White Paper

Soil-Site Management Protocols & Best Management Practices (BMPs) for Utility Scale Solar Site (USS) Development and Management in Virginia – Version 2

USS Site Under Active Development in Southside Virginia (image from DEQ/AEP)

Primary Authors:

W. Lee Daniels, Professor[1], Land Rehabilitation, wdaniels@vt.edu
Ryan D. Stewart, Professor[1], Soil Physics & Hydrology, rds@vt.edu
John Ignosh, Senior Extension Specialist[2], jignosh@vt.edu
David Sample, Professor[3], Stormwater Management, dsample@vt.edu

Collaborators:

Pat Donovan, GIS Specialist[1], padanova@vt.edu
Mike Genthner, Soil Scientist[1], mgenthner@vt.edu
John Fike, Professor[1], Forage & Grazing Management, jfike@vt.edu
Ben Tracy, Professor[1], Forage Ecology, btracy@vt.edu

[1]School of Plant & Environmental Sciences, Blacksburg Campus
[2]Department of Biological Systems Engineering, Northwest District Extension Center
[3]Department of Biological Systems Engineering, Hampton Roads AREC

https://landrehab.org/home/programs/solar-farms/

March 5, 2026

Table of Contents

Executive Summary

Large areas of the Mid-Atlantic region will be converted into photovoltaic (PV) panel "solar farms" over the coming decade. In particular, development of Utility Scale Solar (USS) facilities (≥ 5 MW) will potentially impact at least 200,000 acres of existing agricultural and forested landscapes in Virginia; the Virginia Department of Environmental Quality (DEQ) currently estimates over 350,000 acres could potentially be affected by 2045 (McPhillips et al., 2024). Even small local projects (< 5 MW) can lead to significant landscape impacts, since site development requires up to 10 acres/MW to accommodate panels, drainage and stormwater systems, access roads, collection & transmission infrastructure, and buffers.

Impacts vary dramatically based on local site conditions and infrastructure development practices. However, 10% to > 75% of the existing soil landscape will likely undergo some level of disturbance. Widespread areas of disturbed soil surface remain bare for weeks to months during active construction, leading to short-term sediment loss and greater stormwater peak flows. Full compliance with the Virginia DEQ (2024) Minimum Standard 1 (MS 1) will largely mitigate these short-term risks. Complete revegetation to an acceptable (≥ 75%) self-sustaining perennial cover generally takes several years and may require multiple seeding operations.

Prediction, management and rehabilitation of these soil x landform effects is critical for (a) minimizing sediment losses, (b) managing and reducing stormwater impacts, and (c) return of these lands to productive uses following site decommissioning. At Virginia Tech, we are actively working to address the full range of issues and challenges associated (1) planning and permitting, (2) installation & stabilization, (3) active management and (4) long-term closure of USS facilities related to local soil and water quality protection. We encourage and support full transparency throughout the project lifetime with respect to planning and permitting procedures, expected short- versus long-term impacts, and scientifically based projections for medium- and long-term site potential productivity for various uses.

In this White Paper, we present our overview of the challenges that development, active management and closure of USS sites pose to local soil and water quality, along with our recommended best management practices (BMPs). Minimizing overall soil disturbance, particularly via limiting net cut/fill and grading, is of paramount importance. Limiting and remediating soil compaction during the entire USS lifecycle is also critically important to enhance rainfall infiltration and maintain overall soil quality. Prompt compliance with existing DEQ and local erosion control guidelines, appropriate active site vegetation management practices, and final remediation upon decommissioning can largely offset initial site disturbance impacts. However, certain impacts for installation of essential infrastructure (e.g. stormwater conveyances and ponds) will more than likely be permanent.

<u>This document reflects our scientific opinion and position as of March 5, 2026, and will be revised and updated as needed due to changes in research findings or regulations.</u>

List of Abbreviations and Acronyms

AOI – Area of Interest

ASS – Acid Sulfate Soil

BMP – Best Management Practice

CN – Curve Number

DCR – Virginia Department of Conservation and Recreation

DEQ – Virginia Department of Environmental Quality

ESC – Erosion & Sediment Control

FIW – U.S. Department of Interior Fish & Wildlife Service

LDA – Land Disturbing Activity

MW – Megawatt

NMP – Nutrient Management Plan

NRCS – Natural Resources Conservation Service

NWI – National Wetland Inventory– https://www.fws.gov/program/national-wetlands-inventory/wetlands-mapper

PV - Photovoltaic

RV – Runoff value (also Rv)

SW – Stormwater

SWM – Stormwater Management

SWMM – Stormwater Management Model (USEPA)

TCLP – Toxicity Characteristic Leachate Procedure (USEPA)

USEPA – United States Environmental Protection Agency

USS – Utility Scale Solar

VALEN – Virginia Land & Energy Navigator; https://valen.ext.vt.edu/web_portal/about

VDACS – Virginia Department of Agriculture and Consumer Services

VRRM – Virginia Runoff Reduction Method Guidance & VRRM | Virginia DEQ

WSS – Web Soil Survey – https://websoilsurvey.nrcs.usda.gov/app/

Overview and Background

Large scale utility-scale solar (USS) development is relatively new to Virginia and has greatly accelerated in the past five years by a combination of state (e.g. the 2020 Virginia Clean Economy Act) and federal energy infrastructure policy initiatives. Development of USS facilities with power generation capabilities of > 5 MW will potentially impact at least 200,000 acres of existing agricultural and forested landscapes in Virginia over the next decade; Virginia DEQ currently estimates over 350,000 acres could be affected by 2045 (McPhillips et al., 2024). The intensity of impacts varies dramatically based on local site conditions and infrastructure development practices. Anywhere from 10% to > 75% of the existing soil landscape will undergo some level of substantial disturbance at most sites (**Figures 1 and 2**). Prediction, management, and rehabilitation of these soil x landform effects is critical for (a) minimizing sediment losses, (b) managing and reducing stormwater impacts, and (c) preparing to return these lands to productive use following site decommissioning. Therefore, a range of essential Best Management Practices (BMPs) need to be prescribed and implemented during the full project lifecycle including (1) preliminary planning/design/permitting, (2) active site development and stabilization, (3) long-term site operation, and (4) final site infrastructure removal and decommissioning.

Review of Existing Studies on Impacts of USS on Soil & Local Runoff

Extensive USS development in the mid-Atlantic region of the U.S. is a relatively new phenomenon, and few published studies are available to date (December 2025) based on actual impacts to soil and water resources, revegetation, and post-disturbance land use potentials. However, extensive directly related studies have been conducted by Virginia Tech (https://landrehab.org/) and a wide range of our colleagues at other universities and agencies across the USA for over 50 years to assess direct impacts of mining, road construction, and urbanization on both agricultural and forest soils and local water quality. Collectively, land and soil disturbance processes and rehabilitation practices are well-understood and a number of these important underlying studies and findings are described and cited later in this document.

With respect to published studies on solar site development, several studies in varied soil/climatic zones report the strong influence of panel shading and architecture on soil temperature/moisture relationships (Hassanpour et al., 2018; Lambert et al., 2021). Choi et al.

Figure 1. Utility-scale solar (USS) facilities during initial stages of development and stabilization in the Virginia Piedmont. During the initial establishment phase (top) trenching, cut/fill and grading activities will disturb anywhere from 15 to > 75% of most sites. Once final grading is completed and infrastructure is installed (bottom), full revegetation and stabilization against erosion losses may take several years. In general, revegetation practices should result in ≥ 75% living perennial cover of the intended or other appropriate species, which are most commonly mixed grass/legume stands. Note the “drip line” evident below the panel edges. Image by W.L. Daniels.

Figure 2. Fully stabilized three-year-old site on a similar Piedmont soil landscape to **Figure 1**. Once permanently revegetated, sediment losses and runoff are greatly reduced, but the landscape will still have been considerably transformed with respect to overall landform, soil, and hydrologic conditions. Removal of USS infrastructure at site decommissioning (not shown) will lead to another cycle of soil disturbance that will require some level of remediation, particularly if the land is intended to be returned to pre-existing agriculture or forestry land uses. Image by W.L. Daniels.

(2020) described the generally negative effects of infrastructure development on long-term (7-year) differences in important soil chemical and physical properties over time, while Choi et al. (2023) detailed and advocated for the maintenance and use of native vegetation within USS sites for improvement of soil conditions following installation disturbance. Yavari et al. (2022) and Hernandez et al. (2014) provided detailed overall reviews of the potential impacts of USS development on landscape hydrology, stormwater management, and potential effects on receiving streams. Current ongoing research by Nair et al. (2023) in Pennsylvania is focused on application of more advanced modeling approaches (e.g., USEPA SWMM) to better predict the influence of various panel configurations and soil/site conditions on runoff.

One widely cited modeling study based in Maryland concluded that the addition of panel arrays would not increase overall site runoff per se. However, that finding was based on the assumptions that that (1) underlying conditions (e.g. vegetation status) of the receiving soil surface would promote infiltration, and (2) that the panels could potentially lead to concentrated "drip lines" if not mitigated for via use of gravel beds or more aggressive surface stabilization (Cook & McCuen, 2013). Elamri et al. (2018) also spoke to the potential for the development of "drip lines" and other localized concentrated flow zones under installed panel edges. To our knowledge, the only regional publication that directly addresses solar infrastructure development vs. agricultural production practices is the well-referenced White Paper from North Carolina (NCSU, 2019) that explores a number of topics similar to our Virginia issues and efforts, as presented next. Our research group is currently conducting an intensive field-based study to quantify actual runoff vs. modeled assumptions from a range of USS sites in Virginia. Initial results based on two years of data indicate that developed USS catchments generate higher volumes of runoff with more rapid time to concentration than adjacent undeveloped control sites (Stewart et al., 2025).

One particularly important regulatory challenge facing the USS industry in Virginia is direct compliance with Minimum Standard #1 (Stabilization; Virginia DEQ; 2024). Any denuded area with bare soil must be stabilized within 7 days after final grade is achieved on any portion of the site. Furthermore, temporary stabilization must be applied to any disturbed areas that will be left dormant for more than 14 days. Therefore, stabilization (e.g., mulching & revegetation) should be done contemporaneously with final grading and installation of racking posts and other infrastructure as development operations progress across the disturbed landscape. Statewide assessments by Virginia DEQ in 2024 (McPhillips, 2024) and 2025 (M. Rolband, personal communication) indicated that > 50% of all Permit-by-Rule (PBR) sites were out of compliance with MS-1. We provide specific recommendations for integrating effective soil stabilization practices in close coordination with initial grading and installation practices later in this paper.

The majority of published studies to date on USS development have indicated that some level of short-term soil degradation is expected, particularly a reduction in infiltration due to overall surface and subsoil compaction coupled with loss of soil aggregation (structure). Of particular importance is the loss of connection between larger soil macropores responsible for the majority of downward saturated flow water movement. Most studies, including our own, have concluded that USS development will potentially increase local site runoff, particularly during the development phase, but some studies have discounted that notion (e.g., Cook & McCuen, 2013). Several of the studies cited above also reported lower levels of soil organic matter and nutrients along with an increase in short-range variability in soil moisture and temperature regimes due to a combination of simple shading/interception by the panels and routine site cut/fill/grading practices. However, there is a wide range of BMPs that can be applied to sequential USS development and long-term management protocols to either minimize or mitigate these impacts over time.

Our primary purpose in this paper is therefore to describe and recommend an optimal suite of site x soil management practices that are applicable to the full range of USS site development, management, and final decommissioning practices. We consider some level of "soil disturbance" to be an inevitable product of the overall process, but one which can be readily mitigated over time via application of well-established soil reconstruction and revegetation practices that have been successfully applied to mining and construction sites for decades.

USS Permitting and Regulation in Virginia

Currently (2025), USS permitting and development are regulated in Virginia by a mixture of programs depending on the size of the proposed site. Some larger projects (i.e., > 150 MW) are reviewed by the State Corporation Commission (SCC) while smaller projects (5 to 150 MW) are typically reviewed by the Department of Environmental Quality (DEQ) under Permit by Rule (PBR) procedures. These procedures were developed by Virginia DEQ under mandate from Virginia House Bill 206, *Small renewable energy projects; impact on natural resources (2022),* (https://lis.virginia.gov/cgi-bin/legp604.exe?221+sum+HB206). The final rule was published and made effective in June 2025 (https://law.lis.virginia.gov/admincode/title9/agency15/chapter60/); various assumptions and requirements from that rule are discussed in detail in this White Paper. This regulation requires appropriate assessment, mitigation protocols and oversight be applied for projects ≤ 150 MW that would disturb a total of more than 10 acres of NRCS defined prime farmlands, certain classes of preserved forests, and 50 acres or more of contiguous forest lands. Finally, relatively small (< 5 MW) local projects are generally regulated and permitted by local county or city land disturbance and zoning regulations.

All USS projects are subject to Virginia DEQ Erosion & Sediment Control (ESC) and stormwater management (SWM) requirements along with local conditional use zoning and construction permitting requirements, the latter which vary widely across the Commonwealth. In 2022, DEQ published site-specific guidance for solar site SWM and ESC protocols.. Subsequently, much more extensive SWM and ESC guidance, including updated revegetation practices, were included in the newer Version 1.1 of the DEQ ESC/SW Manual, which became effective on July 1, 2024 (https://online.encodeplus.com/regs/deq-va/index.aspx). These revised and more detailed requirements are now in force for all new permit applications.

Depending on their location, projects may also be subject to jurisdictional wetland impact (i.e., Section 404) or Chesapeake Bay Act setbacks, buffers, and restrictions. On the local level, many cities and counties are requesting a more detailed description of longer-term site infrastructure removal and decommissioning practices, particularly with respect to return of USS affected areas to previous land use potentials (e.g., agricultural production). The preservation of prime farmland soils and productivity, along with unique water quality and habitat values associated with forested lands, continue to be particularly important to a range of stakeholder groups. Thus, the combination of ongoing regulatory developments, coupled with increasing public interest in USS development impacts, should lead to more uniform implementation of statewide policies on USS site selection, development, and closure practices.

Rationale for Current Positions and Recommendations

The positions and recommendations presented here are based on our collective 50+ years of research and outreach experience on impacts and stabilization of land-disturbing activities, including mining, road construction, urbanization, and wetland restoration and creation. The specific practices recommended here are evolving and are based on our assessment of civil plans/geotechnical reports and actual site conditions for dozens of proposed or implemented USS sites in Virginia since 2020.

The opinions and positions expressed here are intended as supplementary to existing and developing Virginia DEQ (or other) regulatory requirements. Our recommendations are complementary with existing SWM+ESC BMP requirements. Our insights and recommendations are also informed by an ongoing runoff study supported by the Virginia DEQ and industry partners that includes monitoring at five different sites to date (Fall 2025). At each site we have installed three continuous water quantity and quality monitoring stations at the base of catchments undergoing USS development and stabilization along with another three external reference control catchments that represent their original undisturbed condition(s). This project completed its second full year of measurements and preliminary interpretations are available at https://www.deq.virginia.gov/water/stormwater/stormwater-construction/guidance-vrrm. These summary recommendations will be reviewed and updated periodically.

Framework for Overall USS Site Development, Management, and Closure

All USS development, management, and closure practices should protect local soil and water quality and associated ecological functions and values, including return of decommissioned project areas to productive agriculture, forestry or other pre-planned uses. Essential to this commitment is the application of a range of BMPs that are designed to minimize impacts to soil and water resources during and after site development. Following infrastructure removal, the developer should commit to rehabilitation and restoration of any disturbed areas to optimize their productivity for varied post-closure uses. Those future land uses are difficult to predict, but may include continued renewable energy production, agricultural practices, silviculture, or other more urban uses with concurrence of landowners and other key stakeholders. Key to this effort is the commitment to full transparency throughout the long-term (25+ year) relationship with local and regional stakeholders with respect to planning and permitting procedures, expected short- vs.

long-term impacts, and scientifically based projections for medium- and long-term site productivity potentials for various uses.

Specific Objectives of this White Paper

1. Develop recommended protocols for defining and minimizing soil disturbance of high-quality agricultural or forest soils during the installation and decommissioning stages of the site's life cycle, specifically using BMPs that are consistent with definitions and final regulations of Virginia HB 206, *Small renewable energy projects; impact on natural resources,* and other current (2024) regulatory development initiatives in Virginia.

2. Recommend appropriate procedures for remediation of soil disturbance and hydrologic impacts at various stages of the project's life cycle that are also consistent with Virginia SWM and ESC mandates, mitigation protocols required by HB 206, and other applicable regulations.

3. Provide site-specific strategies and associated protocols to quickly establish vigorous vegetation for both (a) initial ESC requirements of MS-1 and (b) longer term, low maintenance site management needs that accommodate alternative agricultural uses such as sheep grazing, and (c) final restoration to original land uses or approved alternatives.

4. Recommend soil, site, and animal management practices that will maintain or enhance soil quality and health over time. Important indicators include organic matter, aggregation, carbon sequestration potentials, and maintenance of infiltration rates.

5. Provide estimates of the likely effects of soil disturbance and various recommended remediation practices on the future productivity of the lands for various uses, including return to agriculture or forestry, following final site infrastructure removal and decommissioning.

6. Suggest alternative approaches for runoff prediction from USS sites, including adjustment of National Resource Conservation Service (NRCS) curve numbers (CNs) or Virginia Runoff Reduction Method (VRRM) runoff coefficients for predicting effects of site disturbance activities and/or remediation efforts on stormwater flows.

7. Combine all the aforementioned information and recommendations into a summary list of BMP guidelines that can be shared with landowners and other interested local stakeholders.

8. Provide guidance for understanding the new impact mitigation requirements for impacts to > 10 acres of NRCS prime farmland (**Appendix A**).

9. Review a range of suggested soil and vegetation management machinery and implements that would be compatible working in confined areas within USS paneled arrays **(Appendix B).**

Overview of Soil Disturbance and Minimization/Mitigation Protocols

Soils defined, including profiles vs. horizons

Soils are comprised of mineral and organic matter, along with associated microbial communities, which occur at the earth's surface, are capable of supporting rooted vegetation, and are responding to soil-forming factors, i.e., parent material, climate, vegetation, topography, and time (Jenny, 1941). Soils include pore spaces between solid particles that can be filled with fluids such as water or air, or most commonly both phases. The arrangement of different soil individual particles into large units occurs due to a process known as aggregation, and the overall arrangement of aggregates and particles (including the pore spaces between them) is referred to as soil structure. Soils are dynamic and vary over the landscape due to the complex interactions of soil-forming factors such as climate, vegetation, and topography over time. Relatively undisturbed soils in Virginia are characterized by distinct layers with depth that are called *horizons* and that can be observed in road cuts or borings as *soil profiles*. The organic matter-enriched mineral topsoil is the *A horizon*, the underlying clay and Fe-oxide rich layer is *the B horizon*, and the partially weathered parent material below the common zone of rooting is the *C horizon*. Intact forest soils also commonly contain a litter layer (*O horizon*) at the surface and often include a light-colored acid-stripped horizon between the A and the B called the *E horizon*. If hard bedrock is encountered within the depth of excavation, this is referred to as the *R layer*.

Most native soils in Virginia are quite old in age (>10K to 2M years) and highly weathered, leading to relatively high accumulations of clay and Fe/Al oxides in their B horizons along with acidic (i.e., low) pH throughout the profile. The uppermost soil horizons supporting plant growth (A and E horizons) are generally referred to as ***topsoil*** while the underlying B and C horizons are ***subsoil***. However, it is important to note that many soils in Virginia have been heavily eroded due to historic agricultural practices, which accounts for the widespread occurrence of red and yellow former B horizon material at the surface. More detail on soil profiles and general Virginia soil properties can be found in Daniels & Haering (2018).

Soil disturbance as defined and applied to USS

Land-disturbing activity (LDA) is defined in Code of Virginia § 62.1-44.15:24 as "a man-made change to the land surface that potentially changes its runoff characteristics including clearing, grading, or excavation" (unless specifically exempted), may be subject to regulation under the Virginia Erosion and Stormwater Management Act (VESMA) the Virginia Erosion and

Stormwater Management Regulation, 9VAC25-875, the Erosion and Sediment Control Law for Localities (https://online.encodeplus.com/regs/deq-va/doc-viewer.aspx#secid-94)

However, for the purpose of this document, we (VT SPES & BSE) define soil disturbance as any activity that leads to a significant alteration of the original soil profile that directly limits plant growth or increases surface runoff and potential for sediment losses. Examples of disturbance activities commonly encountered in USS development include:

- Removal, storage and reapplication of topsoil.
- Grading to level panel arrays or engineered structures and roads and/or interconnect corridors that leads to exposure of subsoil at the surface and/or significant soil compaction.
- Trenching for cables.
- Development of stormwater conveyances and detention ponds and outlets.
- Concentrated traffic that compacts the soil to levels that limit rooting and water penetration.
- Stump pulling and extensive root-raking/rock-picking following forest clearing.
- Other practices that lead to disturbance and mixing of the pre-development soil profile to a depth $\geq$ 6 inches.

The disturbance threshold for mandatory compliance with ESC requirements (including MS-1) vary to some extent by locality, but the general threshold is 10,000 ft^2 for most areas and 2,500 ft^2 within the Chesapeake Bay Preservation Area (or less in certain localities).

From a practical standpoint, minimal surface grading that (a) disturbs no more than six inches of the profile, (b) does not expose or highly compact the underlying subsoil (B and C horizons), and (c) is stabilized immediately (7 to 14 days) is not defined here as "significant". However, complete removal, storage and return of the topsoil over an altered subsoil is considered a "significant disturbance" and will likely lead to decreased soil productivity without appropriate remediation following soil profile reconstruction. Similarly, extensive exposure of bare subsoil materials for extended periods of time is also considered significant.

Timing and Coordination of Initial and Permanent Stabilization during USS development

As required for significant land-disturbing activities that meet the minimum size threshold (2500 to 10,000 ft^2), external ESC and SW controls are first installed. These measures typically include silt fencing and temporary sediment + stormwater control BMPs of various size and configurations. Subsequently, the existing vegetation is removed (if forested) and grading is accomplished to prepare the site for driving posts and hanging panel racks (**Figure 3**). Access roads and internal water conveyances are also roughed in. The land clearing and grading progresses across the landscape, often leaving tens to hundreds of acres of bare soil exposed to rainfall impacts and runoff over an extended period of time while upright posts are installed along with trenching and other infrastructure. Lateral drive shafts, racks and panels, and final cabling systems are then installed at some point during the construction process.

Figure 3. Initial stage of USS development on a sloping site over moderately erosive Clifford series soils. The external silt fence BMP around the forested strand has been installed and temporary sediment traps are being installed. Over 100 acres of this tract was open at this time. ***Areas like this must be stabilized if left bare (denuded) for more than 14 days***. Once at final grade, the site must be stabilized within 7 days even if posts are being actively installed. Image by W.L. Daniels.

In order to fully comply with MS-1 it is essential that any areas at final grade receive stabilization (mulch/revegetation) within 7 days of being placed at final grade. Other areas that are not at final grade must be stabilized within 14 days. From a practical standpoint, this means that the initial revegetation effort should be made before the initial posts are placed or during that operation. It is also likely that this initial stabilization will be damaged to some extent by machine operations during installation of the full racks and panels. It is likely that at least two successive stabilization (revegetation/mulching) efforts will need to be applied to most sites to successfully meet the MS-1 requirements. Therefore, we recommend that an appropriate temporary seeding and stabilization effort be applied as soon as final grading is completed (**Figure 4**) and before posts are driven/installed. A follow-up perennial seeding/stabilization prescription should be applied immediately after all racks, panels and cabling systems are installed.

