Literature Review of Monitoring Methodology and Wetland Impacts from Solar Facilities

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ARROWWOOD ENVIRONMENTAL

Fitzgerald Environmental Associates, LLC.

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Introduction

We have conducted a comprehensive review of the current scientific literature on topics related to solar development in agricultural wetlands. The goal of the literature review is two-fold: First, to identify the broader scientific research that has been conducted and review whether any conclusions have been drawn from this research regarding the impacts of solar development on wetland function. We reviewed the current knowledge and substantive findings as well as any methodological contributions to the topic.

Secondly, we evaluated the effectiveness of past methodologies used in Vermont to monitor the impacts of solar projects on wetlands. To date, those methodologies have primarily focused on vegetation monitoring. Arrowwood has worked closely with Vermont Wetlands Program staff to develop and implement some of the current vegetation monitoring protocols for assessing vegetation at solar arrays. We draw upon this practical experience, incorporating our own lessons learned, when evaluating the effectiveness of the existing protocols.

This summary memorandum outlines the findings of the literature and existing methodology review which will help inform the development of a revised and more comprehensive methodology for the current project.

Impacts from Solar Facilities

General Impacts

The body of scientific literature about solar power is vast and continually growing as more solar facilities become developed. However, the number of studies that look at direct environmental impacts from solar facilities during the construction and operational phases is quite limited. We could find no published works that directly address the potential impacts of solar facilities on wetland functioning. However, in this literature review we focus on work that has been done on related topics which can shed light on these potential impacts.

Much of the literature published about the environmental impacts of solar facilities focuses on very broad and general impacts. These include the environmental impacts of panel production (life cycle assessments), greenhouse gas emissions, energy payback time, and comparisons with traditional sources of energy (Akella, Saini, & Sharma, 2009; Gunerhan, Hepbasli, & Giresunlu, 2009). A few papers have dealt with the installation of solar facilities but offer only broad statements such as "avoiding ecologically sensitive areas" to decrease environmental impacts

(Tsoutsos, Frantzeskaki, & Gekas, 2005). Stoms et. al (Stoms, Dashiell, & Davis, 2013) developed a model for choosing solar sites that would minimize environmental impacts, but this focused on the southwestern United States and focuses on general factors.

One of the largest studies done on general environmental impacts from solar installations was a Federal Environmental Impact Assessment of solar facilities in the southwestern United States (BLM/DOE, 2012). This assessment found that current construction standards could lead to direct impacts such as soil disturbance, habitat loss and fragmentation, wildlife mortality and spread of invasive species. Indirect impacts such as surface water quality degradation from soil erosion and herbicide drift may also occur. Many of these impacts can be minimized or avoided by careful siting of solar facilities, co-location with agricultural or other marginal lands, and concerted revegetation efforts post-construction (Macknick, Beatty, & Hill, 2013).

The Department of Energy also produced a report on vegetation in solar facilities entitled Native Vegetation Performance under a Solar PV Array at the National Wind Technology Center (Beatty, Macknick, Mccall, Braus, & Buckner, 2017). This report focuses on techniques to re-establish vegetation beneath solar facilities post-construction as well as evaluating how this newly established vegetation can replace lost ecosystem functions. Most of this work, however, is relevant to the xeric tallgrass prairie ecosystems where moisture is a major limiting factor in plant establishment and re-vegetation. Many of the management methods and ecosystem function therefore have little relevance to solar facilities in wetland and wetland buffers in the Northeast.

Turney & Fthenakis (2011)studied the potential environmental impacts on the operational phase of solar facilities. They identified 32 different impacts: 22 beneficial, 4 neutral, and 6 that required further study. They organized the impacts into five different categories: 1) land use; 2) human health; 3) wildlife and habitat; 4) geo-hydrologic resources; and 5) climate and greenhouse gases. Impacts to wetland resources mainly fall under category 4) geo-hydrologic resource impacts. They concluded that possible impacts from the operational phase of a solar facility could include erosion of topsoil, increase of sediment load or turbidity in streams, reduction of filtration of pollutants from air and rainwater, reduction of groundwater recharge or increased likelihood of flooding. However, the authors admit that these are based on scientific projections rather than measurements and that studies are needed to determine if these impacts do occur.

