<u>**Research Proposal**</u>

Determining Impacts of Utility-Scale Solar on Stormwater Runoff and Soil and Water Quality and Providing Design Criteria

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Executive Summary

Development of utility-scale solar (USS) energy installations across the Commonwealth of Virginia will likely impact several hundred thousand acres of land in various uses (e.g., agriculture and forestry) over the next twenty years. The conversion of existing landscapes to USS poses many questions for landowners, local planners and officials, regulators, non-profit organizations (NGOs), and the industry, with a dominant concern being the potential for greater runoff flows and increased sediment and nutrient losses. We have worked collaboratively with a wide range of partners on similar issues related to urbanization, mining, and road/utility corridor development since the 1980s. Here we are responding to the Request for Proposals (RFP) issued on February 2, 2023 by the Virginia Department of Environmental Quality (DEQ) to develop a new integrated research program that addresses current and future questions associated with USS development. Our program will document actual USS runoff from six sites, evaluate and fit models to multiple monitoring locations ($n \geq 6$) at each site, and develop new site-specific stormwater and soil management approaches for USS development in Virginia. Additionally, we will address recent policy issues, including (a) the relative imperviousness of solar panel arrays and (b) the assignment of appropriate curve numbers (CN) in commonly utilized stormwater compliance tools, such as the Virginia Runoff Reduction Method (VRRM). This work will produce more accurate estimates for stormwater volumes and nutrient loadings from USS sites.

We have commitments from multiple cooperators (AES, Dominion, Energix, and Urban Grid) to assess and select three fully developed/revegetated sites for this study along with three sites that we will monitor from pre-development through at least three years following stabilization. All study sites will have appropriate controls located in close proximity and representing similar conditions as the solar installations. Our cooperators have pledged a minimum of $250,00 of in-kind services and $338,000 of cash match to enhance our research efforts. Final research sites will be selected based on region, topography, expected future USS development, and other factors, and will be approved by DEQ. Each monitoring location will be instrumented to collect continuous data on rainfall, surface water level, air temperature, and specific conductance (SC), as well as flow-weighted composite samples from individual storm events. Samples will be analyzed for pH, sediment, nitrogen and phosphorus forms, and other parameters of interest.

In addition to the short-term and applied data collection and analyses described above, this study also has a substantial underlying basic research objective, which is to develop and verify a site-specific runoff model applicable to Virginia conditions. This effort will be executed as an integrated Virginia Tech and Virginia State University research program that will also produce substantial added value for our outreach programs. Our combined research team is clearly the most qualified group in the Commonwealth to address this RFP. We propose to conduct the research program for a total cost for DEQ of $3.48 M over a six-year extended research period.

This study will be one of the largest to provide land use-specific runoff data since the National Urban Runoff Program (NURP) study in the 1980s. Our efforts will provide data that can potentially be generalized and applied to other land uses such as active construction, managed turfgrass, natural areas, etc. We look forward to the possibility of working with DEQ and our industry cooperators on this important study.

Introduction and Overview

Development of utility-scale solar (USS) energy installations across the Commonwealth will likely impact several hundred thousand acres of land over the next twenty years. While the conversion of existing landscapes to USS poses many questions for landowners, local planners and officials, regulators, NGOs, and the industry, the dominant concerns are related to understanding whether these installations have the potential to increase runoff and nutrient and sediment losses at the landscape scale. These risks are closely associated with site development impacts on local soil and landform conditions, as well as how soil and vegetation quality respond during site stabilization and subsequent operations. A related longer-term issue is whether the industry can return lands to their pre-disturbance condition once the infrastructure is removed.

Hydrologic models such as the Natural Resources Conservation Service (NRCS) TR-55 and related compliance tools such as the Virginia Runoff Reduction Method (VRRM) are used to size stormwater basins and other best management practices (BMPs), and can be applied to estimate the risk of major storm-related failures and releases (Hirschman et al., 2008). Current policies and regulatory proposals are focused on the need for the industry to address the relative imperviousness of panel arrays in modeling predictions along with mitigation of overall impacts to prime farmland and forest productivity over the long term. There is a wide range of stormwater, sediment, and nutrient runoff/loss models that can be used for these purposes, but no published studies to date have compared, validated, and calibrated these models with actual site-specific USS stormwater discharge measurements in the mid-Atlantic region. Therefore, the accuracy and applicability of these models to Virginia remain poorly understood.

