size on erosion control and stormwater quality by comparing a compost blanket, a mulch blanket, a 2:1 compost to mulch blanket and a 1:2 compost to mulch blanket. All blankets met AASHTO particle size guidelines except the compost blanket which had too high a percentage of particles passing through a 0.25” (0.6 cm) sieve. Particle sizes and results are shown in Table 3.2. As the percentage of small particles increased, total runoff decreased while total solids loss increased. However as the percentage of large particles increased, peak runoff rate and total solids loss decreased while total runoff increased *(21)*.

Table 3.1: Performance of 1” compost blankets

Compost Blankets*	**Particle Size Distribution**			**% reduced total solids loss****	**% reduced total runoff volume****
	% < 1” (2.5 cm)	**% < ¾” (1.9 cm)**	**% < ¼” (0.6 cm)**		
Mulch	94	82	28	85	46
1:1 compost: mulch	96	89	52	80	40
Compost	99	96	74	36	35

Source: Results based on Bhattarai et al. *(20)*
*1” deep compost blankets were applied to a 16% slope.
**Averaged between 2 simulated rainfall events applying 1.71”/h of rain for 30 minutes.

Table 3.2: Performance of 1.5" compost blankets

Compost Blankets*	Particle Size Distribution			% reduced total solids loss**	% reduced total runoff volume**
	% < 1" (2.5 cm)	% < ½" (1.9 cm)	% < ¼" (0.6 cm)		
Mulch	99	64	30	98.6	34
1:2 compost: mulch	99	85	67	98.1	54
2:1 compost: mulch	99	89	76	97.0	67
Compost	99	99	95	94	60

Source: Results based on Faucette et al. *(21)*
*1.5" deep compost blankets were applied to a 10% slope.
**Averaged between two simulated rainfall events, each of which applied 4"/h of rain for one hour.

Not all studies have shown compost blanket particle size to significantly affect soil erosion. An earlier study by Faucette et al. *(14)* compared seven different compost blankets and three different mulch blankets for their effect on soil erosion and found that while the mulch treatments generally exhibited the lowest total solids loss and runoff, the results were not significantly different from the compost blankets. Additionally, an aggregate size analysis found that erosion control was not well correlated to particle size in this study *(14)*.

A parallel study to Faucette et al. *(14)* that used the same compost and mulch blankets noted that the compost blankets produced a higher percentage of vegetative cover and biomass than the mulch blankets, due to the higher percentage of small particles *(22)*. The finest mulch blanket had a particle size distribution of 100% of particles smaller than 1" (2.5 cm), 98.9% of particles smaller than 0.625" (1.6 cm), and 94.9% of particles smaller than 0.25" (0.6 cm) *(14)*. Further research testing the establishment of various vegetation types in compost blankets with different particle size distributions is needed to support more specific recommendations

While the above studies investigated how particle size relates to erosion control under rainfall conditions, work by Zhu et al. *(3)* investigated the erosion control capacity of compost under concentrated inflow conditions. Here concentrated inflow conditions describe conditions in which concentrated surface water enters a compost blanket from an uphill position. The mechanism by which compost blankets control erosion under concentrated surface water inflow conditions appears to be the formation of microdams. Microdams form as a portion of the surface water enters the pore space of the compost matrix and deposits its suspended particles. The deposited particles interlock and form a dam. The microdam slows the water velocity, increasing infiltration and results in the additional deposition of suspended particles. When the dam breaks the process repeats itself slightly further downhill *(3)*. A follow-up study comparing a coarser erosion control compost (avg. particle size 2.19 mm or 0.08") and yard waste compost (avg. particle size 1.65 mm or 0.06") to bare soil (avg particle size 0.053 mm or 0.002") determined that microdam formation is dependent upon increased particle sizes and greater pore space. Only the erosion control compost was composed of a sufficiently large particle size to generate microdam formation *(2)*.

A range of compost blanket particle size distributions have proven highly effective at reducing soil erosion caused by raindrop impact and sheet flow *(14, 20, 21, 23)*. Based on this research, it appears that within the particle size range identified in AASHTO guideline R 52-10 *(16)*, compost blankets with a higher percentage of larger particle sizes are more effective at reducing soil erosion. Importantly, composts with average particle sizes of less than 1.65 mm (0.08") do not form microdams, which appear to be a critical mechanism by which compost blankets reduce erosion and rill formation caused by surface water flow *(2)*. Zhu et al. *(2)* found that coarser compost blankets are less susceptible to concentrated surface water inflows than less coarse compost blankets. And compost blankets in general have been shown to be very susceptible to erosion by concentrated surface water inflows on 3:1 slopes *(23, 24)*.

Organic Matter Source

Compost can be derived from a wide variety of organic matter sources including yard trimmings, separated municipal solid waste, biosolids, manure, and agricultural, forestry, and food waste or byproducts *(16, 19)*. The types of organic matter that compost is derived from affects compost physical and chemical characteristics. Generally, compost and compost blankets derived from biosolids (treated sewage sludge) and manures have smaller particle sizes and higher nutrient levels while yard waste composts and compost blankets mixed with mulch tend to have larger particle sizes and lower nutrient levels. *(15, 23, 25)*.

In Georgia, compost blankets derived from municipal solid waste with mulch and from biosolids were shown to increase extractable organic carbon and soil organic matter over an 18-month period *(25)*. An earlier study by Faucette et al. *(14)* found that among seven compost blankets tested, the biosolids compost blanket lost the most N in runoff even though it contained less total nitrogen and nitrate than the poultry litter compost (a mixture of composted poultry manure, spilled feed, feathers, and bedding material) in a pre-rainfall analysis. Since the biosolids compost blanket lost less or an equivalent quantity of solids during the rain event, this study provides evidence that the source of compost materials affects the availability of nutrients to runoff.

The source of organic matter for compost blankets have been shown to affect physical and chemical compost characteristics, but unlike specific physical and compost characteristics such as nutrient content and particle size *(2, 9)*, the source of organic matter itself has not been shown to directly affect erosion control or native grass and forb establishment. It thus seems that compost specifications should focus on the compost's physical and chemical characteristics, rather than the its organic matter source.

Percentage Organic Matter Content

AASHTO guidelines recommend compost blankets applied in conjunction with seeding contain 25–65% organic matter on a dry weight basis, while compost blankets applied on sites that will not be seeded contain 25–100% organic matter. Research was not found that investigated the effect of compost blanket organic matter content on soil erosion and native grass and forb establishment. Two studies indicate that different compost blankets have a varying ability to increase soil organic matter, but these studies do not find the compost's organic matter levels to be related to increased soil organic matter *(15, 25)*.

It is unclear how the content of organic matter in compost blankets affects soil organic matter. In Rhode Island it was found that 5 cm of incorporated yard waste compost (residential yard wastes including leaves, grass clippings, and sticks) was more effective at increasing soil organic matter than 5 cm of incorporated biosolids *(15)*. Meanwhile Faucette et al. *(25)* measured the effect of 2” and 4” deep compost blankets on soil physical qualities over an 18-month period. Prior to sampling, the surface compost layer and the A horizon were removed, then soil cores were taken 15 cm deep in the Bt horizon. Both the 2” and 4” biosolids compost blankets significantly increased soil organic matter, while the yard waste compost blankets did not. This is interesting as the biosolids compost had a very similar amount of organic matter as the yard waste compost (202 g/kg and 193 g/kg, respectively).

In conclusion, the existing literature is not clear how compost organic matter content affects soil erosion and native grass and forb establishment.

Soluble Salt Conductivity
AASHTO *(16)* recommends that compost blankets contain a soluble salt content no greater than 5 dS/m, equivalent to a total salt concentration of 4,000 ppm. This salt concentration limit is supported by a salt tolerance greenhouse trial of 21 native grass species conducted in Rhode Island *(26)*. The lowest salt concentration tested in these trials was 5,000 ppm, which resulted in some slight degree of observed salt stress for all tested native grasses except for *Bromus ciliatus*[N] (fringed brome), which exhibited severe salt stress symptoms at this concentration.

However, Brown et al. *(26)* subsequently found in roadside plant trials that native grass establishment was not significantly correlated with soil salt levels. No other research was found testing soil or compost salt levels on native grass establishment. Based on this limited information, it seems that native grasses would not experience salt stress in a compost blanket complying with the current AASHTO guideline of 5 dS/m. Yet it should also be noted that no literature was found providing evidence that compost blankets with higher salt levels would negatively affect native grass and forb establishment.

Mineral Nutrient Content
Compost is capable of providing macro and micronutrients in a controlled manner over time due to its large amount of humus, a highly stable form of organic matter characteristic of all compost, and its correspondingly large cation exchange capacity *(19)*. Barton et al. *(9)* adds a note of caution when adding any type of organic matter alongside native grass and forb seed, warning that organic matter containing excessive nitrogen will result in higher weed pressure. Barton echoes the pre-planting fertilization recommendations previously discussed *(8, 11, 12)*. Additionally, there is some literature suggesting that certain compost blankets high in N, P, and K may cause increased weed pressure and nutrient runoff *(13, 14, 25)*.

In Virginia, Dunifon et al. *(13)* found that a 2.35 cm deep poultry litter and wood waste compost blanket resulted in significantly higher total N, P, K, Mg, and Zn in the soil two years after application. Faucette et al. *(14)* found that 5 cm deep aged poultry litter blanket (poultry litter that is several months old but was not composted) and a biosolid compost blanket both lost significantly higher amounts of N, P, and K than bare soil when exposed to

16 cm/h of rainfall for 60 minutes on a 10% slope, although the biosolids lost more total N than the poultry litter. While not significantly different, the five other compost blankets tested all lost many times the total amount of N, P, and K than the bare soil control. While this study did not investigate the effects of nutrients on vegetation establishment, the authors noted concern for nutrient contamination to water bodies adjacent to sites using compost blankets.

A later study by the same authors compared yard waste, municipal solid waste + mulch, biosolids, and poultry litter + mulch compost blankets for their effect on desirable and undesirable vegetative cover *(25)*. In this case the desired vegetation was *Cynodon dactylon*[E] (Bermuda grass). One year after seeding the biosolids compost blanket, which has previously been shown to contain high levels of total N (1.09% N by weight) and high levels of N in an available form (1460 NO_3 mg/Kg) *(14)*, had significantly more weed biomass and a higher weed-to-Bermuda grass ratio than the other three compost blankets.

In Maryland, a greenhouse study compared 2” deep biosolids compost blankets, greenwaste compost blankets, topsoil, 2:1 topsoil to greenwaste compost, and 2:1 topsoil to biosolids compost on 4:1 and 1:1 slopes *(27)*. Rainfall events were simulated every two weeks at a rate of 4”/h. Two rainfall events lasted 15 minutes, two lasted 30 minutes, and two lasted 45 minutes, for a total of 12” of water applied to each treatment over the course of 12 weeks. Runoff was measured and analyzed for nutrient content. They found that runoff from the 2” deep biosolids and greenwaste compost blankets often contained greater total P and total N concentrations than the topsoil control or the topsoil and compost mixes. However, the 2” compost blankets also resulted in less total runoff than the control and other treatments, and when total nutrients lost in runoff is examined there are no significant differences between treatments and no trend is apparent. The authors conclude by warning of the potential for compost blankets to be a source of surface water nutrient pollution and recommend that in Maryland compost blankets only be used on slopes with a grade of 20:1 or less.

Faucette et al. *(14)* conducted a study investigating the relationship between compost blanket’s physical and chemical properties and corresponding total solids loss and nutrient loss during rain events. None of the measured physical and chemical properties had significant correlation ($r > 0.70$) with total N lost and total nitrate lost, the strongest correlation being initial total P for total N lost ($r = 0.45$) and initial total P for total nitrate lost ($r = 0.33$). However initial total nitrate was significantly associated with total ammonium lost ($r = 0.96$), with total P lost ($r = 0.96$), and with total phosphate lost ($r = 0.96$) *(14)*.

Compost blankets containing excessive nutrient levels have been shown to increase soil nutrient levels, nutrient runoff, and weed biomass *(13, 14, 25, 27)*. It is known that native warm-season grasses establish slowly, exhibiting little above-ground growth during the first year *(7, 11)*, and do not benefit from high nutrient levels *(8, 12)*. The increased weed biomass stimulated by excessive nutrients would negatively affect native warm-season grass seedlings due to lack of light. It would thus seem likely that compost blankets containing excessive nutrients would inhibit native grass and forb establishment due to increased weed pressure, though there are no current studies that directly test this proposed relationship. Since total nitrate of compost blankets strongly correlates with ammonium and total P lost during rain events *(14)*, setting a maximum threshold for nitrate concentrations in compost blankets may be effective at reducing the risk of nutrient runoff.

Stability and Maturity of Compost Materials

Compost stability refers to a point at the end of the composting process where the organic matter is resistant to further degradation, while maturity refers to a compost being ready for a particular end use such as use as a planting medium *(28)*. Compost stability is often measured indirectly through the compost's respiration rate. The two most commonly recommended tests for compost respiration are its carbon dioxide evolution rate and oxygen uptake rate *(16, 28)*. The respiration rate (either a measurement of oxygen consumed, or carbon dioxide released) measures the microbial activity of the compost. When the compost is stable the respiration rate is usually low because microbial activity is low. In stable compost most of the available organic matter has already been consumed, the microbial population reduced, and thus the respiration rate reduced. In younger or less stable compost there is still an abundant food source of available organic matter, which supports a larger microbial population and thus a higher respiration rate. Stable compost has a larger humus fraction, which contributes to the compost's ability to absorb water and retain large amounts of nutrients over time.

One study testing seven different compost blankets applied 5" deep on a 10% slope measured total solids lost under simulated rainfall at a rate of 16 cm/h applied for 60 minutes *(14)*. Statistical analysis revealed that in this compost respiration rate was significantly correlated with total solids loss ($r = 0.92$). As compost respiration rate decreased, total solids lost decreased. While this study indicates that compost stability may be tied to the erosion control capacity of compost blankets, the authors recommend that more research is needed to confirm the results, and do not offer any compost stability guidelines at this time *(14)*.

Currently AASHTO guidelines for compost blankets state that compost stability and maturity is not applicable for erosion control purposes, but is if the compost blanket is to be planted *(16)*. For compost blankets on which vegetation is to be established, the compost's carbon dioxide evolution rate should be less than 8 mg CO_2-C per gram organic matter per day *(16)*. However the work of Faucette et al. *(14)* indicates a strong correlation between compost respiration rate (compost stability) and total solids lost during rain events. In addition to the carbon dioxide evolution rate, AASHTO recommends using a second test when determining compost maturity. Considering that the carbon dioxide evolution rate tests compost stability rather than maturity, the second test should measure compost maturity using a bioassay to test plant growth *(28)*. No studies were found investigating how compost maturity affects vegetation establishment.

C:N Ratio

The ratio of carbon to nitrogen (C:N) in compost affects the rate of decomposition during the composting process and the availability of nitrogen to plants once applied to roadsides. Carbon molecules form the basis of all the molecules that make up living organisms and N is an important component of proteins; therefore, every type of living organism has a C:N ratio. Soil microbes require a C:N ratio of 24:1 for the production of their proteins and tissues *(29)*. Therefore, when organic materials with a C:N ratio > 24:1 are added to soil, soil microorganisms begin to scavenge for nitrogen, which reduces the amount of soluble N in the soil and potentially causing nitrogen deficiency in plants *(29)*. In certain situations the C:N ratio can be used to measure the stability of compost, such as when the compost raw materials begin with a high C:N ratio, but it is recommended that an additional test such as the carbon dioxide evolution rate or oxygen uptake rate be used when determining stability *(28)*.

A study by Faucette et al. *(14)* tested the effect of seven different compost blankets with varying physical and chemical properties for their effect on total runoff, total solids loss, and nutrient loss. Statistical analysis found that the C:N ratio of the tested compost blankets did not significantly correlate ($r > 0.70$) to total runoff, total solids lost, total nitrogen lost, nitrate lost, ammonium lost, total P lost, or total phosphate lost *(14)*.

AASHTO currently does not have a specification for the C:N ratio of compost blankets *(16)*. A literature review on compost stability and maturity reports that there seems to be agreement that finished composts should have a C:N ratio between 10:1 and 20:1, similar to that of stable organic matter found in soil *(28)*. However it has not yet been shown that the C:N ratio of compost blankets significantly affects soil erosion, slope stabilization, nutrient loss, or native grass and forb establishment *(14)*. Thus, a C:N ratio specification doesn't appear necessary at this time for compost blankets used for the purposes of slope stabilization, erosion control and native grass and forb establishment. As noted in the previous section, Mineral Nutrients, total compost nitrate has been shown to strongly correlate with ammonium and total P loss from compost blankets during rain events *(14)*. Compost's total nitrate levels would be a better measure than its C:N ratio when determining a compost blanket's potential to cause nutrient runoff.

Mycorrhizal Activity
Johnson et al. *(30)* mentions that native warm season grasses are reported to rely on mycorrhizal associations more often than cool season grasses. When soil is mechanically disturbed, as happens on roadside construction projects, hyphal networks are destroyed and it may be necessary to inoculate the soil with arbuscular mycorrhizae *(29)*. It is known that organic matter additions to the soil surface favor fungal decomposers over bacterial decomposers, but it is not known how surface compost applications affect the arbuscular mycorrhizae that form symbiotic relationships with plants *(29)*. No literature was found in the search that evaluates mycorrhizal activity in composts or explores how beneficial mycorrhizal activity may be supplemented.

Physical Contaminants
In an Iowa study researchers expressed dissatisfaction with a yard waste compost blanket due to the poor aesthetic resulting from contamination with plastic bags and twine *(23)*. AASHTO guidelines require that compost used for compost blankets contain less than 1% of man-made physical contaminants (plastics, trash, refuse) on a dry weight basis *(16)*. In addition, Busby *(8)* recommends that compost used along roadsides in Illinois be free of plastics and other human debris greater than ¼" in size. Contamination of compost with physical contaminants has been reported to lead to an undesirable aesthetic, but evidence was

not found that indicates these contaminants have any effect on soil erosion or native grass and forb establishment.

3.1.6. Compost Blanket Depth

While many different compost blanket depths have been utilized by different studies, far fewer studies isolated compost blanket depth as an independent variable and tested its effect on one or many dependent variables.

In Iowa, a 2–3” (5–7.5 cm) deep compost blanket applied to 2.5 m long (8.95”) plots significantly increased the time to runoff (60 minutes) compared to the bare soil control (9 minutes) *(31)*. An earlier study, also in Iowa, found 2” (5 cm) deep compost blankets increased water storage and significantly reduced soil bulk density in the top 15 cm (5.9”) of soil compared to a bare soil control *(32)*. This study also found that three years after compost blanket application and planting native forb density was significantly higher in the 2” (5 cm) compost blanket than the bare soil control. No significant difference in plant density was found three years after compost blanket application and planting between the 2” (5 cm) compost blanket and bare soil control for the four native warm-season grass species tested. Faucette et al. *(21)* tested a yard waste compost blanket and two different yard waste plus wood mulch (1:2 and 2:1) compost blankets at a depth of 1.5” (3.8 cm) on a 1:10 slope. Under a simulated rainfall rate of 4”/h (10 cm/h) for one hour, all three 1.5” (3.8 cm) compost blankets reduced total solids loss by 93% or greater prior to vegetation establishment and by 96% or greater after common Bermuda grass establishment compared to the bare soil control.

In Maryland, a 1” deep biosolid compost blanket and a 1” (2.5 cm) deep green-waste compost blanket were tested in the field on 2:1 and 1:1 slopes *(27)*. Neither compost blanket resulted in significantly different amounts of total sediment lost compared to a topsoil control after 12” (30.5 cm) of total rainfall was applied at a rate of 4”/h (10 cm/h) over a number of storm events. It should be noted that the particle size distribution of the two composts was similar to or finer than that of topsoil. As noted earlier in this review, larger particle sizes usually associated with compost has shown to correlate to total solids lost. Additionally, the treatments were broadcast seeded after compost blanket application with a 95% *Schedonorus arundinaceus*^{E} (tall fescue) and 5% *Poa pratensis*^{E} (Kentucky bluegrass) seed mixture at a rate of 200 lbs./ac (178 kg/ha) and monitored for vegetation establishment. No significant trends were apparent in vegetation establishment between the 1” (2.5 cm) deep compost blanket treatments and the topsoil control.

Three studies isolated compost blanket depth as an independent variable, one examining its effect on soil characteristics and turfgrass establishment and two examining its effect on soil erosion. Evanylo et al. *(33)* tested the effects of 1” (2.5 cm) and 0.25” (0.6 cm) compost blanket depths on soil physical and chemical properties and on cool-season turfgrass establishment. A one-time inorganic fertilizer addition was applied with the 0.25” (0.6 cm) deep compost blanket. The 1” (2.5 cm) depth resulted in higher soil C, N, P, K, Mg, and Ca and lower bulk density than the 0.25” (0.6 cm) depth 840 days after application. Both depths resulted in significantly higher nutrient levels and lower soil bulk densities than the bare soil control. Turfgrass biomass was significantly greater at 180 days post-application in the 1”

(2.5 cm) compost blankets compared to the 0.25” (0.6 cm) compost blankets, although no significant difference existed at 840 days post application.

An Iowa DOT study tested biosolids, yard waste, and bio-industrial compost blankets applied at both 2” (5 cm) and 4” (10 cm) depths on roadsides with a 3:1 slope for their effect on soil erosion *(23)*. Oats, timothy rye, and clover were established, and plots were subjected to rainfall at a rate of 3.7”/h (9.4 cm/h) for over an hour. No significant differences in rill or interrill erosion were found between the 2” (5 cm) and 4” (10 cm) compost blanket depths, indicating that under these slope and rainfall conditions a 2” (5 cm) deep compost blanket is sufficiently deep to prevent rill and interrill erosion. It should be noted that while these compost blanket depths were tested for erosion control under a vegetated condition, this study did not examine the effect of depth on vegetation establishment.

Faucette et al. *(34)* examined the performance of 0.5” (1.25 cm), 1” (2.5 cm), and 2” (5.0 cm) deep compost under simulated rainfall of 2”/h (5 cm/h), 4”/h (10 cm/h), and 6”/h (15 cm/h). This study found that as the compost depth increased, total solids loss decreased. At the higher rainfall rates, the 0.5” (1.25 cm) deep compost blanket did not always significantly reduce total solids loss compared to the bare soil control.

The EPA states that compost blankets are usually applied at a depth of between 1” and 3” (2.5 and 7.5 cm) *(19)*. AASHTO provides more specific guidance, recommending specific depths based on annual rainfall amounts and whether or not vegetation will be established in conjunction with the compost blanket *(16)*. These recommendations are outlined in Table 2 of AASHTO standard practice R52-10 and are as follows: depths of 0.5–0.75” (1.25–1.9 cm), 0.75–1” (1.9–2.5 cm), and 1” –2” (2.5–5 cm) for areas that receive low (1–25” or 2.5–63.5 cm), average (26–50” or 63.5– 27 cm) and high (>51” or >130 cm) annual precipitation amounts, respectively, for compost blankets applied in conjunction with seeding or other vegetation establishment method. Depths of compost blankets applied without any corresponding vegetation establishment effort are to be installed at depths of 1–1.5” (2.5–3.75 cm), 1.5–2” (3.75–5 cm), and 2–4” (5– 0 cm) for low, medium, and high annual precipitation amounts, respectively.

The above studies have shown that compost blanket depths as shallow as 1.5” (3.75 cm) are capable of significantly reducing soil erosion under rainfall intensities as high as 4”/h (10 cm/h). However AASHTO *(16)* recommends that in addition to rainfall amount and intensity other factors such as concentrated surface water inflow, slope grade, and slope length should be taken into account when designing compost blanket depth. While no research has looked at the effect of slope length on compost blanket performance, there is literature examining the effect of concentrated surface water inflow and slope grade on compost blankets of varying depths.

Concentrated Surface Water Inflow

Two studies by Zhu et al. previously described in the particle size section *(2, 3)* investigated how compost blankets perform under concentrated surface water inflow conditions. They found that 3” (7.5 cm) deep compost blankets were capable of significantly decreasing total solid loss under high concentrated surface water inflow rates compared to bare soil *(3)*. A follow-up study testing 2” (5 cm) deep compost blankets found them to significantly reduce total solids loss under high concentrated water inflow conditions *(2)*.

While compost blankets 2”–3” (5– .5 cm) deep have been shown to reduce erosion under concentrated surface water inflows on modest slopes up to 7% grade, compost blankets remain susceptible to washout and rill erosion on steeper slopes or on sites with a greater surface water inflow rate. Maine DOT reports problems with the use of 4” (10 cm) deep compost blankets on slopes that receive concentrated inflow or contain groundwater weeps *(24)*. Therefore on sites receiving concentrated surface water inflow, it is currently recommended to combine compost blankets with other soil erosion control measures, such as compost socks or compost filter berms 1–2’ (30–61 cm) high and 2–4’ (61–122 cm) wide which will diffuse or divert the water *(16, 19)*.

Slope Grade

Slope grade is known to be a significant site factor affecting the erosion control capacity of compost blankets. An extensive laboratory study by Faucette et al. *(34)* tested nine compost blankets at three different depths (0.5”, 1”, and 2”) (1.25 cm, 2.5 cm, and 5 cm) on slopes at a 4:1, 3:1, and 2:1 grade. Simulated rainfall was applied for 1 hour at a rate of 2”/h (5 cm/h) for the first 20 minutes, 4”/h (10 cm/h) for the second 20 minutes, and 6”/h (15 cm/h) for the final 20 minutes. The 0.5” (1.25 cm) compost blankets significantly reduced erosion during all three rainfall events on the 4:1 slope, and during the first 20 minutes interval at 2”/h (5 cm/h) on the 3:1 slope. Meanwhile the 1” (2.5 cm) and 2” (5 cm) compost blankets significantly reduced soil erosion at all rainfall intensities on slopes up to 2:1 compared to the 0.5” (1.25 cm) blanket and bare soil control. However, there was no significant difference in erosion between the 1” (2.5 cm) and 2” (5 cm) deep blankets on slopes up to 2:1. This study demonstrates that compost blankets as shallow as 1” (2.5 cm) can significantly reduce erosion during high intensity rainfall events on slopes as steep as 2:1.

AASHTO states that compost blankets can be used on slopes up to 2:1, and potentially on 1:1 slopes if slope length and compost depth are appropriately considered *(16)*. On steep slopes where erosion control is the primary goal, the coarser woody fraction of compost should be increased *(16, 19)*. On slopes 1:1 and steeper, compost blanket particle size and depth should be designed for the site-specific application, and/or combined with an erosion control practice to stabilize both the compost and the hillside *(19)*.

In general, deeper compost blankets provide more soil erosion control than shallower compost blankets. The primary factors influencing the compost blanket depth necessary to significantly reduce soil erosion appear to be rainfall and slope grade. Compost blankets 0.5” (1.25 cm) deep significantly reduce soil erosion on modest slopes up to 4:1 under heavy rainfall intensities up to 4”/h (10 cm/h) *(34)*. Deeper compost blankets 1–2” (2.5–5 cm) thick are proven to significantly reduce soil erosion on steep slopes up to 2:1 under heavy rainfall intensities up to 4”/h (10 cm/h) *(34)*. While no studies tested compost blankets on slopes greater than 2:1, both the EPA *(19)* and AASHTO *(16)* indicate they have the (unresearched) potential to reduce soil erosion on slopes up to 1:1.

3.1.7. Compost Blankets and Weed Pressure

The literature provides evidence that the use of compost blankets along roadsides may reduce weed pressure for up to three years after application. Singer et al. *(32)* reported that over the course of three years, plots of bare compacted soil treated with 2” (5 cm) deep yard waste compost blankets and seeded with native warm-season grasses consistently had lower densities of annual weeds. An Iowa DOT study compared weed biomass over two years on roadsides receiving 2” (5 cm) and 4” (10 cm) deep compost blankets and found that both compost depths reduced weed biomass by 66% compared to the bare soil control *(23)*.