Hernandez et al. (2014) also lists a number of potential effects that solar development can have on the environment including: changes in land surface temperatures, changes in microclimate and local hydrology, changes in precipitation regime, erosion, landuse and land cover change, water pollution, and soil contamination. The potential ecological results of these impacts include alteration of nutrient dynamics, invasive species infestations, and water stress. They also briefly mention solar facilities collocation with agricultural activities and the potential positive effects. Like the Turney & Fthenakis (2011) paper, these impacts are based on theory and not actual measurements.

Finally, a brief study was conducted in Vermont of four (4) commercial solar arrays located in wet meadow sites to examine the potential secondary effects from solar arrays on wetland soils, hydrology and vegetation (Crary, 2015). This study did not find any consistent impacts to soils, hydrology, or vegetation. These sites did not require extensive grading or soil disturbance and potential changes to the site may not have developed during the relatively short time following the installation of the array.

Soils

Soil Compaction

Soil compaction and soil density are important indicators of soil function and health. Compaction is typically caused by heavy vehicle traffic or tillage, and soils are particularly susceptible to compaction when wet (Raper, 2005). The loss of large pores in the soil structure affects water and air movement and can limit the depth and area available for root growth. The preferential loss of macropores also increases soil sorptivity which further reduces infiltration (Horton et al. 1994). Compaction typically occurs from forces at the soil surface, however the highest degree of soil compaction may be observed deeper in the soil profile (20-30cm). Natural and mechanical processes can more easily and quickly reduce surface compaction compared to subsurface (Raper, 2005). Compaction in the surface layer increases runoff and erosion and reduces infiltration. Subsurface compaction reduces water storage and drainage and can stop the development of deep roots (Moebius-Clune et al., 2016). Infiltration tests and cone penetrometer readings across a range of controlled compaction levels indicated that following land use conversion, soils were effectively non-compacted or compacted, with only a slight decrease in infiltration between moderate and extreme compaction levels (Gregory, Dukes, Jones, 2006).

Vehicle traffic is the primary mechanism for soil compaction at sites where extensive grading is not required during land use conversion (i.e. construction of commercial solar arrays). Heavy compaction is possible during the installation of solar arrays, particularly if the site is wet during installation. A smaller degree of ongoing compaction is expected from maintenance and mowing activities, particularly if these are concentrated within defined travel lanes (North Carolina Clean Energy Technology Center, 2017). Vehicle compaction can be reduced by minimizing the effective weight through either smaller vehicles or wider tires. Infiltration measurements within the wheel track formed from a single pass of a light tractor indicated a 30% reduction in infiltration rate (Raper, 2005). This impact could be far greater with heavier equipment and/or vehicles with narrower tires.

Soil compaction can be naturally mitigated through freeze/thaw cycles, biological processes, and root growth. Mechanical processes such as tillage are also frequently used to reduce surface compaction. No-till areas may be more resilient to vehicle compaction due to the formation of soil macropores and increased resistance to compaction due to increased soil bulk density (Raper, 2005). Subsurface compaction may never be fully mitigated through natural processes, especially in heavy or wet soils (Voorhees, 1983). Soil penetrometers are a useful tool for identifying the degree and location (depth) of compacted soils layers and can be used to direct mechanical compaction mitigation strategies such as subsoilers (Raper, 2005).

Soil Temperature and Processes

The microclimate effects of commercial solar arrays have been identified as an important gap in our understanding of potential environmental impacts associated with land based renewable energy installations. Solar panels reduce ground surface temperature, and alter rainfall patterns, wind speed, and wind turbulence. The combined effect on soil moisture and temperature is expected to impact soil carbon cycling, potentially reducing the net CO_2 reduction associated with solar energy (Armstrong, Waldron, Whitaker, & Ostle, 2014). Armstrong et al. (2014) also showed that daily average soil temperatures could be up to 5^{0}C cooler under the panels (see Vegetation section below).