Current (2024) Virginia DEQ guidance for temporary seeding practices is found at https://online.encodeplus.com/regs/deq-va/doc-viewer.aspx?secid=743#secid-743 and more detailed guidelines for permanent seeding are at https://online.encodeplus.com/regs/deq-va/doc-viewer.aspx?secid=752#secid-752. This new guidance supersedes the standard "Green Book Recommendations (1992)" and we strongly recommend use of the new protocols on all USS sites.

Figure 4. Final stage of grading on a strongly sloping site in Southside Virginia over moderately erosive Clifford soils. Local ridge summits have been lowered via cuts and excess soil filled into local concave areas above drainage heads. Topsoil was not salvaged and reapplied over this portion of the site. External and internal BMPs and conveyances are in place, but the initial phase of installing racking posts has not begun. *Areas at final grade must be seeded to a permanent revegetation cover within 7 days of final grading*. In addition to conventional hydroseeding, tacked straw mulch is recommended for steeply sloped areas and EC 2 matting for internal water conveyances. Image by W.L. Daniels.

Impacts of soil disturbance on soil productivity, rooting, yield, infiltration/runoff

The most immediate and obvious impact of active USS site development is removal or suppression of existing vegetation and any existing litter layers (O horizons), which exposes individual soil particles and aggregates to direct rainfall impact leading to detachment, suspension, and transport when runoff conditions occur. Sediment loss from erosion is further enhanced by the degradation of structural aggregation in the surface by compaction, smearing, and lack of active plant rooting as discussed next. Therefore, insofar as possible, the existing topsoil horizons should be left intact and exposure of deeper subsoil materials should be minimized. Retention of even 60-70% vegetation, plant litter or mulch cover drastically limits sediment detachment and local transport while enhancing infiltration (Coppin & Richards, 1990; Weil & Brady, 2017). That being said, it is also clear that establishment of necessary herbaceous vegetative covers will usually require sufficient seedbed preparation to ensure direct soil-seed contact.

Soil disturbance influences plant growth in many ways; the most common limitation in recently constructed sites is compaction. When soils become compacted, solid particles become compressed into and fill these open larger pores, resulting in relatively high bulk densities. The common range of bulk density for a dry mineral soil is ~1.25 to 1.95 g/cm^3. While the relationship between bulk density and rooting impedance is also dependent on moisture development and the degree of aggregation and structure, values above 1.80 g/cm^3 for sandy soils and 1.45 g/cm^3 for massive (i.e., non-structured) clays are considered to be root limiting (Weil & Brady, 2017). Actively growing plant root tips are very fine in size, soft and pliable, and must find continuous pores large enough to proliferate through soil since they cannot physically displace soil particles per se (Carson et al., 1971). However, once a root has penetrated into a continuous pore, it can radially widen that pathway due to its ability to apply substantial axial spreading forces. The commonly observed phenomenon of tree roots buckling a sidewalk is due to this axial spreading pressure after the fine root tip has exploited the linear crack between the concrete and the underlying subgrade. Thus, the common assumption that simply establishing “deeply rooted vegetation” will loosen a compacted subsoil layer over time is fallacious unless its fine root hairs are able to exploit continuous vertical pore spaces.

Increased bulk density and loss of aggregation and structure also leads to decreased surface soil infiltration rates and decreases in saturated permeability (e.g. Ksat) of subsoil layers. In combination, these factors typically lead to greater runoff from compacted vs. uncompacted soils. Maintenance of soil structure is very important for both rooting and water penetration. Well-aggregated topsoil is usually relatively loose in the hand and contains readily visible rounded and subrounded aggregates. Well-structured subsoils in Virginia typically contain more angular blocky aggregates that enhance downward and lateral root and water movement along their cracks (macropores), even if the soil bulk density within aggregates is relatively high. When soils are graded, cut and filled during active cut/fill development processes, much of their native structure is degraded and lost (Booze-Daniels et al., 2000; Daniels, 2018) due to grading related compaction and/or smearing of clayey cut faces.

Deep-seated soil compaction can be remediated to some extent (but not completely) via deep ripping with dozer-pulled shank rippers or tractor-pulled no-till winged rippers or chisel-plows.

However, this approach is only viable on disturbed areas of USS sites if applied before panels are mounted to uprights or following infrastructure removal. Alternatively, a wide range of smaller rippers and near-surface tillage implements is also available for use in confined settings (e.g., rows in the middle of panel arrays). Selected examples of compatible equipment are presented in **Appendix B**. It is important to understand that in order for deep-ripping to be successful, the soil moisture content must be at an appropriate water content for the dense subsoil material to shatter. If the soil is too wet, the shanks will pull through the material with very little effect and the traces will quickly seal back together (e.g. like a knife through peanut butter). On the other hand, if the subsoil is too dry, the implements will pull up large chunks of subsoil to the surface and require much larger equipment and fuel usage. In some instances, damage to the implements may occur in highly compacted and very dry soils. Therefore, timing of deep ripping operations needs to be coordinated with onsite evaluations of subsoil moisture conditions (NRCS, 1998).

Exposure of typical red/yellow high clay subsoils (Bt horizons) during the development process also leads to low pH (< 5.5), enhanced solubility of phytotoxic aluminum (Al), and lower levels of essential plant nutrients (N-P-K and Ca+Mg). These limitations need to be remediated via liming and fertilization before revegetation. Subsoils are also higher in silt and clay particles and much lower in organic matter, which leads to enhanced sediment detachment and losses in runoff when compared to sandy or loamy topsoils. Clayey subsoils are also subject to being smeared and sealed when they are cut and filled, which further amplifies rooting and water movement restrictions (Daniels, 2018). However, it is important to note that much of the Piedmont and Upper Coastal Plain suffered from extensive soil erosion through the mid-1900s, frequently leaving exposed red/yellow clayey subsoils as the remaining surface (Trimble, 2008). Similar erosion occurred on many steeper sideslopes in the limestone valley and Blue Ridge regions. Therefore, it is important to note that USS disturbance impacts to soil quality and productivity may not be as great on these previously degraded soils when compared to NRCS prime farmland soils where the existing native topsoil resource is still largely intact (by definition).

Finally, it is important to note that practices such as stump pulling, extensive root and rock raking, and slash burning can also lead to significant soil disturbance and short-range variability in essential soil chemical and physical properties (Aust et al., 1998). Concentrated skidder trails and load out areas are particularly susceptible to compaction and rutting, particularly during wet periods. Where compatible with site development, forest litter layers should be left intact until the final intended vegetative cover is established.

Use of Web Soil Survey (WSS) and other online tools for initial assessment of soils & wetlands for regulatory compliance and planning

Initial investigations of site soil and landscape conditions should be completed via utilization of mapping and interpretive resources available from NRCS Web Soil Survey (WSS; https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm), USDI-FIW National Wetlands

Inventory (NWI; https://www.fws.gov/program/national-wetlands-inventory/wetlands-mapper) and others (e.g. VDE & USGS geologic mapping). Much of this information is also available for application to USS site assessment and planning via the Virginia Land & Energy Navigator VaLEN tool; https://valen.ext.vt.edu/web_portal/about.

Soil information derived from WSS or via onsite investigations is used for a wide array of applications in the overall USS permitting and development process:

- Assignment of runoff curve numbers (CN) or runoff values (RV) for SWM and ESC planning and predictions via NRCS TR-55 or VRRM procedures.
- Preliminary identification of wetland/hydric soils and riparian buffer areas.
- Identification of local surface drainage networks.
- Determination of extent of NRCS prime farmlands per HB 206 requirements.
- Initial identification of karst features.
- Projections of overall soil depth and rock outcrop abundance.

Examples of a current WSS base map, prime farmland overlay and map unit legend for a hypothetical USS project area in the southern Piedmont of Virginia (Pittsylvania County) are presented in **Figure 5** and **Table 1**. The current NWI map for that same potential project area is given in **Figure 6**. In addition to their obvious utility in identifying dominant soil types, slope classes, and potential riparian/wetland zone boundaries, these combined resources can also provide an abundance of interpretive information via their linked databases and other resources. This initial determination is very important since HB 206 requires a range of mitigation protocols for any project directly regulated by Virginia DEQ (5 to 150 MW) that entails disturbance of > 10 acres of NRCS prime farmland or > 50 acres of contiguous forest resource. Mitigation for smaller forest tracks that are under conservation or taxation easements prior to disturbance is also required. The mitigation requirements for HB 206 vary based on the extent and depth of soil disturbance and whether appropriate soil/vegetation management practices are prescribed over time. **Appendix A** contains three examples of how mitigation credits and requirements for examples site scenarios would be calculated and applied per HB 206.

Note that it is very important to understand the effects of the original mapping and compilation scales for these interpretations. For example, WSS maps have been compiled and published to match the USGS quadrangle scale of 1:24,000, which means that the smallest delineations would be ≥ 2.5 acres of contrasting soil types or slope classes. In fact, the smallest delineations found in most WSS maps for Virginia range from 5 to 10 acres. It is also important to understand the mapping unit legend naming conventions used. For example, where a legend indicates one soil series name (e.g., Clifford), one can generally assume that up to 85% of the soils occurring in that unit (consociation) would classify as Clifford or as similar soils in terms of use and management (e.g., Bentley or Nathalie series soils). However, up to 15% of that same map unit may contain strongly contrasting soils (e.g., frequently flooded areas containing the Codorus-Comus series). Furthermore, two or more soil names occurring together in the map unit legend indicate a “soil complex”, which occur when soils with differing use and management limitations are found in a regular pattern together and cannot be separated at the 1:24,000 scale. Much more information on soil mapping protocols, map unit concepts, field/lab methods and procedures is found in the NRCS Soil Survey Manual (2017).

Table 1. Soil map unit legend for Web Soil Survey (WSS) Area of Interest (AOI) depicted in Figure 5. An example of the full standard WSS output is given in Appendix A. Soil map units named for one soil series (e.g. Clifford) are presumed to be approximately 85% Clifford or similar soils in use & management. However, map units such as 8A (Codorus-Comus complex) with two given series names contain soils with dissimilar use & management potentials that commonly occur together, but could not be separated at the scale of field mapping and compilation (e.g. 1:24,000). More detailed information on soil series is available at https://www.nrcs.usda.gov/resources/data-and-reports/official-soil-series-descriptions-osd.

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
1B	Nathalie sandy loam, 2 to 7 percent slopes	All areas are prime farmland	6.7	0.8%
1C	Nathalie sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	16.9	1.9%
2C	Bannertown fine sandy loam, 7 to 15 percent slopes	Not prime farmland	6.5	0.7%
4B	Clifford sandy loam, 2 to 7 percent slopes	All areas are prime farmland	42.2	4.9%
4C	Clifford sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	123.7	14.3%
5B3	Clifford sandy clay loam, 2 to 7 percent slopes, severely eroded	Farmland of statewide importance	310.0	35.8%
5C3	Clifford sandy clay loam, 7 to 15 percent slopes, severely eroded	Farmland of statewide importance	143.6	16.6%
8A	Codorus-Comus complex, 0 to 2 percent slopes, frequently flooded	Not prime farmland	18.3	2.1%
11B3	Minnieville clay loam, 2 to 7 percent slopes, severely eroded	Not prime farmland	21.8	2.5%
11C3	Minnieville clay loam, 7 to 15 percent slopes, severely eroded	Not prime farmland	4.3	0.5%
12B	Enott fine sandy loam, 2 to 7 percent slopes	Farmland of statewide importance	4.0	0.5%
12C	Enott fine sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	3.1	0.4%
16C	Halifax sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	8.0	0.9%
22B	Bentley sandy loam, 2 to 7 percent slopes	All areas are prime farmland	6.7	0.8%
23B	Clover fine sandy loam, 2 to 7 percent slopes	All areas are prime farmland	1.9	0.2%
26D	Fairview fine sandy loam, 15 to 25 percent slopes	Farmland of statewide importance	145.6	16.8%
W	Water		1.6	0.2%
Totals for Area of Interest			**865.1**	**100.0%**

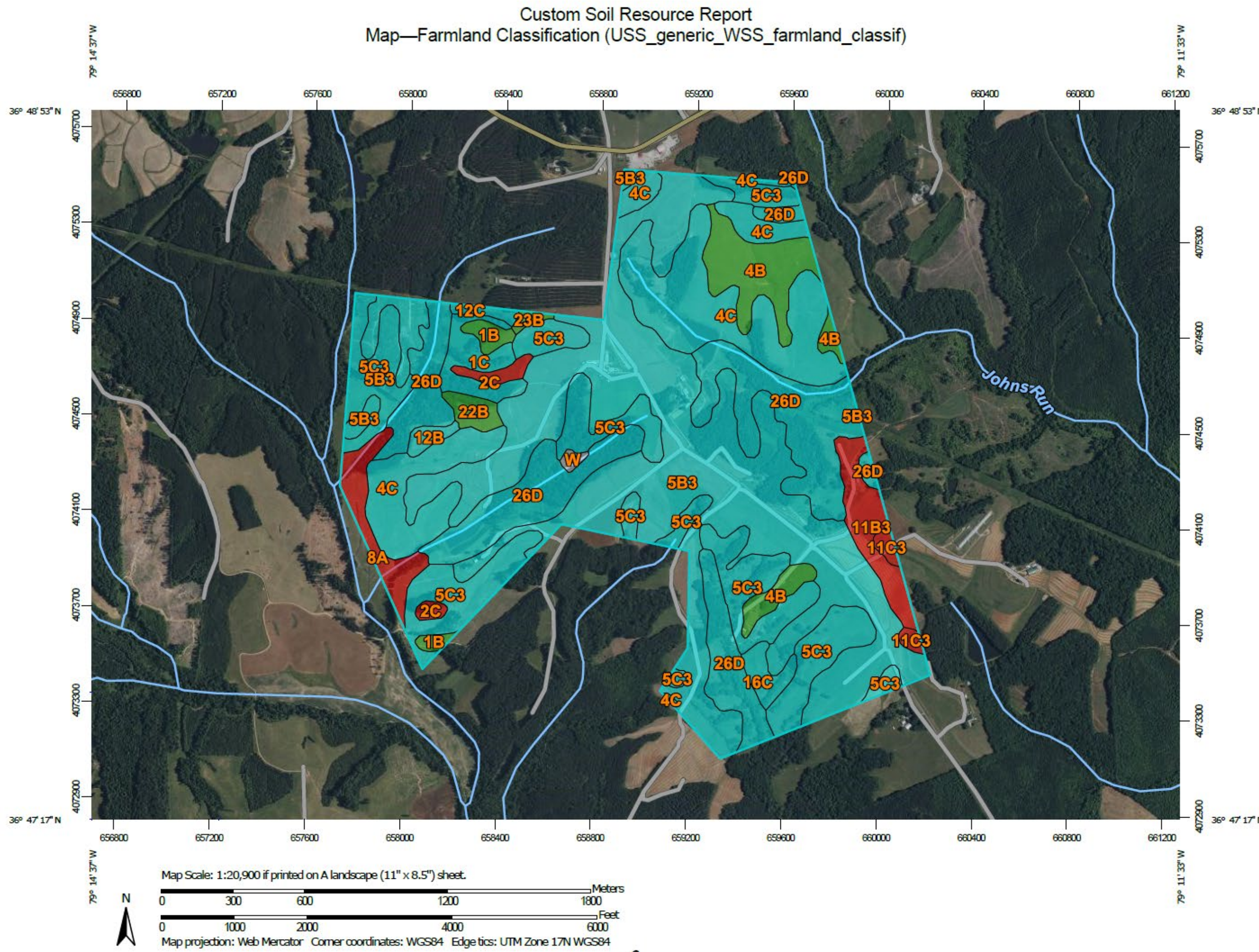


Figure 5. Web Soil Survey (WSS) soil map for a hypothetical USS area in Pittsylvania County south of Lucks. The areas in green shading qualify as NRCS prime farmland, total ~60 acres on gentle A and B slopes (≤ 7%), and would require mitigation under Virginia HB 206. The areas in light blue shading are designated as farmlands of statewide importance, but would not require mandatory mitigation under HB 206. It is important to note that this soil map was produced at a final compiled scale of 1:24,00 and that any dissimilar soil bodies less than ~ 5 acres in size would not have been delineated separately.

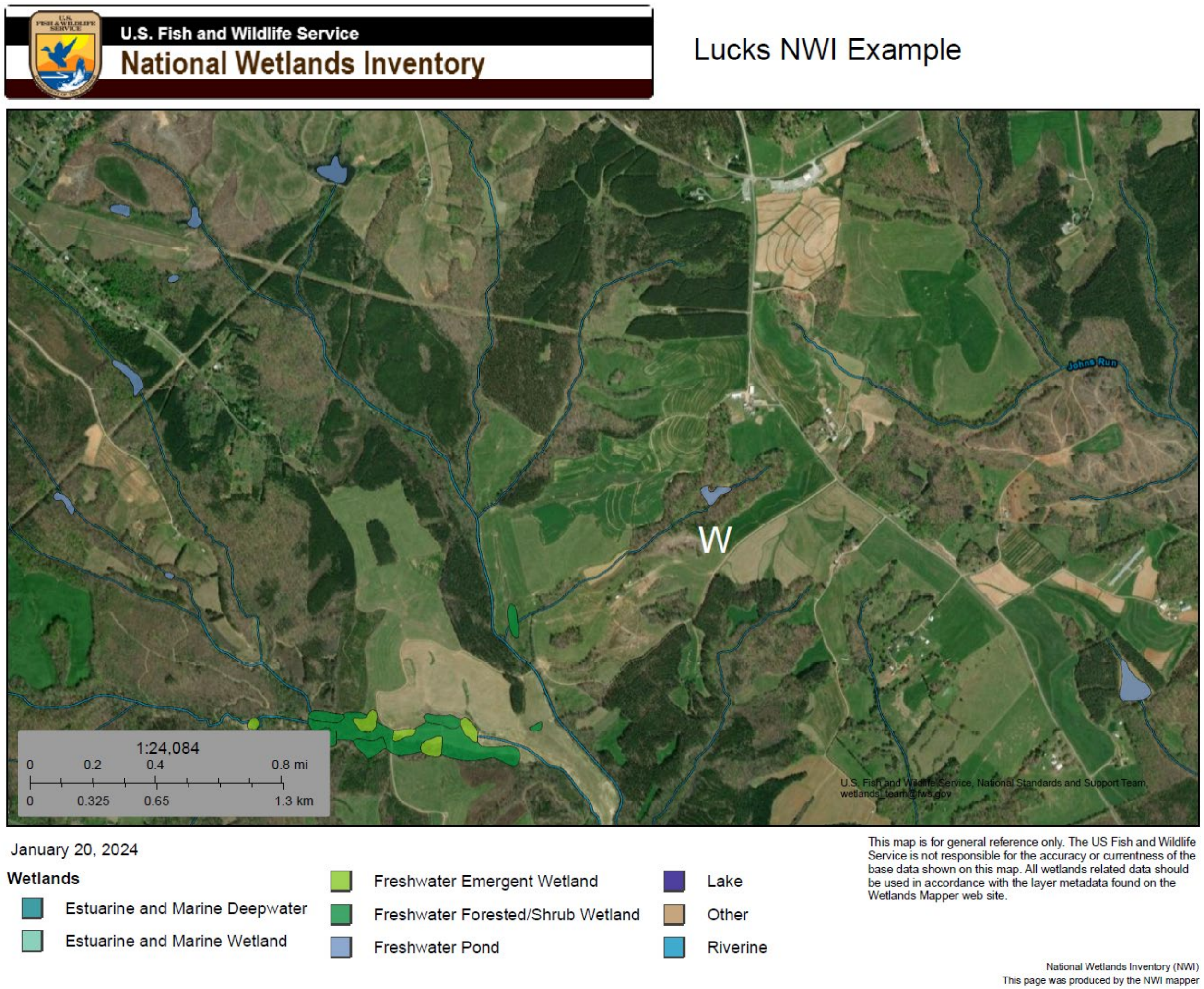


Figure 6. National Wetlands Inventory map and legend for the area south of Lucks in Pittsylvania County, Virginia. This view is expanded beyond the actual proposed project area shown in **Figure 5** above to show the nearest potential jurisdictional wetlands. The "W" point labeled here corresponds to the pond symbol mapped in **Figure 5**. Note that the four drainages from WSS appear here as "Riverine" and would need to be buffered.

Regardless of their scale limitations, careful review and interpretation of these mapping resources, particularly spot symbols, is critical to initial site assessment and development planning. For example, upon review of the WSS map for this site, (**Figure 5**; **Table 1**), we can see the following:

- The dominant soil type over much of the property is the Clifford Series, which is deep and contains no major subsoil rooting or drainage limitations, but does contain a Bt horizon with high clay content over a highly weathered saprolitic (rotten rock) C horizon.
- Where the Clifford soils occur on summits with relatively low slope classes (B; < 7%), they meet NRCS criteria for "Prime Farmland", while on steeper C slopes (7-15%) they are classified as "Farmland of Statewide Importance".
- This project area contains over 10 acres of NRCS prime farmland and impacts to those areas would need to be mitigated per HB 206.
- The site also contains several tracts of contiguous forest that may also require mitigation (see **Appendix A**).
- Note that a number of the Clifford and other map units are separated out due to their severe erosion class (e.g., 5B3 vs. 4B), indicating that the majority of the original topsoil resource has been eroded due to past agricultural or forest harvesting practices.
- Contrasting major map units on the site include Minnieville soils (on sideslopes, redder, and severely eroded) and Codorus-Comus complex (flooded in drainways).
- Clifford, Minnieville and similar upland Piedmont soils in this region are derived from highly micaceous crystalline rocks and may contain numerous sand and silt sized mica flakes in their subsoils, which can complicate their compaction into local fills.
- This particular Area of Interest (AOI) only contains one demarcated "special symbol" (W for a small pond), but it is critically important to review all special symbols that appear on a given WSS map. Special symbols denote areas of land use interpretive importance such as rock outcrops, wet or marshy spots, or sinkholes that were not large enough (e.g. < 5 acres) to be delineated and compiled at the scale of mapping, but clearly influence land use at a finer scale.
- Four established natural drainage ways (concave swales or first-order stream channels) are noted as blue lines. These may or may not conform with USGS topographic map requirements for "blue line streams", but do indicate clear local drainage patterns.

Similarly, review of the NWI maps (**Figure 6**) indicates the following:

- No wetland boundaries are included within the proposed site boundaries, but the site does include riverine areas (shown again as blue lines). The soils immediately adjacent to the blue-lined drainages on both maps are likely to be much more restricted in internal drainage (wetter) than their enclosing map units (**Figure 5**), but were too limited in extent to be separated at the scale of mapping. They would then be part of the "15% dissimilar soils" fraction previously discussed for consociations.

These examples illustrate how review of multiple sources of mapping and imagery for a given project area can greatly aid initial site assessment and planning; however, they do not replace site specific field verification and delineation by qualified soil scientists and wetland delineators.