A similar study by Persyn et al. *(35)* found that 2” (5 cm) and 4” (10 cm) deep biosolids, yard waste, and bio-industrial compost blankets significantly reduced weed biomass compared to bare topsoil and subsoil controls (plots where topsoil had been removed). Additionally, no significant difference in weed biomass was found between 2” (5 cm) and 4” (10 cm) compost blanket depths. Singer et al. *(32)* suggested that 2” (5 cm) deep compost blankets act as a barrier reducing annual weed germination. The findings of Persyn et al. *(35)* support the idea that a 2” (5 cm) compost blanket depth is sufficient to create such a barrier and that significant additional weed control is not achieve by doubling the compost blanket depth to 4” (10 cm). What has not been investigated is how these compost blanket depths affect native grass and forb establishment.

3.1.8. Compost Blanket Application Methods

Compost blankets can be applied using a bulldozer, skid steer, manure spreader, hand shovel, or pneumatic blower *(16, 19)*. The EPA recommends using pneumatic blowers on sites with steep or rocky slopes *(19)*. Since pneumatic blowers propel compost towards the ground, filling in nooks and crannies, this application method has the added benefit of reducing water movement between the soil and the compost layer *(16)*. To reduce the chance of concentrated sheet flow from offsite undermining the compost blanket, it is recommended that compost blankets be spread 3’ beyond the ridgeline of the slope or incorporated into existing vegetation *(16)*. According to AASHTO *(16)* applying water to newly installed compost blankets can also help settle the compost and reduce erosion. No studies were found which investigated the effect of compost blanket application methods on native grass and forb establishment.

A survey of 20 state DOTs conducted in 2009 regarding their use of compost for slope stabilization and erosion control found that 74% of the state DOTs surveyed do not impose time-of-year restrictions for compost applications to roadsides (compost applications includes, but is not limited to, compost blankets) *(24)*. For those states that do impose time-of-year restrictions, one of the listed reasons was to coincide compost application with seeding periods. Seeding periods are addressed in more detail in the subsequent section titled Seeding Timing.

3.1.9. Benefits of Establishing Native Grasses and Forbs

Permanent vegetation establishment is usually the long-term goal of newly graded roadside construction projects. Native grasses and forbs are an increasingly desired roadside plant community due to their ability to control erosion and improve site ecology as well as to provide habitat and forage for native wildlife, including pollinators.

Vegetation establishment is the most effective method to stabilize slopes and reduce soil erosion along roadsides *(9).* According to the EPA, on slopes greater than 2:1, rapid establishment of a thick vegetative cover is the key to successful erosion control *(19)*. Established native warm-season grasses have deep root system profiles that make them ideal for soil stabilization and erosion control on steep sites *(9, 12, 26)*. Miller et al. *(12)* illustrates this point with an example of a 6" tall big bluestem seedling, which can potentially have a root system 4' (1.2 m) deep and 1' (0.3 m) wide. Based on his work revegetating abandoned mining sites, Miller et al. *(12)* reports that warm-season native grasses are capable of reducing rill and gully erosion by the end of their first growing season.

Brown et al. *(26)* conducted a greenhouse root profile study of 19 species of native grasses. Based on this study, the authors recommend combining deep-rooting warm-season native grasses like *Schizachyrium scoparium*[N] (little bluestem) and *Eragrostis spectabilis*[N] (purple lovegrass) with shallow rooting, quick-to-establish cool-season grasses, such as *Festuca subverticillata*[N] (nodding fescue) which is widespread throughout New England or *Festuca rubra ssp. pruinosa*[N] (red fescue) which in New England is confined to coastal habitats. The former will help to stabilize the slope, while the latter provides quick surface cover, slowing surface erosion and providing an aesthetically pleasing roadside soon after seeding. In addition to erosion control and slope stabilization, the root systems of native grasses are capable of mitigating compaction over time as illustrated in an Iowa study utilizing *Bouteloua dactyloides*[E] (buffalo grass) and *Bouteloua gracilis*[E] (blue grama grass) *(31)*.

Native grass and forb communities established along roadsides have the potential to provide important habitat types and ecological services. State DOTs manage an estimated 10 million acres of land nationwide *(36)*. Brown et al. *(26)*, citing a personal communication from K. Berger and P. August, estimated that there are around 600,000 acres (242,817 ha) of mowed roadsides along limited access highways in Rhode Island, Connecticut, and Massachusetts combined. In contrast, there is less than 10% of this amount, including roadsides, (estimated 50,000 acres or 20,235 ha) of natural grassland in this same region *(26)*.

Survey work in Rhode Island has shown that far from being an ecological wasteland, roadsides can serve to provide important habitat. The authors identified 80 species of grasses and forbs, 45% of which were native (*26)*. The plant community composition is important because un-mowed roadsides dominated by native grasses and forbs support greater pollinator abundance and diversity than roadsides dominated by non-native plants *(36)*. A study in Iowa found that restored prairie communities along roadsides supported twice the diversity and five times the abundance of butterflies as roadsides dominated by non-native plant communities *(37)*. Restored prairie roadsides also saw a twofold decrease in butterfly mortality, as butterflies were less likely to leave the prairie roadside strip than the roadside strip dominated by non-native plants.

In addition to providing invertebrate habitat, the EPA states that use of compost blankets to establish native grass and forb communities is a valuable strategy to mitigate climate change, as grasslands are a major terrestrial carbon sink *(19)*.

3.1.10. Designing Native Grass and Forb Seed Mixes

Designing native grass and forb seed mixes appropriate for the intended use and geographic range is an important step towards successfully achieving slope stability, erosion control and vegetation establishment goals. When constructing native grass and forb seed mixes several factors must be considered: seed mix proportions, tailoring different seed mixes to different site conditions, ease of specific species establishment, and the selection of cover and nurse crops.

Seed Mix Proportions

Deciding on the proportion of grass to forb seeds is the first decision to make when designing a seed mix *(9)*. Those seed mixes only containing native grass seed leave niches unfilled *(8)*. It is recommended that a portion of the seed mix consist of forbs, including legumes which help to reduce weed competition and provide nitrogen fixation *(7-9)*. Barton et al. *(9)* provides an example grass-to-forb ratio of 60:40 based on seed count. Native grass and forb seed mixes designed by industry leaders such as Ernst Conservation Seed, Prairie Moon Nursery, Johnston Seed Co. and Prairie Nursery have grass to forb ratios ranging from 92:8 to 37:63 *(38, 39)*.

The ratio of grasses to forbs has a significant effect on plant community appearance, diversity, and seed mix cost. Grass-to-forb ratios of 80:20 or 60:40 will result in grass dominated plant communities, while 30:70 ratios often become prohibitively expensive due to the higher cost of forb seed *(40)*. Ratios of 50:50 will result in a balanced grass and forb plant community and will achieve higher plant diversity than less balanced seed mixes *(40, 41)*. As long as grasses and forbs each make up some portion of a seed mix, the literature does not indicate how a specific grass-to-forb ratio affects establishment and persistence of the intended plant community.

Designing a seed mix with a balance of different plant growth patterns has a significant effect on successful establishment and persistence of native grass and forb communities *(7, 40)*. Without a mixture of short-lived, quick-to-establish plants and long-lived, slow-to-establish plants, new plantings will either face establishment or persistence issues *(40)*. Traditionally, seed mixes have overemphasized long-lived, slow-to-establish species, but there is an increasing emphasis on including a portion of short-lived, quick to establish species that act as nurse crops. A nurse crop is a quick germinating and fast-growing species that is competitive with weeds and provides a favorable environment for the long-lived, slow-to-establish plants. Nurse crops are discussed further in the section Cover Crops and Nurse Crops.

Kuzovkina et al. *(7)* recommends basing seed mix proportions and species selection on a reference site. The reference site should be within the geographic area within which the seed mix is to be used, have recently undergone a disturbance, and been revegetated by a native grass and forb community. The species diversity and abundance at this reference site can then be used to inform the creation of the seed mix.

The *Manual for the Establishment of Native Grasses on Roadsides in New England (7)* recommends that seed mixes contain the following components which are outlined in Table 3.3: dominant or keystone species (warm-season grasses), cool-season grasses, nurse crops, annuals, legumes, and perennials with flowers for aesthetics and pollinators. Warm-season grasses chosen as the dominant species should be widely occurring within the geographic area and easy to propagate. Table 3.3 gives recommended species for each of the above functional groups for New England seed mixes. Additionally, the *Manual for the Establishment of Native Grasses on Roadsides in New England (7)* contains an extensive index of plant profiles for grasses, sedges, and forbs native to New England that show potential for use in roadside plantings.

The research team did not identify any studies that tested specific native grass or forb species establishment in conjunction with compost blanket use. However, the Illinois DOT conducted a survey of roadsides seeded four to six years ago with native grasses and forbs *(8)*. The survey identified a list of the most common native grass species including: *Andropogon gerardii*^{N} (big bluestem), *Schizachyrium scoparium*^{N} (little bluestem), and *Panicum virgatum*^{N} (switchgrass) and the most common native forbs were *Ratibida pinnata*^{E} (yellow coneflower) and *Heliopsis helianthoides*^{E} (oxeye sunflower). Based on the survey results and a literature review, the Illinois DOT survey recommended in Illinois that use of *Sporobolus heterolepis*^{N} (prairie dropseed) be replaced by *Tridens flavus*^{N} (purpletop) and *Bouteloua dactyloides*^{E} (buffalo grass). *Panicum virgatum*^{N} (switchgrass) is reported in several places to outcompete other native warm-season grasses including *Andropogon gerardii*^{N} (big bluestem) and *Sorghastrum nutans*^{N} (Indian grass) *(9, 12)*, and its potential to dominate plantings should be considered before being included in seed mixes.

A study in Iowa compared three native grass and forb seed mixes with varying grass-to-forb proportions on a pure live seed (PLS) basis *(41)*. The 1:1 grass to forb seed mix was found to result in higher species diversity than the 1:5 and 5:1 seed mixes.

In summary, an overall proportion of grasses to forbs between 50:50 and 60:40 on a pure live seed basis is desirable for roadside native grass and forb seed mixes *(9, 41)*. A more detailed specification should be developed for seed mixes based on the functional groups proposed by Kuzovkina et al. *(7)* and described in Table 4. Nurse crops and cover crops should not exceed 15–20% of the seed mixture on a pure live seed basis or there is a risk they will outcompete the establishing native grasses and forbs *(7)*. Warm season grass species should make up a significant portion of the seed mix, as these will provide critical soil stabilization. If *Panicum virgatum*^{N} (switchgrass) is to be included in a seed mix, it should not be more than 20% of a seed mix a PLS basis, as it tends to outcompete other native warm-season grasses.

Table 3.3: Recommended native plants for roadsides

Seed Mix Functional Groups	Recommended* Species Native to New England**
Dominant/Keystone species	*Schizachyrium scoparium*[N] (little bluestem)
Cool-season grasses	*Elymus virginicus*[N] (common eastern wild rye), *Elymus canadensis*[N] (great plains wild rye)
Nurse and/or cover crops	*Elymus virginicus*[N] (common eastern wild rye), *Chamaecrista fasciculata*[N] (partridge sensitive-pea)
annuals	*Erigeron annuus*[N] (annual fleabane)
Fast establishing wildflowers	*Monarda fistulosa var. mollis*[N] and *Monarda fistulosa var. fistulosa*[N] (wild bergamot), *Chamaenerion angustifolium*[N] (narrow-leaved fireweed), *Erigeron strigosus*[N] (rough fleabane), *Hieracium kalmii*[N] (Canada hawkweed), *Lactuca canadensis*[N] (tall lettuce), *Prunella vulgaris ssp. lanceolata*[N] (common selfheal), *Capnoides sempervirens*[N] (pink-corydalis)
Legumes	*Lespedeza capitata*[N] (round-headed bush-clover), *Desmodium canadense*[N] (showy tick-trefoil), *Baptisia tinctoria*[N] (yellow wild indigo).
Selected Forb Species for Pollinators and aesthetics	*Monarda fistulosa var. mollis*[N] and *Monarda fistulosa var. fistulosa*[N] (wild bergamot), *Symphyotrichum novae-angliae*[N] (new-england aster), *Solidago spp.*[N+E] (goldenrods)

*Recommended by Kuzovkina et al. *(7)*.

****** "Native to New England" means that the naturally occurring wild populations of the listed species are present in one or more of the following states: CT, MA, RI, NH, VT, ME. When constructing seed mixes, check whether species are native to the specific area where they are to be used by searching the Native Plant Trust's GoBotany website https://gobotany.nativeplanttrust.org.

3.1.11. Specialized Seed Mixes for Specific Site Conditions

Many sources recommend tailoring seed mixes to specific site conditions *(7-9, 26)*. The *Enhancing Delaware Highways—Roadside Vegetation Establishment and Management Manual (9)* recommends selecting species adapted to the moisture conditions of the site. Kuzovkina et al. *(7)* recommends that state Cooperative Extension soil tests and percolation tests be performed on every site and used to match the best seed mix to the site.

It has been recommended that specific seed mixes be developed for a variety of specific site conditions including on slopes greater than 3:1 or in danger of slip erosion, high salt areas like road shoulders and ditches, view corridors, and water saturated low-lying conditions *(8, 26)*. For slope stabilization in Rhode Island, Brown et al. *(26)* recommends a seed mix consisting of the low growing grasses *Festuca rubra*[N+E] (red fescue), and *Schizachyrium scoparium*[N] (little bluestem) and the deep rooted native grasses *Panicum virgatum*[N] (switchgrass), *Andropogon gerardii*[N] (big bluestem), *Panicum amarum*[N] (bitter panic grass), and *Sorghastrum nutans*[N] (Indian grass).

A native grass salt tolerance greenhouse study in Rhode Island identified significant differences in salt tolerance between species, cultivars, and ecotypes *(26)*. In general, native cool-season grasses appeared to be more salt-tolerant than native warm-season grasses. Interestingly, subsequent roadside trials showed no relation between salt tolerance and native grass survival. Despite the roadside trial results, the authors still recommend planting less salt-tolerant native grasses outside of the "high salt area," which they define as 10' from the roadside edge. Within the high salt area, Brown et al. *(26)* recommend planting the highly salt-tolerant native grass *Agrostis perennans*[N] (autumn bentgrass). *Eragrostis spectabilis*[N] (purple lovegrass) is also recommended for use in the high salt zone once commercial seed becomes available.

Cover Crops and Nurse Crops

Long-lived native grass and forb plantings require cover crops and/or nurse crops in the short term to reduce erosion and weed pressure until the seeded species establish. A cover crop is a temporary monoculture planted for erosion control when roadside construction is completed outside of the optimal native grass and forb planting window *(7)*. This differs from nurse crops, which are crops included in permanent plantings that are usually composed of a small proportion of fast-growing and short-lived species that are not overly aggressive in habit. Nurse crops reduce soil erosion, improve aesthetics, and create a favorable environment for the slower growing native species to establish in during the first year *(7, 8, 12)*.

Cover crops are useful for rapidly establishing vegetative cover to reduce soil erosion on project sites during non-ideal times of year for the establishment of native grasses and forbs. The resulting cover-crop monoculture will die completely over winter and not compete with the desired species in the seed mix. For the New England area, Kuzovkina et al. *(7)* recommends *Avena sativa*[E] (grain oats) for use from spring to Aug. 1 and *Triticum aestivum*[E] (winter wheat) from Aug. 1 to winter. *Glycine max*[E] (soybeans), *Dalea purpurea*[E] (prairie clover), *Desmodium* species, and *Silphium perfoliatum*[E] (cup plant) are recommended as alternative cover crops in a report prepared for the Illinois DOT *(8)*.

Many sources recommend including nurse crops as part of native grass and forb seed mixes, as many native grasses are slow growing and take several years to establish *(7-9, 12, 26)*. A number of species have been recommended as good nurse crops to use with native grass seed mixes. Miller et al. *(12)* recommend *Lolium perenne*[E] (perennial ryegrass) when seeded at less than 3 lbs. Pure Live Seed (PLS)/ac (3.4 kg PLS/ha), as it doesn't outgrow the native grasses and should be outcompeted within two to three years. Barton et al. *(9)* recommend *Elymus canadensis*[N] (great plains wild rye), Brown et al. *(26)* suggest using *Elymus trachycaulus*[N] (slender wheatgrass), and Kuzovkina et al. *(7)* name *Elymus virginicus*[N] (common eastern wild rye) and *Chamaecrista fasciculata*[N] (partridge sensitive-pea) as potential nurse crops.

No literature was found advising against using nurse crops, although Busby *(8)* advises choosing species that are not overly aggressive to avoid competition with desired long-term vegetation. For the New England area, it is recommended that the proportion of nurse crop seed by PLS count not exceed 15–20% of the seed mix to ensure adequate space and resources for the slower-growing native grasses and forbs *(7)*. Desirable stand density is discussed further in the section Stand Density and Seeding Rates.

A Maryland field study tested how different nurse crop species affected the establishment of native grasses over a two-year period *(42)*. A native grass seed mixture was applied at a rate of 9.5 lbs. PLS/ac (10.6 kg PLS/ha) along with each of the 10 nurse crops tested, including the three natives *Elymus canadensis*[N] (great plains wild rye), *Elymus viriginicus*[N] (common eastern wild rye), and *Lespedeza capitata*[N] (round-headed bush clover) at a rate of 2.7 lbs. PLS/ac (3.0 kg PLS/ha), 2.4 lbs. PLS/ac (2.7 kg PLS/ha), and 2.2 lbs. PLS/ac (2.5 kg PLS/ha) respectively. On a PLS basis *Elymus canadensis*[N] (great plains wild rye), *Elymus viriginicus*[N] (common eastern wild rye), and *Lespedeza capitate*[N] (round-headed bush clover) make up 7.1%, 4.5% and 7.9% of the seed mix respectively. These nurse crop seeding rates are significantly below the maximum proportion of the total seed mix of 15–20% advised by Kuzovkina et al. *(7)*. After two years, *Elymus canadensis*[N] (great plains wild rye) resulted in a desirable grass density of 1.0 plant/ft^2 (10.8 plants/m^2), *Elymus virginicus*[N] (common eastern wild rye) in 0.9 plants/ft^2 (9.7 plants/m^2), and *Lespedeza capitate*[N] (round-headed bush clover) in 1.2 plants/ft^2 (12.9 plants/m^2). Desirable stand density is discussed further in the section Stand Density and Seeding Rates.

There is strong agreement in the literature that nurse crops should be included as part of a native grass and forb seed mix. *Elymus canadensis*[N] (great plains wild rye), *Elymus viriginicus*[N] (common eastern wild rye), and *Lespedeza capitata*[N] (round-headed bush clover) have been tested and proven effective nurse crops when seeded at a rate of 7% on a pure live seed basis as part of a native grass and forb seed mix *(42)*. Additional recommended nurse crops include *Lolium perenne*[E] (perennial ryegrass), *Elymus trachycaulus*[N] (slender wheatgrass), and *Chamaecrista fasciculata*[N] (partridge sensitive-pea) *(7, 12, 26)*. Meanwhile *Avena sativa*[E] (grain oats) is recommended as a spring cover crop and *Triticum aestivum*[E] (winter wheat) as a fall cover crop for New England *(7)*.

The *Manual for the Effective Establishment of Native Grasses and Forbs on Roadsides in New England* recommends that seed origin be given as much consideration as species selection because the use of nonlocal seed can negatively affect local plant populations through outbreeding depression *(7)*. Outbreeding depression refers to the resulting loss of biological fitness of progeny resulting from the interbreeding of distantly related individuals of the same species and happens when plants of a certain species originating form a nonlocal population interbreed with the local populations of that species. Therefore it is recommended that native grass and forb seed in seed mixes originate from a local species ecotype sharing the same level III ecoregion as the project site where the seed mix is to be used *(7-9)*.
An ecoregion is a geographic area where the type, quality, and quantity of ecosystems is generally similar. The US EPA has defined a hierarchy of ecoregions in the United States that range from the largest and most general (level I ecoregions), down to the smallest and most specific (level IV ecoregions) *(43)*. Ecotype is a term used to describe a subset of a species that is specifically adapted to certain environmental conditions, but that are not different enough from the general species populations to be classified as a subspecies. Local

plant populations often are classified as ecotypes. Ecotypes are often better adapted to their respective regions of origin, and thus it is desirable to use local ecotypes in roadside revegetation projects because they will have a competitive advantage over nonlocal populations *(9)*. As early as 2002, state DOTs in Georgia, Ohio, Utah, South Dakota, and Maryland have reported utilizing local ecotypes in roadside seed mixes *(44)*

Sourcing seed from level III ecoregions prevents roadside revegetation projects from causing outbreeding depression and minimizes the risk that the seed used will not be adapted to local environmental conditions *(7, 8)*. It not only matters where seed originates from, but how it is collected. Maintaining local genetic diversity within a planting is thought to be an important factor affecting the long-term success of a planting *(7)*. Busby *(8)* recommends that seed be collected from "generation 0" collections, while Kuzovkina et al. *(7)* advise that species specific harvesting protocols will need to be developed that specify both how many sites within a region and the number of parents within each site to sample in order to maintain local genetic diversity.

Additionally, seed from other states of species considered rare in the area where the seed mix is to be used should be excluded *(7)*. Using seed of rare species in roadside seed mixes may hinder rare plant conservation efforts by causing confusion between planted and remnant populations, gene flow that leads to outbreeding depression, genetic swamping of remnant populations near planting sites, changes to pollination quality and quantity, and introduction of diseases and pests *(7, 45-48)*. Therefore prior to including a native species in a roadside planting mix, check its conservation status on the GoBotany website run by the Native Plant Trust (https://gobotany.nativeplanttrust.org/). If a species is considered rare in the area where seeding is to occur, that species should be excluded from the seed mix.

There are currently very few sources offering seed of New England ecotypes of native grass and forb species. Ernst Conservation Seed Inc. (Meadville, PA) sells seed of New England ecotypes for only a few species of native grasses and forbs (Table 3.4), although Mark Fiely (personal communication) of Ernst Conservation Seeds expects that their offerings will expand at some point in the future. Additionally, Mark Fiely (personal communication) is not aware of other seed producers selling New England ecotypes of native grass and forb seed. Heather McCargo (personal communication) of The Wild Seed Project (Portland, ME) offers seed collected from plant populations within the state of Maine for a number of grass and forb species, however inventory in limited and not currently sold in bulk. A number of additional organizations including New England Wetland Plants (Amherst, MA), Earth Tones Native Plants (Woodbury, CT), and Nasami Farm (Whatley, MA) grow plugs and pots of native grasses and forbs from New England ecotype seed, but do not sell the seed itself.

Table 3.4: Available New England ecotype seed

Species	Ecotypes
Andropogon gerardii[N] (big bluestem)	APB (Albany Pine Bush, NY) ecotype
Elymus virginicus[N] (Virginia wildrye)	'Madison' supposedly has VT parentage to go with NY, OH, and PA
Eragrostis spectabilis[N] (purple lovegrass)	RI ecotype
Lespedeza capitata[N] (round-headed bush-clover)	RI ecotype
Schizachyrium scoparium[N] (little bluestem)	APB ecotype, LI ecotype

Note: Based on the offerings of Ernst Seed, the only source this research found offering New England ecotype seed for sale by species on a commercial scale.

3.1.12. Stand Density and Seeding Rates

The goal of roadside revegetation is to achieve sufficient stand density and vegetative cover to stabilize the roadside, control soil erosion, manage growth of invasive species, and be aesthetically pleasing. A stand density of 1 plant/ft^2 (10.8 plants/m^2) is capable of achieving a closed canopy in a mature native warm-season grass planting *(7, 12)*. However, it can take over three years for native warm-season grasses to mature, and it is unclear what interim native warm-season grass density is desirable and can be used to measure the success of a planting one year after seeding. Kuzovkina et al. *(7)* recommend for native grass and forb plantings on New England roadsides, that plant densities the spring after seeding be between 20 and 25 plants/ft^2 (215 – 269 plants/m^2. However, Miller et al. *(12)* characterize a successful native warm-season grass planting on reclaimed mine sites should have a minimum of 1 grass plant/ft^2 (10.8 plants/m2) by Sept. 1 of the first year of a spring planting. While Miller and Kuzovkina et al. do not agree on desirable stand densities within the first year of planting, they do agree along with other sources that seed should be bought and seeding rates specified on a Pure Live Seed (PLS) basis *(7-9, 12)*.

Pure live seed (PLS) is defined by Barton et al. *(9)* as "the percentage of specified seed that will germinate and can be determined by multiplying the pure seed percentage by the germination percentage and dividing by 100." Also, it is important to note that the application rates by weight (lbs. PLS/acre) of each species in a seed mix is heavily influenced by each species' seed weight. Barton et al. (2009) give the example of *Asclepias tuberosa*[N] (butterfly weed) which has heavy seed (67,000 seed/lb. or 147,709 seed/kg) and *Schizachyrium scoparium*[N] (little bluestem) seed which is light (260,000 seeds/lb. or 573,202 seed/kg). A seed mix with a 50:50 ratio of grasses to forbs by PLS would have roughly 4 times more lbs. PLS of *Asclepias tuberosa*[N] than lbs. PLS of *Schizachyrium scoparium*[N] *(9)*. Additionally, Miller et al. *(12)* advise buying seed that is pre-stratified, so that it is ready for germination.

The literature search found no studies that tested different native grass and forb seeding rates and resulting stand densities in conjunction with compost blankets. One Kentucky study investigated various fescue seeding rates into a compost blanket on a 3:1 slope and based on their results recommends a seeding rate of 3–5 lbs./1000 ft^2 (15–24 kg/1000 m^2) *(49)*. It is unclear how this may inform seeding rates of a PLS basis of native grasses and forbs.

Perhaps more relevant are a number of studies and reports that test and recommend varying native grass and forb seeding rates without the use of compost blankets.

A two-year study in Iowa tested the effect of three different seeding rates of native grasses and forbs on the density and diversity of the resulting roadside prairie community *(41)*. Results indicated that the density and diversity of native forbs was more responsive to an increase in PLS/ft^2 than native grasses, while an increasing native grass PLS/ft^2 resulted in a greater reduction of weed biomass than increasing native forb PLS/ft^2. The authors recommend a native grass seeding rate of 26–50 PLS/ft^2 (280–538 PLS/m^2) to achieve a stand density of 1.0 grass plant/ft^2 (10.8 grass plant/m^2) and a native forb seeding rate of equal to or greater than the native grasses in order to increase the planting's species richness.

In Maryland, Adamson et al. *(42)* found that a native grass seed mix of eight species seeded at a rate of 9.5 lbs. PLS/ac (10.6 kg PLS/ha) or roughly 4 million PLS/ac (10 million seed/ha) in conjunction with a nurse crop at a rate of 2.2–2.7 lbs. PLS/ac (2.5–3.0 kg PLS/ha) or 192,000–352,000 PLS/ac (474,432–869,792 PLS/ha), depending on the nurse crop species resulted in desirable native grass densities from 0.9 to 1.3 plants/ft^2 (9.7–12.9 plants/m^2) after two years. This native grass seeding rate is close to the 10–5 lbs. PLS/ac (11.2–16.8 kg PLS/ha) native forbs seeding rate that Aldrich et al. *(44)* recommend for wildflower planting. It is also in line with the seeding rates of 5 lbs. PLS/ac (5.6 kg PLS/ha) native forbs and 5–10 lbs. PLS/ac (5.6–11.2 kg PLS/ha) native grasses that Barton et al. *(9)* recommend for roadsides in Delaware. These sources all recommend total native grass and forb seed mix application rates of between 10 and 15 lbs. PLS/ac (11.2 and 16.8 kg PLS/ha).