Hydrology

Solar arrays contain a moderate density of impervious surfaces (panels) that are mounted over vegetation and soil. Studies have attempted to measure and model the potential impacts to site hydrology due to this atypical rainfall/runoff scenario (Barnard, Agnaou, & Barbis, 2017; Cook & Mccuen, 2013). Solar farms are typically designed to maximize energy production and row spacing is typically determined by the minimum width required for maintenance access. A hydrologic modeling study of a solar array found that the concentrated runoff from rows of solar panels was infiltrated within the shaded area of the next row downslope, resulting in no significant increase in runoff volume or peak flow under a range of rainfall depths and intensities (Cook & Mccuen, 2013). This study assumed healthy vegetative cover and that the site was graded to maintain sheetflow. This study also modeled the potential soil erosion considerations resulting in concentrated flow under the dripline of the solar panels and predicted a ten-fold increase in the kinetic energy of rainfall under these driplines. This suggests that vegetation maintenance under the dripline is a critical requirement for reducing erosion within solar arrays.

The Pennsylvania Department of Environmental Protection and Maryland Department of Environmental Protection have developed guidance for hydrology and stormwater associated with commercial solar installations (Maryland Department of the Environment, 2013; Pennsylvania Department of Environmental Protection, 2011). Solar arrays can be considered pervious if the following conditions are met:

- Minimal grading required for construction
- Spacing between panels is equal to or greater than the width of the panel rows (Figure 1)
- Panels should be constructed on gradual slopes (<5%)
- Level spreaders or other devices to restore sheet flow are recommended for sites with 5-10% slope
- Vegetation coverage should be >90%
- Mowing should occur as infrequently as possible and maintain at least 4” of vegetation height
- No application of fertilizer or pesticide to vegetated areas
- Panel heights should be set to increase vegetation growth, but be low enough to reduce dripline erosion

The Maryland Department of the Environment (2013) has also developed recommendations for solar arrays spacing the sheetflow structures to maintain natural hydrology (Figure 1).

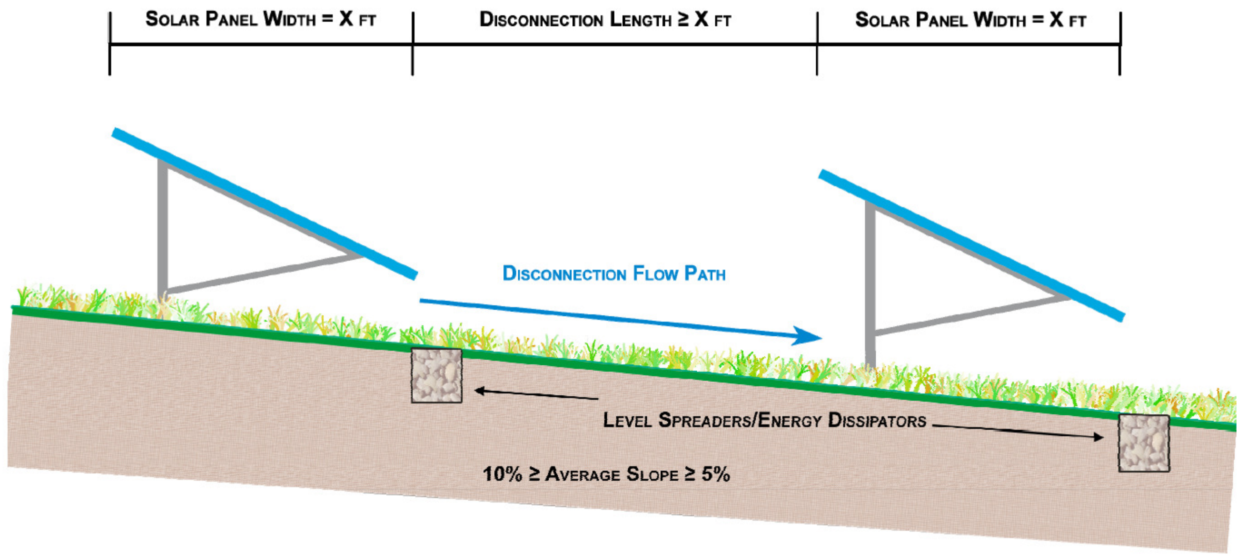

Figure 1: Recommended row spacing and sheetflow structures for maintaining natural hydrology (MDE 2013).