Our team has worked collaboratively with a range of partners on similar issues related to urbanization, mining, and road/utility corridor development since the 1980s. Here we are responding to the Request for Proposals (RFP) issued on February 2, 2023 by the Virginia Department of Environmental Quality (DEQ) to develop a new integrated research program that addresses current and future questions associated with USS development. In addition to responding to the RFP's objectives, we will also address a range of recent policy issues including (a) the relative imperviousness of solar panel arrays and (b) the assignment of appropriate curve numbers (CNs) in commonly utilized runoff models, including VRRM. This study will be one of the largest to provide land use-specific runoff data since the National Urban Runoff Program (NURP) study in the 1980s (Schueler, 1987; USEPA, 1982), and will provide data that can likely be generalized over to other land uses such as active construction and managed turfgrass sites.

Over the past two years, we have worked with an array of USS site developers and their consultants, landowners, local planners and officials, and the regulatory community to better understand the full range of issues addressed by the current DEQ RFP. As documented in the "Industry Support" section and in our attached letters of support, we have firm commitments from the private sector for site access along with significant in-kind and cash contributions. While we are open to expanding our proposed scope of work to additional sites and cooperators beyond what is described in this proposal, we are confident that the current scope of work and requested budget from DEQ are both sufficient to meet the research objectives described herein.

Research Objectives

1. **1.** Establish a replicated network of permanent stormwater flow and water quality monitoring points at multiple USS facilities in Virginia.

2. Quantify the effect of USS development on important soil quality parameters such as infiltration and runoff partitioning, soil aggregation and bulk density, and associated internal soil drainage and permeability.

3. Analyze differences in the spatial variability of important soil properties related to extent, depth, and type of soil disturbing activities.

4. Compare actual site-specific data for runoff parameters with available and utilized compliance tools and resources.

5. Provide numeric recommendations for (a) VRRM runoff factors for Total Phosphorus (TP) and Total Nitrogen (TN) per acre per year for the studied land cover types, and (b) recommended CN adjustments for soil type and land cover based on the range of design and construction practices found in USS facilities that can be used in models like TR-55.

6. Determine whether available or modified compliance tools and resources can provide accurate predictions of stormwater responses across varying site conditions. If such tools are insufficient, recommend revisions or alternatives.

Study Framework and Methods

Working with our committed USS site developers and consultants, we will first review the range of potential study sites that have been made available (see Table 1 and Appendix A) and evaluate them based on size, status (e.g. planned vs. developed), and soil/landform/hydrologic conditions. Per the RFP requirements, we will select a minimum of three sites each that meet the following criteria:

A. Fully established, revegetated, and operating sites where weather and runoff data can be collected and compared to original modeling efforts and to alternative models. Data collected from these sites will provide cooperators with initial useful results in ≤ 1 year.

B. Sites where monitoring systems can be installed pre-development and then carried through the full development process of construction, stabilization, and operations. This effort will necessarily be longer term (3-5 years), but the initial data will be made available to industry cooperators following initial QA/QC to better inform their current stormwater and erosion and sediment control (ESC) modeling efforts.

Under both scenarios, we will monitor multiple sub-catchments (locations) within each site along with nearby control drainage areas that are not impacted by USS. We anticipate selecting three sites representing each scenario (Category A vs. B). Full deployment of the field monitoring networks described here will involve six total sites and up to seven individual monitoring locations per site, as described in the following sub-sections.

The final selection of sites will occur within 90 days of receipt of funding from DEQ and will be based on the following criteria:

- Relative geographic location (e.g., Coastal Plain, Piedmont, or Valley & Ridge) as related to existing and projected USS development.
- Local site topography (e.g. well-expressed surface drainage) to allow for the installation of monitoring equipment without extensive site disturbance beyond that associated with normal USS site development.
- Availability of suitable adjacent or nearby relatively undisturbed areas for the establishment of control sites.
- Quality of existing vegetation cover for Category A sites.
- Appropriate timing of access for Category B sites.
- Extent and quality of pre-development permitting data, hydrologic reports and modeling information, and consultant cooperation.
- Presence of either potential acid sulfate soil materials or karst features.