However, not all sources have found a native grass and forb seeding rate of 10–15 lbs. PLS/ac (11.2–16.8 kg PLS/ha) to be adequate. Interestingly enough, in the same manual in which Barton et al. *(9)* describe a general recommended seeding rate of 5 lbs. PLS/ac (5.6 kg PLS/ha) native forbs and 5–10 lbs. PLS/ac (5.6–11.2 kg PLS/ha) native grasses, a specific seed mix for medians is described as having a seeding rate of 2.7 lbs. PLS/ac (3.0 kg PLS/ha) native forb and 18.2 lbs. PLS/ac (20.4 kg PLS/ha) native grasses, almost double the rate of the general recommendation. It may be that in certain situations, such as median plantings, where site conditions can be expected to increase seedling mortality, it will be necessary to increase seeding application rates. Fall seeding may be another such situation. Kuzovkina et al. *(7)* recommend increasing native grass and forb seeding rates by 40–50% when dormant seeding to account for reduced germination and increased mortality from soil borne diseases and seed predation. It is also possible that increased seeding rates may be required on steep slopes or sites with especially poor soil.

In Pennsylvania, a seed mix of 17 lbs. PLS/ac (19.1 kg PLS/ha) native warm-season grasses, 16.3 lbs. PLS/ac (18.3 kg PLS/ha) native cool-season grasses, 3.16 lbs. PLS/ac (3.5 kg PLS/ha) forbs, and 64 lbs./ac (71.7 kg PLS/ha) spring oats seeded onto steep roadsides with poor soil resulted in a native grass and forb stand density of less than 1 plant/ft^2 (10.8 plants/m^2) after two years *(30)*. This density is less than desired densities outlined by both Miller et al. *(12)* and Kuzovkina et al. *(7)*. It is unclear what factors were involved in the poor native plant stand density. The native grass and forb seeding rate may have been inadequate for the site conditions, which included a steep slope and poor soil. It is also possible that native plant densities were negatively affected by the spring oats seeding rate, which made up a significantly higher proportion of the seed mix than the 15–20% recommended for a nurse crop by Kuzovkina et al. *(7)*.

It has been shown that a seeding rate of 10–15 lbs. PLS/ac (11.2–16.8 kg PLS/ha) of native grass and forb seed is capable of establishing a native plant density equal to or greater than 1 plant/ft^2 in certain situations *(41, 42)*. However, it seems likely that this seeding rate will need to be increased when site or planting conditions are expected to cause excessive seedling mortality. Such conditions may include roadside medians, steep slopes, poor soils, and dormant seeding in the fall. As previously discussed, unequal seed weight between species can cause a seeding rate recommendation given in lbs. PLS/ac to result in very different numbers of PLS to be applied depending on the species used. Therefore, it may be preferable to instead describe seeding rates in terms of PLS/ac. Seeding rates between 1 million and 4 million PLS/ac (2.5–10 million PLS/ha) have been shown to achieve native grass stand densities of 1 plant/ft^2 (10.8 plants/m^2) *(41, 42)*. This seeding rate is further supported by *The Tallgrass Restoration Handbook*, which states that seeding rates of 20–80 PLS/ft^2 (0.9–3.5 million PLS/ac) have been used to successfully reestablish native grass and forb prairie plant communities *(40)*.

3.1.13. Seeding Timing

Spring has long been viewed as the best time to plant seed of all type, including seed of native grasses and forbs. There is typically abundant moisture for germination, seedlings have time to develop prior to the heat and drought of summer, and a full growing season to mature before facing their first winter. Due to the potential for heatwaves and drought, summer is not viewed as an optimum time for seeding. There is growing interest in the potential of dormant seeding in the fall. Dormant seeding involves planting seed in the fall prior to the ground freezing, but late enough that cool soil temperatures prevent seed from germinating. Busby *(8)* recommend fall seeding when soil temperatures 1" deep are 40^{o} F or less. The seed experiences freeze-thaw cycles and periods of cold through winter, before ideally germinating in the spring, much as seed would experience naturally if seed were left to fall from the parent plant at the end of the growing season. It is thought that germination of some species may be enhanced when dormant seeded in the fall.

However, the literature is not conclusive as to the optimal time of year to plant native grass and forb seed. More sources indicate that dormant fall seedings of native forbs is preferable to spring. The *Manual for the Establishment of Native Grasses and Forbs on Roadsides in New England (7)* and an Illinois DOT *(8)* report on native vegetation establishment for erosion control both recommend dormant seeding in the fall for native forb establishment. Results from a Georgia field study testing planting timing with different native grass and forb species also support dormant seeding forbs in the fall *(50)*. *Rudbeckia hirta*^{E} (black eyed susans), *Coreopsis lanceolata*^{E} (lanceleaf coreopsis), *Pycnanthemum virginianum*^{N} (mountain mint), *Monarda fistulosa*$^{N+E}$ (wild bergamot), *Asclepias tuberosa*^{N} (butterfly weed), *Chamaecrista fasciculata*^{N} (partridge pea), *Asclepias incarnata*^{N} (swamp milkweed), and *Coreopsis tripteris*^{E} (tall coreopsis) all had a higher percentage of vegetative cover 12 months after planting when dormant seeded in the fall rather than the spring. Yet Barton et al.

(9) report that consistently better native perennial forb establishment in Delaware has been achieved with spring plantings rather than fall.

When it comes to the optimal seeding time of native grasses there is again disagreement in the literature, but out of the literature surveyed there appears to be more evidence supporting spring as the optimal seeding time *(7, 9, 50-52)* than fall *(50, 51)*. Kuzovkina et al. *(7)* state that the best time to establish native warm-season grasses in New England is between mid-May *(9)* to late June. Ideally the grasses should have a growing season of 100–120 days to establish roots prior to winter, and they require a minimum soil temperature of 65^{o} F (18.3^{o} C) to germinate. Field studies testing the effect of seeding timing on native grass establishment in North Carolina *(51)*, Illinois *(52)*, and Georgia *(50)* have found that the native grass species tested have higher establishment rates when seeded in the spring as opposed to the fall. There are exceptions to this general finding.

At one of two sites in the North Carolina study, *Schizachyrium scoparium*[N] (little bluestem) had significantly greater vegetative cover four years after planting when fall seeded than when spring seeded *(51)*.

In summary, based on the literature surveyed, it appears that forbs benefit the most from dormant seeding in the fall, while higher native grass establishment is reported when seeding in the spring. If dormant seeding native grasses, Kuzovkina et al. *(7)* advise increasing the seeding rate by 40–50% to account for increased seed mortality and predation over winter and also recommends including annuals and cool-season grasses in the seed mix that will establish rapidly and reduce weed pressure.

3.1.14. Seed Placement in Compost Blankets

There are three possible options for seed placement when planting compost blankets. Seed can be planted into or on top of the soil surface, and then the compost blanket applied on top, seed can be incorporated into the compost blanket, or seed can be applied on top of the compost blanket. Very little literature was found that recommends or tests different native grass and forb seed placement in relation to compost blankets. Among these few sources, the EPA states that native grass and forb seed is typically incorporated into the compost prior to compost blanket application *(19)*. Incorporation ensures even distribution within the compost, where the seed is secure and unlikely to be washed away by stormwater. Incorporating seed into compost, which can then be applied by a pneumatic blower sidesteps the problem that arises from relying on mechanical spreaders or a Traux drill seeder, both of which do not perform optimally when used on the unlevel terrain that often characterizes roadsides *(7, 9)*

In Delaware, Barton et al. *(9)* report successfully establishing native warm season grasses and forbs from seed incorporated into sawdust and applying the sawdust/seed mixture as a 1” (2.5 cm) deep surface application. The sawdust was observed to act as a mulch, suppressing weeds while providing a growth medium for the seed. Based on this work, Barton et al. *(9)* recommend mixing native seed in with composted yard waste and applying it as a surface application, although the depth of said application is not specified. The compost is predicted to create a favorable environment for germination, and incorporation of the seed ensures good seed-to-compost contact. While no other literature was found specifying how to apply native seed in conjunction with compost blankets, there are many sources offering guidance on seeding native grasses and forbs into topsoil.

The two most important factors for successful native grass and forb establishment from seed are good seed-to-soil contact and a strict planting depth of 0.25” *(7-9, 12, 51)*. Incorporating native seed into compost seems to assure good seed to soil (or in this case compost) contact, but it is less clear how compost blanket depths of 1– 2” (2.5– cm) or more may affect the germination rates of incorporated native seed. It may be that compost blankets several inches deep will require higher rates of incorporated seed, as a large portion of the seed will be deeper than the optimal 0.25” (0.6 cm) planting depth. The literature review was not conclusive with respect to this issue.

3.1.15. Maintenance of Compost Blankets and Native Grass and Forb Plantings

Site Monitoring

It is extremely important that sites be monitored after the installation of compost blankets and planting of native grass and forb seed. Barton et al. *(9)* recommend that new native grass and forb plantings on Delaware roadsides be inspected 4–6 weeks after non-dormant season planting by personnel trained to differentiate between desirable and undesirable species to determine weed species present. Similarly, Kuzovkina et al. *(7)* recommend inspecting new plantings along New England roadsides three weeks after planting to evaluate weed pressure and inform management strategies. Additional inspections of plantings and of compost blankets should be conducted after each major rainfall to determine if erosion/washout has occurred *(7, 19)*. If part of the compost blanket has washed out, compost and seed should be reapplied, and if necessary additional stormwater best management practices (BMPs) such as compost filter socks installed.

Mowing

Managing weed competition is an important factor affecting the establishment of native warm-season grasses *(50)*. Native warm-season grasses initially concentrate their growth in their roots, and the leaves and stems often don’t exceed 1’ (0.3 m) in height by the end of the first year *(7)*. This means that native warm-season grasses are especially susceptible to weed competition during the first one to three years during which they are establishing. However their initially slow above-ground growth means that mowing, when properly timed at specific heights, can be used as a management tool to selectively reduce the competitiveness of certain weedy species *(7-9, 12, 50)*.

The timing and frequency of mowing impacts the composition of the vegetative community present *(9)*. Earlier mowing between April 15 and May 15 is required for the control of cool-season grasses and weeds in New England, while a later mowing in mid to late May is necessary to control shrubs and tree saplings *(7)*. It is recommended that native grasses and forbs be mowed repeatedly during the first year at height of 6” (15 cm) whenever weeds reach a height of 8-12” (20–30 cm) *(7, 8)*. Once the native grasses reach 6” (15 cm) tall, adjust mowing height to 12” (30 cm) *(7)*. The use of mowing is to prevent annual weeds from setting seed and to insure proper light for native grass and forb seed germination and establishment *(7)*.

During the second year of establishment, both Kuzovkina et al. *(7)* and Miller et al. *(12)* recommend mowing once in mid to late June to prevent annual and biennial weeds from setting seed, while Busby et al. *(8)* recommend mowing once in mid spring and again in late spring. If heavy weed pressure exists, mow as necessary later in the second year to a height just above the native grass foliage *(7)*. If the weeds grow too tall before mowing during the first and second years of establishment, the cuttings may smother the native grass seedlings *(7, 8)*. If weeds are over 2' (0.6 m) tall prior to spring mowing, Busby et al. *(8)* recommend removing the clippings to avoid suffocation. Kuzovkina et al. *(7)* recommend using flail mowers rather than rotary mowers because flail mowers chop the cut material, thus reducing the chance that the small native grass seedlings will be smothered by clippings.

In the third year of establishment and beyond, mow once in the spring and remove the cut material *(7)*. Busby et al. *(8)* recommend that successfully established stands of native grasses and forbs should be mowed once every two to three years in the spring and the residue removed. Mowing and removing the residue in the spring simulates a prescribed burn by exposing the soil to sunlight, causing it to warm earlier in the season. This promotes shoot growth of native warm-season grasses and many forbs *(7, 12)*.

Spring mowing is preferable to fall for several reasons. A study in Oklahoma testing *Panicum virgatum*[N] (switchgrass), *Sorghastrum nutans*[N] (indiangrass), *Andropogon gerardii*[N] (big bluestem), and *Schizachyrium scoparium*[N] (little bluestem) establishment observed that the native grasses produced mature seed during September of the second growing season *(53)*. The seed was left on the plants and germinated the following spring, increasing native stand density 5–10%. Therefore, it is recommended that fall mowing should either be avoided or occur late enough in the season that warm-season grass seed has already matured. Native grass and forbs plantings have aesthetic value and add winter interest *(9)*. Additionally, letting the vegetation stand through winter allows the tissue to begin to decay, making it easier on the mowing equipment in spring, while at the same time providing habitat for overwintering organisms *(9, 36)*.

Mowing has been shown to significantly impact pollinators by causing direct mortality to the relatively non-mobile egg and larval stages *(36)*. To reduce the negative impact of mowing on pollinators, Kuzovkina et al. *(7)* report that the Wild Seed Project in Maine (https://wildseedproject.net/) advocates for the practice of mosaic mowing *(54)*. Mosaic mowing involves staggering the mowing time for alternating sections of roadside. This ensures that there are always patches of unmowed vegetation along roadsides to supply pollinators with forage and overwintering sites. Busby et al. *(8)* raise the concern that a consistent annual mowing time would impact some native species more than others and recommends alternating spring and fall mowing established plantings. Mosaic mowing has the potential to be compatible with an annual mowing that alternates seasons, and if the fall mowing is timed appropriately late, also follow the recommendation of King et al. *(53)* to allow native warm-season grass seed to fully mature prior to cutting.

Kuzovkina et al. *(7)* recommend that state DOTs find or develop a software capable of tracking mowing regimes for the different maintenance practices associated with traditional cool-season turf and native warm-season grass plantings, as the mowing frequency and height is different. A cool season turf mowing regime mistakenly applied to native grass and forb plantings could negatively affect long-term establishment. A tracking software would seem additionally relevant if mosaic mowing was to be practiced for native grass and forb plantings, as mosaic mowing would add another layer of logistical complexity.

Mowing is a necessary management strategy for native grass and forb plantings. However, it is crucial that the timing and mowing height be correct because improper mowing will do more harm than good to the native grasses and forbs. Mowing should occur often during the first year, at a height just above the native grass seedlings or 6" (15 cm), whichever is greater. In the second year, mowing should be done twice in the spring, with the second cut occurring around June, at a height just above the native grasses. In the third year and beyond a single mowing should occur in spring and the residue removed. Flail mowers should always be used as they reduce the chance that desirable seedlings are smothered by cuttings. Mowing that disrupts the native grasses reproductive cycle should be avoided, as seed produced by native warm season grasses has been shown to fill in gaps and increase stand density the subsequent year.

Chemical Weed Control

Chemical weed control is another tool available for use in roadside planting maintenance programs. Sometimes the aggressiveness of weed species or the terrain of the roadside might make mowing an ineffective or impractical weed management option. Kuzovkina et al. *(7)* recommend using Plateau® or Panoramic®, imazapic-based herbicides. They kill plants with faster metabolisms and when used at the proper concentrations most native warm-season grasses and some native forbs, such as *Chamaecrista fasciculata*^{N} (partridge sensitive pea), *Rudbeckia hirta*^{E} (black-eyed susan), *Achillea millefolium*^{N} (yarrow), and *Lupinus perennis*^{N} (perennial lupine), are tolerant. Another strategy applicable to warm-season grass plantings is to use a general herbicide like glyphosate early in the spring before native warm-season grasses emerge *(9)*.

Invasive Species

Invasive species can prove a challenge for roadside managers and commonly overrun desirable plantings. While it is beyond the scope of this literature review to provide an overview of invasive species management techniques, a few interesting research studies on the control of *Reynoutria japonica*^{E} (Japanese knotweed) surfaced in the literature survey. *Reynoutria japonica*^{E} is proving to be a highly invasive species that is very difficult to control and is found throughout the state of Massachusetts.

3.2 General Practices Interview Survey

This survey of practices used for compost application and seeding of native grasses and forbs by regional DOT experts started with interviews from Northeastern states. During these interviews other experts were recommended to interview from other states, including Wisconsin, Minnesota, Washington, Texas and Maryland. And these DOT experts, in turn, recommended interviews with experts from native species seed companies and landscape professionals with substantial experience in establishing native grasslands and meadows. A full listing of interviewees can be found in Section 2.2.2.

3.2.1. Compost Blanket Uses

Compost blankets are being used in many states to stabilize slopes. Beverly Storey (Texas) reports that compost blankets are used extensively in conjunction with seeding for roadside slope stabilization and erosion control on slopes up to 3:1. Washington DOT regularly uses compost blankets in conjunction with seeding or a secondary erosion control BMP for roadside slope stabilization. Maryland formerly used compost blankets for stabilization of slopes up to 1:1, but no longer does because of lower success on slopes of 2:1 or greater. Researchers at the University of Maryland are currently conducting field research studying compost nutrient content and its effects when applied to roadsides (results not available). In Virginia, compost and compost blankets are used regularly for stormwater BMPs along roadsides and road basins.

Connecticut DOT does not use compost blankets for slope stabilization. However, Susan Fiedler, Connecticut DOT, reports that its Highway Design Unit occasionally uses compost blankets to establish cool season turfgrasses on stakeholder projects involving private landowners. These projects are all on relatively flat sites. Vermont does not use compost blankets on highway roadsides (source: Heather Voisin).

Compost blankets are commonly used for slope stabilization and erosion control by the states represented in the interviews. In most instances, compost blankets are used in conjunction with vegetation establishment, most commonly cool season turfgrasses.

3.2.2. Compost Blanket Application DOT Specifications

State specifications for site preparation vary. Topsoil is commonly tilled and/or tracked prior to compost blanket application. Some states require that the subgrade be “ripped” (deep scarification). Texas applies compost blankets onto sites with tilled or untilled subsoil. In Virginia, after soil preparation, two herbicide treatments are applied at two-week intervals prior to seed and compost application. Larry Weaner (Pennsylvania) also stresses the importance of weed management and recommends a fallow period planted with a cover crop that is later treated with herbicide after a full warm and cool season growing season, all prior to seeding the desired vegetation.

Compost blankets are either mechanically spread or pneumatically applied. The Texas DOT pneumatically applies 2” to 3” compost blankets. Connecticut mechanically spreads a 2” compost blanket. The Washington DOT recommends applying a 2” to 3” compost blanket pneumatically via blower trucks to avoid soil compaction, although sometimes contractors mechanically spread it. Virginia’s Fairfax County applies compost blanket 4” deep for drainage basin and stream restoration projects. When Maryland DOT previously used compost on roadsides, compost blanket depths of 4” were utilized.

Compost blanket depths of 2” to 3” are the most common depth in the specs described. Both mechanical and pneumatic compost application are frequently used, but pneumatic blowing seems to be preferred in order to reduce soil compaction on the site.

3.2.3. Summary of Challenges and Successes of Compost Blankets

Bob LaRoche (Maine-consultant) reports that 4” compost blanket application worked very well for erosion control and did not present erosion problems. However, according to John Krouse (Maryland DOT), ongoing University of Maryland research examining the use of 0.25” to 1” compost blankets has reported some erosion problems and is concerned that the use of nutrient heavy compost may contribute to water quality problems from roadside runoff.

Texas DOT has successfully used 2–3” compost blankets to stabilize roadside slopes, with signs of erosion only surfacing when extreme precipitation occurs after compost application. The Washington DOT has had success using 2–3” compost blankets to control erosion throughout different areas of the state that receive vastly different rainfall quantities and intensities.

Virginia’s Fairfax County had problems using a 4” compost blanket on a cloverleaf basin that had steep (3:1) slopes and was adjacent to a large paved area which drained into it. Eventually most of the compost was washed into the bottom of the basin. Other Fairfax County compost blanket projects have had erosion issues related to concentrated surface water flow.

Washington DOT personnel have reported encountering challenges when using compost blankets in certain situations. Rill erosion has occurred where compost blankets are subject to point sources of surface water flow, such as funneled roadway runoff. Sites where the water table rises or seeps are present often experience compost runoff. Additionally, extreme precipitation events following compost application on steep slopes can lead to some erosion. Compost depths greater than 3” applied to steep slopes are prone to slumping during rain events.

In Washington compost blankets at increased risk of erosion will be covered by Long Term Mulch (a hydraulically applied wood-based erosion control product), seed, sod, or erosion control blankets. If heavy rains are in the forecast, contractors in Washington have been reported to overlay the new compost blanket with plastic.

DOT personnel and researchers across a large geographic span have success using 2–3” compost blankets to reduce erosion and help stabilize slope. However, intense rainfall, concentrated surface water entering the compost blanket, seeps, sites with rising water tables, and compost depths greater than 3” on steep slopes often result in erosion and slumping. These situations require combining compost blanket use with other erosion control BMPs.

3.2.4. Factors Affecting Successful Slope Stabilization with Compost Blankets

Appropriate surface preparation and correctly specified compost material and depth appear the most crucial components to successfully reducing erosion and stabilizing slopes using compost blankets. Also reported as important factors are the timing of compost application and the establishment of >75% living vegetative cover.

3.2.5. Alternative Measures of Slope Stabilization

Virginia's Fairfax county commonly uses wood chip mulch to stabilize the slopes of stormwater basin and stream corridor restoration projects. Connecticut uses biodegradable matting and cool season grasses for slope stabilization, and occasionally will use a conservation or coastal seed mix containing some native warm season grasses. Maryland uses straw blankets, lightweight excelsior blankets, or woven coconut fiber in conjunction with vegetation establishment to stabilize slopes. Washington state uses a variety of slope stabilization techniques, sometimes in conjunction with compost blankets and sometimes not. These include Long-Term Mulch, seeding, erosion control blankets, coir logs, and addition of quarry spalls into soil.

Washington has reported successful use of all alternative measures in varying combinations to stabilize slopes. They report that when proper slope stabilization methods are used, steep cut slopes seem to stabilize after one or two years.

3.2.6. Seeding on Compost Blankets for Slope Stabilization

Seed Mix Composition

More state DOT interviewees report using cool-season grass seed mixes for slope stabilization than native grasses and forbs. Washington, Connecticut (for stakeholder DOT projects), Maryland (when slopes are greater than 4:1), and Maine use cool season grasses for slope stabilization. Western Washington only uses cool season grasses, while eastern Washington uses cool season grasses and forbs. Texas DOT uses seed mixes that include native grasses and forbs for erosion control and slope stabilization on slopes up to 3:1. Connecticut DOT utilizes several different native grass and forb seed mixes including a conservation mix, floodplain mix, coastal mix, and wildflower mix for general DOT projects (not for special projects coordinated with specific private clients). Meanwhile, Maryland routinely uses native warm season grass and wildflower seed mixes for roadside projects that are not to be mowed on slopes up to 4:1.

Professor Katia Engelhardt (Maryland) has been conducting three-year monoculture growing trials of alternative, low and slow growing species for use along roadsides. Out of the 20 species examined, preliminary results show the native warm season grasses *Boutelloua curtipendula*[N] (sideoats gramma), *Eragrostis spectabilis*[N] (purple lovegrass), *Schizachyrium scoparium*[N] (little bluestem), and *Sporobolus heterolepis*[N] (prairie dropseed) receiving the best rank based on establishment, maintenance, slope stabilization, and stress resistance. Katia emphasized the outstanding performance of *Boutelloua curtipendula*[N]. Overall findings show that warm-season grasses are well-adopted to roadside conditions, and once established, provide durable, low-maintenance cover.

Nurse crops are commonly seeded in conjunction with roadside seed mixes. Maryland reported using oats with late fall or winter seeding. Maine and Washington plant annual rye.

Mark Fiely (Pennsylvania), horticulturalist with Ernst Conservation Seeds, strongly advises that native grass and forb seed mixes always be planted in conjunction with a nurse crop. Similarly, Larry Weaner, landscape designer (Pennsylvania) recommends planting a cover crop prior to seeding, or planting a nurse crop in tandem with the native grass and forb seed mixture

In summary, based on interviews, it appears that cool season grasses are more commonly used on steep slopes for erosion control and stabilization. However, research indicates that native warm season grasses are well adapted to roadside conditions. Furthermore, native grass and forb mixes have been reported to effectively stabilize slopes and reduce erosion on roadside slopes up to 3:1. Nurse crops are almost universally seeded along with native grass and forb seed mixes.

Site Factors Reported to Affect Seed Mix Composition and Establishment

Roadside soil types are not reported as having a significant effect on the type of seed mix used or establishment success. Interviewees pointed out that most roadside projects involve massive soil disturbance, and often a contractor brings in the future topsoil as a blend made to fit project specifications. However, Texas DOT does specify different species and seeding rates for erosion control based on whether clay or sandy soils are to be planted.

Roadsides have environmental factors that that might determine the selection of species and the mix compositions. According to Professor Katia Engelhardt, roadside plantings must deal with increased heat, salt, and drought stress. In addition, projects have unique sun and hydrological conditions that need to be considered with regard to seed selection such as shorelines and floodplains.

Seeding Timing

Seed timing is related to seasonal moisture availability and heat. Interviewees describing practices in southern states tended to have planting windows in early spring or even over winter. John Krouse (Maryland) observes increased establishment and less weed pressure in Maryland when native grasses and forbs are planted in February and March. He has observed increased winter annual weed pressure during fall plantings, and problems with the weed giant foxtail when planting later in the spring around May. Further south, in Virginia's Fairfax County, the planting window is from November to June, and in Texas, district specific planting windows fall between February and May.

The Connecticut DOT seeding windows are between March 15 and June 30 and Aug. 15 and Oct. 30. Both Larry Weaner and Mark Fiely advocate spring or fall seeding for native grasses and forbs. Weaner notes that either planting time will have advantages for certain species (spring seeding is preferable for warm-season grasses, and fall season is preferred for forbs), and that late spring planting can reduce cool-season weed pressure.

Seed Application Method
The interview surveys identified a wide range of seeding practices, both in how seeding is applied and where seed is placed in relation to compost blankets. Maryland and Virginia's Fairfax county place seed on top of compost blankets, in Fairfax using a mechanical spreader. In Washington, seed is either hydroseeded on top of compost blanket, or continuously mixed into compost and then pneumatically spread to the specified compost blanket depth. Both methods are reported as being highly successful in Washington. Texas is the only state which broadcasts seed mixes underneath compost blankets prior to their application.

Larry Weaner (Pennsylvania) states that the traditionally preferred method of planting native grasses and forbs with a drill seeder cannot be applied to compost-covered slopes which is the focus of this research. This is in part because of the inherent difficulty and safety concerns related to tractor-pulled drill seeding equipment on slopes. Based on the knowledge that only seeds in the top 0.5" of compost will germinate, Larry recommends a two-stage operation where first the compost blanket is applied to the specified depth (1–2.5"), followed by application of a thin layer (less than 1") of a compost-seed mixture. This would reduce seed waste compared to mixing seed into the entire compost blanket, and only having a fraction of the seed at the correct depth for germination.

Applying seed on top of compost blankets is the most common practice. However mixing seed into a surficial compost application has come up as a viable alternative, and compost injected seed has been reported as highly successful at establishing the intended vegetation in Washington state.

Dwayne Stanlund (Minnesota) reports that Minnesota DOT requires certified training on the specific equipment used for compost and combined compost-seed applications. Minnesota requires equipment with an integrated seed auger that keeps the grass and forb seeds uniformly mixed within the top compost layer.

3.2.7. Factors Affecting Successful Vegetation Establishment and Slope Stabilization

Washington DOT personnel note that seeding timing, soil quality, soil surface preparation, and rainfall are all important factors that affect successful vegetation establishment. On sloped sites, slope stabilization practices such as Long-Term Mulch, compost, compost socks, and coir logs help increase the change of successful native grass and forb establishment. John Krouse notes that straw or lightweight netted excelsior blankets are not conducive to native grass seed germination and establishment.

