BUREAU OF WATERSHED MANAGEMENT
PROGRAM GUIDANCE

WATERSHED MANAGEMENT TEAM
Storm Water Runoff Management Program

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Post-Construction Storm Water Management Options for Ground-Mounted Solar Array Areas

2-23-2024
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This document is intended solely as guidance and does not contain any mandatory requirements except where requirements found in statute or administrative rule are referenced. Any regulatory decisions made by the Department of Natural Resources in any matter addressed by this guidance will be made by applying the governing statutes and administrative rules to the relevant facts.

APPROVED:

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A. Introduction/Statement of Problem Being Addressed

Large-scale solar facilities are a new technology that presents unique circumstances for storm water management. As construction of these large-scale solar facilities results in more than an acre of land disturbance, projects are required to obtain storm water permit coverage under s. NR 216.42 (1), Wis. Adm. Code. Projects that incorporate the use of impervious surfaces as part of the overall development plan are required to meet post-construction storm water management requirements under subch. III of ch. NR 151, Wis. Adm. Code. An impervious surface is defined under s. NR 151.002(17), Wis. Adm. Code, as "an area that releases as runoff all or a large portion of the precipitation that falls on it, . . . [r]ooftops, sidewalks, driveways, gravel or paved parking lots, and streets are examples of surfaces that typically are impervious." Large-scale solar panel installations meet the definition of an "impervious surface" if they include "an area that releases as runoff all or a large portion of the precipitation that falls on it."

This document intends to provide example implementation and design considerations for projects proposing to utilize native vegetation under and around ground-mounted solar panels to demonstrate compliance with post-construction storm water performance standards in ss. NR 151.122 to 151.124, Wis. Adm. Code. The implementation and design considerations are supported by current scientific knowledge and established hydrological principles. The use of vegetation is one of several options an applicant or permittee may use to demonstrate compliance with these requirements. Facilities may also use alternative means of demonstrating compliance.

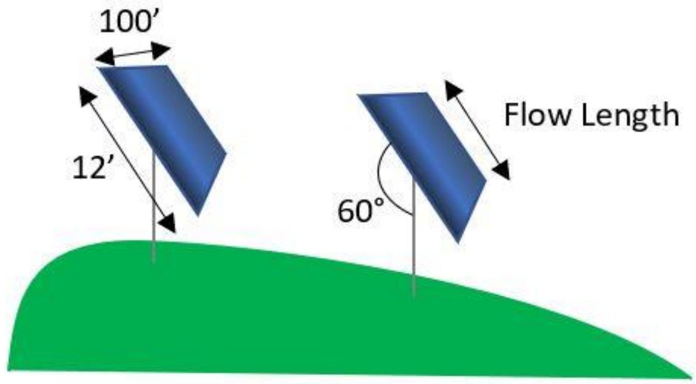
B. Objectives

This guidance identifies the conditions under which the vegetation under and around ground-mounted solar arrays may be considered a storm water management practice sufficient to satisfy post-construction performance standards under ss. NR 151.122 to 151.124, Wis. Adm. Code. Other approaches to demonstrating compliance with these performance standards may be used. This guidance provides one example. Project proponents are encouraged to contact department staff during civil site design to discuss location-specific conditions.

C. Background and Definitions

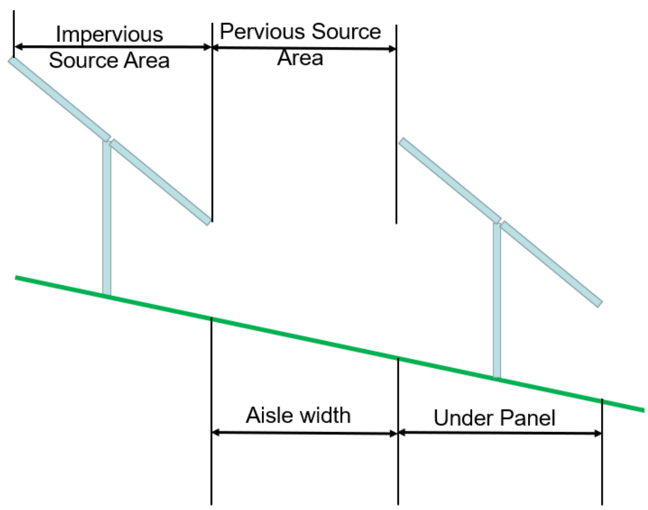
Ground-mounted solar array installations have become increasingly common as a means of power generation in Wisconsin and elsewhere in the country. The size of ground-mounted solar array areas ranges from a few acres to over 1,000 acres. The area under solar arrays is generally vegetated, creating a landscape that is a combination of pervious meadow beneath the arrays (acting as vegetated filter strips) and disconnected impervious surface above the vegetation. The distance for an impervious surface to be considered disconnected is identified in the guidance document titled "Modeling Post-Construction Storm Water Management Treatment" #3800-2020-01.