Following our initial review process, the final six sites (or more) that we determine to best meet the above criteria will be submitted for approval by DEQ. Detailed field assessments will begin within two weeks of DEQ's concurrence and receipt of financial assurances. Initial monitoring equipment (e.g., hydraulic controls and continuous sensors) will begin being installed within 60 days of site approval and confirmation by site cooperators

We presume that industry/landowner cooperators will provide on-site support as needed, including access, security, power if needed, and periodic field checks of equipment under emergency conditions. Cooperators may also supply weather data, but we are prepared to install equipment for that as well. Our plan, as detailed below, is to acquire and install all necessary field equipment ourselves. However, depending on the final research coordination arrangements between potential sponsors, regulators, and field cooperators, we are also willing and able to work with data collected from similar equipment installed by cooperators.

Table 1: List of USS collaborators and number of potential sites. A refers to sites that have already been developed and restored; B refers to sites that may undergo USS development during the project duration. Full commitment letters from each cooperator can be found in Appendix A.

Collaborator	**Potential sites**	**Match**	**Sites (only Category A shown)**
Dominion Energy	8 (A = 3; B = 5)	Cash ($250,000) In-kind (≥ $250,000)	Scott Solar (Powhatan Co.) Bedford Solar (Chesapeake) Spring Grove I Solar (Surry Co.)
Urban Grid	4 (A = 0; B = 4)	To be considered	NA at this time
AES Corporation	2 (A = 1; B = 1)	To be considered	Skipjack Solar (Charles City Co.)
Energix	7 (A = 3; B = 4)	Cash ($88,000) In-kind ($TBD)	Hollyfield (King William Co.) Mt. Jackson (Shenandoah Co.) Rives Road (Prince George Co.)

Several cooperators (i.e., Dominion and Energix) are offering significant in-kind and cash matching for this proposal beyond the direct DEQ budget associated with this proposal. Two other cooperators (AES and Urban Grid) have pledged potential sites for review and inclusion in the study and will consider matching support if one or more of their sites are chosen for final study. We will utilize these matching funds to (a) improve basic field monitoring to include turbidity, (b) assess other water and soil quality parameters of concern, and (c) increase the intensity of field operations for site visits for soil quality and better documenting how temporal changes in soil and plant systems affect runoff parameters over time.

Monitoring Efforts

Field Monitoring Design

We will establish six research sites, with three representing each of the monitoring scenarios (**A** – developed/revegetated and **B** – pre- through post-development). Each site will be sufficiently large and contain minimal slope/drainage conditions to support the design and objectives. We will install a minimum of six monitoring locations at each site.

We propose to instrument three stormwater runoff locations within each primary USS project site along with three matching locations in a nearby undeveloped control/reference area. In some instances, one or more of these control areas may be inside of the USS facility boundary if the area is part of an undisturbed buffer. As needed, Virginia Tech and Virginia State University will work with local Cooperative Extension personnel and other local contacts to approach neighboring landowners for access to control locations. Depending on local site conditions, we may also establish another monitoring location at the inlet of existing stormwater basins at the active USS site. Thus, the total monitoring design will require up to 42 complete field equipment and instrument arrays.

We will install a hydraulic control (i.e., weir or flume) at each identified monitoring location (Figure 1), and we will develop rating curves to estimate flow as a function of measured water depth. Surface water level and specific conductance (SC) will be monitored in each hydraulic control. We will also instrument each location to collect data on rainfall, and will measure air temperature at each site if not available from site cooperators. Depending on availability of matching funding, we will also deploy other continuous sensors (e.g., nitrate-N). Data will be collected at sufficiently high resolution (e.g., every 15 minutes) to capture intra-storm behavior. Depending upon the location, data will be made available via a cell phone connection; otherwise, data will be stored on-site and downloaded periodically (at a minimum monthly).

Each monitoring location will be instrumented to collect flow-weighted event samples, which will be analyzed for pH, total suspended solids (TSS), and nitrogen and phosphorus forms. Auto-samplers will be typically used to collect composite samples when the following conditions occur: (1) rainfall depth greater than 2.54 mm in 30 minutes, and (2) an increase in water level. Samples will be collected in a 15-L polyethylene bottle. The analysis sample will be gently shaken to be uniformly mixed and then subdivided into the analysis containers using a U.S. Geological Survey Churn Splitter. Additionally, within-storm samples will be collected to assess constituent behavior across the storm hydrograph (pollutograph); this information can be used to assess the potential of a first flush, and/or build-up and wash-off of pollutants. However, these campaigns require a much larger sample count (i.e., as much as 10-15 times the number of samples), so they will only be performed on a limited number of locations and storms.