Vegetation

The impacts of solar arrays on plant growth, diversity and community composition has received very limited study in the scientific literature. There have been a few studies which have examined the microclimate changes resulting from the installation of solar arrays and how these changes may impact plants. One of these studies found that daily average temperature and relative humidity were comparable beneath solar arrays compared to between arrays, but soil temperatures were greatly reduced in the shaded plots (Marrou, Guilioni, Dufour, Dupraz, & Wery, 2013). Another study (Armstrong, Ostle, & Whitaker, 2016) showed that both ambient temperature and soil temperature were found to be "cooler under the PV arrays during the summer and between the PV arrays during the winter". They determined that this cooling is likely to be significant in terms of ecosystem function because changes of this magnitude (up to 5.2°C) have been known from other studies to alter many key plant-soil processes, from productivity to decomposition.

Of particular interest to the current study are the potential impacts to plant diversity and above-ground plant biomass. Armstrong et al. (2016) also found that the areas under the arrays were less diverse, dominated by grasses and less productive than the control and gap areas. However, those differences likely result from the fact that the gap and control areas were seeded differently than the areas under the arrays. Arrowwood Environmental (Arrowwood Environmental, 2017), however, also noted that the areas under the arrays were more dominated by grasses than the areas in between the arrays, so these results may occur regardless of the bias of differences in seeding. The Armstrong et al (2016) study was one of the only studies directly examining the impact of solar arrays on vegetation.

The most obvious effect that a solar panel may have on plants in the array field is the introduction of shade. The life histories and shade tolerance of many different plant species have been documented (Givnish, 1988) as well as the role that shading may have on the succession of plant communities (Huston & Smith, 1987). Because different plant species have evolved to thrive under different light-shade conditions, the abrupt introduction of shade may have the effect of shifting species composition, as noted above (Armstrong et al., 2016; Arrowwood Environmental, 2017). In general, differing light and shade conditions can impact a wide variety of factors such as leaf and root architecture, species composition, plant productivity, plant height and reproductivity (Niinemits, 2010), though most of the work in this field has been conducted in forest canopy environments. All of these features may ultimately impact wetland functioning, though limited research has been conducted on this topic.

Among two of the most important impacts that solar arrays may have on wetland functioning include plant diversity and above-ground biomass (plant productivity). Some work has been conducted on the impacts of plant diversity on ecosystem functioning. In multiple papers, Tilman and others established that biodiversity is crucial to grassland ecosystem functioning, especially in terms of stability from disturbances such as drought (Tilman, D, 1994; Tilman et al., 1997) However, limited work has been conducted on this topic in wetland ecosystems. Working in an aquatic system, Engelhardt & Kadlec (2001) determined that species richness did not have significant effect on the resilience of species biomass or respiration after disturbance.

Much less work has been done documenting the effects of plant diversity specifically on wetland functioning. Engelhardt (2001) showed that diversity could increase phosphorus retention, but this was done in a truly aquatic (lacustrine) wetland system. Callaway, Sullivan, & Zedler (2003) showed that for a restored wetland, more species rich assemblages produced more biomass and accumulated more nitrogen than single species and unplanted plots. In addition, Chabrerie et al. (2001) found that more diverse and productive wetland plant assemblages resulted in higher rates of denitrification in estuarine wetlands in France. From these studies, it appears that nutrient retention and water quality functioning can be positively correlated with wetland plant diversity in some systems.

The function of erosion prevention and sediment control may also be impacted by wetland plant diversity. Ford et al. (2016) found that in salt marshes in the United Kingdom, soil erosion rates fell with increasing plant species richness. These effects were more pronounced in erosion-prone sandy soils than in less erosion-prone clay soils. In these systems, species-richness was positively correlated with root biomass, which likely resulted in the differences in erosion that were documented. This study, however, was conducted in estuarine wetlands subject to high erosive forces. No studies have been conducted for situations similar to the solar facilities in wetland environments where high erosive forces are not present.