NRCS & VA prime and important agricultural & forested lands definitions

Preliminary identification of prime farmlands and contiguous forest lands is essential for future compliance with HB 206 provisions as previously described above and for development of appropriate operational BMPs and decommissioning protocols. Recent work by the Virginia Cooperative Extension and agency colleagues on related energy regulation (HB 894 - 2022) produced a public report that coalesced all available state and federal definitions and information on land use mapping resources (Goerlich et al., 2022). That working group provided the following definitions and explanatory text for Prime Farmland:

> *The HB 894 Workgroup was tasked with developing a map or repository of prime farmland in Virginia as defined in §3.2-205 of the Code of Virginia. This section defines prime farmland as:* ***"...land that has the best combination of physical and chemical characteristics for producing food, feed, fiber, forage, oilseed, nursery, and other agricultural crops with minimum inputs of fuel, fertilizer, pesticides, and labor, and without intolerable soil erosion. Prime farmland includes land that possesses the above characteristics but is being used currently to produce livestock and timber. It does not include land already in or committed to urban development or water storage…"*** *(Code of Virginia §3.2-205 Part C, 2008).*
>
> *At the federal level, prime farmland is defined in the Code of Federal Regulations 7 CFR §657.5(a) as:* ***"...land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops, and is also available for these uses (the land could be cropland, pastureland, rangeland, forest land, or other land, but not urban built-up land or water). It has the soil quality, growing season, and moisture supply needed to economically produce sustained high yields of crops when treated and managed, including water management, according to acceptable farming methods. In general, prime farmlands have an adequate and dependable water supply from precipitation or irrigation, a favorable temperature and growing season, acceptable acidity or alkalinity, acceptable salt and sodium content,***

and few or no rocks. They are permeable to water and air. Prime farmlands are not excessively erodible or saturated with water for a long period of time, and they either do not flood frequently or are protected from flooding⋯" *(Code of Federal Regulations 7 CFR §657.5(a)(1), 1978).*

As noted previously in the example WSS/NWI study area (Figs. 5 and 6), individual states can also designate other specific soils as being "unique" or as "additional farmland of statewide importance" that do not otherwise meet the NRCS prime farmland criteria. These lands may be involved in specialty crop production or be limited to some extent by slope, erosion class or other management factors. These areas are not subject to HB 206 mapping and mitigation requirements at the Virginia state level, but are often highly productive and valuable, and therefore may require other mitigation considerations if required by local or state authorities. Furthermore, certain Virginia localities (e.g. Fauquier County) also employ alternative land use categorization criteria that may be more detailed and differ from NRCS.

The Goerlich et al. (2022) report cited previously includes references and links to a wide array of other forest and ecological land classification systems used by state and federal agencies, along with an integrated set of web resources to identify and map both prime farmlands and various categories of forest lands and other natural resources in Virginia. As noted previously, this resource is available online as the Virginia Land and Energy Navigator (VaLEN) and was fully deployed in early 2023.

Acid sulfate soil risk assessment and investigation

Local exposure of sulfidic geologic materials that quickly weather into acid sulfate soil (ASS) conditions poses the single greatest localized risk to soil and water quality at USS sites. Fortunately, ASS impacts are usually limited to less than several acres, but the costs of remediating these materials is very high. Thus, all proposed USS sites should be evaluated for their potential to encounter and expose sulfidic geologic materials that can oxidize to generate acid sulfate soil (ASS) and associated very low ($pH < 4.0$; Fanning et al., 2004) soil and surface water runoff conditions.

Detailed guidance on recognizing, avoiding, and managing ASS materials is available at https://landrehab.org/home/programs/acid-sulfate-soils-management/. Related methods and criteria are also now in Chapter 6 of the online Virginia DEQ combined SW/ESC Manual. A downloadable Google Earth .kmz file is available from that site that allows the user to make a preliminary determination of ASS risk, based on current Virginia Department of Energy interactive geologic mapping, related Virginia Tech research, published USGS/VDE mapping and reports, and other published literature. The acid sulfate soil risk map is also available on the VaLEN site: https://valen.ext.vt.edu/.

The highest risk of USS development encountering ASS materials occurs in the Coastal Plain region where intact reduced (anaerobic) sulfidic materials can potentially be exposed in stormwater ponds excavated into lower landscape positions (**Figure 7**). In general, as long as active grading and cut/fill operations remain in well-drained and oxidized upland soil landscapes with red or yellow subsoils, the risk is low. Additional more limited areas of high risk occur over certain mineralized formations in the Piedmont.

Figure 7. Exposure of acid sulfate soil (ASS) materials in a deep stormwater pond excavation in Miocene age Coastal Plain sediments in the Fredericksburg area. The darker gray sulfidic materials are reduced due to long-term burial at depth (anaerobic) and then oxidize to form sulfuric acid and very low pH (< 3.5) and metal enrichment (Al, Fe and Mn) in soil and receiving waters. Remediation of these materials required very heavy lime applications (> 30-50 tons ag lime per acre incorporated to six inches). *<u>Note:</u>* This site is **<u>not</u>** from the area depicted in **Figures 5 & 6** above, but these materials commonly occur at depth throughout the Coastal Plain, eastern Piedmont, and certain other Virginia locales. In general, the risk of these materials on USS sites is associated with deeper stormwater pond excavations. More information on ASS is available at https://landrehab.org/home/programs/acid-sulfate-soils-management/. Image by W.L. Daniels.

Finally, it is important to reemphasize that due to their scale limitations, final onsite confirmation of soils and wetland delineations, particularly for prime farmlands, jurisdictional wetlands, and ASS should be made by a qualified professional soil and/or wetland scientist. This step would be particularly applicable and advised if the proposed site is above the area thresholds for prime farmland (i.e., 10 acres) or forest impacts (i.e., 50 acres) per HB 206 mitigation requirements.

Recognition of short- vs. long-term soil impacts

Developing an appropriate plan to minimize and mitigate soil disturbance requires an understanding of the nature and differences between short- and long-term impacts. Certain impacts such as exposure of bare soils to erosion losses must be rapidly mitigated via immediate revegetation, mulching, or other short-term erosion control measures. However, as noted earlier, establishment of most post-disturbance vegetative covers will require at least some short-term exposure of bare soil on any graded or cut/fill areas. Fortunately, surface exposure of low pH and infertile subsoil materials can be quickly remediated via lime and fertilizer additions coupled with effective revegetation. Similarly, moderate surface soil compaction (< 6" deep) can be rapidly remediated via conventional tillage practices (**Appendix B**). However, significant root-limiting compaction and loss of vertical macropore interconnection, particularly when it occurs deeper than 6", will take years to be remediated by natural freeze-thaw and wet-dry cycles. Root-limiting compaction/structure loss occurring at depths ≥ 12" should be considered a permanent long-term negative impact that could potentially limit plant productivity and water penetration, during and after the USS project, unless it is remediated via deep ripping practices (as discussed next).

Avoidance, minimization, and rehabilitation of soil impacts

Prediction, recognition, and mitigation of significant impacts to prime farmland and larger blocks of contiguous forest by USS projects has been required since June 2025 with the full implementation of HB 206. Mitigation must be considered as an ongoing process that first involves site development planning that avoids direct surface soil impacts (e.g., use of low tire pressure equipment for panel infrastructure placement coupled with limited grading and topsoil removal). The second component of the mitigation process is minimization of impacts via limiting grading, trenching and the overall cut/fill footprint insofar as possible. This effort should then be followed by appropriate remedial measures such as surface tillage to loosen compaction and rapid topsoil return for quick revegetation of these areas. Finally, it is important to realize that certain impacts (e.g., subsoil exposure in cut/fill; significant compaction) will more than likely be persistent limitations for the lifetime of the project and will require a combination of deep and shallow tillage and soil amendment in the final site rehabilitation phase. As detailed in the following section, it is also important to recognize that complete restoration of areas of heavily disturbed prime farmland soils to 100% of their previous levels of rowcrop productivity may not be possible (Daniels et al., 2003; 2018).

Overall USS Project Lifecycle and Potential Soil Impacts

Initial site development phase

Topsoil removal and storage will generally lead to degradation of topsoil quality over time with respect to organic matter content, pH and fertility, depending on length of storage, storage berm configuration, and vegetation condition. Temporary topsoil storage berms should be located on well-drained landscape positions, have sideslopes shallower than 2.5:1, and be stabilized with deeply rooted vegetation. Topsoil removal, particularly via dozer push and tracking, will lead to compaction of the underlying subsoil to some extent and will smear and degrade soil structure at the contact. Return spreading and regrading of topsoil will lead to further surface soil compaction under most conditions and rutting if reapplied under wet conditions.

General site grading and deeper cuts and development of fills will generate fundamentally differing materials. General site grading (≤ 12”), even with topsoil salvage and return, results in some degradation of topsoil microbial communities along with increased short-range variability in physical and chemical soil properties of the graded areas. Deeper cuts (e.g. > 12-18”) to develop terraces, roads, or stormwater basins will expose vertical soil profiles with strongly differing properties with depth. Deeper B horizon cut faces will usually be much more acidic and infertile than exposed A+E horizons and will generally require heavier lime and NPK fertilizer applications for revegetation. Cut clay horizons are also subject to smearing and sealing when excavated while wet. Fill materials are frequently compacted intentionally to maximize strength/stability and minimize their volume to limit haulage distances/costs. Fills also commonly contain strongly differing layers with respect to texture and density that limit water penetration and “perch” local saturated zones, particularly in the winter months. More detail on these contrasting materials on active construction sites is available in Daniels (2018) and Booze-Daniels et al. (2000).

Trenching for cabling or other infrastructure (e.g., culverts) will generate strongly mixed soil horizons, bringing subsoil B and C horizons to the surface, particularly if topsoil is not salvaged. On some USS sites, trenching is the most extensive type of soil disturbance.

Building/structural pads and surrounding cuts/fills for transformers and other engineered structures pose a relatively minimal footprint impact, but would still need to be accounted for.

Stormwater conveyances and ponds will produce variable zones of partially cut and fill areas. On many sites, stormwater ponds will be the deepest and steepest exposed cut slopes for revegetation of exposure of both active normal soils and potential ASS materials. Moderately to strongly sloping sites will also likely contain internal sediment traps and sumps that will cause local disturbance during emplacement and removal.

Permanent and temporary roads and work areas will involve cut/fill on sloping sites and will be compacted and can be covered in aggregate for both short- and long-term use.

General site grading to level panel racking arrays or developed infrastructure will lead to moderate local soil mixing and compaction, depending on topsoil removal and return practices and soil moisture content during active site operations.

Operational phase (following initial ESC/SWM release)

Soil temperature and moisture conditions will vary greatly under panels (particularly fixed) and alleys between panel runs. In general, zones beneath panels will be drier and cooler (Yavari et al., 2022), which leads to strong differences in vegetation establishment and maintenance over time between areas directly under panels versus between rows and in open or buffer areas.

Routine mowing and maintenance can potentially compact surface soils in high traffic such as panel array alleys if wheel tracks are not varied over time.

Road corridors and substation/transformer pads will generate locally concentrated runoff.

Panel "drip lines" will develop, particularly for fixed arrays or where active storm onset controls are not employed for tracking arrays (Yavari et al., 2018). These drip lines concentrate local erosion risk, particularly if revegetation and soil cover requirements are not met.

Panel imperviousness and its effects on actual runoff versus proper application of runoff modeling parameters is currently controversial and subject to research validation (Shobe, 2022). As noted in the following section, conservative adjustment of curve numbers (CN) or other runoff coefficients (e.g., RVs in VRRM) should be included for long term SWM planning.

Decommissioning phase

A repeat of direct impacts via panel and cable infrastructure removal will occur with similar focused soil impacts to those occurring during site development. In particular, removal of trenched cabling and culverts will produce significant linear disturbances. Removal of roads and infrastructure will produce localized disturbances.

Final overall site grading should be limited wherever possible, but will be required for roads, stormwater conveyances and ponds and other engineered structural areas.

Topsoil return from long-term stockpiles (if employed) will likely lead to some re-compaction of both returned A+E horizon materials and underlying materials.

Short-term bare soil exposures from all combined final closure practices will produce another period of enhanced runoff and sediment loss risk; a new round of active ESC measures will be required.

Recommended Revegetation and Vegetation Management Strategies

Essential revegetation concepts for short-, medium-, and long-term management

First and foremost, it must be recognized and understood that the overall revegetation and management strategy employed at a USS site has two primary goals (1) short-term and immediate control of enhanced erosion/stormwater losses leading sequentially into (2) medium and long-term maintenance of the site and projected operational phase land uses (simple ESC, grazing, natives/pollinators, etc.). This necessarily requires changes in management strategy and inputs over time. Above all, the demands over the entire project lifecycle demands need to be projected and planned for *before* any disturbance occurs.

Following are general recommendations for BMPs to protect, preserve and restore soil quality at USS development sites within Virginia and throughout the Mid-Atlantic region. These recommendations also have direct bearing on ESC and SWM compliance. Final specific recommendations should be tailored for application to differing parts of the site depending on the intended operational land use. For example, very different establishment protocols would be used for (a) general mixed grass/legume mowed areas, (b) native grass/pollinator plantings, and (c) livestock grazing systems. More detail on specific seeding practices appears next.

Immediate short-term ESC is needed during site development. Virginia combined SW/ESC protocols or any more stringent local standards must be met. In particular, *at least* 75% living vegetative or intact litter/residue/mulch/EC matting cover should be established within 7 days of any final grading or 14 days of non-managed (inactive) exposure of bare (denuded) soils, regardless of prior installation of BMPs such as silt fencing, compost socks, sediment detention sumps, etc.

Pre-established BMPs must be well-maintained, including vegetated buffers, drainage swales, stormwater berms and other prescribed site-specific SWM & ESC practices.

General guidance for temporary and perennial seedings should be followed. Guidelines and resources are available for Virginia and specific regions, including recommended seed mixes successfully used in other disturbance sectors (e.g., southwest Virginia coal mining and statewide road stabilization); for more information refer to Skousen & Zipper (2018) and Booze-Daniels et al. (2000).

According to Virginia DEQ MS-1 (Stabilization) and associated guidance, permanent (BMP C-SSM-10) or temporary (BMP C-SSM-09) soil stabilization shall be applied to denuded areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization shall be applied within 7 days to denuded areas that are not at final grade but will remain dormant for longer than 14 days. Permanent stabilization shall be applied in areas to be left dormant for more than one year. Thus, it is critically important that disturbed areas within a USS development be stabilized incrementally over time and that large, denuded areas are not left unvegetated, particularly during the winter period that typically has enhanced runoff.

- Slope, aspect (i.e., the direction of the landform), and panel shading interactions affect revegetation success and short-range species diversity, particularly on south-facing slopes > 5%. Only very shade tolerant species will persist under low fixed panels. Mixed cool season grasses and legumes will be favored in partially shaded zones (including under tracking panel edges) while warm season grasses (and invasive annuals) are favored in full sun alleyways between panel rows. It is therefore advantageous to use diverse seed mixes of both grasses and legumes with a range of adaptations.

- In general, temporary seeding strategies with annual species are used in the winter and summer seasons. Seedings using perennial species are most successful during the spring or fall. In some instances, perennial seeding strategies can be employed year-round, but with lower likelihood of success. More details on integrated seeding strategies are found next.

- Pure grass perennial stands will require periodic N fertilizer applications every two to three years to maintain sufficient viable and living cover (≥ 75%). Therefore, establishment and maintenance of mixed grass and legume stand with at least 25% legume cover is recommended to maintain N availability to the dominant grass cover over time unless periodic N fertilization is planned.

- Temporary seeding is needed for late fall and winter and annual species such as cereal rye (*Secale cereal*) or annual ryegrass (*Lolium multiflorum*) should be utilized. Late spring and summer temporary seedings should be with German millet (*Setaria italica*) or other heat-tolerant annual species. All initial perennial seedings should also include a cover/nurse crop such as cereal rye in the fall and German millet in the spring.

- A wide range of perennial grasses is available; use at least two different species when possible. Mixes of tall fescue (*Festuca arundinacea*) and hard fescues (*Festuca rubra or ovina*) and orchardgrass *(Dactylis glomerata*) have been successfully established across a wide range of environments.

- Similarly, at least two regionally adapted legumes should be included. Birdsfoot trefoil *(Lotus corniculatus*), Korean/Kobe lespedeza (*Lespedeza striata/stipulacea*) , white and red clover (*Trifolium pratense/repens*) do well in Virginia, as do a wide range of sweet and white clovers. Use of Chines/sericea lespedeza (*Lespedeza cuneata*) and crownvetch (*Coronilla varia*) should be avoided, as both are now considered invasive by Virginia Department of Conservation and Recreation (DCR). Use of tall fescue (unless containing novel endophyte) in certain equine grazing or hayland environments is not recommended.

- Unfortunately, there are few native species, particularly legumes, which can establish rapidly enough to meet the combination of short-term ESC and longer-term management goals discussed in this document. Therefore, the use of non-native or "naturalized" species will be necessary for most seedings, particularly for initial erosion and sediment control needs around/under panel arrays.

- A wide range of potentially suitable species for permanent seedings can be found in C-SSM-10 that includes species adapted to all regions of Virginia. However, while tall fescue is included in the majority of regional cool season grass suggested mixes, other alternatives (e.g. orchardgrass) are more desirable for many grazing scenarios.

- However, it is feasible to apply multi-year management protocols involving conventional nurse species for initial ESC followed by more diverse native grass and pollinator-friendly seed mixes (DeBerry et al., 2019); https://www.dcr.virginia.gov/natural-heritage/pollinator-smart. These plantings are most appropriate for external buffers and open areas away from panel arrays, but they can also be compatible with panels if taller species are avoided and mowing is carefully timed.

- Alternatively, once a site is successfully stabilized with a conventional mixed grass/legume stand, there is a range of methods available to convert the stand over time to native grasses and flowering pollinator species. These methods involve suppressing competing non-native and weedy species competition via mowing, tillage, or herbicide applications, and minimizing fertilizer N and P applications. Certain highly competitive species (e.g., tall fescue) should not be included in initial seed mixes if this approach is being considered.

- Overall, very different establishment and management strategies may be required for routine operation within panel array areas compared with plantings in other drainage or buffer areas which could be managed with taller native plant species and/or pollinator species.

- There are number of pollinator-friendly species that can be readily established into mixed grass/legume stand for grazing systems, particularly for cattle (Ghajar et al., 2022). Expertise on actively managing forage systems for sheep in agrivoltaic systems is available from Dr. John Fike (jfike@vt.edu) and for "bee-friendly beef" from Dr. Ben Tracy (bftracy@vt.edu) and their forage management colleagues at Virginia Tech. For the past 5 years, Tracy's research team has been researching various methods to successfully establish native grasses and wildflowers under different environmental conditions while Fike's has extensive experience with sheep grazing systems.

- Active grazing should be limited until a viable perennial and suitable forage stand is established with at least 75% living cover.

- Even with actively managed grazing some level of mowing management will be required for most USS facilities.

- Surface soil compaction will be the most common limiting factor across any USS development site. Any areas that are denuded to the extent that they require temporary or permanent seeding should be de-compacted with appropriate soil tillage implements to at least 4 inches below the final grade surface. A range of soil tillage and management equipment options suitable for use in relatively confined areas within USS panel arrays is described in **Appendix B**.

Underlying and supporting concepts for successful revegetation

- *Use VDOT green tag variety recommendations* & VDACS certified seed (http://www.virginiacrop.org/vdot-green-tag-program.html) whenever possible. For tall fescue, do not use KY-31 unless absolutely necessary; it is inferior to modern improved varieties. All seeding rates should be on a Pure Live Seed (PLS) basis (Skousen & Zipper, 2018; Booze-Daniels et al., 2000).

- *Use at least two different perennial grasses and two perennial legumes* along with an appropriate cover/nurse crop. Diverse seed mixes increase your overall chance of revegetation success, particularly when you expect high local variability in soil and microclimate conditions (e.g., on USS sites).

- *A rapidly germinating cover crop is important* to (1) protect the soil from raindrop impact, (2) delay sheet flow and local sediment movement, (3) take up highly soluble forms of N and P and slowly return them to the soil via root and litter decay, and (4) provide shade and a more appropriate microclimate for the slower establishing perennials beneath them.

- *Establishing legumes in the permanent perennial stand is essential* to assure long term plant-available N supply to companion grasses *unless* routine fertilization is planned for mowed/managed areas. Legumes also take up initially available soluble P forms and transform them into organically complexed forms, enhancing P cycling and availability.

- *All legumes must be seeded with their appropriate and genus/species specific Rhizobia sp. bacterial inoculant*; the inoculant should be fresh (< 6 months old) and stored properly until used. Many seed merchants now provide the inoculant within a seed coating.

- *Hydroseeding is the preferred method* for rapid revegetation on most sloping and disturbed sites, but certain sites with low slopes or adequate seedbed preparation can be established via broadcast seeding or drilling (either conventional or no-till).

- *Hydroseeding efforts should include paper or, preferably, wood fiber mulch* at ≥ 1500 lbs per acre. Straw mulch should also be used on problematic sites and can be integrated into hydroseeding via the "two step method" (Booze-Daniels et al., 2000). EC 2 and EC 3 erosion control matting (per VA ESC specifications) should be used on particularly problematic steeper or adverse soil areas.

- *Fertilizer additions are essential to hydroseeding mixes* and should be based on appropriate recent site soil testing recommendations. However, some N and P fertilizers increase acidity (lower pH) and soluble salts to levels in the tank mix that can negatively affect seed and *Rhizobia* viability after prolonged exposures. Therefore, lime should be added to tank mixes as indicated on fertilizer labeling and seeding operations should commence quickly (≤ 1 hour) following additions of seed+inoculants (Brown et al., 1983).

- *In order to maintain legume viability, the soil pH must be > 5.5* and remain above that level over time. Lime rates should be based on appropriate soil test samples (https://www.soiltest.vt.edu/sampling-insttructions.html) taken from the site and applied as Virginia Certified Agricultural Limestone meeting the fineness guarantee and calcium carbonate equivalence (CCE).

- *Apply the specified lime rate*, even when using highly soluble products. A number of commercial liming products are marketed as being highly soluble based on their fineness and more rapid reaction rate when applied via hydroseeding. These products are often marketed as being needed at much lower rates (e.g. 200–400 lbs/acre) when compared with agricultural limestone. While these products can be quite effective at modifying soil pH in the upper ½" of soil for a relatively short period of time (months) they do not replace the full and longer-term efficacy of the fully specified rate of agricultural lime.

- *Use successive applications* when adding lime at rates greater than the equivalent of 2-3 tons of CCE lime per acre. Pre-application of the lime before seeding with some level of incorporation is recommended where feasible.

- *Request supporting evidence from the vendor when considering additives and admixtures*, many of which are available and promoted in the hydroseeding and general ESC markets. Their actual cost effectiveness should be carefully considered based on credible supporting evidence of their cost-effectiveness in similar applications. Microbial additives and liquid lime products warrant particular scrutiny.

- *Many native species (grasses, legumes and other forbs) are not compatible with hydroseeding* and require hand seeding, broadcasting or drilling. It is also important to point out that native species seedings usually require lower fertilizer and lime applications than conventional erosion control mixes.

- *Conventional soil testing procedures are calibrated for expected natural soil conditions and may not accurately predict actual nutrient availability for highly disturbed soils* where underlying low pH, high clay or fresh geologic materials are being evaluated. This is particularly true for P, which may therefore be needed at much higher levels than recommended by a given soil test.

- *Any soil pH test value < 4.2 should be considered as a potential indicator of acid-sulfate soil conditions* and will require appropriate screening protocols (https://landrehab.org/home/programs/acid-sulfate-soils-management/).

- *Extensive "tracking-in" and smoothing of final revegetation surfaces is counter-productive* to revegetation and enhances short-term runoff and sediment losses. In general, leaving the surface roughened up is a best management practice. Leaving narrow terraces intact across steeper slopes is also encouraged (Booze-Daniels et al., 2000).