During the first full year of the project (2023/2024), we will focus on installing the automated water quality collection apparatus at one site representing each scenario (e.g. 2 sites x 7 installations = 14 monitoring locations). Assuming we can collect 20 to 30 event samples per year, we will split the samples and test two handling protocols. In the first procedure, samples will be filtered, analyzed for TSS, pH, and SC, and then preserved through freezing. The samples will then be shipped to an on-campus laboratory at Virginia Tech for nutrient analysis and other measurements as needed. For the second protocol, samples will be sent to a Virginia Environmental Laboratory Accreditation Program (VELAP)-certified lab following current U.S. Environmental Protection Agency (EPA)/DEQ protocols, including relevant hold times, etc. We will then statistically compare all parameters between datasets to decide which lab protocols will be followed while expanding water quality sampling to all monitoring locations (up to 42 total).

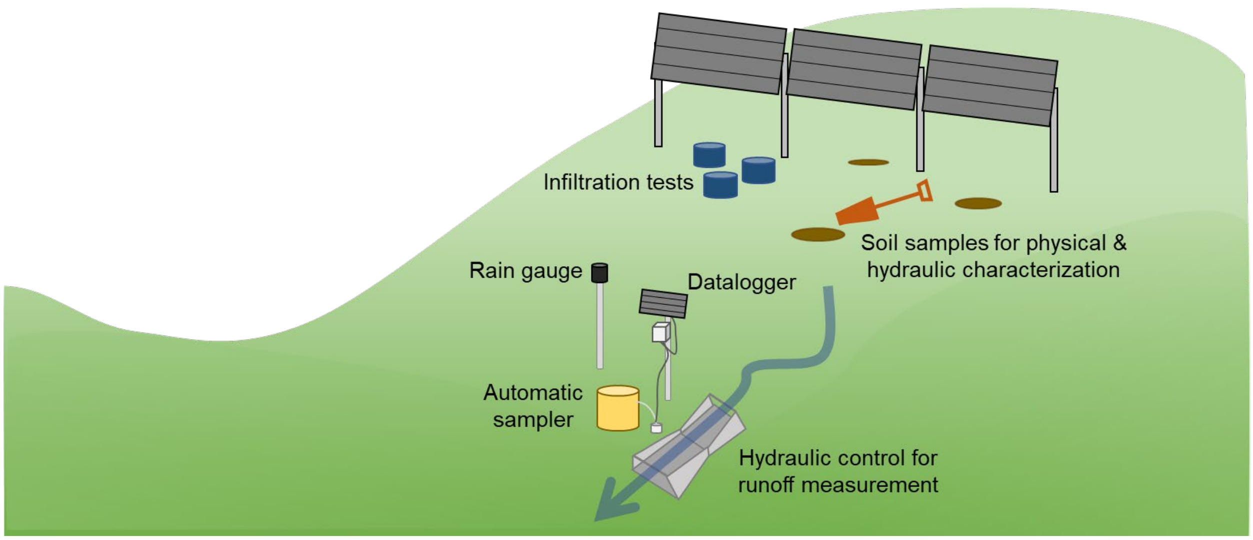

Figure 1. Example of planned instrumentation and sampling at a USS monitoring location.

Soil Quality Monitoring

In addition to monitoring stormwater parameters as described above, we will quantify the extent of soil disturbance, overall vegetation cover, and rooting depth in the areas within and outside (controls) of the USS systems being monitored. These efforts will include the following parameters (at a minimum) within each monitoring sub-catchment:

- The extent of disturbance to original soil morphology and horizonation due to cut/fill, grading, and trenching
- Soil bulk density with depth and as influenced by panel arrays & installation
- Surface and subsoil soil texture and aggregation
- Infiltration measurements using surface-placed single-ring infiltrometers (with multiple ponding depths) and subsurface saturated hydraulic conductivity (K_{sat}) using borehole permeameter tests at a minimum of two depths per location.