Monitoring Methodology Review

Soils

Soil Sampling

Soil health is an important consideration for any project requiring land use conversion. Assessment of physical, chemical, and biological properties of soil has gained attention as a critical land management consideration. Soil characteristics can be highly variable within a single land use area; therefore, most soil health sampling techniques require subsampling within the study area (Moebius-Clune et al., 2016). Soil samples and other measurements of soil health such as soil compaction are collected in several randomized locations within the study area (Figure 2). Soil samples are typically collected from the top 6" of the soil profile to characterize the primary rooting zone and tillage depth. Additional sampling from 6-24" can be completed to assess nutrient leaching (Moebius-Clune et al., 2016; Natural Resource Conservation Service, 2012)

Soil Testing

Standard soil tests determine the pH, nutrient, micronutrient, and organic matter content of the soil. Additional analyses can be performed to determine concentration of heavy metals, aggregate stability, pathogens, salinity, available water capacity, and soil respiration rates. A shovel or a soil core sampler are used for collection. Approximately 15 soil core samples are recommended for each soil test sample. The soil cores are mixed in a bucket and a subsample is collected and bagged for analysis (Natural Resource Conservation Service, 2012). Typically, 1-2 cups of soil are required for analysis.

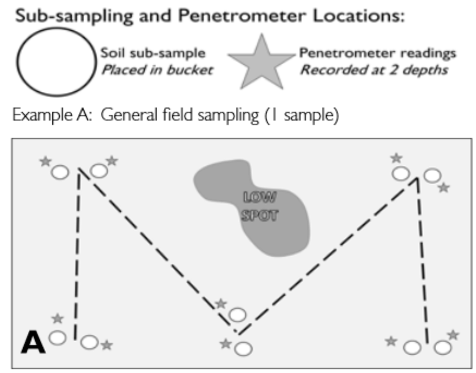

Figure 2: Example of sample collection locations for composite soil test samples and soil penetrometer readings (Moebius-Clune et al., 2016).

Soil Hardness

Surface and subsurface hardness (compaction) may be characterized with a soil penetrometer. Soil penetrometer measurements are much faster to collect than bulk density analysis and can provide information at varying depths within the soil profile (Raper, 2005). Penetrometer readings should be collected when the soils are at field capacity (2-3 days after a saturating rainfall event). The penetrometer is fitted with a ½" or ¾" conical tip and is slowly pushed into the soil. The smaller tip (1/2") should be used in all but very soft soils. Maximum pressure readings should be recorded at the surface, in the top six inches, and from 6-18". Alternatively, the soil resistance can be recorded for every depth interval throughout the profile (e.g. every 2 inches), these data can be plotted to identify specific depths of compaction as shown in Figure 3. Values above 300psi are considered "compacted" and likely to reduce root growth and mobility of beneficial soil organisms (Duiker, 2002; Gregory, Dukes, Jones, 2006; Moebius-Clune et al., 2016).

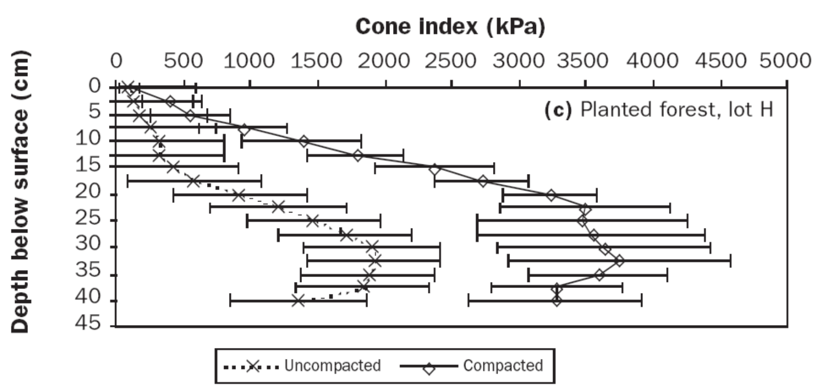

Figure 3: Soil compaction plot showing a consistent increase in Cone Index (compaction) and a larger increase near the bottom of the soil profile in a wooded site that was cleared for development (Gregory, Dukes, Jones, 2006).