- *Regardless of the guidance provided previously, the timing of seeding (particularly for perennial stands) is often the most critical factor for initial revegetation success.* Late spring perennial cool season species seedings are particularly subject to failure due to initial germination followed by summer heat and drought stress.

Recommended Soil, Site, and Animal Practices for Enhancing Soil Quality

The term "soil quality" was first introduced in the 1960s by Doran and others (Karlen et al., 2001) in association with efforts to identify and quantify indicator soil properties that were most closely related to combined plant productivity, water quality protection, and overall managed ecosystem stability. Work across a wide range of climatic and plant management zones have generally indicated that several parameters, particularly organic matter content, bulk density, rooting depth, and degree of aggregation are the most consistent indicators of soil quality, complemented by local variables such as soil pH, texture, and relative fertility levels. Over the past twenty years, many of the original concepts of the soil quality have evolved into the current federal and private sector emphasis on "soil health" (https://www.nrcs.usda.gov/conservationbasics/natural-resource-concerns/soils/soil-health), which incorporates added emphasis on soil microbial and biological functions, sustainability, and overall resiliency to disturbance.

For USS development and management, a range of practices are encouraged in all phases of site development and management that will (1) improve overall vegetation growth and resilience, (2) protect local and regional water quality, and (3) potentially lead to development of C-sequestration or nutrient reduction credits.

Specific suggested grazing management practices

- Intensive and rotational grazing practices should be employed to enhance and support overall operational vegetation management needs along with recycling N and P internally within the grazing areas in lieu of frequent fertilization. Vegetation height of forage should be monitored to determine when animals are moved/rotated around the site to avoid overgrazing.

- Panel height, wiring, and mechanical configurations may need to be adjusted and modified for particular grazing species if employed. For example, many species will readily benefit from daily shade provided by panel arrays, but the height will vary for sheep (lower) versus cattle (higher). Animals rubbing against exposed gears or other mechanical interferences also need to be accounted for or prevented.

- Site revegetation plans should be carefully tailored to produce a forage stand suitable for the intended animal grazing system type and intensity.

- Maintenance of deep-rooted perennial vegetation in disturbed areas should lead to significant increases and then stabilization of soil organic matter and aggregation with time (e.g., over decades). The establishment of such vegetation has important benefits and implications for the restoration of the site back into decommissioned land uses.

- Periodic soil testing of all contrasting management areas and recommended lime/fertilizer amendment should occur every three to five years for low maintenance areas (e.g., mowed panel arrays) and more frequently for more intensively managed or problematic areas (e.g., bare soil patches).

Practices to enhance and document changes in soil quality

- Where and when possible, the application of appropriate organic soil amendments should be considered, including composts, biosolids or animal manures. However, all such applications must occur within sound nutrient management planning (NMP) guidelines to ensure minimal losses of nitrogen (N) and phosphorus (P).

- Differing zones (panels, open areas and buffers) of the USS site will likely have differing management protocols and should be sampled for soil quality separately every three to five years following successful establishment.

- The following parameters are recommended for soil quality monitoring at USS sites at which assertions are being made with respect to carbon sequestration or other soil quality improvements. Soil samples should be collected prior to disturbance and from the final graded surface to inform initial revegetation prescriptions. The same areas should be sampled every five to ten years, and at final closure in the A horizon and upper B horizon, and should include a statistically valid design that compares differing management zones (e.g., within panel areas versus buffers or external control sites). These samples should be assessed for:

    1. Organic matter (humus) content along with total C, N and P;

    2. Aggregation/structure size/type/strength and stability;

    3. Bulk density via core ring sampler or other methods;

    4. Surface soil infiltration rate; and

    5. Routine plant available macro- and micro-nutrients, pH and soluble salts.

- To develop accurate carbon sequestration rate estimates, the following minimum protocols should also be employed:

    1, Establish baseline levels using valid control areas that are external to the panel areas and represent the pre-existing soil properties and land use (i.e., before USS development) to the extent possible;

    2. Collect soil samples from the surface to at least 18”; 40” is preferred by NRCS.

    3. Quantify soil carbon content and soil bulk density following accepted laboratory methods; and

    4. Account for field spatial variability due to disturbance and panel arrays, etc., for example by using a grid-based approach or a random sampling scheme that includes different areas representing that variability.

Other concerns regarding soil & water quality

We recognize that a wide range of other concerns exist with respect to the potential effects of USS development, management and decommissioning on soil, surface water and groundwater quality. In particular, several published research articles (Zeng et al., 2015; Ramos-Ruiz et al. 2017) reported on the potential risk of heavy metal leaching from Cd/Te panels and have generated considerable public comment and concern. We are aware of these issues and concerns and are actively evaluating a wider range of available studies. At this point in time (February, 2026) we can offer the following general opinions on this particular issue/concern:

- The two articles of primary public concern employed methods (e.g., TCLP) that are utilized to simulate long-term conditions within a landfill environment and are not directly applicable to what would occur at an installed and managed USS facility.
- The panel materials employed in these two studies were ground to < 5 mm for the Ramos-Ruiz (2017) paper and < 0.06 mm for Zeng et al. (2015) paper and subjected to aggressive leaching methods that differ considerably from those encountered with ambient rainfall interacts with panel arrays and underlying soils and vegetation.
- Another recent publication (Robinson and Meindel, 2019) reported on a similar leaching/extraction (via TCLP) study for actual field site soils (in NY under monocrystalline-Si panels). These authors found detectable (but limited) enrichment in soils closer to panels, but deemed the levels to be lower than would be associated with "ecosystem risk".
- There is a wide range of scientific and non-scientific literature and reporting available on this topic. However, actual site-specific and replicated field studies on relative soil accumulation compared to normal background conditions are very rare.
- We are aware of several ongoing investigations at national and state institutions that are studying metal accumulation and mobility under field conditions. Hopefully, these other researchers will report their findings over the next several years.
- We believe this issue could (and should) be directly and readily addressed in the field under a range of panel types (e.g. Cd/Te vs. Mono/Polycrytalline-Si vs. Fixed/Tracking panels). Any such study should include appropriate control areas outside of the USS facility.
- We will continue to analyze and evaluate all applicable studies and resources on this and other soil quality issues as they become available. We will provide updates on this and other important soil quality issues as new results become available.

Predicting Effects of Soil Disturbance and Remedial Practices on Post-Closure Soil and Landscape Productivity

Increasingly, stakeholder acceptance of new USS development projects is requiring the development of closure plans that include projected protocols for either returning the site to its original land use or to some similar alternative use. To date, there has not been any specific published research on the range of issues covered in this document; however, there have been a number of directly related studies conducted in Virginia and the eastern USA from mining reclamation and highway revegetation efforts. Several pertinent studies are summarized and cited in the next section.

Virginia Tech has conducted over 30 years of replicated research experiments and field studies on the restoration of prime farmlands to varying post-mining uses including prime farmland, hayland or pasture (Daniels et al., 2018), and commercial loblolly pine plantings https://landrehab.org/.

Results from our specific studies in Virginia indicate the following:

- Reclamation of significantly disturbed and reconstructed areas to productive row-cropping systems is possible with adequate deep ripping, surface tillage, liming, and fertilizer applications. Utilization of organic amendments (e.g., biosolids) enhances the rate of recovery (Wick et al., 2013), but long-term yields (i.e., over 10 years) should still be expected to be reduced by ~15 to 25% relative to comparative adjacent prime farmlands under identical management (Daniels et al., 2003; 2018). Limitations are due primarily to surface and subsoil compaction, poor aggregation and internal drainage, and associated seasonal wetness or drought stress.
- Reclamation of pasture productivity to pre-disturbance levels is possible for disturbed prime farmlands and highly likely for lower productivity non-prime areas (Teutsch et al., 2008). However, deep ripping may still be necessary to eliminate seasonal wetness due to poor internal soil drainage that can pose management limitations for hay production (e.g., spring and fall equipment access).
- The survival and initial growth of loblolly pines is enhanced by weed control and direct fertilization into the planting hole, but is inhibited by broadcast fertilizers that encourage nearby herbaceous competition. Compared with regional performance on undisturbed Piedmont soils, pine tree growth may be slower for the first few years after planting due to subsoil compaction, but can equal or exceed undisturbed soils for later years (e.g., 4-15 years after planting). Longer term effects of subsoil compaction on pine growth are still under study and beneficial effects of deep ripping were obvious from soil pit studies at year 12. Contact wdaniels@vt.edu for more details on pine growth results.

Related coal mining research in the 1980s on highly productive prime farmlands in Illinois and Kentucky that involved complete reconstruction of A, B, and C horizon profiles produced similar results (Dunker et al., 1992):

- Deep ripping, often to 48"+, was required along with periodic surface tillage to establish and maintain productivity.
- Soil horizon placement methods strongly influenced both subsoil and topsoil compaction and yield reductions. Best results were obtained by avoiding use of pan-scrapers, end-dumping returned soils in closely spaced piles, followed by minimal final dozer grading.
- Soil P was usually the most common limiting nutrient, but was easily remedied via repeated fertilization.
- Return to ~90% of pre-mining productivity was achieved over multiple seasons in a number of studies, but was strongly influenced by seasonal weather variations and the choice of crop variety.

Extensive research into restoration of both commercial and native forest productivity following significant disturbance in Illinois (Ashby, 1998) and the central Appalachians (Burger & Zipper, 2018) has indicated that:

- Overall soil depth to compaction or other rooting limiting layers is the primary tree productivity limiting factor as long as pH is within normal ranges (e.g., 4.5 to 6.5).
- Deep ripping and establishment of seedlings into ripper traces is an appropriate BMP. Recent work by our group at Virginia Tech strongly reinforces these findings for mineral sands mined lands returned to loblolly pine production.
- Rough grading is superior to smooth grading for seedling establishment and growth and for limiting initial runoff and sediment losses.
- Initial seedling survival and growth is enhanced by minimizing use of competitive herbaceous companion species (e.g., tall fescue) and by decreasing initial N fertilizer rates. Erosion was minimized as long as total ground cover was ≥ 50%.

Furthermore, several recent literature review (Brehm & Culman, 2022) and site-specific studies (Brehm & Culman, 2023) on the effects of pipeline corridor installation and rehabilitation on crop yields also indicate consistent decreases in rowcrop yield potentials due to combined effects of soil compaction and degraded structure (aggregation).

Combined, these studies across a range of disturbance environments emphasize the importance of being transparent with stakeholders from initial conceptual stages through final closure to ensure that expectations are reasonable and clearly attainable based on the anticipated degree of disturbance and the final soil reconstruction and revegetation practices that will be employed.

Accounting for Soil Disturbance in Stormwater Modeling

There is also a general lack of USS-specific research and findings in the mid-Atlantic region that compare actual versus predicted runoff and sediment losses. One of the few published studies to date (Cook & McKuen, 2013) compared modeling simulations and was not based on field observations. However, recent practical experience by the industry, and initial research efforts by Virginia Tech, indicate that the following areas deserve attention when developing or applying models to predict stormwater quantity and quality from USS sites:

- The official guidance from the NRCS (2007) regarding assignment of Hydrologic Soil Groups (HSG's A, B, C and D) clearly states that the concept is not applicable to disturbed soils and alternative methods should be employed. One recommended approach (also required by Virginia DEQ GM 2022-12 as cited earlier) is for users to account for disturbance during the active site development and stabilization phase by adjusting HSG's up one letter (e.g., from B to C) when assigning values for NRCS/TR-55 Curve Numbers (CN; https://www.hec.usace.army.mil/confluence/hmsdocs/hmstrm/cn-tables) or for VRRM runoff volume (Rv); Current guidance is also available in the DEQ 2024 Online Stormwater Handbook.

- Unless appropriate remediation measures are taken during site stabilization to alleviate soil compaction and maintain other important soil quality parameters (e.g., aggregation and infiltration), the CN and Rv values utilized for estimating runoff should be higher than for the original undisturbed conditions.

- USS developers should understand the limitations of interpretive scale as discussed earlier when using Web Soil Survey maps for aggregating modeled predictions for runoff, sediment loss and nutrient loading. On-site validation and confirmation will often be necessary.

- Any assignment of CN and Rv values to USS stormwater and erosion estimates should attempt to account for the influence of differences in soil disturbance and associated short-range variability and the unpredictability of essential infiltration/runoff partitioning estimators.

- Currently there is some debate regarding the validity of current estimates of the relative imperviousness of solar panel array fields and overall revegetation effectiveness on fully stabilized sites for maintenance of disconnected sheet flow conditions during most storm events (Shobe, 2022), but very little if any actual site-specific research has been done to validate those assumptions. Temporary ESC and SWM BMPs should be sized to account for impervious panel + bare ground runoff conditions during the site stabilization phase.

- In addition to the commonly used runoff modeling approaches discussed earlier, a number of more detailed and event-based approaches are available. These include the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS), the USEPA Storm Water Management Model (SWMM), K2/O2 (Kineros2-Opus2), HYDRUS, among others. HEC-HMS is a lumped-parameter hydrologic model, primarily used in larger watersheds. SWMM is also a lumped-parameter hydrologic model, but it contains detailed modeling of BMPs, and is fully capable of water quality modeling. The K2/O2 model combines the spatially-distributed KINEROS2 (KINematic runoff and EROSion) watershed model with Opus2, a soil profile/biogeochemical model. K2/O2 models hydrology, sediment transport, and nutrient cycling in small- to medium-sized watersheds. HYDRUS was used as the basis of a modeling study underlying the PV-SMaRT stormwater runoff calculator (https://www.nrel.gov/solar/market-research-analysis/pv-smart.html). Additional detail on the potential application of alternative models is available from Dr. David Sample at Virginia Tech.

- The 2022 Virginia DEQ guidance on stormwater policy along with recent online SWM & ESC Manual revisions (July 2024) list a number of specific provisions for solar farm permit applications, including the following:
    - Runoff predictions must account for panel imperviousness.
    - However, rainfall sensors can be installed to move panels toward a vertical stow position to reduce the net effects of the imperviousness adjustment.
    - Panel coverage x imperviousness calculations should conform with Virginia DEQ GM 2022-12) or subsequent final guidance as issued in July 2024.
    - HSG's should be adjusted up one letter (e.g. B to C) for disturbed areas (as detailed above).
    - Surfaces should be revegetated within the specified timeframe (7 days for temporary grading and 14 days for final grading), and other measures may be required to maintain unconnected surface water flow following peak rain events.

- As noted earlier, our research group is currently conducting an intensive field-based study to quantify actual runoff versus modeled assumptions from a wide range of USS sites in Virginia (n = 6). Initial (2-year) results from multiple sites indicate that developed USS catchments generate higher volumes of runoff with more rapid time to concentration than adjacent undeveloped control sites (Stewart et al., 2025).

Final Soil and Site Reconstruction BMPs for Varying Land Uses

The majority of USS development proposals in Virginia and the Mid-Atlantic region are accompanied by an assertion that disturbed project areas will be returned to their original land use capability following site decommissioning after 25-30 years of active service. Many localities now require some level of performance bonding and guarantees around this assumption, and HB 206 requires closure planning for sites that fall under PBR regulation by DEQ. Since the vast majority of USS sites in Virginia are less than five years old, it is difficult to predict the extent to which these areas will actually be converted back into agricultural or forested land uses as opposed to continued energy production or more intensive uses. Regardless of this uncertainty, some level of final mitigation and remediation will be necessary to eventually return these areas to agricultural or forest use.

Our recommendations for final site reconstruction protocols (listed in the following section) are based on the following rationale and assumptions:

- All USS infrastructure will be removed and the area returned to a land use that is suitable to the landowner.
- Appropriate soil remediation practices will be followed during the active installation and stabilization phase and acceptable management practices will be followed over the site lifetime that allow for vigorous (≥ 75% living cover) perennial herbaceous vegetation to persist for the lifetime of the project.
- Soil quality of significantly disturbed areas, particularly organic matter and aggregation in the topsoil/A horizon, will improve over the operational phase of the project lifecycle.
- Disturbed areas will be clearly identified and mapped during installation and known to closure contractors.
- Deep-ripping of subsoils and other major soil reconstruction efforts will be delayed until final closure (unless essential for stabilization) and based on final closure surface/subsoil conditions, projected final landuse(s), and available technologies/implements needed at that time.
- Final remedial practices may be applied uniformly or differentially based on disturbance maps and final soil quality observations.

Based on these assumptions, we recommend the following reconstruction practices:

Prime farmland: All disturbed areas intended for return to intensive agricultural uses (row cropping or vegetable production) following final site closure will need to be deep ripped to ≥ 24” with shanks ≤ 30” apart in two directions (90º opposed) followed by chisel plowing to just below the topsoil/subsoil contact as needed. The deep tillage event should be conducted under appropriate soil moisture conditions. Existing herbaceous vegetation will more than likely need to be suppressed via tillage or other methods. As discussed earlier, return of highly disturbed areas of prime farmland to 100% of their original row crop productivity and management practices may not be possible.

Pasture and hayland: Disturbed areas should be chisel- or no-till plowed to a depth of 12" and reseeded into appropriate vegetation. Deeper tillage may be required in areas of excess surface soil wetness due to underlying compaction. Areas that remain undisturbed and uncompacted by infrastructure removal and decommissioning efforts may be left in their existing state if the vegetation is suitable for the intended management system.

Forest lands: Significantly disturbed areas (e.g., with root-limiting subsoil bulk density) should be deep-ripped to > 18" in one direction consistent with intended planting spacing. Non-disturbed and/or uncompacted areas may require no further remediation. Competing vegetation on all areas will need to be controlled and/or suppressed with appropriate tillage or herbicides. Tree seedlings should be planted into ripper traces whenever possible.

Other uses: Other non-agricultural or forestry land uses are possible and appropriate site preparation and conversion practices will be dependent upon landowner and local governmental consent. We view continued energy production as a likely long-term land use for many USS sites.

Regardless of the intended final land use, the disturbance history of the overall USS lifecycle will need to be accounted for and will most likely increase local soil spatial variability on the overall restored site relative to the original undisturbed conditions.

Summary of Recommended Protocols & Best Management Practices (BMPs)

Stakeholder Involvement and Transparency

All stakeholders should be committed to the sustainable development and management of USS projects, including return of the decommissioned project area to productive agriculture, forestry or other pre-planned uses. Essential to this commitment is the application of a wide range of BMPs to minimize impacts to soil and water resources during site development and their careful integration into appropriate soil and vegetation management practices during the multi-decadal operational phase. Following infrastructure removal, developers should rehabilitate and restore any disturbed areas to optimize their productivity for the specific post-closure use designated by the landowner. Finally, we encourage and support full transparency throughout the project lifetime with respect to planning and permitting procedures, expected short- versus long-term impacts, and scientifically based projections for medium- and long-term site productivity potentials for various uses.

Pre-Development Assessment and Planning Practices

- Identify all soil types on site using NRCS Web Soil Survey or other resources (e.g., FIW NWI, VT VALEN site, VT Acid Sulfate Soils, Virginia DCR karst, etc.) to categorize prime farmland units (via NRCS criteria), forested areas, wetlands and other sensitive areas and features.
- Verify presumed soil types, forested areas, wetland boundaries and other limiting features via on-site investigations by a qualified professional when needed.
- Collect baseline pre-development data on important soil health indicators, including topsoil depth, organic matter and aggregation, bulk density, and permeability.
- Establish and map appropriate and required buffers around sensitive features, riparian zones, Resource Protection Areas, drainage swales, sinkholes, rock outcrops, wetlands, etc.
- Utilize gathered information to minimize grading (cut/fill) and other site development impacts to existing soil resources while avoiding impacts to particularly sensitive features (e.g. sinkholes and wetlands).
- Utilize conservative runoff estimators (e.g., higher NRCS CN's and/or VRRM RV's) for stormwater and erosion prediction modeling and SWM BMP specifications, particularly during the development/stabilization phase.
- Adjust design BMP SWM volumes to account for (a) site disturbance and (b) panel imperviousness. This effort should include adjusting the Soil Hydrologic Group (HSG) designation per current Virginia DEQ SWM guidance for solar developments.

- Develop detailed *a priori* vegetation establishment and management plans to meet initial site stabilization demands coupled with longer term operational vegetation management needs.

Active Site Development Best Practices

- Carefully establish and maintain all required buffers, setbacks, and all temporary and permanent ESC + SWM BMPs.
- Minimize grading and cut/fill for roads and structures when leveling or reducing slope grade changes for panel arrays, wherever possible.
- Consider dual-axis tracking systems or U-joints in single-axis systems to minimize cut/fill requirements when working on steeper or more undulating terrains.
- Use rain sensors to trigger panels to move panels to more vertical positions when triggered by major rain events.
- Anticipate development of drip lines below downhill panel edges on slopes and develop appropriate strategies to maintain disconnected flow conditions, restore sheet flow, or increase the time of concentration.
- Predict and map all areas of significant soil disturbance including roads, infrastructure (e.g., substation pads), trenches, temporary ESC measures, and engineered stormwater conveyances and ponds.
- Minimize topsoil removal wherever possible and maintain temporary topsoil stockpiles in an aerated condition, covered with deep-rooted vegetation and kept away from wet areas.
- Utilize light agricultural scale machinery with low pressure tires or tracks whenever possible for site development and maintenance activities. Avoid trafficking site soils during wet soil conditions.
- Assume that site development will compact the soil to some extent. Assess and remediate root-limiting compaction and smearing of disturbed surface soil materials to 4-6 inches with appropriate mechanical tillage methods. Add and incorporate soil amendments (lime/N-P-K/organic matter) to all final revegetation surfaces based on appropriate field sampling and soil testing protocols as described by Virginia Tech https://www.soiltest.vt.edu/sampling-insttructions.html or other Virginia DCR approved labs.

- Sample topsoil stockpiles before their return to disturbed areas and develop appropriate liming/fertilization/amendment prescriptions for seeding.

- Where topsoil is not salvaged and returned, assume exposed cut subsoils will most likely be compacted and low in pH and plant-available nutrients; test all contrasting cut/fill regraded areas separately.

- Utilize compost, biosolids, or other appropriate organic soil amendments where possible and feasible. Apply all soil amendments within Virginia DCR/DEQ/VDACS land application, NMP or label requirements.

- Return topsoil to disturbed areas from stockpiles as quickly as site closure conditions allow, or utilize direct haul strategies to immediately move actively collected topsoil to adjacent soil reconstruction areas. Loosen returned topsoil or exposed subsoil for revegetation steps with equipment consistent with use in the confined panel array environment.

- Minimize final smooth grading (e.g. dozer "tracking in") on sloping areas and leave surface roughened up where possible.

- Establish temporary vegetation (to achieve ≥ 75% living cover) within 14 days or less of disturbance wherever possible, including immediately following closure of trenches (returning topsoil back over backfill whenever possible) and installation of panel uprights. Temporary seeding or stabilization with tacked mulch should include any internal rough-graded areas that will not be returned to final grade or permanent vegetation for more than 30 days.

- Establish permanent vegetation (to achieve ≥ 75% living cover, with maximum bare areas of less than 250 ft^2) on all exposed soils within 7 days of final grading with diverse species mixtures for perennial seedings. Ensure legume establishment (≥ 25% cover) unless intensive turf management with routine fertilization is prescribed in post-development protocol.

- Ensure that revegetation strategies meet both short and long-term ESC needs, including coupling with longer term active soil/vegetation/grazing management goals. For example, limit animal grazing activities until the permanent vegetation is fully established and viable (i.e., ≥ 75% living cover).

- Use combined seeding, liming, fertilization, and organic amendment strategies to enhance initial vegetation establishment goals along with enhancing longer term soil health and quality.