While the exact number of measurements in each monitoring location will depend on the local conditions (e.g., soil series, topography), we intend to collect sufficient measurements to quantify spatial variability of these properties in areas with USS versus the adjacent controls (Category A sites), as well as if and how spatial variability of these properties changes during the construction, stabilization, and operations phases of USS projects (Category B sites). These data will also be used to inform modeling efforts that will be the focus of the later phases of the project. With sufficient USS cooperator support, we will also analyze soil organic matter and aggregation along with changes in important soil fertility and quality parameters over time and assess short-range spatial variability under and between panel rows. These parameters can influence soil erosion processes and related water quality impacts.

Vegetation Assessment

The percentage of vegetative cover, near-surface stem density, and species composition will be documented and quantified at each monitoring location. Because our experimental design includes revegetated versus relatively undisturbed controls (Category A sites) and changes during site development and stabilization (Category B sites), we will be able to document how USS installation and revegetation efforts influence vegetation type and density. These data will also be used to validate rainfall interception, sediment detachment, and vegetative resistance to sheet flow modeling parameters and assumptions. If sufficient matching support is available, the vegetation monitoring efforts will be enhanced to include seasonal yield/biomass accumulation, total N and P uptake estimates and relative effects of soil and moisture differences on vegetation assemblages under and between panel rows.

Runoff Modeling Efforts

Note that the monitoring approaches described above are designed to directly provide the data necessary to address and meet the RFP objectives. These data will also be used to improve runoff modeling for USS installations in Virginia, using a process known as “model-based design”. As detailed in the following sub-sections, our modeling effort will have four phases: 1) use the monitoring data to assess the relative impact of USS on local discharge point water quality, 2) evaluate hydrologic/water quality models and compliance tools for applicability to Virginia USS sites, 3) calibrate and verify one or more site-specific runoff models using collected monitoring data, and 4) adapt the runoff model(s) for use in design settings. Because our approach relies on data collected under realistic field conditions at a large number of locations, we expect that the site-specific runoff model will be superior to current design storm methods or generalized annual loading equations based on limited historical data.

Evaluation of VRRM and similar compliance tools

A major component of this project is to use the site-specific soil and runoff data collected in the monitoring locations to evaluate existing runoff compliance methods and then generate a site-specific model that is applicable to Virginia conditions. We envision a two-pronged approach for these efforts. In the short term, we will share site-specific data with each of our USS industry cooperators. We will work with these cooperators and use these data sets to evaluate the relative accuracy of existing runoff models, compliance tools, and design approaches (e.g., VRRM, TR-

55) for each site, determine whether they require improved calibration with respect to issues such as relative imperviousness, and evaluate curve number (CN) assignment and disconnected flow assumptions. As part of this effort, we will also evaluate other runoff or CN estimation models such as the PV-SMaRT model developed by the University of Minnesota and NREL (Great Plains Institute, 2023). This suite of model outputs will provide short-term project results and allow us to translate important runoff data and insight for our cooperators operating in Virginia.

The Virginia Stormwater Management Program (VSMP) requires that BMPs must be assessed for compliance using VRRM or equivalent methods. The VRRM uses the NRCS TR-55 method to estimate runoff for a water quality storm event, expressed as an equivalent depth across a delineated drainage area. The VRRM modifies the TR-55 method by subtracting retention storage provided on-site, then back-calculating a modified CN for use in estimating runoff from each drainage area. For our purposes, we can ignore retention storage, as the drainage areas (sub-catchments) we will select are upgradient of any BMP.

For our first effort, we will develop an initial VRRM assessment for each monitored location. We will work with project partners to collect site data and will otherwise use statewide and local sources of geographic information system (GIS) data. Upgradient catchment areas will be delineated using digital elevation models (DEMs), other available topography, and aerial photography. Site imperviousness will be estimated using site design information to the extent available, and aerial photography when necessary. Soil physical and hydraulic properties will come from our analyzed samples, and will be completed as necessary using Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) data. We will augment our locally collected rainfall and air temperature data using cloud cover and solar radiation measurements from nearby National Climatic Data Center (NCDC) weather stations. The datasets gathered on each site will also be compared to any original runoff and water quality predictions previously developed during the permitting processes.