Pre-development land use is often row crops where a reduction in runoff from predevelopment to post-development conditions is realized as part of the establishment of meadow conditions under and between the solar panels. This was the assumption in Hydrologic Response of Solar Farms (Cook and McCuen, 2013), a study that conducted modeling of a single, fixed-panel solar array placed parallel to ground elevation contours to evaluate the hydrologic impacts of solar farms. The study was considered in developing this guidance document, but this guidance goes beyond it to address variations in panel orientation relative to contours and pre-development land use.



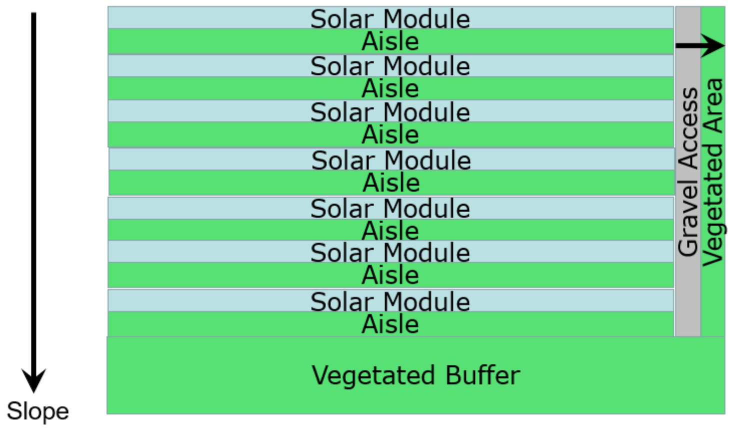
As noted in s. NR 151.122(3), Wis. Adm. Code, current methods to demonstrate compliance with s. NR 151.122, Wis. Adm. Code includes modeling tools tailored to assess the effects of impervious surfaces from classic urban development. The most commonly used modeling tools are Windows version of the Source Loading Assessment Methodology (WinSLAMM) or Program for Predicting Polluting Particle Passage through Pits, Puddles, & Ponds (P8). Each model has certain assumptions and/or limitations that need to be accounted for for the treatment practice to achieve the model’s predicted treatment efficiency.

This guidance is developed specifically to address the performance standards in ss. NR 151.122 to 151.124, Wis. Adm. Code, which cover Total Suspended Solids (TSS), peak flow, and infiltration performance standards for ground-mounted solar arrays, inverters, energy storage dispersed throughout the array area, and associated gravel access roads.



The conditions in the guidance are based on WinSLAMM modeling of a series of pitched roof source areas in series with vegetated buffer strips for an annual average rainfall and Natural Resources Conservation Services Soil Conservation Service (NRCS SCS) June 1986 hydrologic modeling methodology. The type of solar array selected for modeling was a tracked solar array, as it represented the most common type of array used for projects subject to permitting review by the department.

The modeled test of a tracked solar array consisted of two 6’x100’ solar modules (12’x100’ per row) mounted on piles and oriented parallel to topographic contours. The panels were assumed to be oriented at 60 degrees above horizontal, which is a typical ‘storm stow’ position (i.e., a position in which the panels are oriented to reduce the chance of damage from adverse weather events). One 20-foot-wide by 100-foot-long gravel access road that sheet flows to a 20-foot-wide vegetated area was also included in the model, equivalent to 5800-8700 SF of gravel access road per acre. The treatment provided by the vegetation in and around the array area is not intended to offset impervious areas outside of the array area or over the maximum percent impervious area listed in Table 1. Other areas of a project subject to post-construction storm water management were not included in this modeling scenario. A portion of each aisle width equal to the flow length of the upstream panel was excluded from the filter strip to allow the panels to be modeled as disconnected impervious. The balance of the aisle width between rows of panels, as well as the flow length beneath the downstream panel, is modeled as a filter strip.



In response to changing practice, a second case has been evaluated assuming one 7’ panel and a minimum aisle width of 12’. All other assumptions were consistent with previous modeling.