Seeding timing was mentioned by Neil Diboll (Prairie Nursery, Wisconsin) as the most important factor for seeding success. For Massachusetts, he recommends a late spring seed application between May 15 and June 15, or a late summer seed application from Aug. 15 to Sept. 30.

The most consistent maintenance practice post-planting is mowing. Mark Fiely (Pennsylvania), Larry Weaner (Pennsylvania), and Neil Diboll (Wisconsin) stress the importance of a proper mowing regime for the successful establishment of native warm season grasses. Fiely, Weaner and Diboll recommend mowing native warm season grass plantings to a height of 8" whenever growth reaches knee height (16") during the first year through Sept. 1, after which mowing should cease for the remainder of the year. Weaner and Diboll also recommend mowing in the second year at 12" every time growth reaches 16". These mowing heights during establishment selectively cut invasive plants and weeds, leaving the slower-growing native grasses mostly uncut. Once established, native warm-season grasses should be mowed every one to three years in spring. Based on the interviews, this mowing regime does not appear to be currently practiced in the states from which the research team interviewed DOT personnel. Typically, these plantings receive the same low-mow as cool season grasses, or a single annual mowing.

Some interviewees report that weed control is conducted via herbicide spraying when that is a line item in bid, or if the planting doesn't meet the "pay item" specification. One Washington DOT personnel reported that control of invasive or noxious weeds is undertaken as necessary post-seeding. Another common practice is having contractors reseed as needed based on the one-year post-seeding vegetative cover evaluation. Across the board, supplemental watering of desired vegetation post-seeding does not occur. According to Susan Fiedler with Connecticut DOT, on the occasional projects she has seen where the specs do call for supplemental watering, it is not enforced.

Maryland, Washington, and Connecticut all evaluate vegetation establishment one year after planting. This is noted as problematic for native warm season grass and forb plantings, because these species take three years to fully establish, but the contractors are "off the hook" after Year 1. Requirements for desired vegetative cover range from 70% in Washington to 90–95% in Maryland.

The most frequent maintenance roadside vegetation receives post-seeding is mowing, although it is rarely performed at the correct height and frequency optimal for the establishment of native warm season grasses and forbs. Evaluation of a seeding's success is a universal practice and is done based on the percentage of desired vegetative cover one year after seeding. However, this does not work so well for native warm season grass and forb plantings. These plants often take three years to establish and close their vegetative canopy, and therefore it is hard to accurately evaluate the success of establishment at one-year post-seeding.

3.3 Case Studies and Evaluations

3.3.1. Soil Analysis

Soil pH is an indicator of the acidity of the soil and affects nutrient availability, microbial processes, and plant growth. Most New England soils are naturally acidic. Soil pH ranged from 5.3 to 7.5 for the five sample sites (Table 3.5). In general, the "compost" sample had higher pH values than the mixed "soil probe' samples. All compost pH values were within the AASHTO recommended range for compost pH (AASHTO recommended compost blanket pH range for vegetation establishment is 5.0–8.5). Most of the samples were below the 6.5–7.5 pH range in which nutrients are more easily available; however, all were within the pH range that warm-season grasses and native forbs can tolerate.

Cation exchange capacity (CEC) represents a soil's ability to retain and supply nutrients, specifically cations. Soil CEC is usually provided by clay and organic matter particles. Organic matter generally has a higher CEC than clay. The percentage of basic cations, Ca^{2+}, Mg^{2+}, and K^{+}, occupying the CEC is known as the base saturation. Higher base saturation generally means the soil is more fertile because of the availability of needed plant nutrients (potassium, calcium, and magnesium) and low levels of aluminum which is detrimental to plant growth. High base saturation in soils is related to higher pH. Soil and compost sample base saturation was over 50% for Danvers soil and compost, Conway soil and compost, and Longmeadow compost. Base saturation was very low for the Deerfield soil sample (Table 3.5).

The carbon-to-nitrogen ratio is important to decomposition of organic materials. A carbon-to-nitrogen ratio less than 20:1 will mineralize and break down organic nitrogen into inorganic nitrogen, which is the form available to plants. A finished compost generally has a carbon-to-nitrogen ratio of around 10:1 to 20:1. Carbon to nitrogen ratios of 24:1 or greater have too little nitrogen and microorganisms will deplete soil nitrate and ammonium. All sample C:N ratios except the Deerfield compost sample were less than 24:1 (Table 3.5).

Native soil organic matter in most developed areas of New England is usually less than 8% and is typically between 2% and 4% *(55)*. Sample organic matter at the research sites was highly variable ranging from 1.8 to 29.5% (Table 3.5). The Longmeadow samples were very low along with the Deerfield soil sample. Phosphorus, potassium, calcium, magnesium, and sulfur are the major plant nutrients measured using the Modified Morgan extraction procedure. The soil test suggests an optimum range for the crop of interest, which here is conservation planting with warm season grasses for these tests. Nutrient levels were highly variable between samples ranging from low and very low at some sites to above optimum for others (Table 3.5).

Electrical conductivity (EC) is a measure of the amount of salts in soil or water. High soil EC generally occurs in the western United States where there is less rainfall and therefore a greater likelihood of salt buildup in the soil. Naturally occurring salts are from weathering of minerals and rocks; however, salts in the soil can also be from fertilizers and winter road salt applications. Soil electrical conductivity is variable with soil moisture and temperature. Soil EC values less than 1.2 dS/m are considered non-saline for sandy loam soils. Soil EC values for all samples were below 1.0 dS/m (Table 3.6).

Soil bulk density is the weight of dry soil divided by the total soil volume. Soil bulk density increases with compaction and can restrict root growth when higher than 1.8 g/cm^3 for sandy soils. Sandy soils have higher bulk densities. Soil density was less than 1.8 g/cm^3 for all samples (Table 3.6).

Particle size distribution provides a percentage of the sand, silt, and clay fractions for a sample. Sand fractions are particles 0.052.0 mm in size, silt is particles 0.002–0.05 mm in size, and clay is particles less than 0.002 mm in size. Gravel content is the percentage of particles greater than 2.0 mm in size. All soil and compost samples were a type of sandy loam (Table 3.7).

Table 3.5: Soil test summary

	Soil pH	**CEC (meq/100g)**	**Organic matter (%)**	**P**	**K**	**Ca**	**Mg**	**C:N ratio**
Conway soil	6.7	20.9	13.4	15.9	65	3618	146	15.8:1
Conway compost	7.5	38.8	29.5	19	106	7293	253	16.5:1
Danvers soil	6.0	14.9	7.9	5.1	107	1301	139	18.5:1
Danvers compost	5.8	26.1	19.5	18.6	182	2992	336	23.1:1
Deerfield soil	6.1	7.9	2.9	1.2	49	186	23	16.4:1
Deerfield compost	6.3	16.7	18.4	4.6	146	1085	102	26.0:1
Longmeadow soil	5.8	6.3	1.8	3.0	40	471	35	14.8:1
Longmeadow compost	6.3	6.2	2.3	4.7	48	649	46	14.7:1
Waltham soil	5.3	15.6	6.7	6.8	105	897	68	13.4:1
Waltham compost	6.1	12.9	8.0	5.9	95	910	72	16.0:1

Table 3.6: Other soil properties

	Electrical conductivity (dS/m)	**Soil temperature (degrees F)**	**Soil density (g/cm^3)**
Conway	0.76	54	0.59
Danvers	0.41	69	0.58
Deerfield	0.32	68	1.00
Longmeadow	0.11	68	1.06
Waltham	0.26	72	0.86

Table 3.7: Particle size distribution

	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	USDA textural class
Conway soil	8.3	34.9	56.9	39.2	Gravelly sandy loam
Conway compost	6.1	36.0	57.9	20.2	Sandy loam
Danvers soil	8.0	24.5	67.5	18.0	Coarse sandy loam
Danvers compost	8.6	34.0	57.4	22.6	Sandy loam
Deerfield soil	9.3	17.6	73.1	6.9	Fine sandy loam
Deerfield compost	5.4	37.9	56.7	18.0	Fine sandy loam
Longmeadow soil	7.6	17.4	75.0	8.0	Sandy loam
Longmeadow compost	7.7	16.9	75.4	7.4	Sandy loam
Waltham soil	8.9	34.7	56.4	12.9	Sandy loam
Waltham compost	6.9	31.7	61.4	7.3	Sandy loam

*Particle size distribution analysis using the Hydrometer Analysis method first removes the portion of the sample greater than 2 mm using a sieve. The gravel percentage represents the particles greater than 2 mm and is not included in the soil particle size analysis. Only clay, silt, and sand are considered part of the particle size analysis for soil classification. Therefore, only the clay, silt, and sand percentages add up to 100%, while the gravel is given as a % of the original sample.

3.3.2. Vegetation Analysis

In quantifying plant abundance over a large area, measurement of percentage cover is often the most effective method given its relative simplicity and flexibility to site conditions. Visual estimation of percentage cover can be established given a designated, consistent quantifier, such as in a (10 cm x 10 cm) quadrat frame. All vegetation sampling was conducted utilizing these methods of visual estimation of percent cover within a quadrat frame. To improve accuracy of percent cover, the research team used a 1 m^2 PVC frame equipped with a 10 cm grid of fishing-lines in perpendicular directions. This allowed for a 10 cm x10 cm grid to be overlaid above the representative site vegetation, with each grid equal to 1% of 1m^2.

In addition to accurate percentage cover of vegetation, it was critical that all observed plants be diagnosed to species-level, in order to quantify the total percentage cover by a given species, and to assess the effectiveness of seed sown on site to prevent soil erosion. Determination of all observed plants that occurred within a given 1 m^2 quadrat, and their relative abundance, allowed us to analyze which species occurred on site, and which of this subset belong to respective seed mixes. Site visits in early August were determined as an ideal time, given the species used in the seed sowing mixes, to observe diagnostic features associated with determining species accurately. In the event that an observed plant could not be diagnosed to species level on-site, a representative voucher specimen containing diagnostic features was collected for analysis under microscope. All vegetation observed on-site and included in this report are according to nomenclature outlined in the manual *Florae Novae Angliae* and *Manual of Vascular Plants of Northeastern United States and Adjacent Canada (56, 57)*.

This analysis includes coverage of all taxa observed at the five project sites within the randomized 1 m^2 sampling quadrats, percentage cover by species relative abundance to other species (termed "percent cover by species" in figures) observed within sampling quadrats. This analysis also includes "percent ground cover" occupied by all vegetation. In these figures, percent ground cover is defined as total percentage of area observed with vegetation within 1 m^2 sampling grids. In the included figures, percent groundcover was then compartmentalized into "Non-mix Species," as in those taxa occurring within a sampling quadrat that were not listed in the seed sowing mix for that respective site, and "Bare Ground," defined as area not vegetated; observations include exposed soil, mineral substrates, concrete or asphalt remnant structures, leaf litter, or otherwise an area lacking plant life. Further, in percent ground cover, each of the observed species included in the seed sowing mix found are represented with their relative percentage to Bare Ground and Non-mix Species. Essentially, percent cover by species figures show the percentage of ground cover occupied by each species without showing the percentage of bare ground cover, while percent ground cover depicts total ground coverage by generalized groups of plants (non-mix species) and species included in the seed sowing mixes relative to exposed bare ground. Percent cover by species figures can be interpreted to assess potential harm posed by an exotic, non-native, or invasive plant species, or the likelihood of site-dominance by a given species, and otherwise the abundance of one species to all species observed. Percent ground cover figures depict the potential for erosion through bare ground or non-vegetated areas, and the relative establishment success of seed sowing mix species.

In general, across all sites, total vegetative cover generated from seed sowing mix species was relatively high, with a range from lowest seeded plant cover of 43.6% to highest, at 81.7% (Figure 3.1).

Of particular interest is Waltham, which while comparatively low in species diversity (19 unique plant taxa, with 6 of these species included in the sowing mix), exhibited the greatest vegetative cover arising from species included in the seed sowing mixes at 81.7% (Tables 3.14, 3.15). This is likely due to the dominance of *Schizachyrium scoparium*^{N} (little bluestem) and *Panicum virgatum*^{N} (switchgrass) with 20% and 14.2% ground cover, respectively.

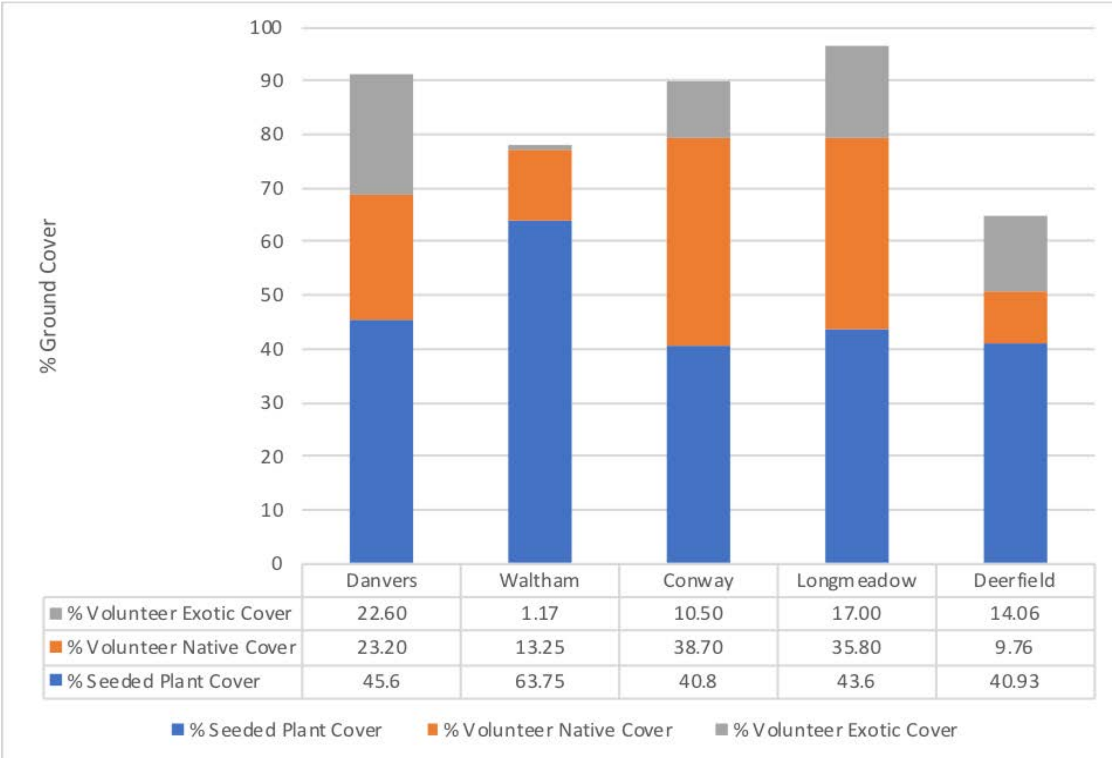

Figure 3.1: Total vegetative cover

Further, total ground cover across all sites showed Conway with the largest percentage of ground cover arising from native species to Massachusetts at 79.5% (Figure 3.2), and the lowest in Deerfield, at 50.7%. This is quantified from both seeded species and volunteer species, simply categorized by whether they are exotic to Massachusetts or native to it. Ground cover by native species at Conway is 79.5%, with total ground cover at 40.8% of ground cover from seed sown in the mix for this site, 38.7% of ground cover from non-mix species (Figure 3.1), many of which included native volunteer species, with only 10.5% of ground cover represented by exotic species.

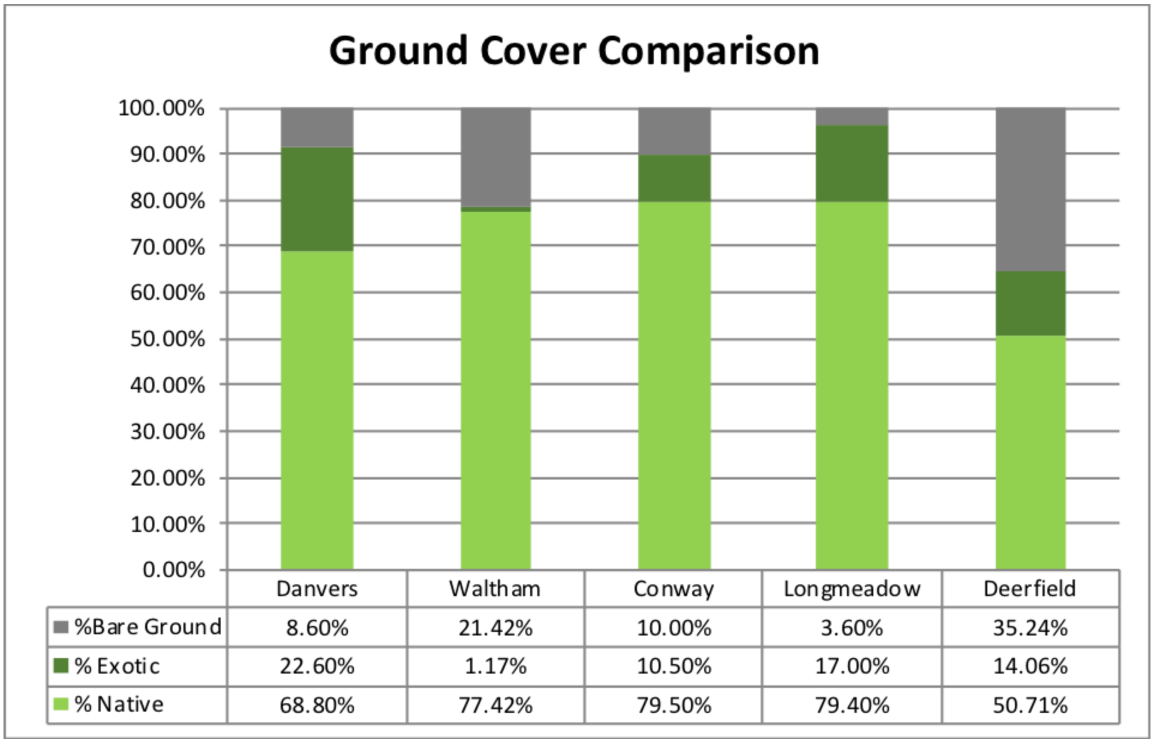

Figure 3.2: Total ground cover

3.3.3. Longmeadow, Route 5

Narrative

The Longmeadow project is a restoration of a construction-access road on a slope from Rte. 5 down to a reconstructed culvert under Rte. 5, located across the street from St. Andrew's Church on Longmeadow Street, Longmeadow (Figures 3.3 and 3.4). Construction details called for the contractor to remove the packed gravel from the construction road prior to spreading compost and planting. However, the soil pit dug during the site visit revealed what appeared to be the construction road in place and covered with a few inches of topsoil. While evidence of compost was not visible to the research team during the initial site visit, MassDOT personnel confirmed that contractor should have applied compost to the site. Based on this information and evidence that the native seed restoration mix (Appendix A, Table 7.1) had been applied, the research team did not reject the site. It is unknown whether this site had been mowed by Mass DOT maintenance personnel after installation.

Observations of Erosion

No signs of erosion were observed. The slope appeared stable and densely vegetated with a mixture of planted and volunteer plant species. There was a small amount of organic material on the surface.

Figure 3.3: Longmeadow site, May 16, 2019

Figure 3.4: Longmeadow site, Aug. 8, 2019

Soil Pit

A test pit was dug mid-slope to a depth of 13”, where a woven, black plastic geotextile was encountered (Figure 3.5). The test pit was flagged. Profile description: organic debris visible, 0–3.5” depth consisted of sandy loam topsoil, 3.5–13” highly compacted crushed stones and stone dust (likely the old construction-access road).

Figure 3.5: Longmeadow soil pit

Note: Geotextile visible below the zero end of the tape measure.

Compost Observations

Compost fragments were not visible on the soil surface or when digging through the O and A horizons.

Vegetation Observations

During the initial site visit May 16, 2009, it was noted that extensive weed populations existed on the site, with mugwort a dominant species. On the site some clumps of native grasses, some cool season turfgrasses, yarrow, and cinquefoil were also observed on May 16, 2019. The second site visit was conducted on Aug. 7, 2019. Vegetation was relatively dense and waist-high (36–42”). *Daucus carota*^{E} (Queen Anne’s Lace) was present throughout the slope, in addition to the vegetation observed on the initial site visit.

Longmeadow: Soil Analysis Results

At the time of sampling, it was not known that compost had not been applied at the Longmeadow site. A surface layer “compost” sample similar to depth of the other sites was taken and included in the analysis. As can be seen by the results, there was little to no difference between the Longmeadow soil and compost samples. Soil particle size distribution shows that the soil is a sandy loam with a low percentage of gravel (Table 3.7). Soil pH was moderately acidic while the “compost” sample was slightly acidic. CEC was similar for the soil and compost samples, and both samples were low, which is common with sandy soils low in organic matter. Percent base saturation was within the optimum range for the compost sample and below the optimum range for the soil sample (Table 3.5). Soil nutrients were low or very low for soil phosphorus, potassium, calcium, and magnesium, and compost potassium, calcium, and magnesium. Electrical conductivity was 0.11 dS/m, soil density was 1.06 g/cm^3, and soil temperature was 68^o F.

Longmeadow: Vegetation Analysis Results

On Aug. 8, 2019 vegetation was analyzed at the Longmeadow site for percent coverage by seed sown in Aug. 2015. Longmeadow included 21 unique plant taxa, with 7 of these represented by the species included in the sowing mix (Table 3.8). In total, five, 1m^2 quadrats were used to establish the representative vegetation on site. Quadrats were chosen randomly, with care taken to exclude obvious outliers within a given site. Total number of quadrats sampled depended largely on the size of the treatment site and accuracy of representative sampling.

Ground cover of vegetation was relatively high at Longmeadow, with 96.4% total vegetation cover (Table 3.9). Total coverage of the Longmeadow site included only 43.6% of ground cover from species included in the sowing (Table 3.9). This may be a result of the thin layer of topsoil due to the remnant packed gravel beneath or lack of compost application. Non-mix species accounted for 52.80% of the vegetation ground cover, and 3.6% of the site included bare ground or otherwise areas where no vegetation was observed at the time of visit (Table 3.9). Longmeadow did not have much bare, exposed soil areas, but areas of leaf-litter and decomposing vegetation.

Of the total plant cover observed at Longmeadow, *Desmodium canadense*^{N} (showy tick-trefoil), *Agrostis hyemalis*^{N} (ticklegrass), *Panicum virgatum*^{N} (switchgrass), and *Daucus carota*^{E} (Queen Anne’s lace) represented the dominant species, with 16.2%, 13.4%, 12.1%, and 10.6%, respectively (Table 3.8).

Longmeadow had many plant species which thrive on thin, regularly disturbed soils such as *Cyperus esculentus*^{N} (nut flatsedge), *Carex annectens*^{N} (yellow-fruited sedge), *C. radiata*^{N} (eastern star sedge), and *Potentilla simplex*^{N} (common cinquefoil), species not observed at any of the other project sites. This is likely a result of the packed gravel remaining in the subsoil. Over time, these species may become less common as disturbance events normalize.

Table 3.8: Longmeadow percentage cover by species

Species	Percentage cover (%)
Agrostis hyemalis[N]	13.40
Panicum virgatum[N]	12.08
Elymus virginicus[N]	7.24
Solidago nemoralis[N]	1.00
Symphyotrichum laeve[N]	4.40
Festuca rubra[N]	1.60
Chamaecrista fasciculata[N]	4.04
Desmodium canadense[N]	16.20
Trifolium aureum[E]	0.20
Lepidium campestre[N]	0.20
Impatiens capensis[N]	0.60
Daucus carota[E]	10.68
Carex annectens[N]	1.20
Solidago rugosa[N]	0.40
Artemesia vulgaris[E]	6.02
Carex radiata[N]	0.40
Oenothera biennis[N]	5.04
Potentilla simplex[N]	1.00
Vitis riparia[N]	5.02
Elymus strigosus[N]	4.24
Cyperus esculentus[N]	1.80

Few non-native, invasive species were observed at Longmeadow, with *Daucus carota*[E] (Queen Anne's lace) and *Artemesia vulgaris*[E] (mugwort) representing the most significant threat of site dominance at 10.7% and 6% of total plant cover respectively (Table 3.8). Near the culvert, *Vitis riparia*[N] (river grape) is extensively established and could potentially impact the area of this site adjacent the culvert.

Table 3.9: Longmeadow percentage ground cover

Species	Percentage cover (%)
Bare Ground	3.60
Agrostis hyemalis[N]	13.40
Chamaecrista fasciculata[N]	4.00
Elymus virginicus[N]	7.20
Festuca rubra[N]	1.60
Panicum virgatum[N]	12.00
Solidago nemoralis[N]	1.00
Symphyotrichum laeve[N]	4.40
Non-Mix Species	52.80

3.3.4. Deerfield, Interstate Route 91

Narrative

This project involved highway and median re-locations associated with reconstruction of two Interstate Route 91 bridges over the Deerfield River. In general, the medians and slopes were graded using “borrow”, then 3” of stockpiled topsoil was re-spread over the borrow. This was then covered by 1” of blower-applied compost topsoil between April 19 and Aug. 16, 2016, with most of it applied in April and June 2016. Restoration Seed Mix Item 765.4 was broadcast at a rate of 25 lbs. PLS/ac after the compost was placed (Appendix A, Table 7.1). The compost source was Rocky Mountain Compost (possibly based in Westfield, MA).

Jeffrey Hendricks was the District Engineer for the project. He was not onsite daily during construction but was involved throughout the construction of the project. According to Hendricks, after seeding, most of the site appeared slow to establish. There were some problems with wind-caused erosion of dry compost before seeds established in some places. Minor localized water erosion was observed in the median north of the Lower Road bridge, where road surface basin drainage wasn’t working and “relief cuts” were made to the “Cape Cod berms” causing concentrated flow on a 6:1 slope in the median. Slope erosion also occurred on the North and South ends of the Deerfield River Bridge between the N-bound and S-bound bridges (Stillwater Road slopes). These slopes were reapplied with compost and seeded with a different seed mix (not the native grasses and forbs).

The initial site visit occurred on May 16, 2019. The north-west embankment at the S-Bound lane of I-91 was inspected. Here no erosion was visible, woody compost fragments were visible on the surface, and most vegetation appeared to be invasive species and weeds (knotweed, mugwort, evening primrose). Little evidence of native grasses was observed.

The median south of the Deerfield River bridges was inspected. Here the entire median had been re-graded completely with borrow, covered with stockpiled topsoil and compost and re-seeded with the restoration seed mix. The median was mostly flat, with an unobstructed southern exposure and made up the majority of the site’s surface area. (Figures 3.6, 3.7). Therefore, soil testing was conducted in this flat median south of the Deerfield River bridges, rather than one of the small sections of steep slopes, in order for the results to be more representational of the site as a whole. Vegetation included a lot of clover and grasses, some native grasses, and some turfgrasses (see Appendix A, Table 7.1 for seed mix).

On Aug. 8, 2019 the second site visit was conducted. Vegetation sampling occurred in the median south of the Deerfield River bridges where the soil testing was conducted, and on the hillside embankment where this section of median slopes down towards Stillwater Road.

A series of 12” x 8” soil cores were taken at 30 intervals in the center of the median just south of the Stillwater Road Bridge and mixed in a bucket for lab testing. A second sample of the organic layer was also taken for lab analysis. The soil density test and the soil pit were also dug here.

Figure 3.6: Deerfield median south of Deerfield River, May 23, 2019

Figure 3.7: Deerfield median south of Deerfield River, Aug. 8, 2019

Observations of Erosion

Visible signs of erosion occurred on the drainage basin in the median to the north of the Deerfield River. Here small rills were present at intervals coinciding with relief cuts in the "Cape Cod berm" at the edge of the pavement (Figures 3.8, 3.9). The concentrated surface water flow downslope from the relief cuts is believed to have caused the observed erosion. The section of median to the south of the Deerfield River where soil and vegetation analysis were done showed no erosion on the flat portion, and only minimal erosion on the slope edges adjacent to the bridge abutments by Stillwater Road (Figure 3.10).