- Avoid seeding Virginia DCR-listed invasive species such as Sericea/Chinese lespedeza and crown vetch into uplands or overall aggressive species such as reed canary grass into wetter pond and drainageway positions.

Post-Development and Operational Site Management Practices

- Maintain diverse mixed grass/legume stands in panel array zones that are consistent with intended maintenance, mowing, or grazing regimes.

- Where possible, use pollinator-friendly and native species in seed mixes that are consistent with panel zone management goals.

- Monitor and document vegetation type, persistence, and cover in differing management zones including under and between panel arrays, disturbed road shoulders, stormwater conveyances and ponds, and in undisturbed buffers. Utilize these observations to adjust management and reseeding practices as necessary.

- Utilize buffers and other non-paneled areas for establishment and maintenance of native grasses and/or pollinator species where feasible.

- Avoid working on-site when soil is wet and use light, low-wheel-pressure vehicles for routine maintenance.

- Establish permanent soil quality sampling and monitoring locations for critical parameters such as organic matter, aggregation, permeability, and bulk density. These locations should include both actively managed undisturbed and reconstructed soil areas to allow for valid documentation of actual soil carbon sequestration rates (if desired for markets or offsets) and other parameters.

- Collect routine soil testing samples from vegetation monitoring areas at least every third year and apply lime, N-P-K fertilizers and other amendments as needed to maintain and meet vegetation management goals for differing management zones.

- Integrate animal grazing management practices such as rotational grazing where possible to assist with vegetation maintenance and enhance soil quality when $\geq$ 75% established viable permanent living cover is maintained.

Final Closure and Decommissioning Practices

- Reestablish all necessary ESC and temporary SWM controls.

- Evaluate existing soil quality parameters, particularly subsoil compaction, for all areas, particularly those that underwent significant disturbance during site development.

- Minimize repeat soil disturbance associated with infrastructure removal following similar or improved practices used during the development phase.
- If indicated as necessary for a given land use (e.g., agriculture or intensive forestry), deep-rip all significantly disturbed areas to ≥ 24 inches, ensuring soils are at appropriate moisture levels to optimize bulk density remediation.
- Soil test all areas for final revegetation prescriptions and apply appropriate lime, N-P-K fertilizer, and organic amendments.
- If necessary, suppress the existing herbaceous stand to allow for establishment of final targeted agricultural, forest or other pre-planned uses such as urban re-development
- Use appropriate tillage practices (e.g., chisel plow, disk, or rototiller) to incorporate final soil amendments and remediate any final surface soil compaction to ≥ 6 inches.
- Monitor rehabilitation efforts for two seasons to ensure appropriate ESC and SWM compliance along with successful establishment of intended vegetation or cropping system.

Acknowledgments

We deeply appreciate the continuing support of our USS industry cooperators, Virginia DEQ, and our colleagues in the School of Plant & Environmental Sciences, the Department of Biological Systems Engineering and the Hampton Roads Agricultural Research & Extension Center (Virginia Beach).

References

Ashby, W.C. 1998. Reclamation with trees pre- and post-SMCRA in Southern Illinois. International Journal of Surface Mining, Reclamation and Environment. DOI:10.1080/09208118908944034

Aust, W.M., J.A. Burger, E.A. Carter, D.P. Preston and S.C. Patterson. 1998. Visually determined soil disturbance classes used as indices of forest harvest disturbance. Southern Journal of Applied Forestry, Volume 22, Issue 4, November 1998, Pages 245–250, https://doi.org/10.1093/sjaf/22.4.245

Booze-Daniels, J.N., J.M. Krouse, W.L. Daniels, D.L. Wright, and R.E. Schmidt. 2000. Establishment of low maintenance vegetation in highway corridors. p. 887-920. In: R.I. Barnhisel et al. (ed.) Reclamation of drastically disturbed lands. Agronomy 41. American Society of Agronomy, Madison, WI. https://www.researchgate.net/publication/338656151_Establishment_of_low_maintenance_vegetation_in_highway_corridors

Burger, J.A. and C.E. Zipper. 2018. How to Restore Forests on Surface-Mined Land. J.A. Burger and C.E. Zipper. Powell River Project Publication 460-123. Virginia Tech Cooperative Extension, Blacksburg.

Brehm, T. and S. Culman. (2022). Pipeline installation effects on soils and plants: A review and quantitative synthesis. Agrosyst Geosci Environ. 2022;5:e20312. https://doi.org/10.1002/agg2.20312

Brehm, T. and S. Culman. (2022). Soil degradation and crop yield declines persist 5 years after pipeline installations. Soil Sci. Soc. Am. J. 2023;87:350–364. DOI: 10.1002/saj2.20506.

Brown, M.R., D.D. Wolf, R.D. Morse and J.L. Neal. Viability of Rhizobium in Fertilizer Slurries Used for Hydroseeding. J. Env. Qual. 12(3): 388-390. https://doi.org/10.2134/jeq1983.00472425001200030016x

Carson, E.W. (Ed.) and others. 1971. The Plant Root and its Environment; Proceedings of the Symposium at Virginia Tech. University of Virginia Press, Charlottesville. https://siris-libraries.si.edu/ipac20/ipac.jsp?uri=full=3100001~!42053!0

Choi, S.K., A.E. Cagle, J. Macknick, D.E. Bloom, J.S. Caplan and S. Ravi. 2020. Effects of Revegetation on Soil Physical and Chemical Properties in Solar Photovoltaic Infrastructure. Frontiers in Env. Sci., 9 p. https://doi.org/10.3389/fenvs.2020.00140

Choi, S.K., J. Macknick, L.P. Yudl, D. Bloom, J. McCall and S. Ravi. 2023. Environmental Co-Benefits of Maintaining Native Vegetation with Solar Photovoltaic Infrastructure. 12 p. AGU -Earth's Future, 11, e2023EF003542. https://doi.org/10.1029/2023EF003542

Cook, L.M., and R.H. McKuen. 2013. Hydrologic Response of Solar Farms. Journal of Hydrologic Engineering, Vol. 18, No. 5, May 1, 2013. http://dx.doi.org/10.1061/(ASCE)HE.1943-5584.0000530

Coppin, N.J. and Richards, I.G. (1990) Use of Vegetation in Civil Engineering. Butterworth, London, 272.

Daniels, W. L. 2018. Managing urban soils. p. 3.1-3.12. In: M. Goatley and K. Hensler (ed.) Urban nutrient management handbook. Virginia Cooperative Extension Publication 420-350. Virginia Tech, Blacksburg, VA. https://www.pubs.ext.vt.edu/430/430-350/430-350.html

Daniels W.L., and K.C. Haering. 2015. Concepts of basic soil science. p. 31-52. In: K.C. Haering and G.K. Evanylo (ed.) The Mid-Atlantic nutrient management handbook. CSES-122. Virginia Cooperative Extension, Blacksburg, VA. Available on-line at: http://pubs.ext.vt.edu/CSES/CSES-122/CSES-122-pdf.pdf.

Daniels, W.L. and C.E. Zipper. 2018. Creation and Management of Productive Mine Soils. Powell River Project, Publication 460-121. Virginia Tech Cooperative Extension, Blacksburg.

Daniels, W. L., and K. C. Haering. 2018. General soil science principles. p. 2.1-2.13. In: M. Goatley and K. Hensler (ed.) Urban nutrient management handbook. Virginia Cooperative Extension Publication 420-350. Virginia Tech, Blacksburg, VA. http://pubs.ext.vt.edu/430/430-350/430-350_pdf.pdf

Daniels, W.L., P.D. Schroeder, S.M. Nagle, L.W. Zelazny, and M.M. Alley. 2003. Reclamation of prime farmland following mineral sands mining in Virginia. Min. Eng. 55(12): 42-48. https://www.researchgate.net/publication/338655955_Daniels_et_al_2003_Reclamation_of_prime_farmland

Daniels, W. L., Orndorff, Z. W., Stilson, C., Zimmerman, C., & Haywood, A. (2018). Development of Effective Rehabilitation Protocols for Mineral Sands Mining in Virginia USA. In Mined Land Reclamation: From Start to Finish. Carlton, VIC, Australia: Australia Institute for Mining and Minerals. Retrieved from http://www.ausimm.com/

DeBerry, D., C. Cyrus, R. Davis, R. Ernst, A. Ernst, R. Hypes, K. Heffernan, S. Baxter, M. Major, J. Bulluck, and K. Dramby. 2019. Virginia Pollinator-Smart Solar Industry: Comprehensive Manual, Version 1.2. Virginia Department of Environmental Quality and Virginia Department of Conservation and Recreation. Natural Heritage Technical Report 19-21. https://www.dcr.virginia.gov/natural-heritage/pollinator-smart.

Dunker, R E, Barnhisel, R I and Darmody, R G (eds), 1992. Prime Farmland Reclamation, 284 p (University of Illinois: Urbana-Champaign). https://www.abebooks.com/Proceedings-1992-National-Symposium-Prime-Farmland/871943132/bd

Elamri, Y., B. Cheviron, A. Mange, C. Dejean, F. Liron, and G. Belaud. (2018). Rain concentration and sheltering effect of solar panels on cultivated plots. Hydrol. Earth Syst. Sci., 22, 1285–1298, 2018. https://doi.org/10.5194/hess-22-1285-2018

Fanning, D., M. Rabenhorst, C. Coppock, W. Daniels and Z. Orndorff. 2004. Upland active acid sulfate soils from construction of new Stafford County, Virginia, USA, airport. Aust. J. Soil Res. 42:527-536. https://doi.org/10.1071/SR03085

Ghajar SM, Wagner JF, O'Rourke M, Tracy BF. 2022. Evaluating methods to establish biodiverse pasturelands with native grasses and wildflowers. Native Plants Journal 23(1):65–74. doi:10.3368/npj.23.1.65

Goerlich, D., P. Donovan, B. Herndon and J. Ignosh. 2022. Virginia Land and Energy Navigator "VaLEN". Initial Report on the Development of a Map for Prime Farmland HB894 Workgroup. December 1, 2022. Due for public release in early 2023.

Hassanpour, A. E., Selker, J. S., & C. W. Higgins. (2018) Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency. PLOS ONE 13(11): e0203256. https://doi.org/10.1371/journal.pone.0203256.

Hernandez, R.R., S.B. Easter, M.L. Murphy-Mariscal, F. T.Maestre, M. Tavassoli, E.B. Allen, C.W. Barrows, J. Belnap, R. Ochoa-Hueso, S. Ravi, and M.F. Allen. 2014. Renewable and Sustainable Energy Reviews 29 (2014) 766-779. http://dx.doi.org/10.1016/j.rser.2013.08.041

Jenny, H. (1941) Factors of Soil Formation: A System of Quantitative Pedology. Dover Publications, New York, 281 p.

Karlen, D.L., S.S. Andrews and J.W. Doran. 2001. Soil quality: Current concepts and applications. Advances in Agronomy, Volume 74, 2001, Pages 1-40. https://doi.org/10.1016/S0065-2113(01)74029-1

Lambert, Q., Bischoff, A., Cueff, S., Cluchier, A., & Gros, R. (2021). Effects of solar park construction and solar panels on soil quality, microclimate, CO2 effluxes, and vegetation under a Mediterranean climate. Land Degradation & Development, 32(18), 5190–5202. https://doi.org/10.1002/ldr.4101

McPhillips, L., A. Buda, Z. Easton, W. L. Daniels, S. Fathel, J. Ignosh, C. Raj, D. Sample. 2024. Best Management Practices to Minimize Impacts of Solar Farms on Landscape Hydrology and Water Quality. STAC Publication Number 24-001, Edgewater, MD. 42 pp. STAC – Chesapeake Bay Scientific and Technical Advisory Committee

Nair, A. A., Rohith, A. N., Raj, C., & L.E. McPhillips. 2023. A Framework to Model the Hydrology of Solar Farms Using EPA SWMM. Environmental Modeling & Assessment. https://doi.org/10.1007/s10666-023-09922-0

NCSU (North Carolina State University), 2019. Balancing Agricultural Productivity with Ground-Based Solar Photovoltaic (PV) Development – White Paper. NCSU – NC Clean Energy Technology Center, 16 p. https://nccleantech.ncsu.edu/wp-content/uploads/2019/10/Balancing-Agricultural-Productivity-with-Ground-Based-Solar-Photovoltaic-PV-Development-1.pdf

NRCS. (1998). Estimating Soil Moisture by Feel and Appearance. USDA NRCS Program Aid Number 1619. Washington, DC. https://nrcspad.sc.egov.usda.gov/DistributionCenter/product.aspx?ProductID=199

NRCS. 2007. Part 630 Hydrology, National Engineering Handbook, Chapter 7 Hydrologic Soil Groups. https://directives.sc.egov.usda.gov/. Washington, DC.

NRCS. 2017. Soil Survey Manual. By Soil Science Division Staff. United States Department of Agriculture. Handbook No. 18. Issued March 2017. https://www.nrcs.usda.gov/resources/guides-and-instructions/soil-survey-manual

Ramos-Ruiz, A. J.V Wilkening, J.A. Field, R. Sierra-Alvarez. 2017. Leaching of cadmium and tellurium from cadmium telluride (CdTe)thin-film solar panels under simulated landfill conditions. Journal of Hazardous Materials 336 (2017) 57–64 , dx.doi.org/10.1016/j.jhazmat.2017.04.052.

Robinson, S.A. and G.A. Meindel. 2019. Potential for leaching of heavy metals and metalloids from crystalline silicon photovoltaic systems. Journal of Natural Resources and Development 2019; 09: 19-24. http://jnrd.info/2016/01/10-5027jnrd-v6i0-01.

Shobe, C. 2022. How impervious are solar arrays? On the need for geomorphic assessment of energy transition technologies. Earth Surf. Process. Landforms. 2022;47:3219–3223. https://doi.org/10.1002/esp.5489

Skousen, J. and C.E. Zipper. 2018. Revegetation Species and Practices. Powell River Project Bulletin 460-122. Virginia Tech Cooperative Extension Division. https://www.pubs.ext.vt.edu/content/pubs_ext_vt_edu/en/460/460-122/460-122.html

Stewart, R.D., L. Mier-Valderrama, J. Hoben, D. Sample, and W.L. Daniels. 2025. Preliminary Report on Runoff Characteristics from Utility-Scale Solar Sites**.** Report by Virginia Tech School of Plant & Env. Sci. to Virginia Department of Environmental Quality per Grant #17368; 12/22/2025. https://www.deq.virginia.gov/home/showpublisheddocument/32469/638995890411730000

Teutsch, C.D., W. L. Daniels, Z.W. Orndorff, M.M. Alley, K.R. Meredith, and W. Tilson. 2008. Impact of soil reconstruction method on yield nutritive value and botanical composition of a mixed grass-legume stand. p. 1267-1282. In: R.I. Barnhisel (ed.) Proc. Am. Soc. Min. Reclam., Richmond, VA. 14-19 Jun. 2008. ASMR, Lexington, KY.

Trimble, S.W. 2008. Man-Induced Soil Erosion on the Southern Piedmont: 1700-1970 (Enhanced Second Edition), 80 pages, Soil & Water Cons. Soc. Amer., ISBN 978-0-9769432-5-9. https://www.swcs.org/resources/publications/man-induced-soil-erosion-on-the-piedmont-printed.

Weil, R.W. and N.C. Brady. 2017. The Nature and Properties of Soils, 15th Ed., Chapters 4 (physical properties) and 17 (erosion). Pearson, NY.

Wick, A.F., W.L. Daniels, Z.W. Orndorff, and M.M. Alley. 2013. Organic matter accumulation post-mineral sands mining. Soil Use and Management 29: 354-364. https://doi.org/10.1111/sum.12058

Yavari, R., D. Zaliwiciw, R. Cibin, and L. McPhillips. 2022. Minimizing environmental impacts of solar farms: a review of current science on landscape hydrology and guidance on stormwater management. Env. Res. Infrastructure and Sustain. https://doi.org/10.1088/2634-4505/ac76dd

Zeng, C., A. Ramos-Ruiz, J.A. Field and R. Sierra-Alvarez. 2015. Cadmium telluride (CdTe) and cadmium selenide (CdSe) leaching behavior and surface chemistry in response to pH and O_2. Journal of Environmental Management 154 (2015) 78e85. http://dx.doi.org/10.1016/j.jenvman.2015.02.033.

Appendix A

Sample Scenarios for Mitigating Impacts from Solar Project Development on Prime Farmland & Selected Forest Areas in Virginia

Sample Scenarios for Mitigating Impacts from Solar Project Development on Prime Farmland & Selected Forest Areas in Virginia

Part of the charge for the HB 206 working group was developing guidance for estimating the potential acreage requirements for mitigation of impacts from solar project development on prime agricultural soils (≥ 10 acres) and selected contiguous forest stands in Virginia. Within the final published regulation (see: Chapter 60. Small Renewable Energy Projects (Solar) Permit by Rule), "prime agricultural soils" means soils recognized as "prime farmland" by the U.S. Department of Agriculture. The Farmland Classification layer from the NRCS Web Soil Survey (WSS) is used to identify prime farmland as defined in the "Federal Register" Vol. 43, No. 21, January 31, 1978. Similar information on the extent of prime farmland for a given parcel is available at Virginia's Land and Energy Navigator (VALEN) online tool from Virginia Cooperative Extension. Under HB 206, all initial prime farmland determinations are based upon the WSS determination and not local, county, or city land use classification systems or categories. For example, many areas may contain "Farmlands of Statewide or Local Importance", but they do not qualify per se for regulation under HB 206. Mitigation options for impacts to a priori determined prime farmland are summarized in Table 1 from the final rule, which is copied below for reference, and includes associated definitions and criteria. Forest impact offsets are discussed later in this appendix.

Table 1
Partial Mitigation Options to Preserve Prime Agricultural Soils

Mitigation Option	Mitigation Actions Required	Mitigation Ratio
Option 1: No Change in Grade	Areas with no change in grade or topsoil removal, no trenching, maintenance of > 75% living vegetative cover, and decompaction to > 6" after decommissioning.	1:10
Option 2: Preservation of Topsoil	Areas with changes in grade due to cut and fill with removal and return of topsoil, decompaction of topsoil to 6" following installation, maintenance of > 75% living vegetative cover for project lifetime, and decompaction to > 24" and surface soil amendment after decommissioning.	1:4
Option 3: Decompaction of Surface Soil on Cut/Fill Areas	Areas with changes in grade due to cut and fill without topsoil salvage and return, decompaction of surface soil following installation, maintenance of > 75% living vegetative cover for project lifetime, and surface soil decompaction and soil amendment to > 6" after decommissioning.	1:2

This appendix describes key steps for determining mitigation area requirements, due to disturbances from utility-scale solar projects which may impact prime farmland and/or selected forest areas, across the sections described below.

SECTIONS

I. Using USDA's Web Soil Survey (WSS) to Identify Prime Farmland

II. Example Scenarios for Calculating Mitigation Requirements Using the "HB 206 Mitigation Scenario Spreadsheet" for Disturbance Areas to:

   A. Prime Farmland
   B. Prime Farmland and Preserved/Conserved Forest
   C. Contiguous Forest Land

Note: The examples utilized here and associated rationale reflect our interpretation of Virginia DEQ policy as of early March, 2026. While the underlying language in HB 206 is set, Virginia DEQ may amend or vary their interpretation of policy applications at their discretion over time.

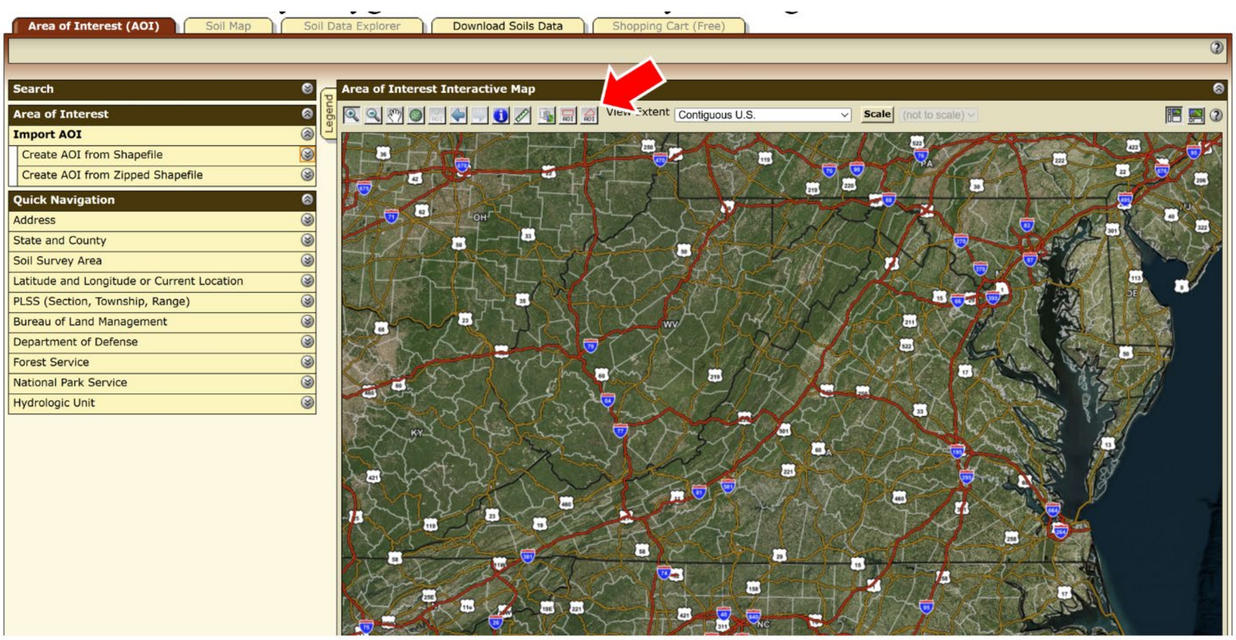
I. USING USDA'S WEB SOIL SURVEY TO IDENTIFY PRIME FARMLAND

The steps below demonstrate how to identify areas of prime farmland for a given parcel of land in Virginia using the public USDA Web Soil Survey (WSS) online tool. The WSS provides soil descriptions for a specific "area of interest" (AOI) which is a user defined polygon. In our example, this area of interest is based on the projected soil disturbance area from a proposed utility-scale solar project. Please visit Getting Started with Web Soil Survey for additional tutorials and web-based user support for the WSS application.