Initial assumptions for pollutant loading of TSS, N, and P will be estimated using the well-known “Simple Method”; which depends mainly upon imperviousness and the event mean concentration (EMC) for the pollutant of interest. Initially, we will use the NURP EMCs, which for Virginia are 1.86 mg/L for TN, 0.26 mg/L for TP, and 62 mg/L for TSS. Since the VRRM and TR-55 methods use a design storm approach, we will select an observed storm event that closely matches the selected design event. We will compare reproduced hydrographs and compute the mass load of sediment nitrogen and phosphorus from our monitoring data.

After performing this initial characterization, we will develop recommendations to adjust loading factors within VRRM and TR-55. For this effort we will vary inputs, including CNs, relative imperviousness, soil hydrological group, and EMC values for TN, TP, and TSS. Parameters will be adjusted until obtaining closest possible matches to observation data (e.g., runoff quantity and water quality), as evaluated using Nash-Sutcliffe Efficiency (NSE) Percent Bias (PBIAS) and correlation. It should be noted that the EMC concept is essentially a square wave, assuming linearity in wash-off load. Therefore, we will analyze our observation water quality data to identify any nonlinearities in wash-off loading, and then use these results to develop any needed revisions for VRRM loading factors. This work will provide improved runoff factors and CN adjustments that can be used to best represent the soil conditions found within USS facilities.

New site-specific runoff model development

Our longer-term objective is to develop and validate a new site-specific runoff model applicable to Virginia conditions. This model may be a calibrated version of an existing product like VRRM or may have a different underlying basis, but either way will be designed with end users (e.g., USS companies and DEQ personnel) in mind. Candidate models that we will explore include the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS), the EPA Storm Water Management Model (SWMM), HYDRUS-2D, and K2/O2 (Kineros2-Opus2), 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. HYDRUS-2D solves the coupled Richards and Advection-Dispersion Equations to depict water and solute movement, and was used to develop the PV-SMaRT model. 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. Where needed, integrated groundwater-surface water models such as Wetbud and Hydrus 3-D will be used in tandem with others.

The developed model(s) will be calibrated by manipulating model parameters within acceptable ranges to achieve the best fits between modeled and observed hydrologic and water quality data. Model fit will be evaluated using NSE, PBIAS, and correlation. Verification will then be performed by running the calibrated model on a new set of data without adjustment. Once validated, the site-specific runoff model(s) will be used to explore alternative scenarios such as establishing predevelopment conditions (if not observed prior to this study), retirement at the end of the design life, and implementation of various BMPs and landscape management practices as a form of model-based design.

Data Quality Assurance, Confidentiality, and Related Issues

All aspects of the field data acquisition, laboratory analyses, and data management and security components of this study will be governed by a rigorous QA/QC protocol approved by all cooperators. We will also develop clear agreements with sponsors, site owners/operators, and cooperators regarding the timing and release of any site-specific information, data, and findings. This step will be particularly important since multiple private sector cooperators along with the DEQ and our VT/VSU university research team will be involved at each site.

Initial data sets from each site will be shared with site cooperators. Revised datasets will be shared after final QA/QC. Overall project-wide results and interpretations will be shared with DEQ at progress meetings. Site-specific findings and data will not be released to DEQ, or the public, until they are reviewed and approved by each site operator. If necessary, more detailed site data and results may be released with actual site locations kept anonymous (e.g., as part of student dissertations) until release of this information is mutually agreed upon.

Project Organization and Personnel Experience and Qualifications

This project will be executed as an integrated Virginia Tech and Virginia State University research program that will have substantial value to relevant stakeholders, including DEQ, the USS industry, and local landowners. Overall technical supervision, site-specific measurements (e.g., infiltration, runoff, soil quality parameters), and associated modeling efforts will be led by Ryan Stewart (https://spes.vt.edu/faculty-staff/faculty/stewart-ryan.html). Soil disturbance studies along with field site and agency liaison will be provided by W. Lee Daniels (https://spes.vt.edu/faculty-staff/faculty/daniels-lee.html). David Sample (https://www.bse.vt.edu/people/faculty/david-sample.html) will lead our efforts on modeling stormwater flows and local water quality impacts. Overall statewide interactions with VT/VSU Extension resources and field equipment support will be led by John Ignosh from our Harrisonburg office (https://www.bse.vt.edu/people/faculty/john-ignosh.html). Field assessment of vegetation, soil quality, and disturbance interactions over time will be coordinated and supervised by Vitalis Temu (https://www.vsu.edu/agriculture/faculty-staff/temu-vitalis.php) at Virginia State University. Maru Kering (https://www.vsu.edu/agriculture/faculty-staff/kering-maru.php) will assist in vegetation characterization and interpretation. Curriculum Vitae for each Co-Principle Investigator (Co-P.I.) are presented in Appendix B.