Figure 3.8: Deerfield Cape Cod berm relief cuts, May 23, 2019

Figure 3.9: Deerfield rill erosion downslope from berm cut, May 23, 2019

Figure 3.10: Stillwater Road bridge abutment, Aug. 8, 2019

Soil Observation and Analysis

An 18” soil pit was dug and flagged (Figure 11). Profile description: 0–1” organic layer with compost fragments visible, 1–3” topsoil, medium brown, sandy loam, and 3–18” of coarse, sandy borrow.

Figure 3.11: Deerfield soil pit

Compost observations
Compost fragments were visible on the soil surface throughout the entire site and were present up to 1” deep in the soil profile.

Vegetation Observations
In the flat section of median where soil sampling occurred, primary vegetation observed included white clover, some warm season clumping grasses, and a mixture of turfgrasses on May 16, 2019. Warm season grasses including *Panicum virgatum*^{N} (switchgrass), *Schizachyrium scoparium*^{N} (little bluestem), and the forb *Chamaecrista fasciculata*^{N} (partridge pea) were found throughout the median south of the Deerfield River Bridge on Aug. 8, 2016. During both site visits, visible areas of bare ground were common.

Deerfield: Soil Analysis
The Deerfield soil was representative of what was described by the specifications with a compost layer, topsoil layer, and borrow layer. Soil particle size distribution classifies both the soil and compost samples as fine sandy loams. However, the soil has around a third more sand, around twice as much clay, and about half the amount of silt as the compost. The

compost also has a much higher gravel percentage which could be the result of the compost layer not yet becoming incorporated into the soil, or poor-quality compost. Soil and compost pH were slightly acidic. CEC was relatively low for the soil sample and relatively high for the compost sample which is representative of the organic matter which was low for the soil sample and high for the compost sample (Table 3.5). Percent base saturation was below optimum for both samples and was very low for the soil sample. Soil nutrients were very low for the soil sample and in the optimum range for the compost sample. This reflects the high level of gravel (borrow) in the soil sample and high level of compost/organic matter in the compost sample (Table 3.7). Both the soil and compost samples were high in iron and the compost was high in aluminum. Electrical conductivity was 0.32 dS/cm, soil density was 1.00 g/cm^3, and soil temperature was 68^o F.

Deerfield: Vegetation Analysis

On Aug. 8, 2019 vegetation was analyzed at the Deerfield site for percent coverage by seed sown in Nov. 2016. Deerfield included 28 unique plant taxa, with 10 of these represented by the species included in the sowing mix (Table 3.10). In total, seventeen $1m^2$ quadrats were used to establish the representative vegetation on site. Quadrats were chosen randomly, with care taken to exclude obvious outliers within a given site. Due to the split project area at Deerfield between the flat portion of the site and the sloping portion at the Stillwater bridge embankment, vegetation analysis quadrats were targeted to these distinct sections. Of the seventeen quadrats sampled, ten of these represent the flat portion of the site, and seven of the sloping portion. Total number of quadrats sampled depended largely on the size of the treatment site and accuracy of representative sampling.

Total ground cover was moderately low at the Deerfield site, with 64.8% of the site total vegetation cover (Table 3.11). Total ground cover from species included in seed mixes at Deerfield amounted to 40.94%, with non-mix species totaling 23.82% of ground cover, and 35.24% representing bare ground or otherwise areas lacking established vegetation. At Deerfield, patchy areas of exposed bare ground are mixed with areas of leaf litter. Of the species included in the seed mix for Deerfield, *Chamaecrista fasciculata*^{N} (partridge pea) is dominant, representing 20.29% of the ground cover. Being an annual species which reproduces by seed, *Chamaecrista fasciculata*^{N} (partridge pea) will likely continue to exhibit dominance at the Deerfield site so long as mowing regimes operate around its seed maturation period (mid-August to mid-October in the Northeast).

Higher biodiversity was observed in the sloping portion of the Deerfield site, with *Verbena hastata*^{N} (blue vervain) and *Agrostis perennans*^{N} (upland bentgrass) observed at 0.88% and 3.76% of total plant cover (Table 3.10) respectively.

Table 3.10: Deerfield percentage cover by species

Species	Percentage cover (%)
Chamaecrista fasciculata[N]	20.29
Sonchus arvensis[E]	0.06
Plantago aristata[E]	0.06
Panicum virgatum[N]	7.35
Taraxacum officinale[E]	0.12
Trifolium pratense[E]	0.12
Artemesia vulgaris[E]	5.82
Trifolium aureum[E]	0.18
Plantago lanceolata[E]	0.12
Echinocloa crus-galli[E]	7.00
Oenothera laciniata[N]	0.29
Agrostis hyemalis[N]	0.24
Agrostis perennans[N]	3.76
Oenothera biennis[N]	0.53
Vicia cracca [E]	0.59
Elymus canadensis[N]	1.82
Verbena hastata[N]	0.88
Erigeron canadensis[N]	3.92
Solidago rugosa[N]	0.88
Schizachyrium scoparium[N]	2.65
Poa pratensis[N]	0.82
Eragrostis spectabilis[N]	1.88
Andropogon gerardii[N]	1.18
Persicaria pennsylvanica[N]	1.65
Rhus hirta[N]	0.88
Lespedeza capitata[N]	1.02
Cephalanthus occidentalis[N]	1.18
Morella caroliniensis[N]	1.18

At Deerfield, the threat of non-native invasive species is significant; given the 35.2% bare ground or areas otherwise lacking established vegetation, the presence of *Artemesia vulgaris*[E] (mugwort) at 5.8% of total plant cover (Table 3.10), and the likelihood of introductions of invasive species' propagules (seeds, root tissues, etc.) along major highways. To limit encroachment of invasive species, it is recommended that the mowing regime follow the reproductive phenology of the dominant species sown and otherwise native at Deerfield, including *Chamaecrista fasciculata*[N] (partridge pea), *Schizachyrium scoparium*[N] (little bluestem), *Agrostis hyemalis*[N] (ticklegrass), *Eragrostis spectabilis*[N] (purple lovegrass) and *Elymus canadensis*[N] (Canada wild rye). The threat of invasive species is much more significant along the flat portion of Deerfield than the sloping section due to the high percentage of bare ground.

Table 3.11: Deerfield percentage cover by species

Species	Percentage cover (%)
Bare Ground	35.24
Agrostis hyemalis^{N}	0.24
Agrostis perennans^{N}	3.76
Rhus hirta^{N}	0.88
Chamaecrista fasciculata^{N}	20.29
Elymus canadensis^{N}	1.82
Eragrostis spectabilis^{N}	1.88
Panicum virgatum^{N}	7.35
Schizachyrium scoparium^{N}	2.65
Verbena hastata^{N}	0.88
Andropogon gerardii^{N}	1.18

3.3.5. Conway, Route 116

Narrative

The project was a restoration/reconstruction of a large retaining wall and sloped embankment on the South River, from the retaining wall to the Rte. 116 road surface (Figure 3.13). The riverbank was restored with several bio-engineering practices including root-wads and brush blankets, all of which appeared stable and successful. After grading was complete, a 2” deep compost blanket was applied to the site, which was then seeded with Restoration Seed Mix Item 765.4 at a rate of 25 lbs. PLS/ac (Appendix A, Table 7.1). The seed was then top-dressed with 0.25–0.50” compost topdressing. The entire site was sloped.

There was one erosion event described by John Pierce, District Engineer, which was caused by cross-road drainage that concentrated runoff flow at the guardrail. The event was repaired, staked, straw bales were added to the stretch of road edge, and vegetation has since re-established.

A soil density test was taken at the toe of slope off North Poland Road, south of the retaining wall (flagged). Twelve soil cores were taken in a transect perpendicular to the slope, mixed, and bought back to the lab for further testing. A second sample of the organic layer was also taken for lab analysis.

Figure 3.12: Conway site on May 17, 2019

Observations of Erosion

On May 17, 2019, the only visible signs or erosion were washout around one of the guardrail posts opposite from where a steep road/driveway intersects with Route 116 (Figure 3.13). The team was advised by MassDOT District Engineer John Pierce that shortly after construction was complete a significant erosion event occurred at this same section of guardrail due to concentrated surface water inflow originated from the steep road intersecting Rte. 116.

Figure 3.13: Conway erosion around guardrail footing

Soil Observation and Analysis
A soil test pit was dug off N. Poland Road south of the retaining wall (flagged). The pit was dug to 13" where large stones prevented digging deeper (Figure 3.14). Profile description: 0–0.5" organic compost, dark brown, fine textured humus with very few woody fragments, 1.5–12" borrow consisting of medium grey mix of sandy clay and crushed stone ranging in sizes from 1.5" to 6" to 12".

Compost Observations
Compost was observed in the top 1.5" of soil. There was almost no coarse woody fraction present.

Vegetation Observations
The entire site was covered with warm-season grasses and forbs contributing to the extremely dense vegetative cover observed (Figure 3.15). Very few weeds were observed and much *Panicum virgatum*^{N} (switchgrass) was observed at the top of the slope behind the guardrail. Some *Reynoutria japonica*^{E} (Japanese knotweed) and *Celastrus orbiculatus*^{E} (oriental bittersweet) were visible.

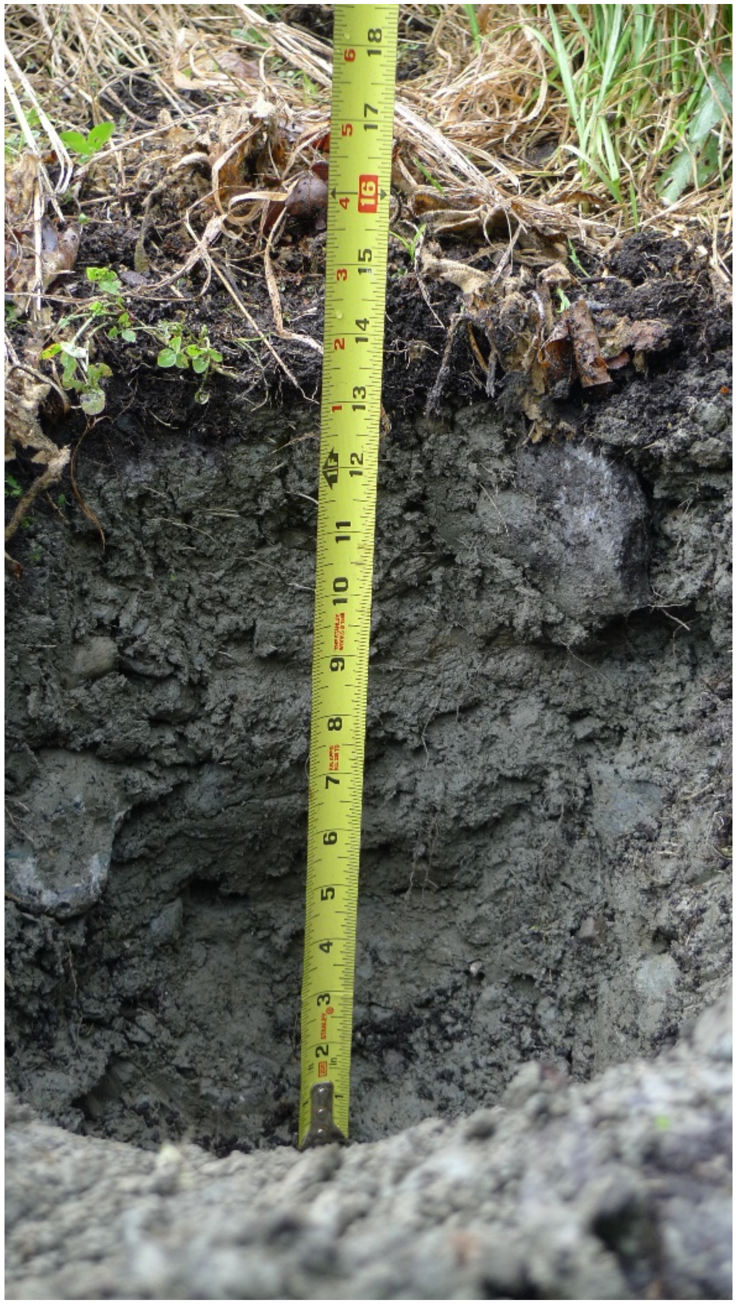

Figure 3.14: Conway soil pit

Figure 3.15: Conway dense vegetation, Aug. 7, 2019

Conway: Soil Analysis

The Conway soil was somewhat different than the other soils. Soil particle size distribution classifies the soil sample as a gravelly sandy loam and the compost sample as a sandy loam. Both samples were similar in proportions of clay, silt, and sand and had a high gravel percentage, with the soil sample being very high (39%). The Conway compost sample was the only sample that was slightly alkaline (7.5) while the soil sample was neutral. The CEC was high for both the soil and compost with the compost having the highest CEC of all samples. This is reflective of the high organic matter content of both samples with the soil having the highest organic matter percentage of all soil samples and the compost having the highest of all compost samples. Conway base saturation was very high for both samples (Table 3.5), which is expected with the pH of the samples. Soil nutrients were also generally high with phosphorus, calcium, and magnesium all above optimum. Potassium was either low (soil) or optimum (compost). Boron and manganese were also above optimum for both samples. Electrical conductivity was the highest of all samples at 0.76 dS/m and the soil temperature was lowest at 54^{o} F (Table 3.6). This is reflective of the sampling day which was cool and wet. Soil density was low at 0.59 g/cm^3.

Conway: Vegetation Analysis

On Aug. 7, 2019 vegetation was analyzed at the Conway site for percent coverage by seed sown in 2015. Conway included 37 unique plant taxa, with 12 of these represented by the species included in the sowing mix (Table 3.12). In total, 10 1m^2 quadrats were used to establish the representative vegetation on site. Quadrats were chosen randomly, with care taken to exclude obvious outliers within a given site. Total number of quadrats sampled depended largely on the size of the treatment site and accuracy of representative sampling.

Vegetation ground cover at the Conway site was high, totaling 90.0% of the project area (Table 3.13). Total coverage of the site included 40.8% of ground cover from seed sown in the mix for this site, 49.2% of ground cover from non-mix species, and 10.0% bare ground or otherwise areas without vegetation. Of the seed sown on site, *Panicum virgatum*^{N} (switchgrass) constituted 14.0% of the site, with *Chamaecrista fasciculata*^{N} (partridge pea) and *Verbena hastata*^{N} (blue vervain) constituting 8.3% and 6.2%, respectively (Table 3.12).

Table 3.12: Conway percentage cover by species

Species	Percentage cover (%)
Panicum virgatum^{N}	14.00
Chamaecrista fasciculata^{N}	8.30
Dicanthelium clandestinum^{N}	0.30
Verbena hastata^{N}	6.20
Elymus virginicus^{N}	5.50
Agrostis hyemalis^{N}	4.70
Rhus hirta^{N}	0.60
Schizachyrium scoparium^{N}	4.60
Elymus canadensis^{N}	2.90
Desmodium canadense^{N}	2.00
Monarda fistulosa^{N}	2.00
Sonchus arvense^{E}	0.10
Vicia cracca^{E}	0.10
Andropogon gerardii^{N}	9.00
Persicaria pennsylvanica^{N}	0.10
Trifolium aureum^{E}	0.20
Rumex acetosella^{E}	0.30
Trifolium pratense^{E}	0.50
Oenothera biennis^{N}	0.40
Geum canadense^{N}	0.40
Dactylus glomerata^{E}	0.60
Solidago gigantea^{N}	5.00
Tussilago farfara^{E}	0.70
Impatiens capensis^{N}	0.80
Solidago canadensis^{N}	3.20
Rhus hirta^{N}	0.80
Daucus carota^{E}	3.40
Vitis labrusca^{N}	0.70
Equisetum fluviatile^{N}	3.30
Quercus rubra^{N}	1.00
Lythrum salicaria^{E}	2.20
Tanacetum vulgare^{E}	1.10
Solidago altissima^{N}	1.90
Artemesia vulgaris^{E}	1.90

Table 3.13: Conway percentage ground cover

Species	Percentage cover (%)
Bare Ground	10.00
Panicum virgatum[N]	14.00
Desmodium canadense[N]	2.00
Solidago nemoralis[N]	0.01
Chamaecrista fasciculata[N]	8.30
Schizachyrium scoparium[N]	4.60
Elymus canadensis[N]	2.90
Andropogon gerardii[N]	900
Non-mix species	49.20

Of the non-mix species present at the Conway site, *Daucus carota*[E] (Queen Anne's lace) and *Solidago gigantea*[N] (smooth goldenrod) represented 3.4% and 5.0% of total plant cover, respectively (Table 3.12). Localized abundance of pollinator-preferred forbs was also observed, including *Monarda fistulosa*[N] (wild bergamot), *Solidago gigantea*[N] (smooth goldenrod), *Impatiens capensis*[N] (jewelweed) and *Solidago canadensis*[N] (Canada goldenrod).

Of the five experimental sites included in this project, Conway represents the highest level of biodiversity across the site, with 25 of the 37 unique species observed considered native to Massachusetts. In addition, no obvious erosion was observed at the Conway site on the Aug. 7 visit. Conway has a high density of vegetation cover consisting of forbs and grasses, many of which will readily seed into the site to continue filling it in.

Very few invasive species pose a threat to this site. This is in part due to the low bare ground area (10%) across the site, and to the low levels of non-native, invasive vegetation. Of these, *Lythrum salicaria*[E] (purple loosestrife) and *Artemesia vulgaris*[E] (mugwort) represent 2.2% and 1.9% of the total cover of plant species on site, respectively. Nearby populations of *Reynoutria japonica*[E] (Japanese knotweed) and *Celastrus orbiculatus*[E] (Asiatic bittersweet) along the South River may pose a risk of establishment if a significant disturbance event occurs at this site.

3.3.6. Waltham, Interstate Route 95

Narrative

This site was a permit project, in conjunction with related work on private property adjacent to I-95 NB. The site is approximately 3,000' long, and 80–200' wide, between I-95 NB, and Third Avenue in Waltham, with two distinct sections. The site has a range of slopes from 2:1 to 3.5:1.

The first section of slope is sandwiched between a 6' retaining wall/swale on the bottom and the Third Avenue Guardrail at the top of the slope (Figures 3.16, 3.17). Numerous dead tree stumps were visible on the slope, having been recently cut flush to grade. This portion of the site was planted with rows of live plugs of switchgrass and little bluestem approximately 30" o.c., parallel to slope and 24" o.c. along the slope between rows. The grass plugs were well-established and had been cut to the ground in the fall of 2018. During the May 23, 2019, site visit a dense layer of straw (the previous season's growth) uniformly covered the ground, acting as a mulch conserving soil moisture and reducing erosion.

The second section of the Waltham site begins at the southern end of the retaining wall and continues approximately 1,500' until encountering a tree line (Figure 3.18). This section of slope was seeded with "3rd Avenue Slope" seed mix (Appendix A, Table 7.2). It has an established stand of mixed herbaceous material with occasional red oaks dispersed throughout, creating a savannah-like landscape.

Figure 3.16: Waltham switchgrass slope, May 23, 2019

Figure 3.17: Waltham switchgrass slope, Aug. 6, 2019

Figure 3.18: Waltham seed mix slope, Aug. 6, 2019

Very few weeds or volunteers were visible, but included a few dispersed specimens of mustard, knotweed, Virginia creeper, and milkweed. Several shrubs planted at the top of the slope along the guardrail were dead (bayberry).

A soil density test was made near the middle of the switchgrass stand, near the top of the slope (to get a flat test location) (flagged). Twelve soil cores were taken along a transect parallel to the slope. The cores were mixed for lab analysis. A second sample of the organic layer was also taken for lab analysis.

Observations of Erosion

There was virtually no erosion visible on May 23, 2019, except for a small area at the south end of the retaining wall where the switchgrass plugs stop (Figure 3.19). Small amounts of compost and sediment were also observed in the drainage ditch at the base of the slope/top the retaining wall (Figure 3.20). Additional erosion was not observed during the Aug. 6, 2019, site visit.

Soil Observation and Analysis

An 18” soil pit was dug in the middle of the site, on the “switchgrass” slope, mid-slope (flagged) (Figure 3.21). Profile description: 0–1” dense straw, 1–2” dark compost, 2–7” medium dark brown loam/clay loam, 7–18” dark yellow sandy borrow and stones ranging in size between 4–8”.

Figure 3.19: Erosion at south end of Waltham retaining wall, May 23, 2019

Figure 3.20: Waltham erosion, Aug. 6, 2019

Note: Eroded compost material is visible in the concrete swale atop the retaining wall.

Compost Observations
An inch of compost was observed underneath a layer of straw throughout the site.

Vegetation Observations
During both field visits, the first section of slope consisted of a *Panicum virgatum*[N] (switchgrass) monoculture. The second section of slope resembled a savannah-like community, with established *Quercus rubra*[N] (red oak) forming a spotty canopy and a mix of warm season grasses, native ryes, and limited forbs established below. Few invasive species were spotted, and evidence of spot application of herbicide was observed.

Figure 3.21: Waltham soil pit

Waltham: Soil Analysis

The Waltham soil and compost samples were classified as sandy loams according to the particle size distribution with similar percentages of clay, silt, and sand. The soil sample had a higher percentage of gravel. Waltham soil had the lowest pH, 5.3, which was strongly acidic, and the compost was slightly acidic. The CEC was fairly high, and the organic matter content was in the high normal range for Massachusetts. Percent base saturation was below the optimum range for both samples. Soil and compost nutrients were in the optimum range for phosphorus and magnesium, and for soil potassium. Levels were low for compost potassium and calcium and soil calcium. Soil iron and aluminum levels were above optimum. Electrical conductivity was 0.26 dS/m, soil density was 0.86 g/cm^3, and soil temperature was 72^o F.

Waltham: Vegetation Analysis
On Aug. 6, 2019, vegetation was analyzed at the Waltham site for percent coverage by seed sown in 2016. Waltham included 19 unique plant taxa, with 5 of these represented by the species included in the seed mix (Appendix A, Table 7.2) or as planted plugs. These five species are *Agrostis hyemalis*^{N}, *Elymus virginicus*^{N}, *Eragrostis spectabilis*^{N}, *Schizachyrium scoparium*^{N}, and *Panicum virgatum*^{N}. In total, twelve $1m^2$ quadrats were used to establish the representative vegetation on site. Quadrats were chosen randomly, with care taken to exclude obvious outliers within a given site. Total number of quadrats sampled depended largely on the size of the treatment site and accuracy of representative sampling.

In total, 64.2% of the Waltham site included ground cover with species of the seed mix sown on site, 14.4% represented non-mix species, and 21.4% represented bare ground without vegetation (Table 3.14). The dominant vegetation at Waltham is little bluestem *Schizachyrium scoparium*^{N} (little bluestem) at the southern portion of the site, and *Panicum virgatum*^{N} (switchgrass) at the northern end, with 20% and 14.2% ground cover, respectively (Table 3.14).

Vegetation ground cover was moderate when compared with other project test sites, with 78.6% of the site covered by vegetation. Erosion at this site was observed but given the 7:2 slope and areas lacking established plants, some erosion is to be expected at the Waltham site. The extensive use of switchgrass in the northern portion of the site does work to cover bare soil well and establish soil stability but is slower to fill in the 0.3–0.5 m exposed areas between individual plants. This site is distinctly segregated by areas of *Panicum virgatum*^{N} (switchgrass) with scattered individuals of *Erechtites hieracifolius*^{N} (American burnweed) and adjacent areas of little bluestem and thin tree canopy cover primarily of *Quercus velutina*^{N} (black oak).

Table 3.14: Waltham percentage ground cover

Species	Percentage cover (%)
Bare ground	21.42
Agrostis hyemalis^N	15.83
Elymus virginicus^N	12.92
Eragrostis spectabilis^N	0.83
Panicum virgatum^N	14.17
Schizachyrium scoparium^N	20.00
Non-mix species	14.42

In future seeding or planting of this site, it is recommended that species be intermixed better, to allow for coverage of bare ground patches, and by establishing diversity of rooting systems to in the soil across the site. The southern portion of the site had higher diversity when compared with the northern portion, with sown seed of *Elymus virginicus*^{N} (Virginia wild rye) and *Agrostis hyemalis*^{N} (ticklegrass) constituting 28.75% (12.92%, 15.83%, respectively) of ground cover (Table 3.14)**.**

With 21.4% of the Waltham site exposed, bare ground, the potential for invasive species encroachment is high. Of the non-native, invasive species observed during vegetation analysis, *Alliaria petiolata*^{E} (garlic mustard) and *Cynanchum louiseae*^{E} (black swallowwort) were observed at 0.08% and 0.17% of total plant cover (Table 3.15). While the percentage of total plant cover observed by these invasive species is low, establishment on site should be prevented as development of a soil seedbank for these species is possible even with few individuals present.

Table 3.15: Waltham percentage cover by species

Species	Percentage cover (%)
Agrostis hyemalis^{N}	15.83
Nuttalanthus canadensis^{N}	0.08
Dicanthelium clandestinum^{N}	0.42
Elymus virginicus^{N}	12.92
Eragrostis spectabilis^{N}	0.83
Oxalis stricta^{N}	0.17
Panicum virgatum^{N}	14.17
Solidago canadensis^{N}	0.08
Sonchus arvensis^{E}	0.25
Schizachyrium scoparium^{N}	20.00
Alliaria petiolata^{E}	0.08
Oenothera biennis^{N}	0.42
Erechtites hieracifolius^{N}	7.92
Cynanchum louiseae^{E}	0.17
Erigeron canadensis^{N}	2.08
Euphorbia cyperassias^{E}	0.25
Linaria vulgaris^{E}	0.92
Quercus velutina^{N}	1.75

3.3.7. Danvers, Route 1

Narrative

The project consists of an oval-shaped infiltration basin located inside the cloverleaf at the on-ramp to southbound Rte. 1 (Figures 3.22, 3.23). After the basin was excavated, the topsoil was rehandled and spread. Except for the rock rip-rap berms (whose voids were filled with compost, but did not receive a compost blanket), the entire project received a 1–2” deep compost blanket. Next, the site was seeded with Restoration Mix Item 765.4, Infiltration Basin/Swale Mix Item 765.457, and Wildflower Mix Item 765.71 (Appendix A, Tables 7.3–7.5). The planting plan (Appendix A, Figure 7.1) maps where each seed mix was applied. The seed mix was applied between May and Aug. 2017 (exact date not available).

The vegetation was well established throughout most of the project. There appeared to be a high percentage of warm-season grasses established. A small area on the east side of the basin showed thin vegetation and minor erosion (Figure 3.24). Here the slope was measured at 2.5:1. Several areas of riprap and energy dissipators on the basin floor were covered with compost, but little vegetation was established (Figure 3.25). The site is marked for no-mowing and appears not to have been mowed in the past year.

Figure 3.22: Danvers drainage basin, May 23, 2019

A soil density test was made on the south side of the basin at the top of the slope (flagged). Twelve soil cores were taken along a transect along the mid-slope, around the basin. The cores were mixed for lab analysis. A second sample of the organic layer was also taken for lab analysis. A soil pit was dug and flagged, also on the south side of the basin, to 16” where large rocks prevented further digging.

Observations of Erosion

The only signs of erosion observed were on the east slope of the basin, where a small, sparsely vegetated patch showed signs of localized rill erosion (Figure 3.24), and within the compost filled rip-rap berms, which were very sparsely vegetated and showed signs of compost loss (Figure 3.25).