Hydrology

A wide range of testing methods and equipment are used for determining soil infiltration rates and hydraulic conductivity. All the methods are based on measurements of time required to drain a volume of water into the soil, typically under saturated conditions. Natural variability within a site can have a significant impact on hydraulic conductivity; therefore, it is recommended to collect multiple measurements to best characterize a given soil/site condition (Nevada Tehoe Conservation District, 2014). The double ring infiltrometer is the most common method for measuring infiltration at or near the soil surface; however, this method requires large volumes of water and may take several hours per sample in sites with heavy soils. Other methods (permeameters) are specifically designed to measure hydraulic conductivity and are typically installed in a borehole. These methods are faster than the double-ring infiltrometer, but they do not quantify surface (Ahmed, Nestingen, Nieber, Gulliver, & Hozalski, 2014).

The Modified Philip-Dunne infiltrometer (MPD) is a new method for measuring infiltration and hydraulic conductivity of saturated soils. The MPD is best suited for determining infiltration at the surface and upper soil layers (top 30 cm). This sampler has significant advantages over other infiltration testing methods due to the reduced sampling time and lower volume of water required for testing (Gulliver, Hozalski, & Nieber, 2007; Nevada Tehoe Conservation District, 2014). The MPD test specifies that the user record the height of water within the column at a time interval determined by the relative infiltration rate of the site (i.e., faster infiltration requires a shorter sampling interval). Typically, these intervals range from 30 seconds in sandy soils to 30 minutes in heavy clay soils. A MPD sampler can be constructed out of readily available materials for under $100, therefore multiple infiltrometers can be deployed concurrently at a site, particularly if longer sampling intervals are anticipated (Nevada Tehoe Conservation District, 2014). The MPD directly measures infiltration rate, it can also be used to calculate soil hydraulic conductivity. Hydraulic conductivity measurement requires a series of soil moisture readings before and immediately after the MPD test (Ahmed et al., 2014).

Vegetation

Vegetation is known to be a ubiquitous part of most wetland systems and is integral to wetland structure and function (Bedford, 1996). Because of this, monitoring vegetation is often a surrogate for measuring wetland function. The methods for monitoring the changes in vegetation over time include a wide variety of techniques to measure a diverse array of vegetation characteristics. An overview of some of the standard protocol, methods and sample design is included in Methods for Evaluating Wetland Condition #10: Using Vegetation to Assess Environmental Conditions in Wetlands (United States Environmental Protection Agency, 2002). For the purposes of this review, the focus will be on the measurement of features of the vegetation that may impact wetland functions and values. Some of the most appropriate methods for this purpose are outlined below.

Floristic Quality Index (FQI)

The Floristic Quality Index was developed by Swink and Wilhelm (1979) in the Chicago region to rate the “naturalness” of the vegetation in a particular area. This method has been expanded upon and used widely throughout the country (Freyman, Masters, & Packard, 2015; Miller & Wardrop, 2006; Rooney & Rogers, 2002; Taft, Wilhelm, Ladd, & Masters, 1997). Recently, vegetation in

Vermont has been categorized and ranked according to this system (Bried, J.T., 2011) and this system was used in a study on wetland vegetation in solar arrays (Crary, 2015). Each species in the state is ranked on the fundamental conservatism that the species exhibits for natural habitats. The statistical analysis that is conducted for each plot yields a rank of the "Natural Area Quality" based on the species ranks. The main outcome of the FQI, therefore, is to determine how an area is recovering from a disturbed condition to a more naturally vegetated condition.

While this analysis is a good way to determine success of a recovering wetland system (for example a wetland restoration) this may be of limited use for the current project. Many of the solar arrays in Vermont occur on agricultural lands that are not dominated by native species. In addition, if grading of a site occurs during construction, reseeding does not typically consist of native species. While there is some evidence that a diverse assemblage of plant species actually functions better (see above) none of those studies differentiated between native and non-native species. While using the FQI may be useful as part of an assessment, employing it alone may not result in data useful to the question of wetland functionality.

Vermont Rapid Assessment Method for Wetlands (VRAM)

The VRAM protocol (Hohn, Lapierre, Heath, & Courage, 2017) uses a collection of various environmental and vegetation data to score a wetland on numerous factors such as wetland size, condition of the wetland, buffer and landscape, hydrology, soils, and habitat. This gives an overall picture of the specifics of the wetland but also puts the wetland into a landscape context. The VRAM methodology also includes collection of in-depth vegetation data, which will be an integral part of the current project.