Based on a 2010 USGS rain garden study (Selbig et. al., 2010), deep-rooted native plantings are associated with measured soil infiltration rates that are 2-3 times that of shallow-rooted non-native grass. In the modeling used to support the development of this guidance, areas planted with deep-rooted native species were assumed to infiltrate at a rate of twice the static design infiltration rate listed in Table 2 of Technical Standard 1002 Site Evaluation for Infiltration for each soil textural class. In keeping with existing technical standards and guidance, a dynamic infiltration rate of ½ the static infiltration rate was used to account for moving water.

D. Example of Conditions That Would Establish Compliance

The post-construction performance standards within ss. NR 151.122 to 151.124, Wis. Adm. Code for the vegetation under, between, and around ground-mounted solar arrays, are expected to be satisfied by demonstrating that the following conditions are met:

1. The area under and between the modules is vegetated per DNR Technical Standard “Vegetative Buffer for Construction Sites” (1054); however, vegetation density is only required to be at 70% minimum density for the vegetation to be considered effective. If there are large areas of either bare soil or undesirable vegetation, this should be addressed as part of

site maintenance. Deep-rooted vegetation provides greater infiltration than turf or shallow-rooted plants. Native vegetation is preferred, followed by deep-rooted, non-native vegetation.

Note: After initial establishment, native vegetation typically requires less maintenance than non-native vegetation, and therefore is a common practice under and around ground-mounted solar operations. Should the use of native vegetation under and around ground-mounted solar panels be undesirable, this guidance does not preclude using another means of demonstrating compliance.

2. The distance between the lowest point of any panel and the ground is less than 10 feet. Distances greater than 10 feet may require additional energy dissipation measures. This is consistent with Minnesota requirements.

3. *Seasonally high groundwater* is at least 12 inches below the proposed grade per s. NR 151.124(4)(b), Wis. Adm. Code. Where drain tile is present throughout the site and will be maintained after construction, the elevation of the drain tile may be considered the seasonally high groundwater level. Repair or replacement of drain tile laterals is likely to be necessary during construction, so provisions for this should be included in the storm water management plan.

4. The ground slope is not steeper than 20%. At steep slopes, the water is moving faster and there is less time for both filtering and infiltration. Steeper slopes are also known to be more prone to erosion.

5. Flow from the panels is delivered as sheet flow from the solar panels to a well-vegetated area. The solar array rows are aligned, to the extent practicable, parallel to topographic contours to limit the potential for concentrated flow along the drip lines. If a drip line will be more than 45 degrees off parallel from topographic contours, one of the following measures is implemented:
    a. Prior to module installation, establish a *nurse crop*. Any erosion observed along the dripline is promptly repaired using an erosion control mat per DNR Technical Standard “Non-Channel Erosion Mat” (1052) in conjunction with grading and seeding.
    b. Establish vegetation during the time between module installation and commissioning, for tracking installations. Once vegetation is established on one side, rotate the module to allow vegetation to establish under the drip line on the other side prior to commissioning. Any erosion observed along the dripline is promptly repaired. Use Technical Standard 1052 in conjunction with grading and seeding where needed.
    c. Implement other practices such as erosion control mat, turf reinforcement mat, and level spreaders to prevent the formation of concentrated flow and eroded channels at the dripline. Technical Standard 1052 provides information on the use and installation of turf reinforcement mats. Technical Standard 1054 provides information on level spreaders.

6. A plan is developed and implemented to prevent or mitigate soil compaction in vegetated areas. The plan describes the proposed activities as part of the project’s storm water management plan. Within this plan, the following are included:

a. Actions to avoid compaction. Examples can include but are not limited to: minimization of mass grading, use of low ground-pressure equipment, limiting access during wet ground conditions, and use of construction matting.
b. How compacted areas will be identified during construction. This may include, but is not limited to: observations of rutting, observation of poor vegetation growth, or on-site soil testing of bulk density or penetrometer pressures.
c. Measures to de-compact soils in areas where mass grading has occurred, or evidence of soil compaction is observed. These measures can include, but are not limited to: implementing compaction mitigation methods described in DNR Technical Standard "Vegetated Swale" (1005), section V.G., or compaction mitigation methods described in the Minnesota Storm Water Manual (https://stormwater.pca.state.mn.us/index.php/Alleviating_compaction_from_construction_activities) .
d. How the effectiveness of avoidance and decompaction measures will be assessed.