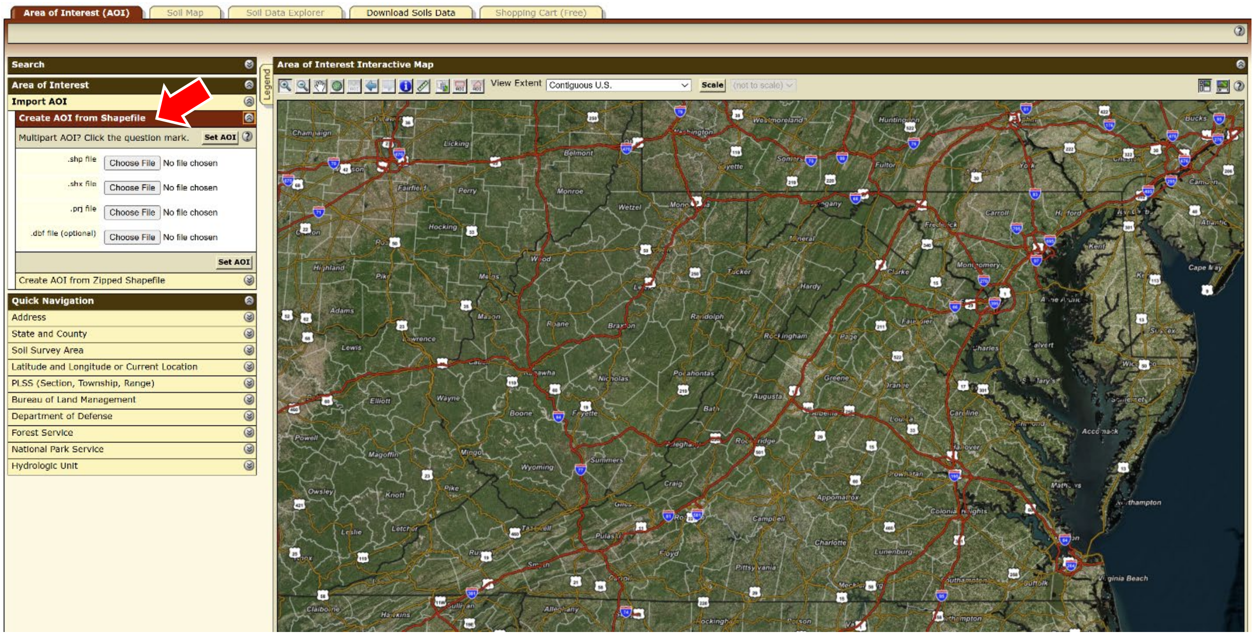
1. This link will take you to the Web Soil Survey.

2. Define the Area of Interest (AOI) describing the solar project disturbance area(s), by either the "Draw Option" or the "Import AOI" option, described below:

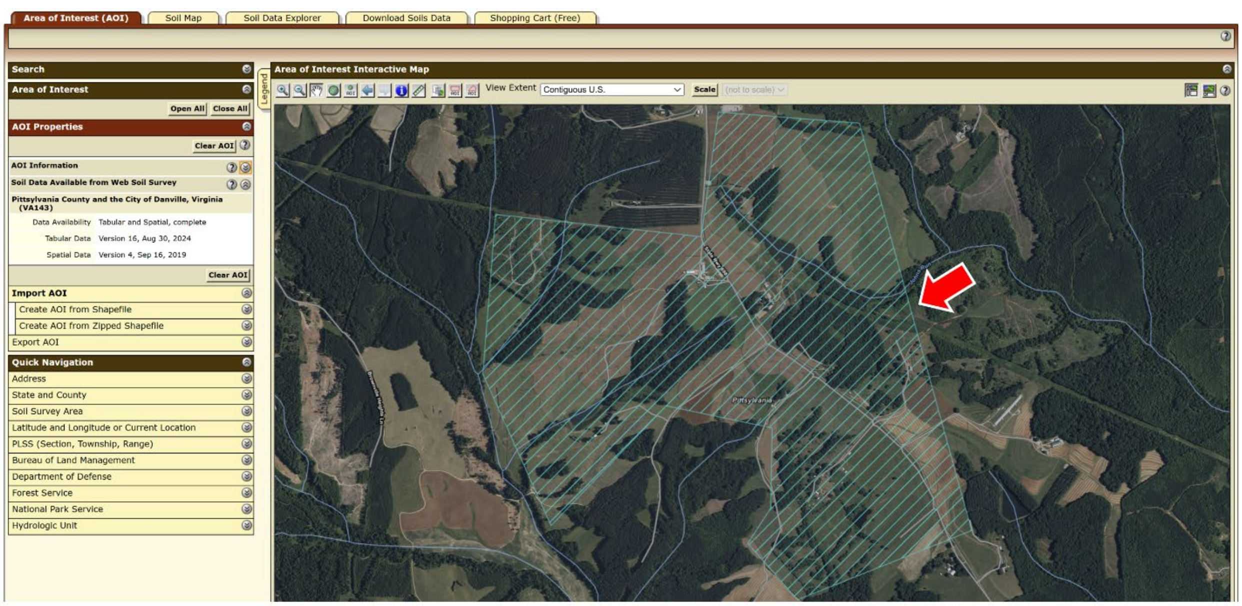
   a. Draw Option:
   Select "Draw AOI by Polygon" or "Draw AOI by Rectangle"



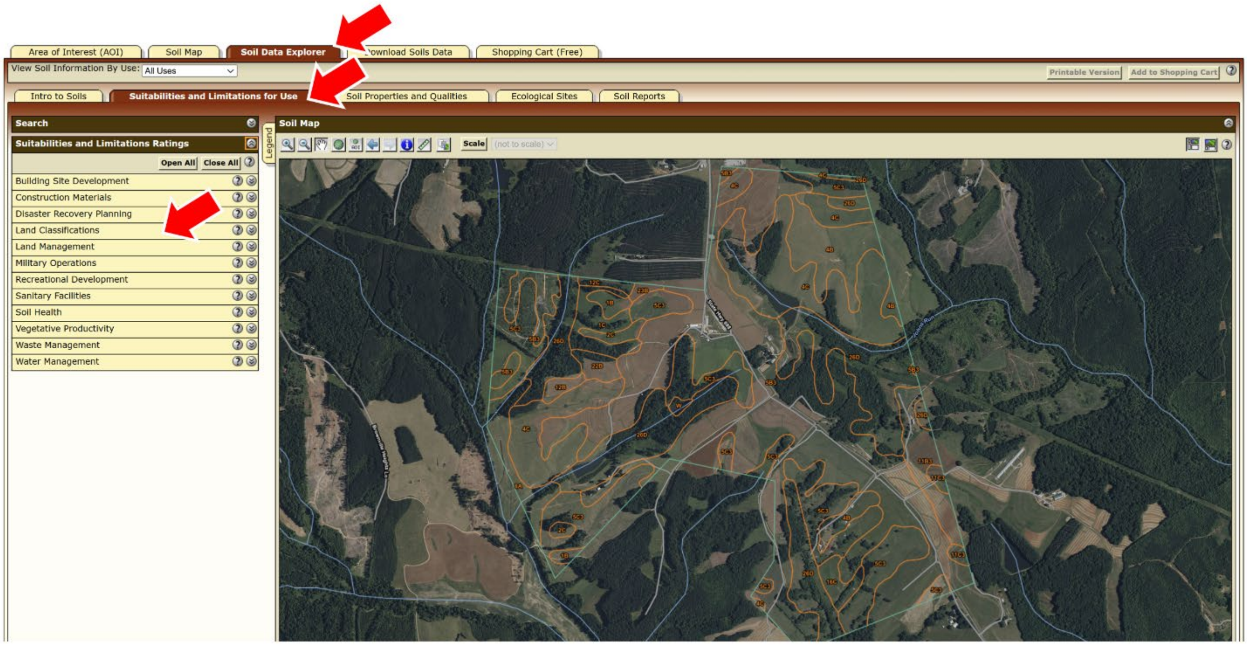
b. Shapefile Option:
Alternatively, you may upload a shapefile (*.shp) to the Web Soil Survey's "Import AOI -> Create AOI from Shapefile"



3. Review the created AOI as represented by the hatched areas of the map:



4. Select the "Soil Data Explorer" tab, then select the "Suitabilities and Limitations for Use" tab and finally select "Land Classifications" from the "Suitabilities and Limitations Ratings" menu.



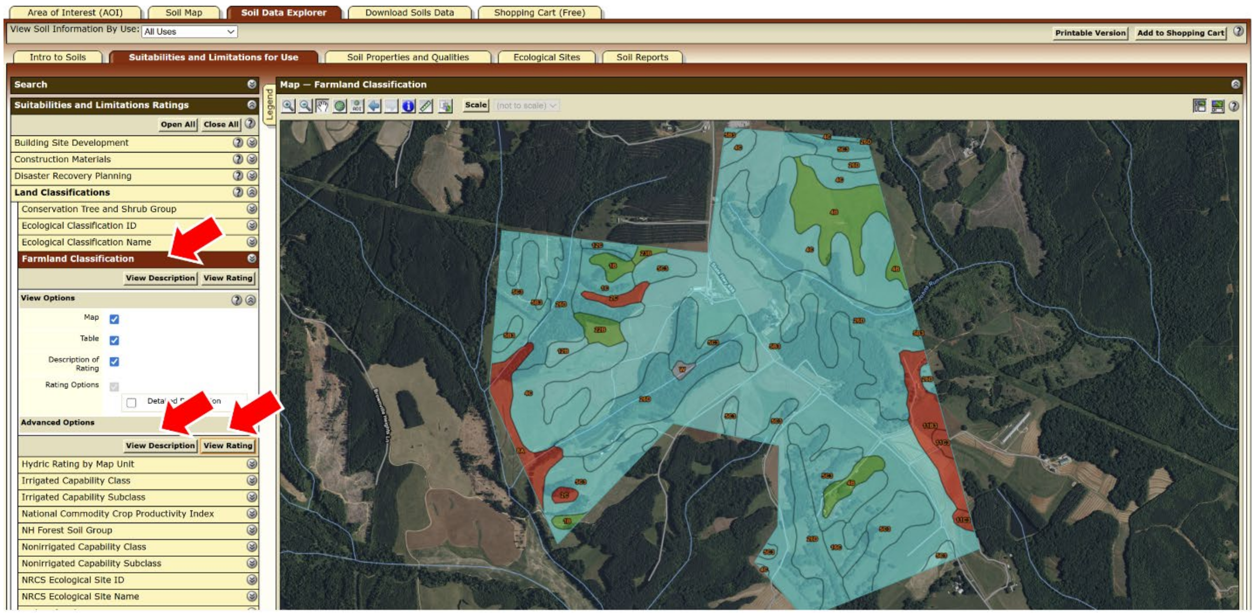
Notice that in the map view there are now many polygons drawn across the AOI, these are delineated soil landscapes that are defined by “soil map units”. Soil map units are identified areas with similar soil components that differ from other areas. Also note that the portions of these soil map unit polygons are often clipped by the boundaries of the AOI, but only acreage within the AOI is compiled in the output tables. Each map unit is named for its dominant soil type (series) or combination of soil series as they commonly occur across the given county. Map units also vary for a given soil type by slope class.

5. Select “Farmland Classification” from the “Land Classification” options. For more details on these classifications, select the “View Description” option to display the message below titled “Description – Farmland Classification”.

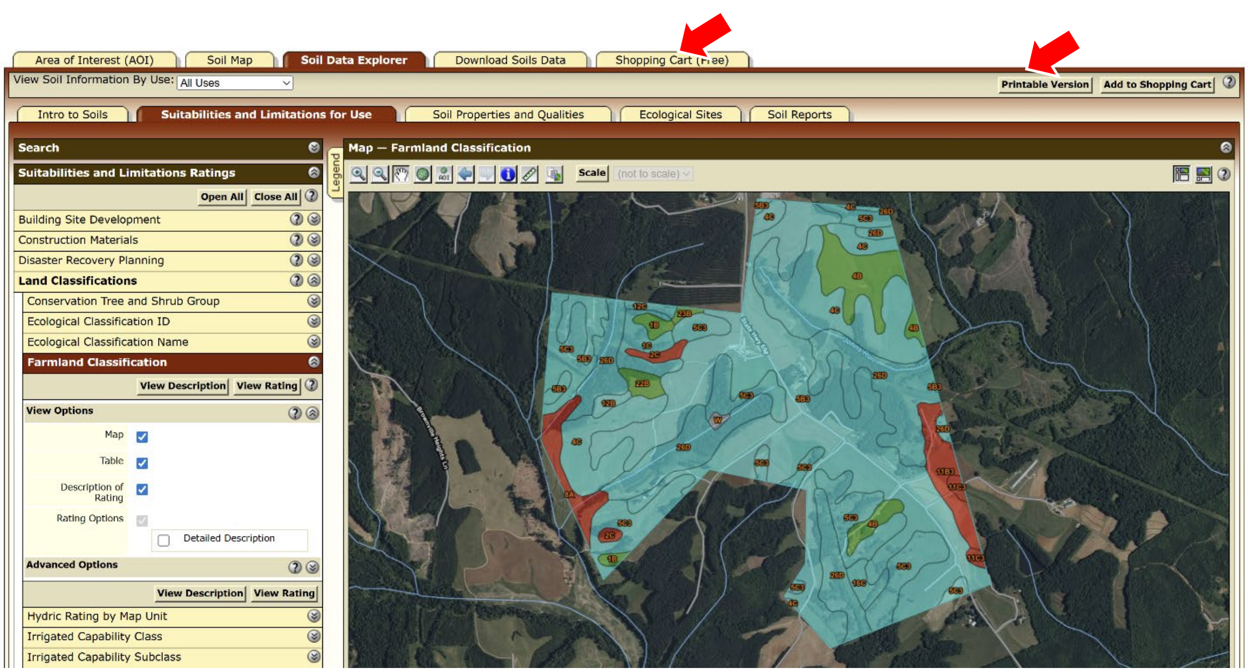
Description — Farmland Classification

Farmland classification identifies map units as prime farmland, farmland of statewide importance, farmland of local importance, or unique farmland. It identifies the location and extent of the soils that are best suited to food, feed, fiber, forage, and oilseed crops. NRCS policy and procedures on prime and unique farmlands are published in the "Federal Register," Vol. 43, No. 21, January 31, 1978.

Now select “View Ratings” to display the Farmland Classification ratings for all Map Units in the AOI.



6. To export a PDF of this information, select "Printable Version", and this will open a new tab for downloading the file. For a more detailed report select the "Add to Shopping Cart" option, then navigate to "Shopping Cart" and select "Check Out" (though, no purchase is required). For each option, please note the original compiled map survey scale (1:24,000) when reviewing and interpreting these output files. At this scale, the smallest possible delineations are 2 to 5 acres (or larger) and up to 15% of all soils within a given map unit may be quite different in use and management from the primary named soil type(s). The scale of the new maps generated will be shown along with a warning if the output scale is significantly larger (e.g. more detailed) than 1:24,000.



You have now created a map which describes the Farmland Classification by Map Unit specific to your AOI. **Figure A-1** and **Table A-1** (below) provide an expanded view of the key farmland classifications that are generated by the more detailed WSS report (Note: the formatting of the WSS generated map legend in the figure has been slightly edited for brevity in this example).

Figure A-1 — Farmland Classification Map

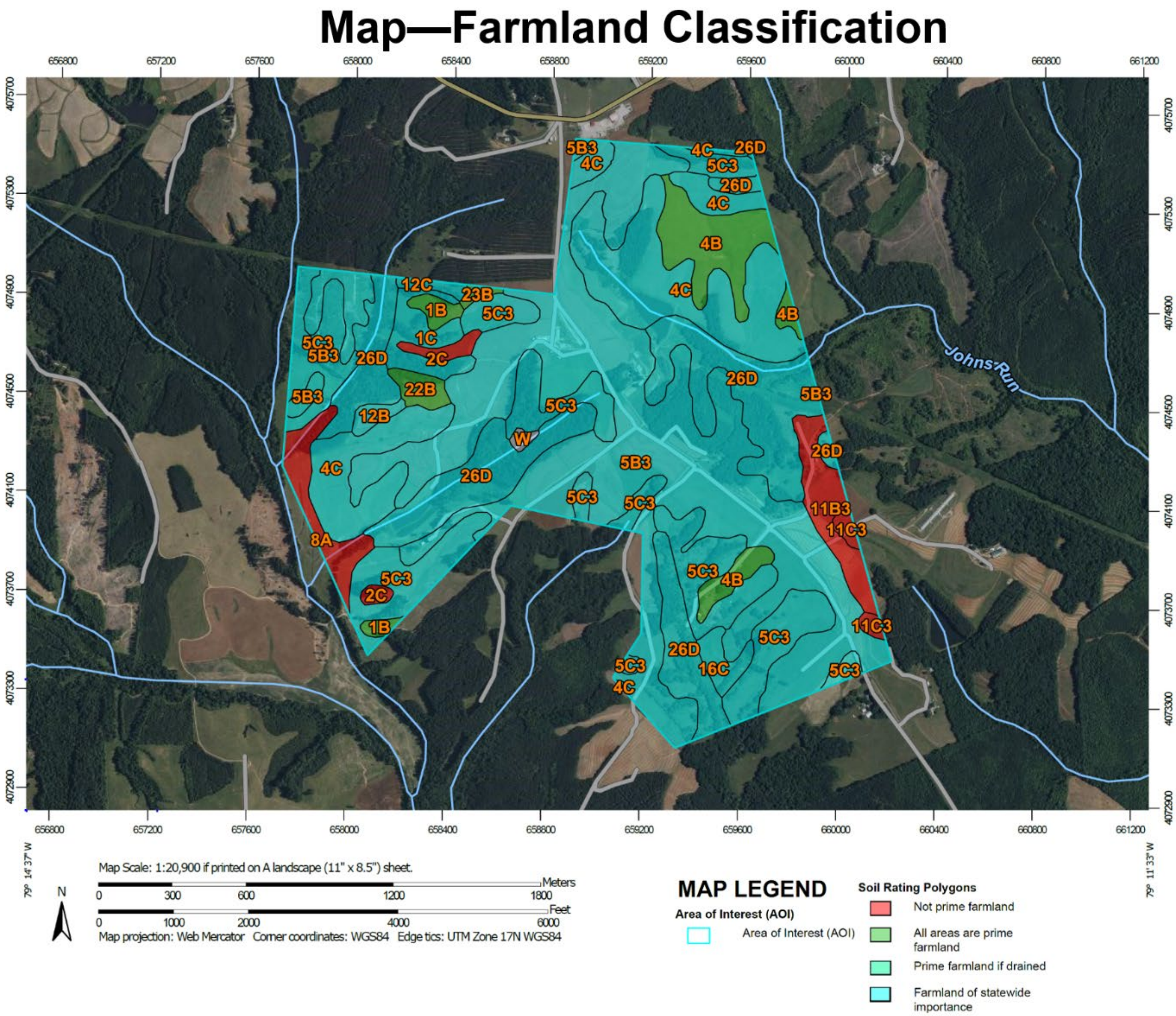


Table A-1 — Map Unit and Prime Farmland Classification

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
1B	Nathalie sandy loam, 2 to 7 percent slopes	All areas are prime farmland	6.7	0.8%
1C	Nathalie sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	16.9	1.9%
2C	Bannertown fine sandy loam, 7 to 15 percent slopes	Not prime farmland	6.5	0.7%
4B	Clifford sandy loam, 2 to 7 percent slopes	All areas are prime farmland	42.2	4.9%
4C	Clifford sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	123.7	14.3%
5B3	Clifford sandy clay loam, 2 to 7 percent slopes, severely eroded	Farmland of statewide importance	310.0	35.8%
5C3	Clifford sandy clay loam, 7 to 15 percent slopes, severely eroded	Farmland of statewide importance	143.6	16.6%
8A	Codorus-Comus complex, 0 to 2 percent slopes, frequently flooded	Not prime farmland	18.3	2.1%
11B3	Minnieville clay loam, 2 to 7 percent slopes, severely eroded	Not prime farmland	21.8	2.5%
11C3	Minnieville clay loam, 7 to 15 percent slopes, severely eroded	Not prime farmland	4.3	0.5%
12B	Enott fine sandy loam, 2 to 7 percent slopes	Farmland of statewide importance	4.0	0.5%
12C	Enott fine sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	3.1	0.4%
16C	Halifax sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	8.0	0.9%
22B	Bentley sandy loam, 2 to 7 percent slopes	All areas are prime farmland	6.7	0.8%
23B	Clover fine sandy loam, 2 to 7 percent slopes	All areas are prime farmland	1.9	0.2%
26D	Fairview fine sandy loam, 15 to 25 percent slopes	Farmland of statewide importance	145.6	16.8%
W	Water		1.6	0.2%
Totals for Area of Interest			**865.1**	**100.0%**

7. **Table A-1** above provides the required information to determine the area of prime farmland impacted by the project. This same data can also be viewed within the Web Soil Survey viewer itself. For example, just below the newly created map of the AOI, you will see a table labeled "Farmland Classification – Summary by Map Unit". This table also describes the AOI by each Map Unit and Farmland Classification Rating in both acres and as a percentage of the total AOI.

   In the example (**Table A-2**) below there are four Soil Map Units rated as "All areas are prime farmland", these include Map Unit Symbols: 1B, 4B, 22B and 23B. The entire AOI is 865.1 acres, of which 57.5 acres are classified as prime farmland. While Web Soil Survey estimates area to tenths of an acre, this analysis will round down to the whole acre. Therefore, 57 acres of prime farmland for this project area will require mitigation (if they are actually disturbed by the utility scale solar (USS) project). Note: Areas that are left "undisturbed" as defined by HB 206 (see below) are excluded from onsite mitigation and offsite conservation easement requirements.

   Table A-2 — Web Soil Survey Output Table

Tables — Farmland Classification — Summary By Map Unit

Summary by Map Unit — Pittsylvania County and the City of Danville, Virginia (VA143)

Summary by Map Unit — Pittsylvania County and the City of Danville, Virginia (VA143)

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
1B	Nathalie sandy loam, 2 to 7 percent slopes	All areas are prime farmland	6.7	0.8%
1C	Nathalie sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	16.9	1.9%
2C	Bannertown fine sandy loam, 7 to 15 percent slopes	Not prime farmland	6.5	0.7%
4B	Clifford sandy loam, 2 to 7 percent slopes	All areas are prime farmland	42.2	4.9%
4C	Clifford sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	123.7	14.3%
5B3	Clifford sandy clay loam, 2 to 7 percent slopes, severely eroded	Farmland of statewide importance	310.0	35.8%
5C3	Clifford sandy clay loam, 7 to 15 percent slopes, severely eroded	Farmland of statewide importance	143.6	16.6%
8A	Codorus-Comus complex, 0 to 2 percent slopes, frequently flooded	Not prime farmland	18.3	2.1%
11B3	Minnieville clay loam, 2 to 7 percent slopes, severely eroded	Not prime farmland	21.8	2.5%
11C3	Minnieville clay loam, 7 to 15 percent slopes, severely eroded	Not prime farmland	4.3	0.5%
12B	Enott fine sandy loam, 2 to 7 percent slopes	Farmland of statewide importance	4.0	0.5%
12C	Enott fine sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	3.1	0.4%
16C	Halifax sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	8.0	0.9%
22B	Bentley sandy loam, 2 to 7 percent slopes	All areas are prime farmland	6.7	0.8%
23B	Clover fine sandy loam, 2 to 7 percent slopes	All areas are prime farmland	1.9	0.2%
26D	Fairview fine sandy loam, 15 to 25 percent slopes	Farmland of statewide importance	145.6	16.8%
W	Water		1.6	0.2%
Totals for Area of Interest			**865.1**	**100.0%**

II. CALCULATING MITIGATION REQUIREMENTS USING EXCEL

A. PRIME FARMLAND ONLY EXAMPLE – AREA II. A

1. To explore mitigation options for impacts to prime farmland, we will use the values determined from the Web Soil Survey example in Section I (above) as the inputs to the "HB 206 Mitigation Scenario Spreadsheet" (See linked Excel file). Mitigation values are defined as shown above in "Table 1: Partial Mitigation Options to Preserve Prime Agricultural Soils" from the final rule (Virginia Department of Environmental Quality. (2025). *9VAC15-60-60. Mitigation plan*. In *Virginia Administrative Code*. Virginia General Assembly).

2. HB 206 also defines that: *"Land disturbance" or "land-disturbing activity" means a man-made change to the land surface that may result in soil erosion or has the potential to change its runoff characteristics, including construction activity such as the clearing, grading, excavating, or filling of land.* Therefore, the majority of a USS site is considered as "disturbed" and subject to regulation.