Army Corps of Engineers Mitigation Guidance (ACOE Guidance)

The ACOE Guidance document is used on ACOE projects to monitor the recovery of wetland restoration projects. This document, however, only provides broad standards for assessing wetlands for mitigation projects and lacks specific methodologies. Even the Ecological Performance Standards (§ 332.5, 2012) referenced in this document refer to using the "best available science" and using reference sites. Personal communication with ACOE staff (Minkin, 2018) confirmed that the ACOE does not prescribe particular vegetation sampling methods. Mr. Minkin, however, did recommend including the following techniques: 1) use random or stratified random sampling, 2) measure species composition and abundance, 3) monitoring changes in invasive species and 4) include some measure of plant vigor to detect changes in primary productivity. In addition, certain methods from the ACOE Guidance such as incorporating performance standards should be considered.

Releve Vegetation Plot

The "releve" vegetation plot method was developed by Mueller-Dombois & Ellenberg (1974) and is still widely used today to characterize vegetation in a variety of applications. This method is currently used by the Vermont Natural Heritage Project as well as the basis for the Wetland Bioassessment methodology and the methods employed at the Charter Hill solar facility (Arrowwood Environmental, 2017). It is likely that this method will also form the basis for vegetation data collection for the current project.

Integral to this (and many other) vegetation monitoring methods is the measurement of plant percent cover. There have been numerous studies which have looked at the effectiveness of various techniques for measuring percent cover. Some studies have found that visual estimates have the highest accuracy, precision and sensitivity for this purpose compared to point frequency and subplot frequency (Brakenhielm & Qinghong, 1995). Other studies have found that visual estimates are more variable than point intercept methods but are better at detecting species and documenting species diversity (Godínez-Alvarez, Herrick, Mattocks, Toledo, & Zee, 2009). Visual estimates also have the advantage of being relatively easy to perform and require no special training or equipment.

Vermont DEC Monitoring Methodology

The vegetation monitoring methodology developed by the Vermont Department of Environmental Conservation (Vermont Department of Environmental Conservation, 2015) has been used at the Charter Hill solar facility (Arrowwood Environmental, 2017). This methodology uses 1mX1m plots and 0.25mX0.25m sub-plots to characterize the vegetation in four different treatments: wetland shade, wetland control, buffer shade and buffer control. Overall, this methodology appears to work well and should be used as a starting place when further developing monitoring methods for the current study. Based on 2 years of implementing this methodology, a few changes should be considered and are outlined below.

According to this methodology, baseline plots are established pre-construction and compared to post-construction conditions. While comparison of plots to a pre-construction condition is ideal, implementation of pre-construction plots is problematic. As mentioned in the monitoring reports (Arrowwood Environmental, 2017), since shade and control plots may only be separated by a few feet, accurately placing these plots before arrays are constructed is not feasible. Control plots for wetland and buffers can be safely placed within conserved areas or areas adjacent to the arrays, but accurately placing a shaded plot may be problematic.

Another difficulty encountered during the monitoring events was re-locating the plots post-construction. Plot corners were marked with orange grade stakes driven in flush with the ground. Wire flags were placed in the center of each plot and the plot location was mapped using sub-meter GPS. Even with this methodology, not all plots could be located after construction. Construction crews will often remove stakes and flagging, and plots must be marked in such a way as to allow for annual mowing. In 2017, plot corners were marked with blue survey whiskers driven into the ground with galvanized nails. The survey whiskers can withstand mowing and are typically visible amidst dense vegetation. The nails also allow for the possibility of using a metal detector to locate plot corners if necessary.

Finally, the Vermont DEC methodology includes a count of stems of every species in the 0.25mX0.25m sub-plots. Counts can be conducted in three different ways depending on the circumstances present: actual counts, counting a sample of the stems and estimating totals, and counting the clumps (for cespitose species). Counting the stems using the first two methods works well and yields data that is comparable. However, since the number of clumps is a different metric, it is not comparable to the number of stems. This adds an unnecessary complication to the data analysis. Including only a count of stems should be considered for the methodology developed for the current project.

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