7. The peak flow performance standards in s. NR 151.123, Wis. Adm. Code are met. This may be demonstrated in the following ways:
    a. Compare predevelopment and post-development curve numbers and the time of concentration. In determining the post-construction curve number, the procedure for calculating a curve number for disconnected impervious surfaces in TR-55 may be used. Predevelopment runoff curve numbers must not exceed the maximums provided in s. NR 151.123, Wis. Adm. Code, for the respective hydrologic soil group. For example, the predevelopment curve number of cover type "woodland" do not exceed a value of 55 for hydrologic soil group B based on the values provided in Table 2 of s. NR 151.123(1), Wis. Adm. Code. Please note that for determining the hydrologic soil group, the department accepts either USGS soil survey data or onsite geotechnical evaluations.
    b. Hydrologic modeling, assuming the panels are disconnected impervious surfaces shows that the peak discharge from the 1-and 2-year, 24-hour storms does not exceed the corresponding pre-development peak discharge.

    Note: For modeling purposes, short, non-native grass should be assumed for sites where pollutant trading credit generation is planned although deep-rooted native vegetation is the preferred BMP. This allows the project to demonstrate compliance with permit requirements with a less robust vegetative cover so that credit can be taken for the incremental improvement provided by the native vegetation.

8. Runoff from areas outside solar array areas is limited to the maximum extent practicable. Excess runoff can limit the amount of pollution control provided by the vegetation. A temporary stabilized diversion swale may be needed to avoid overwhelming storm water erosion and sediment control practices during construction. A permanent stabilized diversion swale may be needed where offsite runoff rates are sufficient to damage vegetation within the array area or create new concentrated flow paths. Where existing concentrated flow paths carry water to the site, disturbance of this flow path is avoided to the maximum extent practicable.

9. The following items are included in the materials submitted with the Notice of Intent (NOI): Panel length, width, spacing of solar panels, mounting height, and orientation. For panels on

tracking systems, please indicate the range of positions including night stow position and storm stow position. If a final decision on panels and tracking systems has not been made at the time of permit application, provide the requested information for the largest panels under consideration and the tracking system with the most limited range of positions.

10. The vegetation under and around the solar array area is included as a storm water best management practice in a long-term maintenance agreement per s. NR 216.47(5), Wis. Adm. Code. The maintenance agreement specifies the actions needed to maintain the vegetation in good condition during facility operation, including repairing any eroded areas consistent with DNR Technical Standard "Seeding" (1059). DNR Technical Standard 1054 provides expectations to maintain dense vegetation, defined as an existing stand of 3" – 12" high grassy vegetation that uniformly covers at least 90% of a representative 1 square yard plot. Woody vegetation shall not be counted for the 90% coverage. No more than 10% of the overall buffer can be comprised of woody vegetation.

11. The layout of the facility uses one or more of the approaches below based on the soil type present in the solar array areas.
    a. The solar array area and buffer area downgradient are planted in native vegetation maintained at a 6" minimum height, no pollutant trading credit is generated as the native vegetation is needed to meet post-construction performance standards. Refer to Table 1: Post-Construction Design Parameters.
    b. Use vegetation to generate pollutant trading credits for areas outside of the native vegetation buffer areas. Such areas are modeled as shallow-rooted non-native grass maintained at a 4" minimum height. See Table 1: Post-Construction Design Parameters and refer to rows containing "Pollutant Credit Generation Desired".
    c. The solar array area is served by a best management practice designed per the post-construction technical standards. Model the solar array area to demonstrate performance standards are being met. Modeling inputs and interpretation should reflect the provisions in the guidance document titled "Modeling Post-Construction Storm Water Management Treatment"
    d. Additional considerations:
        i. Maintain existing drainage patterns or create a series of swales to serve every 100' of slope length for HSG D soils. Design swales based on the recommendations provided in DNR Technical Standard "Vegetated Swale" (1005).
        ii. Protect existing drainage patterns from erosion and/or sediment buildup by ensuring vegetation is established in the surrounding areas.
        iii. Where native vegetation is not feasible, the permittee should 1) provide information as to why deep-rooted vegetation is infeasible; and 2) work with local nurseries to develop and provide a list of seed mixes that would provide similar benefits to deep-rooted vegetation.