3. For this example (summarized above in **Table A-1**), the entire AOI is 865 acres of which 57 acres are classified as prime farmland. We also assume that all prime farmland areas will be "disturbed" by the proposed project.

4. The forested portions within the AOI for this scenario (viewable above in **Figure A-1**) are determined to not be of size or classification type to require mitigation. Next, we determine the acreage that will be mitigated via onsite practices, which for a given unit area is classified as either:

    a. **Option 1: No Change in Grade** - Areas with no change in grade or topsoil removal, no trenching, maintenance of > 75% living vegetative cover, and decompaction to > 6" after decommissioning. (Mitigation ratio 1:10);

    b. **Option 2: Preservation of Topsoil** - Areas with changes in grade due to cut and fill with removal and return of topsoil, decompaction of topsoil to 6" following installation, maintenance of > 75% living vegetative cover for project lifetime, and decompaction to > 24" and surface soil amendment after decommissioning. (Mitigation ratio 1:4); or

    c. **Option 3: Decompaction of Surface Soil on Cut/Fill Areas** - Areas with changes in grade due to cut and fill without topsoil salvage and return, decompaction of surface soil following installation, maintenance of > 75% living vegetative cover for project lifetime, and surface soil decompaction and soil amendment to > 6" after decommissioning. (Mitigation ratio 1:2).

Initial base levels (ratios) of mitigation credit/offset depend on the actual onsite mitigation planned (i.e., Option 1: No Change in Grade; Option 2: Preservation of Topsoil; or Option 3: Decompaction of Surface Soil on Cut/Fill Areas). Each of these options substantially reduces the required offsite compensatory mitigation requirement. Areas that receive no onsite mitigation efforts (other than required ESC stabilization and revegetation) must be compensated for offsite at a 1:1 ratio. Additional mitigation credit is possible via the incorporation of eligible alternative management practices during the project's operational phase, such practices include: Managed Grazing; Active Cropping Including Hayland; or Establishment and Maintenance of Pollinator Smart Habitat/Vegetation. The addition of any one of these practices (to required specifications) further reduces the offsite mitigation requirement by 25% of the base required acreage.

In this example scenario, the development plan indicates the following distribution of impacts across the proposed site classified by their mitigation option and management alternative:

- 17 acres will receive no onsite mitigation and must be compensated for at 1:1 (100%);
- 20 acres mitigated onsite via Option 1 (No Change in Grade) and compensated for at 1:10 (10%);
- 10 acres mitigated onsite via Option 2 (Preservation of Topsoil) and compensated for at 1:4 (25%); and
- 10 acres mitigated onsite via Option 3 (Decompaction of Surface Soil on Cut/Fill Areas) and compensated for at 1:2 (50%)
- Additionally, the developer plans to apply an approved management alternative.

Below, **Table A-3** (HB 206 Mitigation Scenario Spreadsheet) shows 17 acres with no onsite mitigation (a designation which also includes areas, such as: access roads, trenches, foundations, stormwater ponds and excavated conveyances which are considered permanent disturbances). The column titled "Impacted Acres by Mitigation Option" shows 20 acres with no change in grade (Option 1); 10 acres where topsoil is salvaged/returned and the subsoil is deep ripped at closure (Option 2), and 10 acres of surface decompaction + amendment of the surface soil on cut/fill areas (Option 3).

The project also has an implementation plan for an approved onsite management alternative across all areas that receive the onsite mitigation practices (Options 1-3). Therefore, for the "Is There an Implementation Plan for an Approved Onsite Management Alternative?" question on the spreadsheet the "Yes" dropdown option is selected, and the project will receive an additional 25% reduction in offsite compensation requirements. The approved management alternatives will be maintained as such for the duration of the project lifetime.

The spreadsheet calculates the base mitigation required for each option, the calculated results appear in the column titled "Acres of Offsite Mitigation Required". Finally, the spreadsheet sums "Disturbed Prime Agricultural Soils Receiving No Onsite Mitigation" (e.g., which in this scenario is 17 acres) and "Offsite Mitigation Requirement Due to Selected Onsite Mitigation & Management Options" (e.g., 7.125 acres) to calculate the "Total Offsite Mitigation Required" (e.g., 24.125 acres). **Table A-4** (Detailed Mitigation Calculations for Scenario II.A) provides an annotated stepwise example of these calculation steps for this scenario.

Note that the 25% credit for alternative management options is not applied to the 17 acres that do not receive any onsite mitigation efforts. It is also assumed that the chosen alternative management practice can be successfully deployed and managed across all areas receiving the onsite mitigation practices (Options 1-3). Virginia DEQ will provide guidance on this latter determination (applicability and feasibility) during the permit review process.

Table A-3 — HB 206 Mitigation Scenario Spreadsheet Example II.A

Prime Agricultural Soils Disturbed *(Enter Acres)*	57	*Enter Data in Tan Cells*	*Calculated Values Appear in Grey Cells*
Onsite Mitigation Options	**Onsite Mitigation Option(s) Selected** *(Enter Acres)*	**Mitigation Ratios**	**Acres of Offsite MItigation Required**
Option 1: No Change in Grade	20	1:10	2
Option 2: Preservation of Topsoil	10	1:4	2.5
Option 3: Decompaction of Surface Soil on Cut/Fill Areas	10	1:2	5
Is There an Implementation Plan for an Approved Onsite Management Alternative? (e.g., grazing, cropping, or pollinator SMART certification) *(Select Yes or No)*			YES
Summary Output Table			
Disturbed Prime Agricultural Soils Receiving No Onsite Mitigation (Acres) "A"	**Offsite Mitigation Requirement Due to Selected Onsite Mitigation & Management Options (Acres) "B"**		**Total Offsite Mitigation Required (Acres) "A" + "B" = "C"**
17	7.125		24.125

Table A-4 — Detailed Mitigation Calculations for Scenario II.A

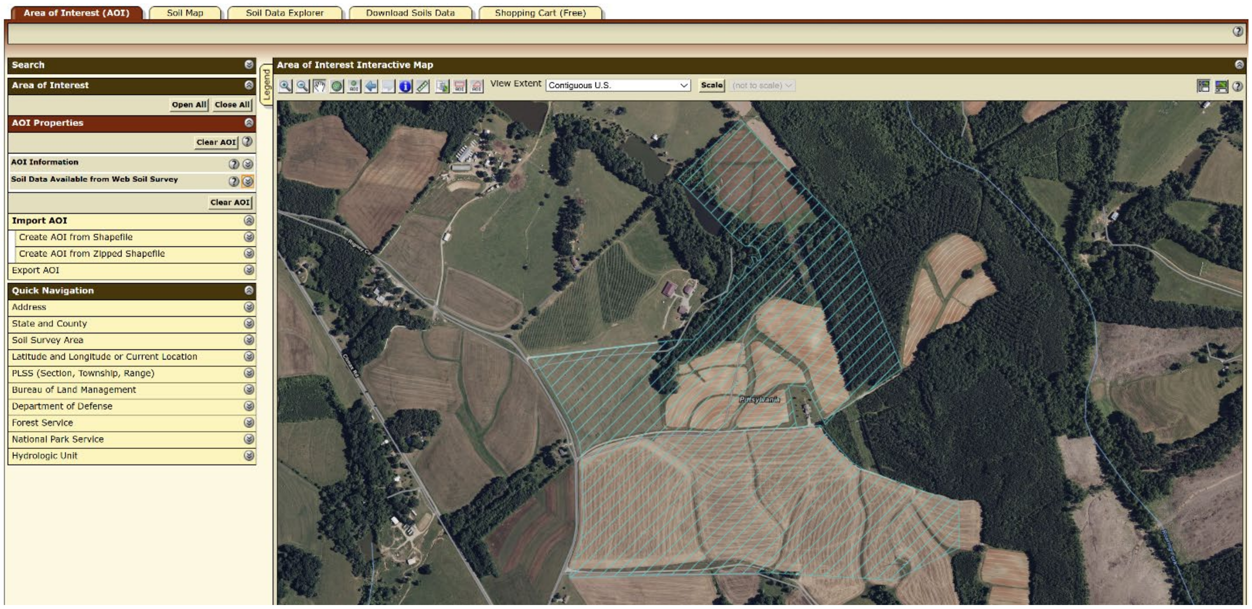
<table>
<tr><th>Onsite Mitigation Options</th><th>Allocated Mitigation Plan (acres)</th><th>Description of the Mitigation Calculation</th><th>Base Offsite Mitigation Required (acres)</th></tr>
<tr><td>None; 1:1 Offsite Mitigation</td><td>17</td><td>The 17 acres that are disturbed with no onsite mitigation efforts require a 1:1 easement offset of 17 acres.</td><td>17</td></tr>
<tr><td>#1: No Change in Grade (Onsite)</td><td>20</td><td>The 20 acres that are disturbed but have no change in grade will require a 1:10 (10%) offset of 2.0 acres.</td><td>2.0</td></tr>
<tr><td>#2: Preservation of Topsoil (Onsite)</td><td>10</td><td>The 10 acres that are managed via salvage and return of topsoil during site development will require a 1:4 (25%) offset of 2.5 acres. This option also assumes deep ripping (24”) of the subsoil at final closure.</td><td>2.5</td></tr>
<tr><td>#3: Decompaction of Surface Soil on Cut/Fill Areas (Onsite)</td><td>10</td><td>The 10 acres that are disturbed with no topsoil return but with surface soil decompaction and soil amendment following final closure will require a 1:2 (50%) offset of 5.0 acres.</td><td>5.0</td></tr>
<tr><td colspan="4">Summation of Mitigation Requirements</td></tr>
<tr><td colspan="3">Adjusted credits to account for approved management alternative:

Formulas:
- Base Requirement = Mitigation Option (Acreage) x Mitigation Ratio
- Management Alternative Reduction = Base Requirement – (Base Requirement x Management Alternative Reduction (25%))
Option 1:
• Base Requirement: 20 acres x 0.1 = 2 acres
• Management Alternative Reduction: 2 acres – (2 x 0.25) = 1.5 acres
Option 2:
• Base Requirement: 10 acres x 0.25 = 2.5 acres
• Management Alternative Reduction: 2.5 acres – (2.5 x 0.25) = 1.875 acres
Option 3:
• Base Requirement: 10 acres x 0.5 = 5 acres
• Management Alternative Reduction: 5 acres – (5 x 0.25) = 3.75 acres
Onsite Mitigation Subtotal: 1.5 + 1.875 + 3.75 = 7.125 acres, rounded to 7.13 acres</td><td>7.13</td></tr>
<tr><td colspan="3">Offsite Mitigation Subtotal (For Areas Where no Onsite Options Are Used): 17 acres</td><td>17</td></tr>
<tr><td colspan="3">Total Combined Offsite Mitigation Requirement (7.13 + 17 = 24.13 acres)</td><td>24.13</td></tr>
</table>

B. PRIME FARMLAND AND PRESERVED FOREST EXAMPLE – AREA II.B

This scenario provides an example of a different proposed utility scale solar (USS) project disturbance zone with impacts to both prime farmland and preserved forest. This scenario is based on a new AOI which is described below.

1. A new AOI is defined within the USDA's Web Soil Survey and is represented by the hatched area of the map below.

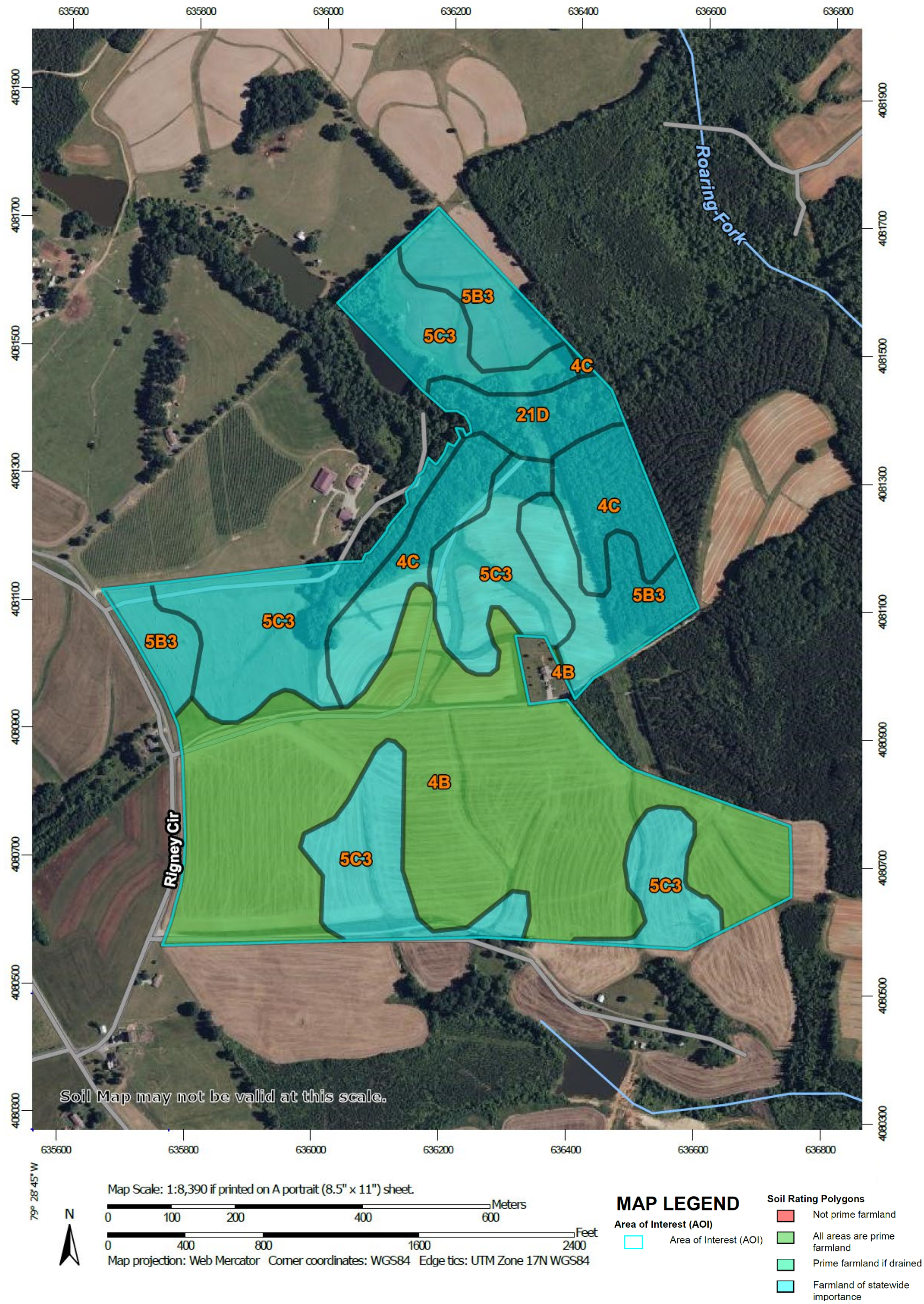


2. The section below provides an expanded view of the key Farmland Classification map (**Figure A-2**) and table generated in the detailed report option of the Web Soil Survey. **Table A-5** below indicates that the total disturbance area is 157 acres, of which 67 acres are classified as prime farmland which would be disturbed by the solar site development. The 67 acres of prime farmland will require mitigation. (Note: the formatting of the WSS generated map legend in the figure has been slightly edited for brevity in this example).

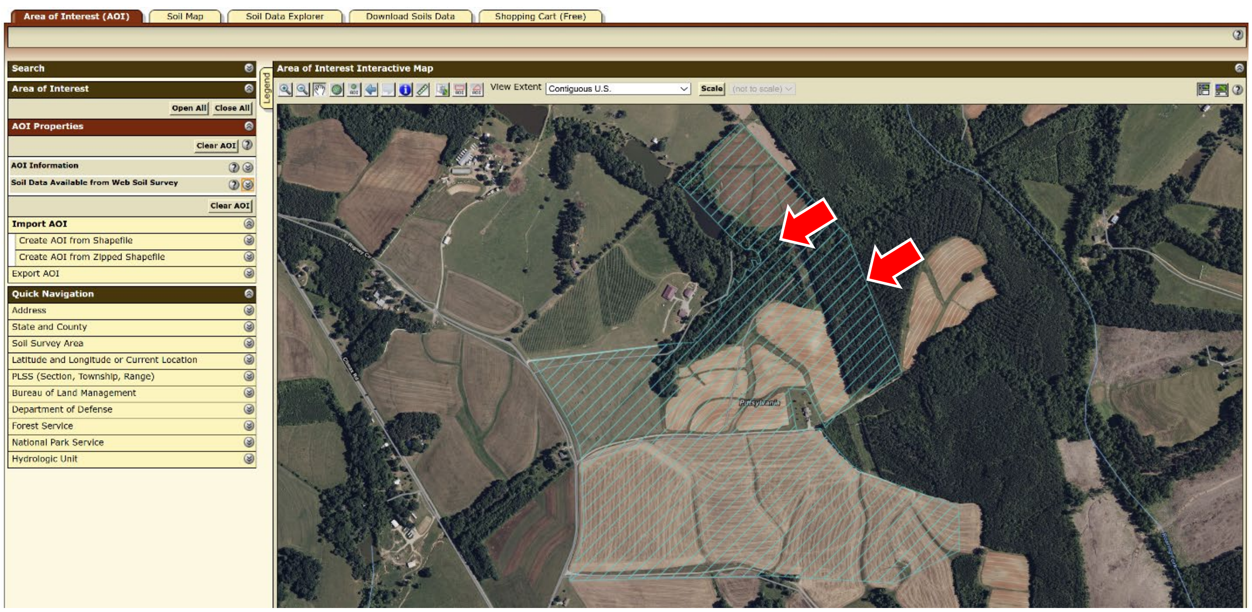
Table A-5 — Map Unit and Prime Farmland Classification for Example II.B.

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
4B	Clifford sandy loam, 2 to 7 percent slopes	All areas are prime farmland	67.1	42.5%
4C	Clifford sandy loam, 7 to 15 percent slopes	Farmland of statewide importance	16.2	10.3%
5B3	Clifford sandy clay loam, 2 to 7 percent slopes, severely eroded	Farmland of statewide importance	19.8	12.5%
5C3	Clifford sandy clay loam, 7 to 15 percent slopes, severely eroded	Farmland of statewide importance	48.8	30.9%
21D	Poplar Forest fine sandy loam, 15 to 25 percent slopes	Farmland of statewide importance	5.9	3.7%
Totals for Area of Interest			**157.8**	**100.0%**

Figure A-2 — Farmland Classification Map for Example II.B.



3. Through additional site review, it is discovered that the forested area in the northern region of the AOI is a special class of preserved forest. The red arrows in the figure below indicate these a priori preserved forest areas. Siting regulations require mitigation for disturbance of any forest lands enrolled in a program for forestry preservation pursuant to [subdivision 2 of § 58.1-3233](#) of the Code of Virginia, which includes parcels enrolled in forest land-use valuations. County land-use tax and parcel records confirm this classification for this forested area within the AOI and disturbance zone. From county records and site data, it is determined there are 24 acres of forest land enrolled in a forestry preservation program, the entirety of which will require offsite mitigation/compensation at 1:1. Note that none of this forested area overlies NRCS prime farmland (Map Unit 4B).



4. At this particular site, the developer is not able to implement installation without causing significant change in grade to all areas, so no acreage qualifies for Option 1. Furthermore, the operating entity has elected to simply maintain the entire site to meet conventional ESC requirements (e.g. > 75% living cover) and will not apply alternative management practices to any areas.

5. To explore mitigation options, we will use the acreage determined above as inputs to the "HB 206 Mitigation Scenario Spreadsheet" (Excel file), which is summarized in **Table A-6** below. Please note that the 24 acres of impact to the preserved forest will need to be compensated for separately from the prime farmland at a compensation ratio of 1:1. Forest disturbances are not included in the spreadsheet calculations as there are no onsite mitigation options for this disturbance type.

6. Similar to the first example (II.A) above, offsite mitigation was reduced by utilizing two of the three options: Option 2 - Preservation of Topsoil and Option 3 - Decompaction of

Surface Soil on Cut/Fill Areas. However, no 25% reduction credit was applied since there was no implementation of an eligible alternative management practice in the mitigated areas of the project.

7. **The total required offsite compensation for the project area will then be 66 acres, comprised of two separate classes of offsite mitigation via conservation easements. Impacts to prime farmland will require 42 acres of offsite mitigation. While impacts to the preserved forest will require 24 acres of separate offsite mitigation via a forest conservation easement.** Per HB 206 regulation and guidance, the prime farmland compensation must occur on another prime farmland area while the forested compensation area will occur separately and is not constrained by soil type.

Table A-6 — HB 206 Mitigation Scenario Spreadsheet Example II.B.

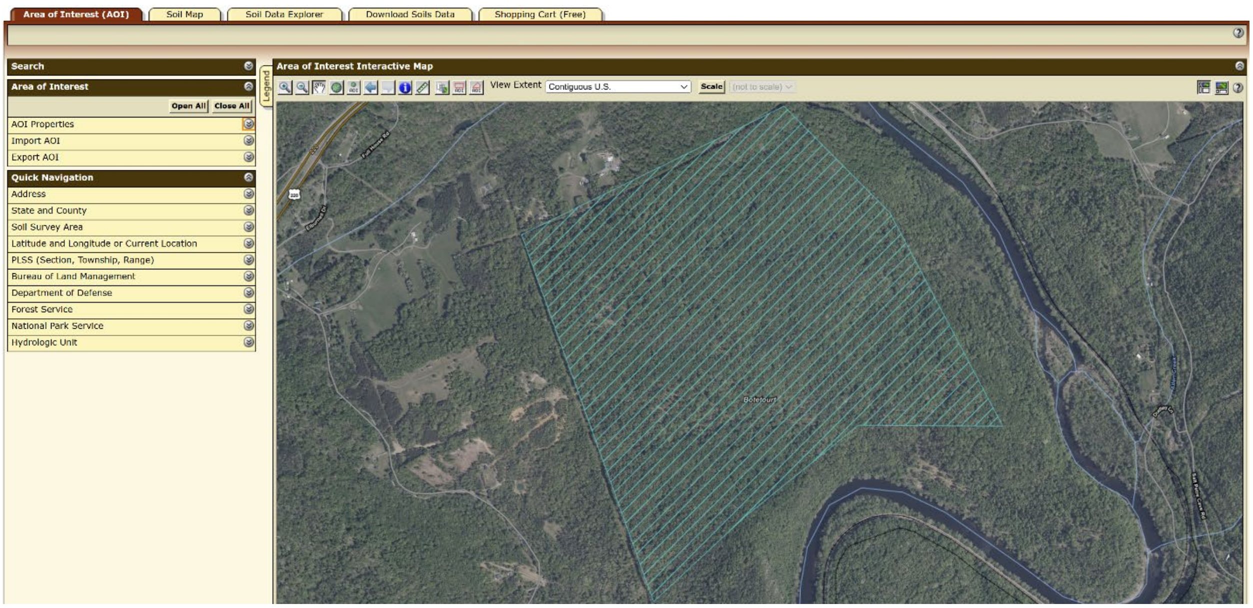
Prime Agricultural Soils Disturbed *(Enter Acres)*	67	*Enter Data in Tan Cells*	*Calculated Values Appear in Grey Cells*
Onsite Mitigation Options	**Onsite Mitigation Option(s) Selected** *(Enter Acres)*	**Mitigation Ratios**	**Acres of Offsite MItigation Required**
Option 1: No Change in Grade	0	1:10	0
Option 2: Preservation of Topsoil	20	1:4	5
Option 3: Decompaction of Surface Soil on Cut/Fill Areas	20	1:2	10
Is There an Implementation Plan for an Approved Onsite Management Alternative? (e.g., grazing, cropping, or pollinator SMART certification) *(Select Yes or No)*			NO
Summary Output Table			
Disturbed Prime Agricultural Soils Receiving No Onsite Mitigation (Acres) "A"	**Offsite Mitigation Requirement Due to Selected Onsite Mitigation & Management Options (Acres) "B"**		**Total Offsite Mitigation Required (Acres) "A" + "B" = "C"**
27	15		42

C. CONTIGUOUS FOREST LAND EXAMPLE

This scenario provides an example of a disturbance zone with impacts greater ≥ 50 acres to a contiguously forested area meeting the HB 206 definitions and policy determinations (see below).