Figure 3.23: Danvers drainage basin, Aug. 6, 2019

Figure 3.24: Danvers area of sparse vegetation showing localized erosion, Aug. 6, 2019

Figure 3.25: Danvers sparsely vegetated rip-rap berm, Aug. 6, 2019

Soil Observation and Analysis
A 16” soil pit was dug in the middle of the site mid-slope (flagged) (Figure 3.26). Profile description: 0–1.5” compost, 1.5–6,5” dark brown sandy loam, 6.5–16” yellow-brown coarse sand/borrow with abundant stones and pebbles of varying sizes.

Compost Observations
Compost was visible on the surface throughout the site.

Vegetation Observations
The site appeared to have high vegetative cover because little bare ground was visible. Clumping warm-season grasses were present during the first site visit on May 23, 2019. In addition to warm season grasses, a number of native forbs were observed on Aug. 6, 2019. The rip-rap check dams were largely devoid of vegetation, despite the application of compost and the wildflower seeding mix.

Figure 3.26: Danvers soil pit, May 23, 2019

Danvers: Soil Analysis
The Danvers soil was classified as a coarse sandy loam and the compost as a sandy loam. The compost had a higher percentage of silt while the soil had a higher percentage of sand (Table 3.7). Both had high gravel contents. Both soil and compost pH were moderately acidic. CEC was high for both samples. Percent base saturation was in the optimum range for both samples. The organic matter content was high for the compost sample, having the second highest percentage. Soil nutrient levels were optimum for phosphorus, potassium, and calcium and above average for magnesium. Compost nutrient levels were above optimum for phosphorus, potassium, calcium, and magnesium. Both samples were high in manganese, the compost was high in zinc, and the soil was high in iron. Electrical conductivity was 0.41 dS/m, soil density was 0.58 g/cm^3, and soil temperature was 69^o F.

Variability in the soil samples was expected as topsoil varied by location. Compost layer sample variability was also expected due to different sources, spreading dates/years, and variability in decomposition of the organic material.

Danvers: Vegetation Analysis

On Aug. 6, 2019, the vegetation at the Danvers site was analyzed for total percent cover represented by species included in the seeding mix for erosion control. In total, 34 unique plant taxa were observed, with 11 of these taxa originating from seed mixes sown on site in Nov. 2017. In total, five $1m^2$ quadrats were used to establish the representative vegetation on site. Quadrats were chosen randomly, with care taken to exclude obvious outliers within a given site. Total number of quadrats sampled depended largely on the size of the treatment site and accuracy of representative sampling.

The vegetation ground cover was high, with 91.4% of the site covered with vegetation, and the remainder representing bare ground without vegetation or exposed areas of substrate (Table 3.16)**.** Of this 91.4% cover, 45.8% is represented by non-mix species and 45.6% represented by the species included in the three seed mixes sown on site (Table 3.16).

Table 3.16: Danvers percentage ground cover

Species	Percentage cover (%)
Bare Ground	8.60
Elymus virginicus^{N}	9.20
Verbena hastata^{N}	8.20
Agrostis perennans^{N}	6.60
Dicanthelium clandestinum^{N}	5.40
Agrostis hyemalis^{N}	4.20
Schizachyrium scoparium^{N}	2.20
Juncus tenuis^{N}	2.00
Chamaecrista fasciculata^{N}	2.20
Solidago nemoralis^{N}	1.00
Rhus hirta^{N}	0.20
Poa palustris^{N}	4.40
Non-mix species	45.80

Signs of erosion were not observed, with much of the 8.6% bare ground including areas of concrete structures for drainage and otherwise non-vegetated areas. Of the species utilized in the seed mix at Danvers, *Elymus virginicus*^{N} (Virginia wild rye) and *Verbena hastata*^{N} (blue vervain) represent the highest level of establishment in ground cover at 9.2% and 8.2%, respectively. Further, while the total percent cover of *Chamaecrista fasciculata*^{N} (partridge pea) is relatively similar to several other forbs and graminoids included in the seed mix at Danvers (at 2.2%), it appeared to cluster at the southeastern end of the site, with little distribution observed throughout. Of the species not included in the seed sowing mix, *Artemesia vulgaris*^{E} (mugwort) and *Daucus carota*^{E} (Queen Anne's lace) represent the largest portion of ground cover relative to all species observed with 10.0% and 9.2%, respectively (Table 3.17). These species, being invasive and non-native in the region, should be monitored for increased spread on site in future years.

Table 3.17: Danvers percentage cover by species

Species	Percentage cover (%)
Elymus virginicus[N]	9.20
Juniperus communis[N]	0.20
Lotus corniculatus[E]	1.20
Verbena hastata[N]	8.20
Lepidium vulgare[E]	0.20
Erigeron strigosus[N]	1.20
Agrostis perennans[N]	6.60
Lactuca biennis[N]	0.20
Euthamia graminifolia[N]	1.60
Dicanthelium clandestinum[N]	5.40
Verbascum thapsis[E]	0.20
Trifolium arvense[E]	1.40
Agrostis hyemalis[N]	4.20
Lythrum salicaria[E]	0.20
Schizachyrium scoparium[N]	2.20
Achillea millefolium[N]	0.20
Juncus tenuis[N]	2.00
Rhus hirta[N]	0.20
Chamaecrista fasciculata[N]	2.20
Solidago nemoralis[N]	1.00
Artemesia vulgaris[E]	10.00
Hieracium caespitosum[E]	0.20
Daucus carota[E]	9.20
Plantago lanceolata[E]	1.40
Oenothera biennis[N]	8.00
Apocynum cannibinum[N]	0.60
Andropogon gerardii[N]	8.00
Solidago rugosa[N]	0.60
Poa palustris[N]	4.40
Prunella vulgaris[N]	0.20
Persicaria pennsylvanica[N]	1.00

3.3.8. Key Findings from Case Study Site Visits and Evaluations

Soil Analysis

Erosion was variable among the five sites as would be expected with variability in slope, planting date, and external influences (e.g., impacts resulting from neighboring roadways). Deerfield, Conway, and Waltham all had reported localized erosion problems that were observed in field inspections (by others prior to this research) and that had been previously addressed. Evidence of erosion during site visits was minimal, and when found was generally the result of concentrated surface flow from specific locations on adjacent roadways. The conclusion drawn from observations at these five sites is that the compost treatment was effective at slope stabilization and that the compost minimized erosion. The Longmeadow site, determined to not have received compost after soil results were analyzed, had no visible erosion, perhaps attributable to the low slope gradient (5:1, 7:1).

Soil test results show variability between locations, which could be expected with the different topsoil and composts used at each site. The pH values ranged from 5.3 to 7.5, CEC ranged from 6.2 to 38.8, base saturation ranged from 16% to 100%, organic matter ranged from 1.8% to 29.5%, and C:N ratio ranged from 13.4:1 to 26.0:1. All samples were sandy loams, with one gravelly sandy loam, one coarse sandy loam, and two fine sandy loams. Percentage clay ranged from 5.4% to 9.3%, silt ranged from 16.9% to 37.9%, sand ranged from 56.4% to 75.4%, and gravel ranged from 6.9% to 39.2%. The pH range for samples should be adequate to support warm season greases and native forbs, and the C:N ratios are such that it should support breakdown and mineralization of nitrogen into the form available to plants. Analysis of vegetation establishment at all sites confirms these expectations.

CEC and base saturation values indicate that nutrient availability may be limited for Longmeadow and Deerfield soils. The low base saturation percentages for the Deerfield and Longmeadow soil samples are reflected in the low to very low levels of magnesium, calcium, and potassium in the soil. The high percentages of base saturation for the Danvers compost, and Conway soil and compost samples are reflected in the above optimum levels of calcium and magnesium for the samples. The above optimum nutrient levels for Danvers and Conway could encourage weed growth and would not benefit warm season grass and native forb growth. The low CEC and low organic matter levels likely reflect the apparent lack of compost application at the Longmeadow site. The low CEC and low organic matter value for the Deerfield soil and higher CEC and organic matter values for the Deerfield compost sample could indicate that the compost has yet to start incorporating into the soil. The higher level of organic matter in the Conway soil sample could indicate incorporation of organic matter. Above optimum levels of calcium and magnesium at the Danvers and Conway sites could potentially be the result of de-icing materials applied to the adjacent roadways.

Overall soil physical and chemical properties would support growth of warm season grasses and native forbs. Soil density and electrical conductivity levels would not restrict root growth. Warm season grasses and forbs do not have high nutrient requirements so even the soils with nutrients in the low range could be sufficient to support growth, especially when the compost has adequate nutrients. To have a definitive understanding of compost incorporation into the soil, soil testing prior to compost application would be necessary. From the results of these tests, incorporation of compost into the topsoil was determined to be variable by site.

Incorporation seems likely to have occurred in Conway with soil organic matter content being 13.4% and having a high CEC. Incorporation is possible in Waltham and Danvers with relatively high organic matter content (6.7% and 7.9%), good CEC, and adequate nutrient levels. The Deerfield site does not seem to have incorporation with high organic matter and optimum nutrient levels in the compost sample and low organic matter and very low nutrient levels in the soil sample. A potential cause of the lack of incorporation is the 26:1 C:N ratio of the Deerfield compost. A C:N ratio greater than 25:1 can indicate the presence of lignin in the compost which resists decay. Other factors that could affect the incorporation rate include soil aeration, moisture level, temperature, and rainfall all of which could have varied amongst the sites. Soil aeration is affected by factors such as compaction which would have also varied by site.

Vegetation Analysis
All sites demonstrated well-established vegetation cover, with observations of erosion relatively low. When observed, erosion occurred in a localized area where vegetation was minimal or absent. Conway, Deerfield, and Waltham all had documented prior issues with erosion events. Conway and Deerfield did not exhibit much if any significant erosion, whereas Waltham did have sparsely vegetated areas where minor erosion was observed. Danvers showed little erosion, save for areas abutting exposed berms and concrete drainage areas, and Longmeadow showed little erosion, but did contain a significant amount of bare, exposed ground (Fig. 3.7).

Among the five project sites, Waltham and Longmeadow exhibited areas where bare ground was relatively high at 21.4%, and 3.6%, respectively (Fig. 3.7, 3.28), and as a result, monitoring of invasive species encroachment (*Artemesia vulgaris*^{E}, *Daucus carota*^{E}) nearby is recommended. In addition, sowing more seed at these two locations in future years of native species, and/or targeted mowing regimes tailored to each sites' native species, would allow for an increase in native seed germination and storage in the on-site soil seedbank.

Among those sites which exhibited the greatest success of the seed sowing mix, Conway and Deerfield showed 55.4% and 40.9% of total ground cover occupied by species included in the seed sowing mix. From an ecological perspective, Conway exhibited the greatest biodiversity with 37 unique species, 25 of which observed considered native to Massachusetts, and 12 of those 25 from the seed sowing mix. Further, some of the bunchgrasses, *Panicum virgatum*^{N}, *Elymus canadensis*^{N}, *and Elymus virginicus*^{N}, observed at both Conway and Deerfield produce deep, fibrous root systems that will improve soil stabilization on site and prevent further erosion given a disturbance event. These deep, fibrous root systems also allow for increased water and nutrient-holding capacities on site, and increased aeration of soil, fostering increased plant growth. In addition to the bunchgrasses present at both sites, each site possesses relatively high numbers of fabaceous (belonging to the Pea Family, or Fabaceae) plants (*Chamaecrista fasciculata*^{N} *and Desmodium canadense*^{N}) which possess rhizobia (bacteria in root nodules) that extract nitrogen gas (N_2) out of the air and convert it to a form of nitrogen that is usable to plants (NO_{3-} or NH_3), also known as nitrogen fixation. This often results in increased NO_{3-} or NH_3 available to adjacent plants, responsible for growth of reproductive tissues (e.g., flowers, fruits, seeds).

All sites appeared to exhibit some degree of successful establishment of seed sowing mix species, with each site possessing different degrees of dominance by individual species. Each site contained *Panicum virgatum*^{N} (switchgrass), a deep-rooted bunchgrass, and nearly every site (with the exception of Danvers) included *Elymus virginicus*^{N} (Virginia wild rye). The combination of these two bunchgrasses, one warm-season (*P. virgatum*^{N}), the other cool-season (*E. virginicus*^{N}) will effectively resist erosion quite well. This combination of warm- and cool-season grasses on nearly every site (Danvers contains *Agrostis hyemalis*^{N} and *A.*

perennans[N], also cool-season grasses but with a shallower root system than *Elymus virginicus*[N]) shows that stabilization will be effective particularly given a mowing regime scheduled around seed maturation and dispersal, at reducing erosion events.

Invasive species often have impacts on seedling establishment in a similar way, in typically producing large colonies of relatively shallow-rooted plants in a short amount of time. Invasive species dominance, therefore, is less likely to aid soil stabilization. Fortunately, none of the five sites exhibited dominance by any single invasive species, though nearly all of them contained *Artemesia vulgaris*[E] (mugwort) within the sampling quadrats. Waltham did not exhibit mugwort within any sampling quadrats, though it was present along the roadway adjacent the site (possibly because of herbicide treatment). *Artemesia vulgaris*[E] (mugwort) is likely to be the major threat to each site, particularly due to their proximity to roadways. *Artemesia vulgaris*[E] (mugwort) typically inhabits anthropogenic areas such as old fields and roadsides with some history of disturbance. In addition, it tends to favor nitrogenous soils. When possible mugwort should be spot treated with herbicide, as it is difficult to control through mowing. Timed mowing for *Artemesia vulgaris*[E] (mugwort) control would conflict with seeding of several native grasses included in site seed sowing mixes and should be avoided. Several other invasive species were observed across all sites, but threats of establishment of any one invasive species was minimal.

3.3.9. Discussion of Key Findings

Erosion Control

There was a substantial variation in slope conditions among the five sites ranging from 1:1 to virtually flat. The research team learned of post-seeding erosion problems at three of the sites: Waltham, Deerfield, and Conway. At all sites this post-seeding erosion was addressed by the contractors installing drainage diversions (Deerfield), rip rap (Conway), reapplication of compost and topsoil (Deerfield, Conway, and Waltham) and reseeding. Site inspections performed under this research project observed very limited, localized erosion problems, mainly at the interface of roadside and road, where concentrated surface water flows into the site. Given that these sites include substantial slope conditions, the research team concludes that the range of compost blanket depths tested (1–2.5”) compost treatment are highly effective in stabilizing the slope up to 1:1 and minimizing erosion when combined with native grass and forb vegetation establishment. On the steeper slopes it was necessary to combine with additional erosion control BMPs, primarily to mitigate concentrated surface water inflow.

The Longmeadow site represents a special condition because it was determined subsequent to the initial site visit to not have received compost treatment. Despite this apparent lack of compost, the Longmeadow site had no significant erosion visible, likely due to the flatter slope gradient (4–5:1).

Soil testing revealed different degrees of incorporation between the sites. Compost was incorporated at Conway, partially incorporated at Danvers and Waltham, and not incorporated at Deerfield. It is not clear what accounted for these varying levels of natural compost incorporation.

The Conway site tested very high for organic matter content. It may be that the organic matter percentage of the compost that was applied here was higher than at the other sites. Another line of speculation is that the close proximity of the site to the stream created a microclimate of increased moisture, which could have sped up decomposition of the compost. Future research could further investigate the effect of compost blankets with varying organic matter content on the soil's organic matter content two to five years after application.

It should be noted that the research team's conclusion that compost blankets in conjunction with native grass and forb establishment effectively stabilizes slopes and minimizes erosion is based on quantitative and qualitative observational evidence, as these few case studies are not controlled experiments and therefore the results cannot be evaluated for statistical significance. This would be an opportunity for future research to build on this study.

Native Grass and Forb Establishment
Field evaluations of vegetation establishment showed that high levels of both total vegetative cover and the seeded species was achieved, although variability was observed between sites. Total vegetative ground cover ranged from 64.7% to 96.4%. The percentage of ground cover comprised of species from the seed mix ranged from 40.8% to 63.8%. Native species as a percentage of ground cover ranged from 50.71% to 79.50%. Volunteer native species make up larger portions of total vegetative cover on the Longmeadow, Conway, and Danvers sites (22.2–38.7%) and smaller portions of total vegetative cover on the Deerfield and Waltham sites (9.8–13.3%). Volunteer exotic species were present at all sites and ranged from 1.2% to 22.6%. The high percentage of vegetative cover, medium to high levels of establishment of seeded species, and relatively low levels of exotic species indicate that overall, native seed mixes used in conjunction with compost blankets are effective at establishing intended native grass and forb species.

The Longmeadow site had a comparatively average seeded species establishment rate, with 43.6% of ground cover being composed of species from the seed mix. However, Longmeadow stood out in that it had the least amount of exposed bare ground (3.6%). This is interesting because the soil testing revealed that the Longmeadow site likely did not receive compost blanket application and the construction specs were not followed. The planted area was previously a gravel construction road which should have been removed and replaced with topsoil prior to planting. However, our soil pit revealed that the road was not removed. Soil testing showed low CEC, nutrient levels, and organic matter levels compared to other sites. Longmeadow is the most mature site, having been planted in 2015, so the plant community has had more time to close its canopy than other sites, which may influence the low % of bare ground. Yet Danvers, the least mature site planted in 2017, bucks this line of thinking as it had the second lowest percentage of bare ground among the five sites (8.6%)

The Deerfield site is relatively flat and received topsoil and a compost treatment, both of which should aid in native grass and forb establishment. However, it has been subject to a cool season mowing regime since project completion and three years after planting has 64.7% vegetative cover. Longmeadow, which as previously discussed is a packed gravel road with several inches of topsoil and no compost, but was not mowed regularly, achieved 96.4%

vegetative cover four years after completion. Waltham, another site with adverse conditions due to the entire site having a severe slope, but not mowed more than once a year achieved 78.6% vegetative cover. The Danvers site had 91.4% vegetative cover two years after planting and did not receive regular mowing. Similarly, the Conway site had 90.0% vegetative cover four years after seeding and was not mowed. These results indicate that a regular, low mowing regime as practiced with cool season turf leads to reduced vegetative cover when applied to projects seeded with native grasses and forbs.

The surrounding land use matrix appears to significantly affect the presence and density of volunteer exotic species on the case study sites. The Longmeadow, Deerfield, and Danvers sites are all surrounded by highly disturbed, urban/suburban land cover. The Longmeadow site is surrounded by a dense suburban area and exotic species comprised 14.1% of the vegetative cover. Deerfield is located on a major interstate median located within a largely agricultural land use matrix and exotic species comprised 17% of the vegetative cover. Danvers is located along a major route within the highly developed area between 495 and Boston and exotic species comprise 22.6% of the vegetative cover. In contrast Conway is located in a matrix containing large tracts of relatively undisturbed deciduous forest and here exotic species make up 10.5% of the vegetative cover, the lowest amount of any all study sites where management measures to reduce exotic species were not employed. It appears that the sites located within land use matrixes featuring heavy human disturbance are correlated with higher levels of exotic species as a percentage of vegetative cover.

The Waltham site was also located in a highly disturbed area in the Boston suburbs, located between a commercial area and the I-95 corridor. Yet despite this surrounding land use, the site only contained 1.2% volunteer exotic species ground cover, the lowest of all five sites. This apparent anomaly is the result of ongoing invasive species management post-seeding. The research team observed signs of target herbicide application throughout the site and was made aware of ongoing invasive species management practices by the contractor. It thus appears that while surrounding land use matrix may govern the invasive species pressure a site faces from nearby sources of propagules or a residual seed bank, the degree of invasive species management during and especially after project completion governs the percentage of vegetative cover comprised by invasive species.

Ongoing management activities appear to negatively influence the recruitment of volunteer native species. At sites with ongoing maintenance activities volunteer native species made up less of the total ground cover. Deerfield was mowed short and frequently according to a cool season turfgrass regime and volunteer native species only made up 9.8% of ground cover. At Waltham regular spot herbicide treatment was used to control unwanted volunteer species and volunteer native species comprised 13.3% of total vegetative cover. In contrast, at the Conway, Danvers, and Longmeadow sites where no management activities occur other than an annual mowing at Danvers, volunteer native species made up 22.2% to 38.7%. Regular, low mowing is known to inhibit the establishment of many native grasses and forbs, which likely results in a decrease in establishment while favoring more disturbance tolerant exotic species. Similarly, while the spot herbicide treatments at Waltham effectively controlled volunteer exotic species, it likely had a negative effect on any native volunteers also trying to take advantage of unfilled niches in the plant community. Therefore, it appears that a strategy of minimal disturbance may lead to increased recruitment of volunteer native species.

These case studies also enable informed speculation on how different native grasses and forbs may persist when seeded in compost blankets. It is important to note that the vegetation data collected from these case studies is not controlled experimental data, and any number of factors besides compost blankets could account for the vegetation community present during this sampling. However given the absence of controlled experimental data in the literature on how compost affects native grasses and forbs, the following observations based on this vegetation analysis may suggest future research and in the meantime help inform seed mix design (Appendix D, Table 7.21).

Juncus tenuis[N], *Elymus canadensis*[N], *Festuca rubra*[N], *Symphyotrichum laeve*[N], *Sorghastrum nutans*[N], *Symphyotrichum novae-angliae*[N], and *Agrostis stolonifera*[N] were used in one or more of the seed mixes and were not present or were present in extremely low numbers. In particular *S. nutans*[N], *S. novae-angliae*[N], and *A. stolonifera*[N] are not recommended as they were seeded at four sites and absent from all. Seeded species that were found at multiple sites or in large numbers include *Verbena hastata*[N], *Schizachyrium scoparium*[N], *Solidago nemoralis*[N], *Elymus virginicus*[N], *Chamaecrista fasciculata*[N], *Agrostis hyemalis*[N], and *Agrostis perennans*[N]. In addition, S*olidago rugosa*[N], *Persicaria pennsylvanica*[N], *Oenothera biennis*[N], and *Dichanthelium clandestinum*[N] were volunteer native species observed at multiple sites and may be additional candidates for use in seed mixes if commercially available.

The case studies give insight into how varying post seeding management strategies affect vegetation establishment on the compost-treated sites observed. Regular low mowing was observed to correlate with an increase in bare ground and a decrease in recruitment of volunteer native species. Spot spraying herbicide to control invasive species appeared to negatively affect invasive species and positively affect seeded native species on the site. However, it did also correspond with decreased volunteer native plants as a percentage of total vegetative cover. Sites that were not mown or only mown once per year had a higher percentage of vegetative cover and less bare ground. Mowing no more frequently than once per year and conducting invasive species management after seeding appear to be key measures that increase the establishment of seeded species and volunteer native species, reduce the portion of bare ground, and increase recruitment of volunteer native species. These affects would in turn contribute towards achieving the goals of slope stabilization, minimizing erosion, and establishing native grass and forb communities.
This study illustrates the successful use of 1–2.5” compost blankets in conjunction with native seed mixes to control erosion and establish native grasses and forbs along roadsides.

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4.0 Recommendations

This section provides a discussion of recommendations for compost blanket application and native grass and forb establishment on roadside slopes based on the literature review, interviews, and site observations conducted specifically for this research project. The previous research tasks on which each recommendation is based will be indicated in abbreviated form in parenthesis, as follows: literature review (LR), interviews (I), and site evaluations and observations (SE).

Please refer to the relevant research task reports/technical memoranda for the detailed methodologies, results and key findings information on which the following recommendations are based. The recommendations provided here are organized according to the specific issues and implementation stages relative to compost blanket applications and establishment of native grasses and forbs on roadsides to control erosion and establish a cover of native species. This same outline of specific issues has been used in the technical memoranda for Tasks 1–3.

In general ideal candidate sites for compost blanket and native seed treatment would be on slopes 3:1 or less, with minimal invasive species, and where the sites can be managed by mowing, both during vegetation establishment and for long term annual mowing. However, such conditions are not typical of many MassDOT roadsides. Based on this research, the following recommendations can improve chances for success.

4.1 Site Preparation for Compost Blanket Application

Finished grade of the soil surface should be prepared to form a smooth layer with no substantial depressions or irregularities. Prior to applying compost, scarify and track the subsoil so that the resulting cuts and ridges are parallel with the contour of the slope (LR, I). Scarifying the subsoil will alleviate soil compaction and reduce slippage of the various soil and compost layers placed on top of the subsoil and help stabilize the slope during the vegetation establishment period after which the plant roots will provide slope stability, especially the native grasses (LR). The scarified subsoil should be raked smooth before spreading topsoil.

4.2 Compost Composition and Stability

Compost should be made from yard waste, farm/food waste, and woody debris. Biosolids and kiln-dried wood are not recommended for compost blanket applications (LR).

Compost should be tested for stability by measuring CO_2 respiration and should not exceed a maximum of 8 mg CO_2-C per gram of organic matter per day. Testing protocols should follow either the US Compost Council using the Testing Method for the Examination of Compost and Composting (TMECC) protocols or ASTM International testing protocols (formerly the American Society for Testing and Materials). If used in field applications, compost does not need to be tested for maturity as this test is more important for container-grown plants where secondary toxic metabolites can accumulate (Solvita Maturity Index, Index rating of at least 6, LR).

Compost should meet the following particle size distribution guideline:

- 100% of particles passing through a 3” sieve (same as current MassDOT spec 751.72)
- 85–95% of particles passing through a 1” sieve (MassDOT spec is 90–100%)
- 70–90% of particles passing through a ¾” sieve (same as MassDOT spec)
- 30–75% of particles passing through a ¼” sieve (current MassDOT spec is 0–75%)
- All on a dry weight basis (LR).

The proposed particle size distribution above is more restrictive than the current AASHTO recommendation for compost blankets and the MassDOT specification for “Compost Topdressing,” Item 751.72. This recommended compost particle-size distribution will more consistently result in a compost mixture with a higher percentage of coarse, woody particles, which have been shown to be crucial in reducing soil erosion (LR). (See the compost blankets tested by Bhattarai and Faucette presented in Tables 3.1 and 3.2)

A minimum particle size analysis under the proposed size ranges above would result in an average particle size of 0.19” (dry weight basis), significantly larger than the minimum average particle size of 0.08” found by Zhu et al. as necessary to form microdams, which are a major mechanism by which compost blankets slow water flow and reduce erosion (LR). While the maximum average particle size scenario will still a include significant ratio of small sized particles that will provide the moisture retention that is important for seed germination.

4.3 Compost Blanket Application

After the topsoil has been properly prepared and graded, the compost blanket should be applied as soon as possible to reduce exposure of the site to erosion. The recommended method is to apply compost blankets with a pneumatic blower (LR, I). This method avoids soil compaction caused by moving heavy equipment across the slope. The force of pneumatically blowing the compost allows the smaller compost particles to fill gaps in the soil surface and helps the compost to better adhere to the soil surface. Additionally, blowing compost is often the only effective and safe means of applying compost to steep slopes.

The pneumatic blower used for compost application should be designed for compost application, with the ability to uniformly and accurately mix and spread the native grass and forb seeds with the compost. Compost should be applied at 30–60% moisture content (I).

Contractor should be required to provide evidence showing the proper amount of compost material has been effectively placed onsite (i.e., truck load tickets) (Note: one inch of compost equals approximately 135 cubic yards of compost material per acre of application area). Contractor should be required to be a certified installer for the pneumatic blower/seed applicator used (I).

Compost blankets should be applied 1–3” thick, depending on the slope conditions, as detailed below (LR, I, SE). Compost applied at 1–3” depths has been shown to significantly reduce soil erosion on a range of slopes up to 3:1 (LR, I). This research found that slopes up to 2:1 were also stabilized with a compost layer (SE). On slopes steeper than 3:1 other erosion controls may be required in addition to, or instead of compost blankets. This determination should be made by the project landscape architect/project engineer and included in the project construction documents.