Table 1: Post-Construction Design Parameters

Hydrologic Soil Group-Vegetation Type-Slope[1]	Minimum Aisle Width[2]	Max panel area + other array area % impervious (excluding substations)	Minimum Vegetated Buffer Width downslope of the solar array[3]	Maximum flow length between interception swales for slopes >4%
A-Native Vegetation Ground Slope <20%	1.0 x L but not less than 10 feet	50%	Same as Minimum Aisle Width	None
A- Native Vegetation with Pollutant Credit Generation Desired Ground Slope <20%	1.0 x L but not less than 10 feet	50%	Same as Minimum Aisle Width	None
B- Native Vegetation Ground Slope <20%	1.1 x L but not less than 10 feet	25%	Same as Minimum Aisle Width	None
B- Native Vegetation with Pollutant Credit Generation Desired Ground Slope <20%	1.1 x L but no less than 10 feet	25%	1P: 10’ 2P: 15’	300 feet
C- Native Vegetation Ground slope ≤5%:	1.2 x L but no less than 10 feet	21%	1P: 20’ 2P: 25’	200 feet
Ground slope >5% and < 15%	1.2 x L but no less than 12 feet		1P: 20’ 2P: 30’	
Ground Slope ≥15%			1P: 25’ 2P: 35’	
C- Native Vegetation with Pollutant Credit Generation Desired	1.2 x L but no less than 12 feet	21%	Ground slope ≤5%: 1P: 25’ 2P: 35’	200 feet
			Ground slope >5% 1P: 30’ 2P: 40’	
D- Native Vegetation	1.3 x L but no less than 12 feet	20%	Ground slope ≤5%: 1P: 25’ 2P: 30’	100 feet
			Ground slope >5% 1P: 30’ 2P: 35’	
D- Native Vegetation with Pollutant Credit Generation Desired	1.3 x L but no less than 12 feet	20%	Ground slope ≤5%: 1P: 25’ 2P: 35’	100 feet
			Ground slope >5% 1P: 35’ 2P: 40’	

[1] Ground Slope is average slope under a discreet grouping of panels.
[2] L=Flow length over module
[3] 1P=1 panel in portrait, 2P=2 panels in portrait orientation

Note: The distances provided above are based on WinSLAMM modeling of typical projects.

Modeling may be used to demonstrate compliance with post-construction performance standards for the solar array areas that do not meet the conditions listed above. Department staff is available to discuss proposed modeling approaches.

E. References

Lauran M. Cook & Richard H. McCuen, Hydrologic Response of Solar Farms, 18 Journal of Hydrologic Engineering 536-541 (2013).

W.R. Selbig & Nicholas Balster, Evaluation of turf-grass and prairie-vegetated rain gardens in a clay and sand soil, Madison, Wisconsin, water years 2004–08: U.S. Geological Survey Scientific Investigations Report 2010–5077, p. 72 (2010).

Minnesota Storm Water Manual, Alleviating compaction from construction activities (2023),https://stormwater.pca.state.mn.us/index.php/Alleviating_compaction_from_construction_activities.

USDA, Urban Hydrology for Small Watersheds, TR-55, Natural Resources Conservation Service, Washington, DC (1986).

Wisconsin Department of Natural Resources, Technical Standard (1053) *Channel Erosion Mat*, (2004), http://dnr.wi.gov/topic/stormWater/documents/dnr1053-ChannelErosionMat.pdf.

Wisconsin Department of Natural Resources, *Modeling Post-Construction Storm Water Management Treatment*, Guidance Document 3800-2020-01 (2020), https://apps.dnr.wi.gov/water/wsSWIMSDocument.ashx?documentSeqNo=118060534.

F. Glossary

Nurse crop: An annual grass included in deep-rooted native vegetation seed mixes to control erosion over the establishment period of the native vegetation.

Seasonally high groundwater: The higher of either the elevation to which the soil is saturated as observed as a free water surface in an unlined hole, or the elevation to which the soil has been seasonally or periodically saturated as indicated by soil color patterns throughout the soil profile.

G. Appendix

A. Considerations for native plant species with typical height range 1-6’
B. Considerations for native plant species with typical height range 1-3’

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***Appendix A: Considerations for native plant species with typical height range 1-6’**