This scenario is based on a new AOI which is described below.

1. A new AOI is defined within the USDA's Web Soil Survey and is represented by the hatched area of the map below.



2. The Farmland Classification below (**Table A-7**) for this AOI indicates that there is no prime farmland present within the disturbance zone. Therefore, no prime farmland is impacted by this project and there are no related mitigation requirements for prime farmland. For clarity, this also means there are no onsite mitigation options or management credits applicable within the AOI.

3. The regulations consider Contiguous Forest Land as:
    a. Land where trees constitute a stand of potential, immature, or mature trees (as defined in § 10.1-1178 of the Code of Virginia). A parcel is considered Forest Land if it was forested at least two years prior to DEQ's receipt of a permit application. Additionally, forest trees are not limited to commercial timber trees.

    b. Forest land that is adjoining, including areas separated by a waterbody (less than 200 feet in width); or roads, driveways, or impervious surfaces, including compacted gravel (40 feet or less in width); and clearings for utilities (200 feet or less in width).

Through additional site review, it is discovered that all forested areas across the AOI meet the statutory definition of Contiguous Forest Land. **Assuming all areas summarized in Table A-7 will be disturbed to some extent, then all the 446 acres will require offsite mitigation at a 1:1 ratio**.

Virginia DEQ is developing further guidance for evaluation of forest land values and their application to HB 206 requirements.

Table A-7 — Map Unit and Prime Farmland Classification for Example II.C.

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
8E	Carbo-Opequon-Rock outcrop complex, 15 to 45 percent slopes	Not prime farmland	135.0	30.2%
20C	Frederick loam, 7 to 15 percent slopes	Farmland of statewide importance	0.6	0.1%
22C	Frederick gravelly loam, 7 to 15 percent slopes	Farmland of statewide importance	3.0	0.7%
24C	Frederick loam, 7 to 15 percent slopes, very rocky	Not prime farmland	95.1	21.3%
24D	Frederick loam, 15 to 30 percent slopes, very rocky	Not prime farmland	183.2	41.0%
51C	Shottower cobbly loam, 7 to 15 percent slopes	Farmland of statewide importance	17.5	3.9%
51D	Shottower cobbly loam, 15 to 30 percent slopes	Not prime farmland	12.4	2.8%
Totals for Area of Interest			**446.9**	**100.0%**

Appendix B

Examples of Soil Tillage and Management Implements Potentially Useful in Utility Scale Solar Sites

Equipment Options for Revegetation and Management of Utility Scale Solar

Suggestions for dealing with soil and plant cover management issues within the space constraints imposed by Utility Scale Solar (USS) infrastructure

Important Disclaimer: The authors of this report do not specifically recommend or endorse any of the commercial products described in this report. Any product shown is simply presented as example of a given type or class of a product.

Introduction

Site visits and meetings with industry and regulatory personnel have confirmed that a pressing concern for management of post-construction utility-scale solar (USS) sites is the rapid re-establishment of a healthy, self-sustaining, low-maintenance vegetative cover.

During site visits, we have identified several factors that likely impede establishment of a healthy, post-construction vegetative cover, including the following:

- Cut-and-fill operations designed to smooth landscapes for installation of panel arrays may remove significant quantities of topsoil and subsoil materials from some areas, exposing subsoil materials that are more stony, more compact, and have lower levels of plant-available nutrients and a lower water-holding capacity than the original soil.
- Filled areas typically exhibit (a) compaction and (b) a lack of soil structure, both of which are likely to increase runoff and erosion, and result in less moisture infiltration and poor aeration within the rooting zone.
- South and west-facing slopes – while desirable from a solar power generation perspective – will be hotter, particularly during the growing season. When such aspect effects are combined with problems of compaction, poor aeration, and reduced water-holding capacity, poor establishment and drought stress of the plant cover is likely to occur.
- During the course of normal USS construction activities, even those areas in which little grading has occurred are likely to undergo soil compaction within the rooting zone. This issue is likely to be even more severe in landscapes which were formerly in forest cover (as opposed to pasture), as logging, clearing, and yarding and loadout activities will already have produced the potential for considerable degradation of the soil resource.
- Finally, the close spacing of panel arrays and restrictions on deep soil cultivation imposed by buried infrastructure severely limit the kinds of tillage practices that can be used in mitigating the worst effects of pre- and post-construction soil disturbance once the arrays are in place.

Different equipment is available that can help to ameliorate compaction and other soil-disturbance-related effects of USS construction and operation. This appendix details some of the options, along with their specifications and potential limitations.

Small footprint equipment options for working in tight spaces

In buffer areas *outside* of the panel arrays, contractors have a wide range of tools available to deal with soil remediation and revegetation problems – much of it adapted directly from the highway maintenance, agricultural, and forestry sectors. As utilities and contractors are going to be quite familiar with this class of equipment, we will not focus on those options here.

However, whatever soil and revegetation issues might occur in the buffer areas, problems are likely to be even more extreme within the panel arrays, given the range of construction activities to which these areas have been subjected. Compounding the problem of how to revegetate and maintain these areas are constraints imposed by the presence of power-generating infrastructure – narrow alleyways, buried or suspended cable arrays, etc. – that make it harder to deal with problems of soil remediation and revegetation.

These limitations necessitate the use of a smaller scale of equipment, one that may even require working at a slower pace. This equipment needs to (1) be useful in helping us to establish and maintain a healthy vegetative cover and (2) when properly operated, not present an undue risk to the power-generating infrastructure. To this end, we've attempted to put together a suggested summary of equipment that might be useful for establishing and maintaining the post-construction vegetative cover.

These mentions should not be viewed as recommendations, either of classes of equipment or of specific products. The goal here is simply to make others aware of equipment that is available, and which *may* prove suitable given the restrictions and compromises inherent in revegetating and managing USS sites. It should be understood that only time and experience will show whether the equipment mentioned here is useful to the industry.

As space constraints may override other considerations, we will begin with the smallest-scale equipment, then explore progressively larger and more expensive options.

Smallest Scale: Two-wheeled tractors

Two-wheeled tractors, aka "walking tractors", look much like the familiar garden tiller but are larger and more powerful and are designed to take a wide variety of attachments for specific tasks (**Figure B-1**). They have a power take-off (PTO), which can power front- or rear-mounted attachments by rotating the tractor's handlebars 180 degrees. Most have engines in the 5 – 15 HP range (several machines run up to 20 HP). Gasoline engines are most common, though some diesel-powered models exist. Two machines that are available for sale in the US are the BCS and the Grillo, both manufactured in Italy but supported by a U.S. dealer network.

As these machines take a variety of PTO-powered implements, have reversible handlebars allowing for front or rear attachment of implements, and can be operated in tight quarters, they may have some application in USS land management. We are not aware of anyone making use of these machines at this time but as some rentals are available, it may be possible to trial these machines in a USS setting. Note: despite the "friendly" appearance of these machines, they can be challenging to handle and – as with any piece of powered equipment – require operator training and experience to ensure safe and effective use.

Figure B-1. BCS Model 853 with Power Harrow attachment. Photo credit: BCS America.

Tractor Dimensions	HP	Pricing, New	Attachments	Comments
18 – 30 inches wide (tractor) Attachment width varies but likely exceeds tractor width.	5 - 15	$3000 - $10,000, tractor only. Attachments are sold separately.	• power harrow • brush/sickle bar/flail mowers • subsoiler (1 shank) • rotary tillers	Adapted to tight spaces. Forward and Reverse gears. Front or rear PTO. Limited power. Slow and tiring to operate.

Of the tillage attachments available for the BCS tractors, the rototillers and the power harrow are potentially the most useful. While neither will help with subsoil problems (there is a single shank ripper available but it is not practical for use at USS scales), the tillers should be able to overturn the soil surface to a depth of 4 – 6 inches, while the power harrow will work the upper 2 – 3 inches while preparing a seedbed.

Where panel row spacings are extremely narrow (e.g., fixed panel arrays on close spacings), these machines may be one of the few options for mechanized equipment. But, while they may have value for spot tasks regardless of panel spacing, their inherent limitations – limited power, Exslow operating speeds and operator fatigue – will likely make them a solution of last resort.

Sub-Compact Landscape Tractors: Ventrac™ and similar

The sub-compact landscape tractors class of machines is larger, more powerful, faster and considerably more comfortable to operate than the two-wheeled tractors. These machines are typified by the Ventrac™ line from Venture Products, Inc. (**Figure B2**). The Ventracs with their articulating/oscillating frame and all-wheel drive are popular for their maneuverability and their versatility, and for their ability to operate on steep slopes when fitted with dual wheels. Most landscape contractors will be familiar with the Ventrac line and many likely already own one or more units. Additionally, Ventrac is now actively marketing to USS maintenance crews, indicating an interest on the part of the company in developing solutions for USS.

Figure B-2. Ventrac fitted with dual wheels and Tough Cut mower. Photo credit: Venture Products, Inc.

Tractor Dimensions	HP	Pricing, New	Attachments	Comments
Width: 48.5 inches (single wheel), 70 inches (dual wheels). Height: 68" – 54" (ROPS folded). Attachment width varies and may exceed tractor width.	25 – 32.5	$25,000 - $35,000, tractor only. Attachments are sold separately.	• Rotary, flail and finish mowers • Aerators • Rakes • Soil cultivator • Seeder	AWD, can maneuver in tight spaces. Front PTO, optional dual wheels, optional class 1 rear 3 pt hitch. No rear PTO and light weight limit tillage options.

While the Ventracs do not have the weight or the horsepower to manage deeper tillage operations, the manufacturer offers a wide range of soil preparation and planting attachments, including rakes, aerators, cultivators, and planters, making them suitable for jobs requiring light to moderate inter-row tillage, and for spot remediation. Certainly, in areas where space allows them to operate, they will be preferable to the two-wheeled tractors discussed above (more power, faster, much-reduced operator fatigue).

Ventrac's DC520 Cultivator is, according to published specifications, capable of tilling to a depth of 5 inches. This unit should be useful for breaking up surface compaction and it may be sufficient as long as soils are not deeply compacted or too stony (sites in the Atlantic Coastal Plain should be mostly stone-free; sites in the Piedmont or Valley and Ridge are likely to be more stony, particularly in areas where microcrystalline and crystalline quartz veins abound in the bedrock, or where extensive pre-installation grading has removed the upper part of the soil profile exposing weathered bedrock).

Compact Track Loaders

Compact track loaders (CTL) are common in the landscape industry and routinely seen in use at USS installations. While not designed for tillage, their compact size and a good combination of power and weight make them potentially useful for relieving soil surface-compaction when fitted with a proper power-rake or ripping attachment (**Figure B-3**).

Loader Dimensions	**HP**	**Pricing, New**	**Attachments**	**Comments**
Width: ~60" – 80" Height: ~80" - 90"	55 – 115	~50,000 - $100,000+, loader only. Used equipment is widely available and less costly.	• Front-mounted ripper from CL Fabrication is $2500 - $5000.	Heavy weight and high HP make them better suited to shallow ripping of compacted soils than Ventrac.

Figure B-3. Deere 333 CTL with CL Industries XR Ripper. Photo credit: CL Industries.

CTL-mounted rippers are of limited availability; however, these third-party implements have potential:

- Front-mounted ripper from CL Fabrication in Clarinda, IA (note the bi-directional shanks and gauge wheels fitted on CL's XR Ripper; **Figure B-3**).
- A likely more expensive and harder-to-get unit from Australia (rear-mounted, permanently attached).
- Another rear-mounted ripper from Burchland indicates ripping capability to five inches.

In addition, many CTL manufacturers offer their own ripping attachments. Check the manufacturer website for additional information. In addition to front- and rear-rippers, there are front-mounted power rakes and at least one disk harrow being marketed for use with CTLs (**Figure B-4**). Both implements should be work to break up surface crusts and compaction.

Figure B-4. John Deere CTL fitted with power rake. Photo credit: John Deere.

<u>Compact and Utility Tractors</u>

Extensive traffic and grading activities associated with construction of USS infrastructure will inevitably result in a soil rooting environment that is more compacted, more poorly aerated, lower in fertility, and probably more acidic as compared to the pre-construction rooting zone. Where post-construction remediation of *subsoil* problems is needed, the previously-discussed equipment options are going to prove inadequate.

Our long experience with revegetation of highly-disturbed landscapes has demonstrated that deep tillage operations are often needed to restore soil productivity. Deep tillage improves water infiltration, root penetration, and soil aeration. In extreme cases, deep tillage might mean pulling a multi-shank subsoiler with a bulldozer, or large tractor equipped with dual wheels or tracks (**Figure B-5**). Due to space constraints imposed by panels and buried infrastructure, such large-scale deep zone tillage in USS settings is not feasible, except perhaps in buffer areas outside of panel arrays.

Figure B-5. D-8 Bulldozer performing deep rip of tailings in a post-mining landscape. Photo credit: John Lewis.

Where panel row spacing allows, the compact and utility classes of tractors support a wider range of tillage operations, including disruption of upper-subsoil compaction, than do walking tractors, subcompact landscape tractors, or CTLs (**Figure B-6**). In addition, flexible PTO options (front, mid, rear), plus a wide range of available Category 1 and 2 three-point hitch-mounted attachments make these tractors broadly useful for the wide range of planting, fertility management, and mowing tasks that might be required in USS land management (**Table B-1**).

Figure B-6. Kubota L3901 compact tractor drawing a Land Pride FC15 cultivator. Photo credit: Land Pride.

There is no single characteristic that separates compact and utility tractors. Compact tractors are generally smaller, lighter-weight tractors with 4WD, diesel engines in the 25 – 50 HP range, and hydrostatic transmissions. Utility tractors are generally heavier tractors with optional 4WD, diesel engines in the 50 – 100+ HP range and some sort of gear-drive transmission. Owing to their greater weight and power, utility tractors will be more effective when deeper tillage operations are needed (**Figure B-7**).

Figure B-7. John Deere 5E series utility tractor drawing a Frontier tandem disc harrow. Photo credit: John Deere.

Compact- and utility-class tractors are available from many manufacturers including John Deere, New Holland, and Kubota. Implements that can be drawn with this class of tractors are also available from many manufacturers, though we will mention Bush Hog and Land Pride as being two well-known makers of aftermarket implements for compact and utility tractors.

In terms of tillage operations for post-construction USS, tillage depth will inevitably be limited by proximity to infrastructure. Deep ripping will be impractical due to the dangers of encountering buried infrastructure and the large size of the tractor needed for such ripping operations. However, where subsoil compaction is suspected, shallower ripping with a smaller tractor could be an option. Manufacturers recommend 30 – 50 HP per shank (see this 1 – 3 shanked subsoiler from Brillion). Space permitting, a medium to large utility tractor drawing a 2- or 3-shank subsoiler could rip alleyways between panel rows to a depth of approximately 15 inches, if so permitted by the operating utility.

When ripping to 15 inches is impractical or unneeded, shallower tillage in the range of 5 - 10 inches can be achieved by chisel plows (**Figure B-8**), field cultivators, and disk harrows of various configurations. At the shallow end, field cultivators (such as the Land Pride FC15 shown in **Figure B-6**) can break up surface compaction to a depth of 2 – 4 inches. Some field cultivators can till, level and finish the soil surface in one pass (**Figure B-9**). Note that the 2 – 4 inch depth is at the *upper* limit of what can be achieved with implements drawn/driven by walking tractors, subcompact landscape tractors, or CTLs (see **Table B-2**).

Figure B-8. Agricultural chisel plow utilized to remove grading related compaction from a mineral sands mining site in eastern Virginia. The shanks are spring loaded to deflect up when rocks or woody debris are encountered and can be adjusted to rip from six to more than twelve inches. Photo credit: W.L. Daniels.

Figure B-9. Image of Perfecta 12 Field Cultivator in use on an acid sulfate soil remediation site in northern Virginia. This implement was utilized to successfully mix agricultural lime > 50 tons/acre of agricultural lime to a depth of six inches on a 3:1 slope. Similar models are available in variable widths and allow for tillage, leveling and soil surface finishing in one pass. Photo credit: W.L. Daniels.

Specialized Vineyard and Orchard Tractors

Specialized vineyard and orchard tractors are sub-classes of compact tractors were developed to manage high-density orchard and vineyard plantings, first in Europe and more recently in the U.S. and Canada. To our knowledge, this class of tractors, along with specialized tillage and mowing equipment developed specifically for use within the tight confines of vineyards and high-density orchards plantings, is largely untested for USS land management. However, because these tractors and associated implements were developed to operate in tight spaces and steep terrain, we feel they merit special mention.

Some of the better-known manufacturers of tractors for the U.S. market (e.g., John Deere, Kubota, etc.) offer narrow models for working in tight spaces (**Figure B-10**). As with the more conventional compact- and utility-class tractors, these machines are outfitted with a standard PTO and a Category 1 or 2 three-point hitch, allowing them to use the majority of tillage and planting implements available for other small tractors.

Figure B-10. John Deere Narrow 5GV utility tractor mowing between closely-spaced vineyard rows. Photo credit: John Deere.

Of the small form, narrow-track tractors in this class, some of the more interesting and highly-developed are those that come out of Italy. The Italian tractors share some features with narrow tractors from other brands (narrow track, high HP and weight in a small form factor), but also offer some unique options not seen in other small tractors, such as articulating/oscillating frames and equal-size wheels/tires for increased traction and added stability (**Figure B-11**). Additionally, some models feature a reversible operator station, allowing the tractor to be driven forward while powering either "front" or "rear-mounted" attachments from a single PTO. In the U.S., importers of such machines include Antonio Carraro US and Ferrari Tractor.

Figure B-11. Italian-built Carraro TGF 8900R tractor being operated in a steeply sloping vineyard. Photo credit: Antonio Carraro.

The biggest obstacles to the adoption of these machines by USS contractors are likely to be their unfamiliarity to landscape professionals, their limited U.S. distribution, and the cost of purchase, parts, and maintenance. We have included them here because they are small, powerful machines adapted to working in tight spaces on steep slopes. Additionally, they are well matched with some unique pieces of equipment that the USS industry should be aware of, such as this hydraulically-actuated swing arm mower from Fischer of Tramin, Italy, capable of mowing under and around sensitive infrastructure (**Figure B-12**).

Figure B-12. Fischer rotary mower with hydraulically-activated swing arms for mowing under grape vines. Photo credit: Fischer.

References

1. Tillage Implements, purpose and ideal use. University of Minnesota Extension. https://extension.umn.edu/soil-management-and-health/tillage-implements-purpose-and-ideal-use
2. Terminology and Definitions for Agricultural Tillage Implements. ASAE S414.1 FEB04. https://efotg.sc.egov.usda.gov/references/public/ME/tillage_implements.pdf
3. Tillage Equipment, Pocket Identification Guide. April 2017, USDA. https://downloads.snapplus.wisc.edu/nrcseprd1323703.pdf
4. Tillage implement design and its effect on soil. Iowa State University Extension. https://crops.extension.iastate.edu/encyclopedia/tillage-implement-design-and-its-effect-soil

Table B-1. Summary of compact and utility tractor options.

Tractor Class	Example	Key Specifications†				Comments	Attachments
		Width* (in)	Height w/ ROPS** (in)	Weight (lbs)	HP (engine)		
Compact	Kubota L3902	55	91.7	2767	37.5	Kubota's L Series of compact tractors from 24.8 – 48.4 HP, HST or gear drive trans, 2WD or 4WD.	Fitted with standard or narrow CAT 1/2 3-pt hitches and 540 RPM PTO. Available implements include: • Tillage • Seedbed preparation • Planting • Liming/Fertilizing • Mowing Available attachments include standard implements for agriculture and landscape industries, plus attachments developed specifically for managing high-density orchard and vineyards.
Utility	John Deere 5090E	83	100	7275	90	Deere's 5 Series utility tractors from 50 – 130 HP, gear drive trans, 2WD or 4WD.	
Specialized Utility	John Deere 5105ML Narrow	62	67.3	8740	105	Deere's Low Profile and Narrow Series Specialty Tractors from 25 – 130 HP, gear drive trans, 2WD or 4WD.	
Italian Specialized Utility	Antonio Carraro TGF 8900R	56	91.6	5100	74	Carraro compact and utility models from 25 – 75 HP. Some models with articulating frames, equal-sized tires or tracks, reversible operator stations. 4WD only.	

† Only intended as a rough guide. Check manufacturer specifications.
* Width approximate and dependent upon tire size.
** Height with foldable ROPS fully deployed.

Table B-2. Summary of compact- and utility-tractor drawn tillage options for USS alleyways.

Implement	Key Specifications†		Examples for use with Compact/Utility Tractors
	Approx tillage depth (in)	**HP Requirement**	
Subsoiler	12 – 15+	30 – 50 HP per shank	Primary tillage implement. Requires larger utility tractor but some 1- and 2-shanked subsoilers available for compact or small utility tractors. • Brillion's 3-shanked SCP-33 / SCPH-33 is rated for a 20 – 40 HP per shank (not to exceed 40 HP). • John Deere video of Frontier 3-shank subsoiler hitched to a 125HP 5 series utility tractor. • Bush Hog model spec'd as 35 HP per shank.
Chisel Plow	6 – 12	10 – 15 HP per shank	Primary/secondary tillage implement. Similar to field cultivator but with heavier frames and tines for deeper soil penetration. Compact/utility models mounted on the 3-pt hitch, with or without gauge wheels. • Brillion says 10 – 15HP per shank, max depth to 12 inches. • Bush Hog All-Purpose Plows for 25 – 65+ HP. • Land Pride SF25 Scarifier for 25 – 50 HP tractors.
Disc Harrow	4 – 8	8 – 10 HP per foot	Primary/secondary tillage implement. Compact/utility tractor models: • Bush Hog Lift or Pull Disc harrows with widths from 5 – 12 feet. • Land Pride DH15 Disc Harrows with 60 – 90 in, use up to 65 HP. • Frontier Disk Harrows with 4 – 12 ft. widths, use up to 80 HP.

Rototiller	4 – 6	6 – 10 HP per foot	Primary/secondary tillage implement. Slower travel speed, likely higher maintenance due to machine complexity, than other tillage options. • Land Pride RTA35 models for to 95 PTO HP tractors • Bush Hog RT models for 25 – 90 PTO HP tractors
Field Cultivator	2 – 4	5 – 8 HP per foot	Secondary tillage implement. Similar to chisel plow but lighter frames and tines for surface cultivation. Models for use with compact/small utility tractors. • Land Pride FC15 for tractors to 50 HP. • Frontier Field Cultivator, 6 ft width for 25 – 45 HP tractors. • Bush Hog row-crop cultivator for 25 – 45 HP tractors.

† Only intended as a rough guide. Check manufacturer specifications.