Table 4.1: Recommended compost depth as determined by slope (LR, I)

Slope	**Compost Depth**	**Notes**
>2:1	2–3”	Recommended additional erosion control measures
3:1–2:1	2–3”	Additional erosion control measures may be recommended for specific site conditions, especially where concentrated surface flow is expected
4:1–3:1	2”	Use standard specifications
4:1 or less	1”	Use standard specifications

It is recommended that compost blanket should not be applied at more than 3” depth. Compost blanket depths of 4” applied to steep slopes have been reported to have problems with slumping under certain circumstances (I, L).

In all cases above, the full depth of compost should be applied in two applications. The base layer should equal total specified depth minus 0.5–0.75” (I). Prior to application of the 0.5–0.75” top layer of compost/seed, the seed mix is to be mixed with the compost in a pneumatic blower equipped with a seed box and mixing auger to assure even seed distribution. The 0.5–0.75” top layer should be applied to assure an even coverage and even distribution of seeds. Two passes of compost application are recommended, with the second pass perpendicular to the first (I). Pneumatic application of compost/seed is recommended for seeding on slopes because hand broadcasting has been reported as extremely difficult to apply evenly on slopes (I). The project landscape architect or project engineer should be onsite during the seeding operation to assure that proper methods are used and that the proper amounts of compost and seed have been applied.

4.4 Seed Mix Design for Compost Blanket Applications

Seed mixes should be comprised of a mixture of native grasses and forbs. Because the native mix is slow to establish, all native seed mixes should include: short-lived, quick-to-establish “sacrificial” cover crop species (oats/winter wheat) and quick-to-establish species (nurse crops) (Virginia and Canada Wild Rye); and slow-to-establish late-successional grass and forb species (LR, I, SE).

Percentages of Pure Live Seeds (PLS) by Plant Type (subject to adjustments for seeding date, see Table 4.3):

- Cover Crop, 10%
- Nurse Crop (cool-season bunch grasses, 7–20%
- Native warm season grasses, minimum of 50%*
- Forbs, 20–40%
- (LR, I, SE)

*Native warm season grasses should be a major percentage (50–80%) of mix when slope stabilization is a primary goal for the planting, because their deep, fibrous root systems are effective for stabilizing slopes (LR).

When available, seed should be sourced from the local or regional ecotypes (e.g., within 200 miles of the seeding site). Regional ecotype seeds are more likely to be adapted to local climatic conditions, are more likely to successfully establish and will complement local genetic biodiversity (LR).

Cool-season bunch grasses function as “nurse crops” in native-species seed mixes. Nurse crops are annuals, biennials, or short-lived perennials that establish quickly but do not persist long term or compete with the long-lived, perennial grassland/prairie species, also known as “climax” grassland species (I). Nurse crops, therefore, help to stabilize slopes while the slower-to-establish native warm season grasses and forbs establish over the first two to three years after seeding. Nurse crops should be incorporated in all seed mixes and make up 7–20% of the mix on a PLS basis (LR, I, SE).

Table 4.2 makes recommendations for possible additions/modifications to the MassDOT specifications. MassDOT has a well-established set of native grass and forb species that are designed for a diversity of site conditions to account for variations in sun and shade, soil moisture and plant height. Site evaluations conducted in this research found that the seed mixes planted generally were successfully established (SE). The site evaluations, however, also identified a number of seed-mix species that were particularly effective and “volunteer” native species that were present on seeded sites but that were not included in the seed mixes. These seed mix species and volunteer species include nurse species, warm-season grasses, and forbs. These species are recommended for possible addition to MassDOT seed mixes (Table 4.2).

Table 4.2: Recommended species for use with compost blankets (SE)

Plant Type	Increase % if…	Recommended Additional Species*
Nurse Crop	• Steep slopes present • High invasive species pressure expected (recommended to provide interim cover to reduce invasive plant pressure)	*Elymus viginicus*[N] (SE), *Chamaecrista fasciculata*[N] (SE), *Persicaria pennsylvanica*[N] (*Polygonum pennsylvanicum*) (SE), *Oenothera biennis*[N] (SE)
Grasses (long-lived perennials)	• Steep slopes present • To reduce seed mix cost	*Schizachyrium scoparium*[N] (SE), *Agrostis hyemalis*[N] (SE), *Agrostis perennans*[N] (SE), *Panicum clandestinum*[N] (SE)
Forbs (long-lived perennials)	• When aesthetics is a major goal • To increase biodiversity • When pollinator habitat/resources are a priority	*Verbena hastata*[N] (SE), *Solidago nemoralis*[N] (SE), *Solidago rugosa*[N] (SE)

Note: Based on the observed presence and percentage of ground cover of native species across the five study sites. These recommended species a mixture of those included in seed mixes and native volunteers. See Appendix D, Table 7.21 for the full list of species observed at each site and their percentage of ground cover.
* This is not meant to be an exclusive list. The species listed here are not adequate on their own to form a balanced seed mix. Rather the list of recommended species is meant to reinforce the use of commonly seeded species that were observed to establish regularly on the study sites, and to suggest commercially available but not often used native species that were observed commonly as volunteers across the sites.

4.5 Seed Mix Rate and Application

Rate
Based on the research findings, it is recommended that native grass and forb seed mixes be applied at a rate of 40–60 Pure Live Seeds (PLS) per square foot (LR, I, SE). This seeding rate should be increased to 50–70 seeds per square foot (with 30–40 of these seeds being native warm season grasses) when seeded on 3:1 slopes or steeper to account for decreased germination from seed washout (LR, I). Seeding rates of native grasses should be increased by 50% for late-summer seeding.

Application
The recommended method for seed mix application is with a pneumatic compost blower that has the capacity to mix seed with compost during application (as described in “Compost

Blanket Application” above). Seed mixes should be mixed with compost and applied via a pneumatic blower as a 0.5” to 0.75” top layer on top of the base compost blanket layer (I). Native grass and forb seed should not be applied more than 0.5” to 0.75” deep in the compost blanket because seed positioned deeper is unlikely to germinate, and therefore would require an increase in seeding rate to achieve the same seed count in the upper 0.5” to 0.75” depth where germination is likely (LR, I).

If a pneumatic blower with the capacity to mix seed with compost cannot be provided, broadcasting of the seed mix is acceptable. Mechanical or hand broadcasting of seed mix is an acceptable, but not recommended, method because of the difficulty to broadcast seed evenly on slopes (I). Regardless of the method of application used, the Project Landscape Architect/Project Engineer should be present during all seeding applications to assure that the application will distribute the seed mix evenly across the site, and position seed at the proper depth for germination 0.5” to 0.75”, to ensure good seed-to-compost contact.

4.5.1. Seeding Rate

These recommendations are specific for seeding dates for recently re-graded highway and roadside construction sites on slopes of 4:1 to 1:1 in Massachusetts.

Seeding dates for a mix of native grasses and forbs on sloped roadside sites are particularly important for several reasons:

- The sites are dependent on natural precipitation, they do not receive irrigation.
- These sloped sites risk soil erosion until vegetation is established.
- Weed pressure can present a challenge to seeding establishment.

Recommended practices for establishing native warm-season grasses and forbs include two preferred seeding date “windows.” These dates are based on average statewide conditions that will vary by geographic location, site location and solar aspect, and the real-time weather conditions. The dates below can be adjusted earlier, or later, in the season based on regional location within the state, and specific site conditions, particularly solar aspect. These recommendations use the standard MassDOT Seed Mixes that include variants for differing moisture conditions and plant height.

4.5.2. Recommended Seeding Windows

Late Spring: May 15 to June 30
This seeding window is best for establishing warm season grasses because soil temperature is generally above 60^{o} F and the warm-season grass species can germinate with no dormancy-breaking requirements. Natural precipitation is generally adequate and extreme heat and drought is not common at this time of year in Massachusetts.

These favorable conditions allow for rapid germination of cover crop and nurse crop grass species and warm season grasses. With germination by early July, seedlings have a sufficiently-long first-season of growth to establish. Some of the forb species will germinate rapidly, others may require a period of moist-cold-stratification in the soil the following winter and germinate the following spring. The cover crop will die off by the following spring.

Seeding Rate Adjustments: Increase the seed rate for native forbs by 25% to account for seed predation/loss before germination.

Late Summer to Early Fall: Aug. 15 to Sept. 30
This seeding window is best for establishing native forbs because it provides conditions for immediate germination, or dormant seeding, and it corresponds with the natural seed dispersal timing of native forbs. At this time of year, all seeds except some forbs are expected to germinate, including the oat/winter wheat cover crop that will provide erosion control in the event that other species don't germinate immediately. Some species will require a season of cold stratification but can be expected to germinate the following spring or summer. Certain forbs may require a period of cold stratification. At this time of year, air temperature is decreasing, soil temperature is generally warm, and moisture is generally available. In the event of unfavorable/unusual weather, warm season grass and forb seeds will remain dormant until the following spring.

Seeding Rate Adjustments: Increase the seed rate for native warm-season grasses by 50% to account for slower germination, seed predation and washout.

4.5.3. Seeding Outside of Recommended Seeding Windows

In practice, there are many reasons that projects will not be able to apply seed in these recommended seeding "windows". It is possible that seeding may need to occur at other times during the annual roadside construction season, from late March until late November. Following are recommendations for expected outcomes, and adjustments that can be made to increase establishment success, for seeding windows outside the two recommended seeding windows above.

Spring Seeding: March 30 to May 14
Generally, from March 30 to April 15, soil temperatures are below 50^{o} F, and many species in the seed mix will not germinate. This is of special concern on steeper slopes where fast cover is important for stabilizing the compost surface. The cover crop (oats) can be expected to germinate when the soil temperature reaches 45^{o} to 50^{o} F, which generally occurs by late April.

Summer Seeding: July 1 to Aug. 14
Seeding in summer is not recommended. If seeding must occur during this period, increase the seed rate by 50% to account for slower germination, seed predation and washout. Most warm season grasses will germinate during this period but may not survive without adequate precipitation. Likewise, nurse and cover crops may not germinate without adequate precipitation raising the risk of erosion.

Fall Seeding: Oct. 1 to Nov. 15
In this seeding window, soil and air temperature are declining and, depending on real-time weather conditions and location, are likely not to provide minimum germination temperatures

for seed germination. Of particular concern is germination of the cover crops (oats and winter wheat). When soil temperature drops below 50º F, germination is unlikely. The native warm-season grasses and forbs are likely to remain dormant until soil temperatures rise above 60º F the following spring. Therefore, an erosion blanket should be applied on top of the seeded compost blanket to reduce the risk of erosion over winter.

Table 4.3: Seeding date recommendations

Seeding Dates	**Spring, 3/30-5/14**	**Late Spring, Summer 5/15-6/30**	**Summer, 7/1-8/15**	**Late Summer, Early Fall, 8/15-9/30**	**Fall, 10/1-11/15**
	ACCEPTABLE BUT NOT IDEAL	PREFER-RED	NOT RECOM-MENDED – delay seeding	PREFERRED	NOT RECOM-MENDED
Cover Crop	Oats (50#acre)	Oats (50#/acre)	Oats (50#/acre)	Oats (50#/acre) Winter wheat 10#/acre	Oats (100#/acre) Winter wheat (20#/acre) With erosion blanket REQUIRED
Seed Mix Adjustments	Increase forbs and grasses 25%	Increase forbs 25%	Increase grasses 50%, forbs 25%	Increase warm-season grasses 50%	Increase warm-season grasses 50%
Comments	Erosion risk before cover crop establishment	Best chance for seeding success	Risk of severe runoff erosion and stand failure from heat/drought. From 7/1 to 7/15, warm-season grasses may germinate if rain is plentiful.	Best chance for seeding success. Warm-season grasses unlikely to germinate until following spring; wild rye and few forbs may germinate.	Erosion control netting required. Reapply compost and reseeding may be required in spring, depending on erosion control.

Notes: These recommendations are the same as the narrative recommendations above. The table is presented for reference and comparison of seeding date options. Applies to roadside sloping sites 4:1 > 1:1, with compost blanket treatment.

4.6 Monitoring during Establishment of Native Grass and Forb Seedings on Compost Blankets

Seeded sites should be monitored periodically during the first two years of establishment for invasive species occurrence and weed presence/pressure, desired native grass and forb germination/establishment, and signs of erosion (LR, I, SE) (see Appendix for proposed monitoring inspection checklist). Substantial presence of invasive and weed species should be treated with herbicide as described under Section 3.7, Management.

This research found that localized erosion is commonly caused by specific areas of concentrated stormwater flow. This type of erosion can be addressed by installing additional erosion control practices as specified by the Project Engineer/Landscape Architect. Erosion should be repaired by reapplying compost and the appropriate seed mix (LR, SE).

4.7 Management during Establishment

4.7.1. Road Signage

MassDOT sites treated with compost blankets and planted with native grasses and forbs should be field-marked with permanent signage to differentiate native grass and forb plantings from adjacent cool season turf areas. Field-marking and signing of native grass and forb plantings, as currently practiced on some Mass DOT-managed highways, is recommended for all native grass and forb plantings so that they can be differentiated from cool season turf areas and receive a less frequent mowing regime and other management recommendations (i.e. invasive species control) (LR, I, SE). Highway signage indicating native plantings, also informs the public that reduced mowing is intentional. Importantly, less frequent mowing of native warm-season grasses and forbs also allows these species to produce viable seed, annually, contributing to more successful, and continuous, establishment over time (I, SE).

4.7.2. Contract Close-out

Because it takes two to three or more years for native warm season grass and forb communities to establish from seed, it is recommended that native grass and forb seeding contracts extend to a minimum of three years after initial seeding before final payment to ensure proper establishment(LR, I).

It is recommended that a density of at least one desirable/mature native grass or forb/ft^2 (or 75% desirable vegetation ground cover) be met (LR, I, SE). It is recommended that MassDOT seek ways that would facilitate establishment of these areas past conventional construction close-out dates.

4.7.3. Mowing to Aid Establishment of Native Grass and Forb Seeded Areas on Compost Blankets

Mowing of native grass and forb plantings, whether done by the contractor or MassDOT maintenance division, is recommended to reduce weed pressure and favor perennial grasses and forbs, following the mowing schedule below also allows for native plants to set seed for the following year thereby renewing the colony.

First Growing Season

During the first growing year, mow to a height of 6” whenever vegetation reaches 12” in height until Sept. 1, after which mowing should cease for the rest of the year. This ensures that adequate light reaches young grass and forb seedlings while inhibiting annual weeds from maturing and setting seed. The native grasses are unlikely to grow over 6” tall the first growing year and therefore will not be negatively affected by mowing (I).

Second Growing Season

During the second year, mow to a height of 12” when the vegetation reaches 16–18” in height to prevent annual and biennial weeds from maturing and setting seed. The native grasses are unlikely to grow over 12” tall the second growing year and therefore will not be negatively affected by mowing (I). Stop mowing on Sept. 1.

Third Growing Season and Beyond

In the third year and beyond, mow once a year in the early spring 1–3” and remove the cuttings, if possible, or perform a second mowing to reduce/chop the mown thatch. This will expose the soil surface, warm the soil and increase desirable native warm-season grass growth to allow native seed to mature. (LR, I, SE).

Mass DOT mowing equipment is capable of this recommended mowing, according to District Engineering staff. If roadside management schedules and practices don’t allow for this recommended mowing, due to seasonal traffic or other reasons, mowing can be done later in the season, the earlier in the season the better, to reduce the maturation of weed seeds. On steep slopes, machine mowing may not be safe or practical. On steep slopes greater than 4:1, mowing with a hand-operated string trimmer, according to the growth schedule above, is recommended. If the recommended mowing schedule is not followed, it is more likely that invasive weeds can become established.

Invasive species should be monitored regularly during the first and second growing years of the establishment period by trained personnel capable of identifying invasive species at the seedling and adult stages of growth. Invasive species and undesired weed species can be controlled with targeted herbicide application methods such as “spot-spray”, “wicking” or “glove of death” application of herbicide (LR, SE). This is especially critical during the first three years after plantings, when grass and forbs are establishing and highly susceptible to being outcompeted by invasive plants. Areas larger than 4 sq. ft. that are herbicide-treated to remove weeds should be re-seeded two to four weeks after herbicide treatment. (spot re-seeding should include a mix of cover crop, nurse crop and several of the warm season grasses and forbs).

4.7.4. Watering

Based on interviews, watering is not recommended. Even when included in the contract, it was found to be hard to enforce and rarely completed by contractors (I). Additionally, if an initial watering is conducted, it is often impractical to follow up routinely which can lead to stand failure. Watering in the middle of a dry spell will stimulate germination, putting seedlings in a very vulnerable state, where a single missed watering or extremely hot spell may kill off the majority of the vegetation (I). With no watering, native grass and forb seed will most likely stay dormant and viable during the dry spell until conditions improve and rainfall occurs.

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5.0 Conclusions and Recommended Future Research

The previous chapter contains recommendations based on the findings of the three separate research tasks presented in Chapter 3, Results. In summary, the results from the literature review, interviews and site evaluations consistently found that compost blanket applications on sloping roadside sites stabilized slopes, except for cases of erosion caused by concentrated stormwater flow. The literature review, in particular, was quite definitive that compost blankets prevent erosion. The research also found that the compost blankets aid the establishment of native grasses and forbs from seed in part by suppressing weeds that hinder native plant establishment. This finding was largely from the interviews and site evaluations as there was very little published literature on them effects of compost blankets on native grass and forb seeding. Most DOT's in the Northeast, and other regions of the country use compost blankets for erosion control and most DOTs use native seeding, but few use compost blankets together with native seeding. In general, other DOTs use cool season grasses with compost blankets because they are easier and faster to establish and are consistent with established practices, including routine mowing. Mass DOT is therefore innovating with the combined use of compost blankets with native seeding. The benefits of native seeding also include supporting biodiversity including pollinators. The research team recommends additional oversight during construction and post-construction monitoring to continue to refine and advance practices for stabilizing disturbed roadsides and establishing native vegetation (Table 5.1).

As more research and experimentation is required to refine the recommendations, the research team recommends that MassDOT include research as part of routine project implementation. For example, comparing varying types of compost, compost depths, or application methods could be implemented as part of selected construction contracts and monitored and documented by MassDOT staff or subject experts. Additional experiments could compare results from alternative seeding dates, seed mixes, seeding rates, and post-seeding monitoring and management.

Alternatively, a more ambitious research project could be implemented with the experiments following rigorous research protocols and conducted by a botanist or other vegetation specialist with extensive experience with seeding. Projects could be designed to compare a variety of replicated treatment experiments that assess the following:

- Compost and seed following various methods of site preparation (over compacted soils, soil rehandled and spread, and 4 inches of loam).
- Different compost depths in combination with the same seed mix.
- Seed application method (mixed with compost top layer vs. broadcast on top of compost).
- Alternative establishment mowing regimes (Year 1, 2, and continuing) species horticulture and ecology.

Such experiments could lead to significant improvements in project success and possibly result in cost savings for future projects.

Table 5.1: Recommended project information to collect

Basic Project Data	
Mass DOT project #	
Date of execution/completion	
Mass DOT Landscape Division Project Manager	
District Engineer/Field Supervisor	
Project location	District, highway #, geographic coordinates, map reference
Project narrative	Project name, brief description, project goals
Project photo file	Pre-construction, during construction, project close out
Soil info	Texture, pH, %organic matter content, moisture level, aspect
Compost specification	
Compost application	Date(s), depth, machinery used, contractor, …
Seed mix used	Species %/weight, application rate, source, seed tags
Seed application date/method	
Additional erosion control used	Construction details and site map
Monitoring Visits	
Date visited and observations	Weeds, invasive species, intended species, photos for each visit
Management Actions by Date	
Mowing	Machinery/height of cut, thatch cut or raked? photos
Herbicide treatment	Herbicide used, rate, target species, results, photos
Reseeding	Seed mix used, rate, application method, photos

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7.0 Appendices

7.1 Appendix A: MassDOT Seed Mixes

Table 7.1: Restoration Mix Item 765.4

	Botanical Name	**Common Name**	**% PLS by Weight**
Grass	*Elymus canadensis*	Canada Wild Rye	20.0%
Grass	*Schizachyrium scoparium 'Camper'*	Little Bluestem 'Camper'	20.0%
Grass	*Sorghastrum nutans 'NE-54'*	Indiangrass 'NE-54'	12.0%
Grass	*Panicum virgatum 'Shelter/Trailblazer'*	Switchgrass 'Shelter/Trailblazer'	12.0%
Grass	*Andropogon gerardii*	Big Bluestem	10.0%
Grass	*Festuca rubra*	Creeping Red Fescue	10.0%
Grass	*Juncus canadensis*	Canada Rush	1.0%
Grass	*Agrostis stolonifera*	Creeping Bentgrass	1.0%
Subtotal			**86.0%**
Herb/Forb	*Chamaecrista fasciculata*	Partridge Pea	6.0%
Herb/Forb	*Desmodium canadense*	Showy Tick Trefoil	5.0%
Herb/Forb	*Aster laevis*	Smooth Aster	1.0%
Herb/Forb	*Symphyotrichum novae-angliae*	New England Aster	1.0%
Herb/Forb	*Solidago nemoralis*	Grey Goldenrod	1.0%
Subtotal			**14.0%**
Total			**100.0%**

Note: Applied to the Longmeadow, Deerfield, and Conway sites at a rate of 25 lbs./ac.

Table 7.2: Waltham (3rd Avenue) Slope Mix

	Botanical Name	Common Name	% PLS By Weight
Grass	*Schizachyrium scoparium ‘Albany Pine'*	Little Bluestem 'Albany Pine'	65.0%
Grass	*Elymus virginicus*	Virginia Wild Rye	28.0%
Grass	*Eragrostis spectabilis*	Purple Lovegrass	12.0%
Grass	*Juncus tenuis*	Path Rush	1.0%
Grass	*Agrostis hyemalis*	Ticklegrass	1.0%
Total			**100.0%**

Note: Applied at the Waltham site at a rate of 25 lbs./ac.

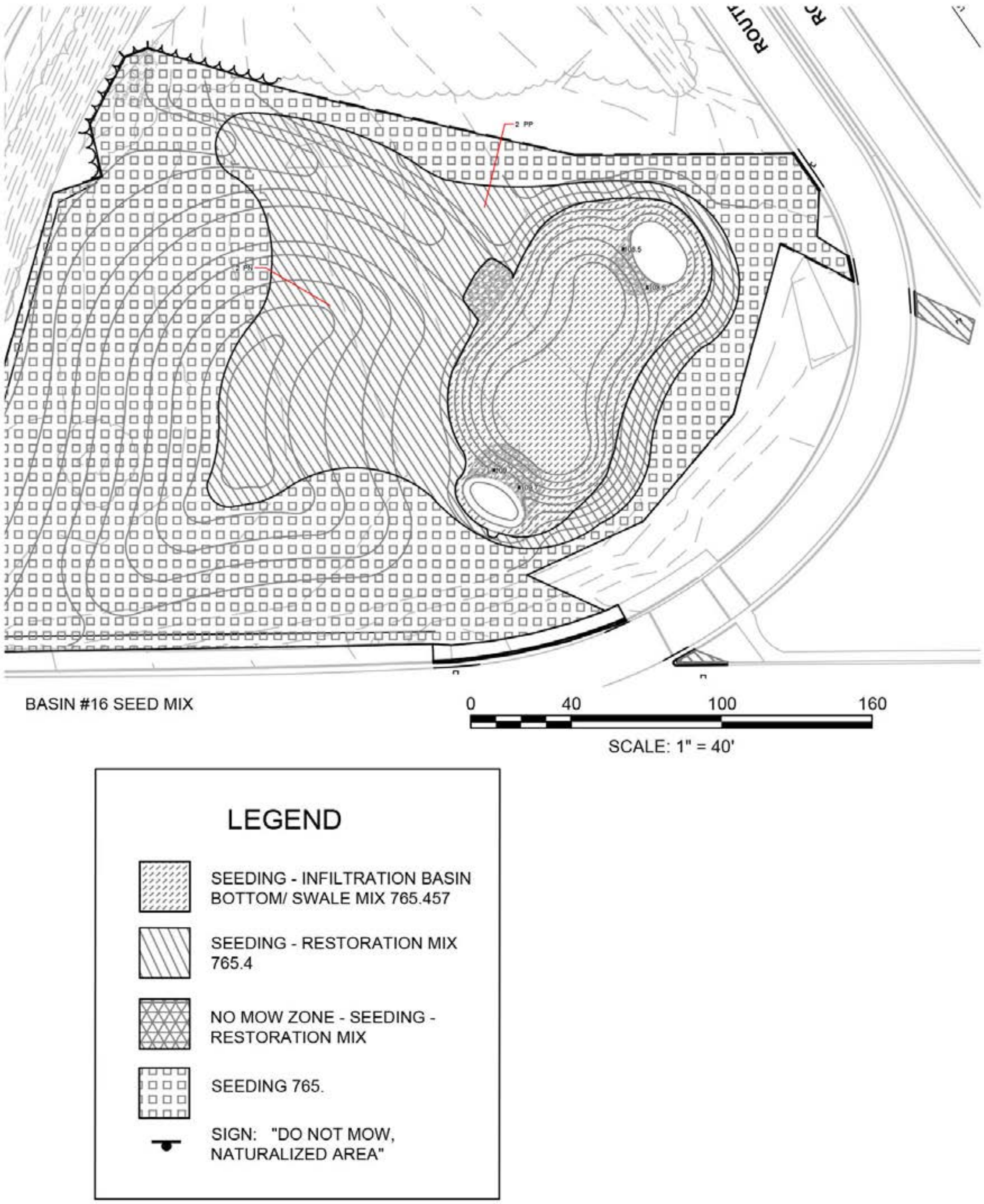

Figure 7.1: Danvers seed mix planting plan

Table 7.3: MassDOT Restoration Mix Item 765.4

Botanical Name	Common Name	% PLS by Weight
Grasses		
Lolium multiflorum	Annual Ryegrass	20.0
Sorghastrum nutans 'NE-54'	Indiangrass 'NE-54'	15.0
Schizachyrium scoparium	Little Blue Stem	15.0
Elymus canadensis	Canada Wild Rye	12.0
Elymus virginicus	Virginia Wild Rye	10.0
Panicum virgatum	Switch Grass	9.0
Festuca rubra	Creeping Red Fescue	8.0
Agrostis perennans	Upland Bentgrass	2.0
Agrostis hyemalis	Ticklegrass	2.0
Herb/Forb		
Chamaecrista fasciculata	Partridge Pea	2.0
Rudbeckia hirta	Black-eyed Susan	2.0
Solidago nemoralis	Grey Goldenrod	1.0
Coreopsis lanceolata	Lance-leaf Coreopsis	1.0
Aster laevis	Smooth Aster	1.0
Total		**100.0**

Note: Applied at the Danvers site at a rate of 30 lbs./ac.