GRASSES, SEDGES, RUSHES	COMMON NAME	HEIGHT	PERCENT OF MIX
Sporobolus cryptandrus	Sand Dropseed	1-3'	2.6
Bouteloua curtipendula	Side Oats Grama	1-3'	12.2
Elymus canadensis	Canada Wild Rye	3-5'	1.7
Elymus trachycaulus	Slender Wheatgrass	2-3'	1.6
Elymus virginicus	Virginia Wild Rye	3-5'	1.2
Panicum virgatum	Switchgrass	4-6'	7.0
Schizachyrium scoparium	Little Bluestem	2-3'	29.7
Total			**56.0**
WILDFLOWERS	**COMMON NAME**	**HEIGHT**	**PERCENT OF MIX**
Achillea millefolium	Native Yarrow	1-3'	4.2
Agastache foeniculum	Lavender Hyssop	2-4'	0.7
Amorpha canescens	Leadplant	1-3'	0.3
Asclepias incarnata	Marsh (Red) Milkweed	3-5'	0.1
Asclepias syriaca	Common Milkweed	2-4'	0.1
Asclepias tuberosa	Butterfly Weed	2-3'	0.1
Astragalus canadensis	Canada Milk Vetch	1-3'	0.3
Chamaecrista fasciculata	Partridge Pea	1-3'	0.2
Dalea candida	White Prairie Clover	1-2'	0.3
Dalea purpurea	Purple Prairie Clover	1-2'	2.1
Desmodium canadense	Canada Tick Trefoil	2-5'	0.2
Heliopsis helianthoides	Early Sunflower	3-5'	0.5
Hypericum pyramidatum	Great St. John's Wort	4-6'	7.0
Aster azureus	Sky Blue Aster	1-3'	0.5
Monarda fistulosa	Wild Bergamot	2-4'	1.2
Penstemon digitalis	Foxglove Beard Tongue	1-3'	1.4
Ratibida columnifera	Upright Prairie Coneflower	1-3'	1.9
Ratibida pinnata	Yellow Coneflower	4-5'	0.7
Rudbeckia hirta	Black-Eyed Susan	1-3'	15.1
Solidago rigida	Stiff Goldenrod	3-5'	1.2
Aster laevis	Smooth Blue Aster	3-5'	0.4
Aster novae-angliae	New England Aster	4-5'	0.5
Verbena hastata	Blue Vervain	3-5'	4.6
Verbena stricta	Hoary Vervain	1-3'	0.7
Zizia aurea	Golden Alexanders	2-4'	0.3
Total			**44.6**

*This appendix provides an example seed mix made up of native species and annual nurse crop. This list of species could be considered in circumstances where the desired typical height ranges from 1-6 feet. Actual seed mixes are expected to vary based on region, soils, and panel height. Other deep rooted, non-native species may also provide similar outcomes to those found in the native species list above.

*Appendix B: Considerations for native plant species with typical height range 1-3’

GRASSES, SEDGES, RUSHES	COMMON NAME	HEIGHT	PERCENT OF MIX
Bouteloua curtipendula	Side Oats Grama	1-3'	4.1
Bouteloua gracilis	Blue Grama	1'	12.1
Carex brevior	Plains Oval Sedge	1'	0.4
Carex sprengelii	Long-Beaked Sedge	1-2'	0.2
Elymus trachycaulus	Slender Wheatgrass	2-3'	0.1
Juncus dudleyi	Dudley's Rush	1-2'	38.7
Juncus tenuis	Path Rush	1'	18.2
Schizachyrium scoparium	Little Bluestem	2-3'	9.7
Sporobolus heterolepsis	Prairie Dropseed	2-3'	0.4
Total			**83.9**
WILDFLOWERS	**COMMON NAME**	**HEIGHT**	**PERCENT OF MIX**
Achillea millefolium	Native Yarrow	1-3'	6.1
Anemone canadensis	Meadow Anemone	1-2'	0.1
Aquilegia canadensis	Wild Columbine	1-3'	0.1
Asclepias tuberosa	Butterfly Weed	2-3'	0.1
Chamaecrista fasciculata	Partridge Pea	1-3'	0.1
Dalea candida	White Prairie Clover	1-2'	0.7
Dalea purpurea	Purple Prairie Clover	1-2'	1.0
Aster laevis	Smooth Blue Aster	3-5'	0.6
Solidago graminifolia	Grass-Leaved Goldenrod	1-3'	1.0
Polygonatum biflorum	Solomon's Seal	3-4'	0.1
Rudbeckia hirta	Black-Eyed Susan	1-3'	5.4
Solidago ulmifolia	Elm-Leaved Goldenrod	2-5'	0.3
Verbena stricta	Hoary Vervain	1-3'	0.8
Total			**16.4**

* This appendix provides an example seed mix made up of native species and annual nurse crop. This list of species could be considered in circumstances where the desired typical height ranges from 1-3 feet. Actual seed mixes are expected to vary based on region, soil, and panel height. Other deep-rooted, non-native species may also provide similar outcomes to those found in the native species list above.