Table 7.4: MassDOT Infiltration Basin/Swale Mix Item 765.457

Botanical Name	Common Name	% PLS by Weight
Elymus virginicus	Virginia Wild Rye	22.0
Puccinellia distans	Alkaligrass	16.0
Carex vulpinoidea	Fox Sedge	15.0
Panicum clandestinum	Deer Tongue	12.0
Panicum virgatum	Shelter Switch Grass	10.0
Poa palustris	Fowl Bluegrass	10.0
Agrostis stolonifera	Creeping Bentgrass	5.0
Agrostis perennans	Upland Bentgrass	5.0
Juncus tenuis	Path Rush	1.0
Juncus effusus	Soft Rush	1.0
Aster novae-angliae	New England Aster	1.0
Eupatorium maculata	Joe-pye Weed	1.0
Verbena hastata	Blue Vervain	1.0
Total		**100.0**

Note: Applied at the Danvers site at a rate of 25 lbs./ac

Table 7.5: MassDOT Wildflower Mix Item 765.71

Botanical Name	**Common Name**	**% PLS By Weight**
Bouteloua curtipendula	Sideoats Grama	38.0%
Elymus virginicus	Virginia Wildrye	15.0%
Sorghastrum nutans	Indiangrass	10.0%
Agrostis perennans	Autumn Bentgrass	4.0%
Chamaecrista fasciculata (Cassia f.)	Partridge Pea	4.0%
Echinacea purpurea	Purple Coneflower	4.0%
Liatris spicata	Marsh (Dense) Blazing Star (Spiked Gayfeather)	3.0%
Penstemon laevigatus	Appalachian Beardtongue	2.5%
Aster novae-angliae (Symphyotrichum n.)	New England Aster	2.0%
Coreopsis lanceolata	Lanceleaf Coreopsis	2.0%
Heliopsis helianthoides	Oxeye Sunflower	2.0%
Lespedeza virginica	Slender Bushclover	2.0%
Rudbeckia hirta	Black eyed Susan	2.0%
Tradescantia ohiensis	Ohio Spiderwort	2.0%
Asclepias tuberosa	Butterfly Milkweed	1.8%
Senna marilandica (Cassia m.)	Maryland Senna	1.5%
Aster laevis (Symphyotrichum laeve)	Smooth Blue Aster	1.0%
Baptisia australis	Blue False Indigo	1.0%
Rudbeckia triloba	Brown eyed Susan	1.0%
Monarda fistulosa	Wild Bergamot	0.5%
Senna hebecarpa (Cassia h.)	Wild Senna	0.5%
Pycnanthemum incanum	Hoary Mountain Mint	0.2%
		100.0%

Note: Applied at Danvers site at a rate of 25 lbs./ac.

7.2 Appendix B: Soil Tests

Table 7.6: Longmeadow soil test results

Analysis	*Value Found*	*Optimum Range*
Soil pH (1:1, H2O)	5.8	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	3.0	4-14
Potassium (K)	40	100-160
Calcium (Ca)	471	1000-1500
Magnesium (Mg)	35	50-120
Sulfur (S)	5.0	>10
*Micronutrients**		
Boron (B)	0.1	0.1-0.5
Manganese (Mn)	3.2	1.1-6.3
Zinc (Zn)	0.5	1.0-7.6
Copper (Cu)	0.3	0.3-0.6
Iron (Fe)	4.5	2.7-9.4
Aluminum (Al)	42	<75
Lead (Pb)	1.9	<22
Cation Exch. Capacity, meq/100g	6.3	
Exch. Acidity, meq/100g	3.5	
Base Saturation, %		
Calcium Base Saturation	38	20-80
Magnesium Base Saturation	5	10-30
Potassium Base Saturation	2	2.0-7.0
Scoop Density, g/cc	1.37	
Optional Tests		
Soil Organic Matter (LOI), %	1.8	

*Micronutrient deficiencies rarely occur in New England soils; therefore, an optimum range has never been defined. Values provided represent the normal range found in soils and are for reference only.

Table 7.7: Longmeadow organic layer test results

Analysis	*Value Found*	*Optimum Range*
Soil pH (1:1, H2O)	6.3	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	4.7	4-14
Potassium (K)	48	100-160
Calcium (Ca)	649	1000-1500
Magnesium (Mg)	46	50-120
Sulfur (S)	6.0	>10
*Micronutrients**		
Boron (B)	0.2	0.1-0.5
Manganese (Mn)	6.3	1.1-6.3
Zinc (Zn)	1.2	1.0-7.6
Copper (Cu)	0.2	0.3-0.6
Iron (Fe)	3.1	2.7-9.4
Aluminum (Al)	33	<75
Lead (Pb)	1.6	<22
Cation Exch. Capacity, meq/100g	3.2	
Exch. Acidity, meq/100g	6.2	
Base Saturation, %	2.5	
Calcium Base Saturation	52	20-80
Magnesium Base Saturation	6	10-30
Potassium Base Saturation	2	2.0-7.0
Scoop Density, g/cc	1.24	
Optional Tests		
Soil Organic Matter (LOI), %	2.3	

*Micronutrient deficiencies rarely occur in New England soils; therefore, an optimum range has never been defined. Values provided represent the normal range found in soils and are for reference only.

Table 7.8: Deerfield soil test results

Analysis	*Value Found*	*Optimum Range*
Soil pH (1:1, H2O)	6.1	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	1.2	4-14
Potassium (K)	49	100-160
Calcium (Ca)	186	1000-1500
Magnesium (Mg)	23	50-120
Sulfur (S)	3.5	>10
*Micronutrients**		
Boron (B)	0.1	0.1-0.5
Manganese (Mn)	9.3	1.1-6.3
Zinc (Zn)	1.1	1.0-7.6
Copper (Cu)	0.3	0.3-0.6
Iron (Fe)	17.5	2.7-9.4
Aluminum (Al)	54	<75
Lead (Pb)	1.1	<22
Cation Exch. Capacity, meq/100g	7.9	
Exch. Acidity, meq/100g	6.6	
Base Saturation, %		
Calcium Base Saturation	12	20-80
Magnesium Base Saturation	2	10-30
Potassium Base Saturation	2	2.0-7.0
Scoop Density, g/cc	1.26	
Optional Tests		
Soil Organic Matter (LOI), %	2.9	

*Micronutrient deficiencies rarely occur in New England soils; therefore, an optimum range has never been defined. Values provided represent the normal range found in soils and are for reference only.

Table 7.9: Deerfield organic layer test results

Analysis	*Value Found*	*Optimum Range*
Soil pH (1:1, H2O)	6.3	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	4.6	4-14
Potassium (K)	146	100-160
Calcium (Ca)	1085	1000-1500
Magnesium (Mg)	102	50-120
Sulfur (S)	10.6	>10
*Micronutrients**		
Boron (B)	0.2	0.1-0.5
Manganese (Mn)	19.2	1.1-6.3
Zinc (Zn)	6.6	1.0-7.6
Copper (Cu)	0.2	0.3-0.6
Iron (Fe)	28.7	2.7-9.4
Aluminum (Al)	99	<75
Lead (Pb)	1.3	<22
Cation Exch. Capacity, meq/100g	16.7	
Exch. Acidity, meq/100g	10.1	
Base Saturation, %		
Calcium Base Saturation	32	20-80
Magnesium Base Saturation	5	10-30
Potassium Base Saturation	2	2.0-7.0
Scoop Density, g/cc	0.65	
Optional Tests		
Soil Organic Matter (LOI), %	18.4	

*Micronutrient deficiencies rarely occur in New England soils; therefore, an optimum range has never been defined. Values provided represent the normal range found in soils and are for reference only.

Table 7.10: Conway soil test results

Analysis	*Value Found*	*Optimum Range*
Soil pH (1:1, H2O)	6.7	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	15.9	4-14
Potassium (K)	65	100-160
Calcium (Ca)	3618	1000-1500
Magnesium (Mg)	146	50-120
Sulfur (S)	31.8	>10
*Micronutrients**		
Boron (B)	0.7	0.1-0.5
Manganese (Mn)	16.0	1.1-6.3
Zinc (Zn)	2.5	1.0-7.6
Copper (Cu)	0.2	0.3-0.6
Iron (Fe)	2.8	2.7-9.4
Aluminum (Al)	12	<75
Lead (Pb)	1.2	<22
Cation Exch. Capacity, meq/100g	20.9	
Exch. Acidity, meq/100g	1.5	
Base Saturation, %		
Calcium Base Saturation	86	20-80
Magnesium Base Saturation	6	10-30
Potassium Base Saturation	1	2.0-7.0
Scoop Density, g/cc	0.89	
Optional Tests		
Soil Organic Matter (LOI), %	13.4	

*Micronutrient deficiencies rarely occur in New England soils; therefore, an optimum range has never been defined. Values provided represent the normal range found in soils and are for reference only.

Table 7.11: Conway organic layer test results

Analysis	*Value Found*	*Optimum Range*
Soil pH (1:1, H2O)	7.5	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	19.0	4-14
Potassium (K)	106	100-160
Calcium (Ca)	7293	1000-1500
Magnesium (Mg)	253	50-120
Sulfur (S)	40.8	>10
*Micronutrients**		
Boron (B)	1.3	0.1-0.5
Manganese (Mn)	20.6	1.1-6.3
Zinc (Zn)	6.2	1.0-7.6
Copper (Cu)	0.3	0.3-0.6
Iron (Fe)	3.0	2.7-9.4
Aluminum (Al)	16	<75
Lead (Pb)	2.2	<22
Cation Exch. Capacity, meq/100g	38.8	
Exch. Acidity, meq/100g	0.0	
Base Saturation, %		
Calcium Base Saturation	94	20-80
Magnesium Base Saturation	5	10-30
Potassium Base Saturation	1	2.0-7.0
Scoop Density, g/cc	0.58	
Optional Tests		
Soil Organic Matter (LOI), %	29.5	

*Micronutrient deficiencies rarely occur in New England soils; therefore, an optimum range has never been defined. Values provided represent the normal range found in soils and are for reference only.

Table 7.12: Waltham soil test result

Analysis	*Value Found*	*Optimum Range*
Soil pH (1:1, H2O)	5.3	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	6.8	4-14
Potassium (K)	105	100-160
Calcium (Ca)	897	1000-1500
Magnesium (Mg)	68	50-120
Sulfur (S)	10.6	>10
*Micronutrients**		
Boron (B)	0.2	0.1-0.5
Manganese (Mn)	5.0	1.1-6.3
Zinc (Zn)	5.4	1.0-7.6
Copper (Cu)	0.4	0.3-0.6
Iron (Fe)	14.1	2.7-9.4
Aluminum (Al)	102	<75
Lead (Pb)	11.5	<22
Cation Exch. Capacity, meq/100g	15.6	
Exch. Acidity, meq/100g	10.3	
Base Saturation, %		
Calcium Base Saturation	29	20-80
Magnesium Base Saturation	4	10-30
Potassium Base Saturation	2	2.0-7.0
Scoop Density, g/cc	1.11	
Optional Tests		
Soil Organic Matter (LOI), %	6.7	

*Micronutrient deficiencies rarely occur in New England soils; therefore, an optimum range has never been defined. Values provided represent the normal range found in soils and are for reference only.

Table 7.13: Waltham organic layer test results

Analysis	*Value Found*	*Optimum Range*
Soil pH (1:1, H2O)	6.1	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	5.9	4-14
Potassium (K)	95	100-160
Calcium (Ca)	910	1000-1500
Magnesium (Mg)	72	50-120
Sulfur (S)	9.8	>10
*Micronutrients**		
Boron (B)	0.2	0.1-0.5
Manganese (Mn)	12.3	1.1-6.3
Zinc (Zn)	6.2	1.0-7.6
Copper (Cu)	0.2	0.3-0.6
Iron (Fe)	5.9	2.7-9.4
Aluminum (Al)	57	<75
Lead (Pb)	8.4	<22
Cation Exch. Capacity, meq/100g	12.9	
Exch. Acidity, meq/100g	7.5	
Base Saturation, %		
Calcium Base Saturation	35	20-80
Magnesium Base Saturation	5	10-30
Potassium Base Saturation	2	2.0-7.0
Scoop Density, g/cc	0.96	
Optional Tests		
Soil Organic Matter (LOI), %	8.0	

*Micronutrient deficiencies rarely occur in New England soils; therefore, an optimum range has never been defined. Values provided represent the normal range found in soils and are for reference only.

Table 7.14: Danvers soil test results

Analysis	*Value Found*	*Optimum Range*
Soil pH (1:1, H2O)	6.0	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	5.1	4-14
Potassium (K)	107	100-160
Calcium (Ca)	1301	1000-1500
Magnesium (Mg)	139	50-120
Sulfur (S)	10.7	>10
*Micronutrients**		
Boron (B)	0.2	0.1-0.5
Manganese (Mn)	6.5	1.1-6.3
Zinc (Zn)	7.4	1.0-7.6
Copper (Cu)	0.6	0.3-0.6
Iron (Fe)	13.7	2.7-9.4
Aluminum (Al)	45	<75
Lead (Pb)	13.9	<22
Cation Exch. Capacity, meq/100g	14.9	
Exch. Acidity, meq/100g	7.0	
Base Saturation, %		
Calcium Base Saturation	44	20-80
Magnesium Base Saturation	8	10-30
Potassium Base Saturation	2	2.0-7.0
Scoop Density, g/cc	1.05	
Optional Tests		
Soil Organic Matter (LOI), %	7.9	

*Micronutrient deficiencies rarely occur in New England soils; therefore, an optimum range has never been defined. Values provided represent the normal range found in soils and are for reference only.

Table 7.15: Danvers organic layer test results

Analysis	*Value Found*	*Optimum Range*
Soil pH (1:1, H2O)	5.8	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	18.6	4-14
Potassium (K)	182	100-160
Calcium (Ca)	2992	1000-1500
Magnesium (Mg)	336	50-120
Sulfur (S)	19.6	>10
*Micronutrients**		
Boron (B)	0.4	0.1-0.5
Manganese (Mn)	12.8	1.1-6.3
Zinc (Zn)	9.0	1.0-7.6
Copper (Cu)	0.3	0.3-0.6
Iron (Fe)	6.2	2.7-9.4
Aluminum (Al)	32	<75
Lead (Pb)	10.3	<22
Cation Exch. Capacity, meq/100g	26.1	
Exch. Acidity, meq/100g	7.9	
Base Saturation, %		
Calcium Base Saturation	57	20-80
Magnesium Base Saturation	11	10-30
Potassium Base Saturation	2	2.0-7.0
Scoop Density, g/cc	0.66	
Optional Tests		
Soil Organic Matter (LOI), %	19.5	

*Micronutrient deficiencies rarely occur in New England soils; therefore, an optimum range has never been defined. Values provided represent the normal range found in soils and are for reference only.

7.3 Appendix C: Lists of All Species Observed by Sites

Table 7.16: Longmeadow, all species observed

Scientific Name	Common Name
Agrostis hyemalis[N]	Ticklegrass
Artemesia vulgaris[E]	Mugwort
Carex annectens[N]	Yellow fruited sedge
Carex radiata[N]	Star sedge
Chamaecrista fasciculata[N]	Partridge pea
Cyperus esculentus[N]	Nut flatsedge
Daucus carota[E]	Queen Anne’s lace
Desmodium canadense[N]	Showy tick-trefoil
Elymus virginicus[N]	Virginia wild rye
Erigeron strigosus[N]	Rough fleabane
Festuca rubra[N]	Red fescue
Impatiens capensis[N]	Jewelweed
Lepidium campestre[N]	Field pepperweed
Oenothera biennis[N]	Common evening primrose
Panicum virgatum[N]	Switchgrass
Potentilla simplex[N]	Common cinquefoil
Solidago rugosa[N]	Rough leaved goldenrod
Solidago nemoralis[N]	Gray goldenrod
Symphyotrichum laeve[N]	Smooth American aster
Trifolium aureum[E]	Hop clover
Vitis riparia[N]	River grape

Note: Highlighted species were included in the seed mix.

Table 7.17: Deerfield, all species observed

Scientific Name	Common Name
Agrostis hyemalis[N]	Ticklegrass
Agrostis perennans[N]	Upland bentgrass
Andropogon gerardii[N]	Big bluestem
Artemesia vulgaris[E]	Mugwort
Cephalanthus occidentalis[N]	Button bush
Chamaecrista fasciculata[N]	Partridge pea
Echinocloa crus-galli[E]	Barnyard grass
Elymus virginicus[N]	Virginia wild rye
Eragrostis spectabilis[N]	Purple lovegrass
Erigeron canadensis[N]	Canada fleabane
Lespedeza capitata[N]	Round-headed bush clover
Morella caroliniensis[N]	Bayberry
Oenothera biennis[N]	Common evening primrose
Oenothera laciniata[N]	Cut-leaved evening primrose
Panicum virgatum[N]	Switchgrass
Persicaria pennsylvanica[N]	Pennsylvania smartweed
Plantago aristata[E]	Bracted plantain
Plantago lanceolata[E]	English plantain
Poa pratensis[N]	Fowl blue grass
Rudbeckia hirta[N]	Black-eyed susan
Schizachyrium scoparium[N]	Little bluestem
Solidago rugosa[N]	Rough leaved goldenrod
Sonchus arvensis[E]	Field sow thistle
Taraxacum officianale[E]	Common dandelion
Trifolium aureum[E]	Hop clover
Trifolium pratense[E]	Red clover
Verbena hastata[N]	Blue vervain
Vicia cracca[E]	Cow vetch

Note: Highlighted species were included in the seed mix.

Table 7.18: Conway, all species observed

Scientific Name	Common Name
Agrostis hyemalis[N]	Ticklegrass
Andropogon gerardii[N]	Big bluestem
Artemesia vulgaris[E]	Mugwort
Chamaecrista fasciculata[N]	Partridge pea
Dactylis glomerata[E]	Orchard grass
Daucus carota[E]	Queen Anne's lace
Desmodium canadense[N]	Showy tick-trefoil
Dicanthelium clandestinum[N]	Deer tongue panicgrass
Elymus canadensis[N]	Canada wild rye
Elymus virginicus[N]	Virginia wild rye
Equisetum fluviatile[N]	River horsetail
Erechtites hieracifolia[N]	American burnweed
Geum canadense[N]	White avens
Impatiens capensis[N]	Jewelweed
Lythrum salicaria[E]	Purple loosestrife
Monarda fistulosa[N]	Wild bergamot
Oenothera biennis[N]	Common evening primrose
Panicum virgatum[N]	Switchgrass
Persicaria pennsylvanica[N]	Pennsylvania smartweed
Quercus rubra[N]	Northern red oak
Quercus velutina[N]	Black oak
Rhus hirta[N]	Staghorn sumac
Rudbeckia hirta[N]	Black-eyed susan
Rumex acetosella[E]	Common sheep sorrel
Schizachyrium scoparium[N]	Little bluestem
Solidago altissima[N]	Tall goldenrod
Solidago canadensis[N]	Canada goldenrod
Solidago gigantea[N]	Smooth goldenrod
Solidago nemoralis[N]	Gray goldenrod
Sonchus arvense[E]	Field sow-thistle
Tanacetum vulgare[E]	Common tansy
Trifolium aureum[E]	Hop clover
Trifolium pratense[E]	Red clover
Tussilago farfara[E]	Coltsfoot
Verbena hastata[N]	Blue vervain
Vicia cracca[E]	Cow vetch
Vitis labrusca[N]	Fox grape

Note: Highlighted species were included in the seed mix.

Table 7.19: Waltham, all species observed

Scientific Name	Common Name
Agrostis hyemalis[N]	Ticklegrass
Alliaria petiolata[E]	Garlic mustard
Cynanchum louiseae[E]	Black swallowwort
Dicanthelium clandestinum[N]	Deer-tongue panicgrass
Elymus virginicus[N]	Virginia wild rye
Eragrostis spectabilis[N]	Purple lovegrass
Erechtites hieracifolius[N]	American burnweed
Erigeron canadensis[N]	Canada fleabane
Euphorbia cyperassias[E]	Cypress spurge
Linaria vulgaris[E]	Butter and eggs toadflax
Nuttalanthus canadensis[N]	Old field toadflax
Oenothera biennis[N]	Common evening primrose
Oxalis stricta[N]	Common yellow wood sorrel
Panicum virgatum[N]	Switchgrass
Poa palustris[N]	Fowl blue grass
Quercus velutina[N]	Black oak
Schizachyrium scoparium[N]	Little bluestem
Solidago canadensis[N]	Canada goldenrod
Sonchus arvensis[E]	Field sow-thistle

Note: Highlighted species were included in the seed mix.

Table 7.20: Danvers, all species observed

Scientific Name	Common Name
Achillea millefolium^{N}	Common yarrow
Agrostis hyemalis ^{N}	Ticklegrass
Agrostis perennans ^{N}	Upland bentgrass
Andropogon gerardii ^{N}	Big bluestem
Apocynum cannibinum^{N}	Hemp dogbane
Artemesia vulgaris^{E}	Mugwort
Chamaecrista fasciculata ^{N}	Partridge pea
Daucus carota^{E}	Queen Anne's lace
Dicanthelium (Panicum) clandestinum ^{N}	Deer-tongue panicgrass
Elymus virginicus ^{N}	Virginia wild rye
Erigeron strigosus ^{N}	Rough fleabane
Euthamia graminifolia ^{N}	Flat top goldenrod
Hieracium caespitosum ^{E}	Yellow hawkweed
Juncus tenuis ^{N}	Path rush
Juniperus communis ^{N}	Common juniper
Lactuca biennis ^{N}	Tall blue lettuce
Lepidium vulgare^{E}	Common pepperweed
Liatris spicata^{E}	Sessile-headed blazing star
Lotus corniculatus^{E}	Bird's-foot trefoil
Lythrum salicaria^{E}	Purple loosestrife
Melilotus alba^{E}	White sweet-clover
Oenothera biennis^{N}	Common evening primrose
Persicaria pennsylvanica^{N}	Pennsylvania smartweed
Plantago lanceolata^{E}	English plantain
Poa palustris^{N}	Fowl blue grass
Prunella vulgaris^{N}	Common selfheal
Rudbeckia hirta^{N}	Black-eyed Susan
Schizachyrium scoparium^{N}	Little bluestem
Solidago nemoralis^{N}	Gray goldenrod
Solidago rugosa^{N}	Rough-leaved goldenrod
Trifolium arvense^{E}	Rabbit-foot clover
Trifolium pratense^{E}	Red clover
Verbascum thapsus^{E}	Common mullein
Verbena hastata^{N}	Blue vervain

Note: Highlighted species were included in the seed mix.

7.4 Appendix D: Species Establishment at All Sites

Table 7.21: Native grass and forb establishment

Species	Longmeadow % Ground Cover*	Deerfield % Ground Cover	Conway % Ground Cover	Waltham % Ground Cover	Danvers % Ground Cover
Achillea millefolium	-	-	-	-	0.20
Asclepias tuberosa	-	-	-	-	0.01**
Agrostis hyemalis	13.4	0.24	4.70	15.83	4.20
Agrostis perennans	-	3.76	-	-	6.60
Agrostis stolonifera	-	-	-	-	-
Andropogon gerardii	-	1.18	9.00	-	8.00
Apocynum cannibinum	-	-	-	-	0.60
Baptisia australis	-	-	-	-	-
Bouteloua curtipendula	-	-	-	-	-
Carex annectens	1.20	-	-	-	-
Carex radiata	0.40	-	-	-	-
Carex vulpinoidea	-	-	-	-	-
Chamaecrista fasciculata	4.04	20.29	8.30	-	2.20
Coreopsis lanceolata	-	-	-	-	-
Cyperus esculentus	1.80	-	-	-	-
Desmodium canadense	16.20	-	2.00	-	-
Dicanthelium clandestinum	-	-	0.30	0.42	5.40
Echinacea purpurea	-	-	-	-	-
Elymus canadensis	-	1.82	2.90	-	-
Elymus virginicus	7.20	0.01	5.50	12.92	9.20
Equisetum fluviatile	-	-	3.30	-	-
Eragrostis spectabilis	-	1.88	-	0.83	-
Erechtites hieracifolia	-	-	0.01	7.92	-
Erigeron canadensis	-	3.92	-	2.08	-
Erigeron strigosus	4.24	-	-	-	1.20
Eupatorium maculatum	-	-	-	-	-
Euthamia graminifolia	-	-	-	-	1.60
Festuca rubra	1.60	-	-	-	-
Geum canadense	-	-	0.40	-	-
Heliopsis helianthoides	-	-	-	-	-
Impatiens capensis	0.60	-	0.80	-	-
Juncus canadensis	-	-	-	-	-

Species	**Longmeadow % Ground Cover***	**Deerfield % Ground Cover**	**Conway % Ground Cover**	**Waltham % Ground Cover**	**Danvers % Ground Cover**
Juncus effusus	-	-	-	-	-
Juncus tenuis	-	-	-	-	2.00
Lactuca biennis	-	-	-	-	0.20
Lepidium campestre	0.20	-	-	-	-
Lespedeza viginica	-	-	-	-	-
Lespedeza capitata	-	1.18	-	-	-
Liatris spicata	-	-	-	-	0.01
Monarda fistulosa	-	-	2.00	-	-
Nuttalanthus canadensis	-	-	-	0.08	-
Oenothera biennis	5.04	0.53	0.40	0.42	8.00
Oenothera laciniata	-	0.29	-	-	-
Oxalis stricta	-	-	-	0.17	-
Panicum virgatum	12.08	7.35	14.00	14.17	-
Penstemon laevigatus	-	-	-	-	-
Persicaria pennsylvanica	-	1.65	0.10	-	1.00
Potentilla simplex	1.00	-	-	-	-
Poa palustris	-	-	-	0.01	4.40
Poa pratensis	-	0.82	-	-	-
Prunella vulgaris	-	-	-	-	0.20
Puccinellia distans	-	-	-	-	-
Pycnanthemum incanum	-	-	-	-	-
Rudbeckia hirta	-	0.88	0.80	-	0.20
Rudbeckia triloba	-	-	-	-	-
Schizachyrium scoparium	-	2.65	4.60	20.00	2.20
Senna hebecarpa	-	-	-	-	-
Senna marilandica	-	-	-	-	-
Solidago altissima	-	-	1.90	-	-
Solidago canadensis	-	-	3.20	0.08	-
Solidago gigantea	-	-	5.00	-	-
Solidago rugosa	0.40	0.88	-	-	0.60
Solidago nemoralis	1.00	-	0.01	-	1.00
Sorghastrum nutans	-	-	-	-	-
Symphyotrichum laeve	4.40	-	-	-	-
Symphyotrichum novae-angliae	-	-	-	-	-
Tradescantia ohiensis	-	-	-	-	-
Verbena hastata	-	0.88	6.20	-	8.20

*Species observed on sites as recorded in Appendix C, but not found and quantified during random quadrat sampling are assigned a 0.01% ground cover in this table.
**Species included in the seed mix for a site have a blue-gray fill.
***In this table 0% ground cover is denoted with a dash.

7.5 Appendix E: Glossary

Bioassay: an experiment to determine the potency or effect of a substance on living cells or organisms.

Biosolids: treated sewage sludge *(16).*

Compost: "the product of controlled biological decomposition of organic material that has been sanitized through the generation of heat and stabilized to the point that it is beneficial to plant growth." *(19)*

Compost blanket: a layer of composted organic material applied as a surface mulch for the purpose of erosion and sediment control on sloped sites. *(16)*

Cover crop: "temporary plantings consisting of a monoculture of annual grasses planted for erosion control when planting of native warm-season grasses has to be delayed." *(7)*

Erosion control blanket: A woven blanket composed of organic and/or synthetic materials that is placed on top of a soil surface for the purpose of reducing soil erosion. Often secured with stakes or landscape staples.

Ecotypes: "fixed genetic subdivisions within the range of a species that have similar characteristics such as growth habit, time of maturity and height" *(9)*

Mulch: an organic material, often ground or chipped, that has not undergone the controlled biological decomposition necessary to create compost.

Noxious weed: a legal definition of weeds that are deemed unlawful to be allowed to set seed or exceed 24" in height *(9)*

Nurse crop: "crops that are included into permanent plantings, are represented by fast growing, short-lived, upright species that do not form a dense cover, thus allowing slower-growing native species to establish." *(7)*

Pure live seed (PLS): "the percentage of specified seed that will germinate" (pure seed percentage x germination percentage / 100). *(9)*

Ripping: a mechanical process of relieving soil compaction using metal tines dragged by a tractor.

Soil erosion: The detachment and transport of soil particles from the soil surface. This can occur by a variety of mechanisms such as rain drop impact, sheet flow, and rill erosion *(58)*

Weed propagules: structures that are capable of reproduction; seeds, roots, tubers, or other plant parts capable of establishing a new plant under favorable conditions.