Our combined research team is clearly the most qualified group in the Commonwealth to address this RFP. Ryan Stewart has been lead P.I. on several recent studies including a project funded by the USDA National Institute of Food and Agriculture focused on reducing pollinator exposure to neonicotinoid pesticides used in row-cropping systems. This project required the instrumentation and deployment of a large number of surface runoff collectors, soil pore-water samplers, and soil samples, and the successes and lessons learned in that project will be applied to this USS work. W. Lee Daniels is the leading expert in the Commonwealth on the prediction of human impacts on soil disturbance and productivity and has extensive independent consulting experience evaluating USS site-specific impacts and soil quality risks. David Sample has worked extensively with different hydrological models, compliance, and design tools, including VRRM. John Ignosh recently organized and led a large integrated research/extension program for Virginia Tech known as the “Solar Panel” and has developed a wide array of contacts in the USS realm. Vitalis Temu is the lead researcher in forage agronomy and ecology at Virginia State University and has recently completed work on growth responses of native warm-season grasses to defoliation management while also assessing effects on wildlife habitat quality. Maru Kering is an expert on plant nutrition and crop physiology, crop production and management strategies, plant-soil interaction and nutrient mining. He recently contributed to a grant funded by SARE to improve cover crop and soil health knowledge sharing and networking.

Other relevant experience and accomplishments by our team members include:

- Experience in developing hydrologic models from site to basin scales, with specific expertise in infiltration/unsaturated zone/soil moisture wetting/drying, evapotranspiration, and interflows as well as rainfall-runoff (Alamdari et al., 2022; Stewart & Abou Najm, 2018; Stewart et al., 2019; Stewart et al., 2017; Stewart et al., 2015).

- Success in conducting multiple runoff and water quality monitoring programs over the past 5 years, forming the basis of three Ph.D. dissertations (Nayeb Yazdi, 2020; Radolinski, 2019; Shahed Behrouz, 2022) and two M.S theses (Erwin, 2019; Maris, 2022)
- Experience working with the Virginia Runoff Reduction Method (VRRM) and its underlying algorithms; for example, we incorporated the VRRM procedure into GIS to map the feasible locations of stormwater BMPs across the City of Virginia Beach (Johnson & Sample, 2017), and used VRRM to predicting water quality (TN, TP, and TSS) values (Sample et al., 2016).
- Success in leading a comparison study of 12 sites across the City of Virginia Beach, including development of a SWMM water quality model of each site and comparing site discharge values (Sample et al., 2016).
- Success in aiding the Virginia Department of Conservation and Recreation with conducting the Urban Nutrient Management Training program.
- Experience in grass/vegetation harvest management strategies and impact on soil nutrient losses and subsequent plant performance (Kering et al., 2012).
- Experience in assessment of revegetation success on surface mine-sites and defoliation management of native warm-season grass stands focusing on growth performance and species composition (Lang et al., 2015; Temu et al., 2015; Temu et al., 2022).

Resources Required and Proposed Staffing

We (Virginia Tech and Virginia State University) propose to conduct the research program described herein for a total cost of $3.48 M over a six-year research period. Our detailed budget and justification is presented in Appendix C. Certain major expenses (e.g., equipment) are included near the beginning of the project to maximize data collection. In addition to direct support (~10% FTE) of our Co-Principal Investigators, we propose to support a full-time post-doc and a field technician for the life of the project with Virginia Tech, a half-time laboratory technician for two years near the start of the project (2023 to 2025), and a full-time post-doc for 3.5 years with VSU. Our budget also assumes a Ph.D. student working for the first three years (2023 to 2026), followed by another Ph.D. student for the final 3.5 years of monitoring and research efforts (2025 to 2029). We will support several undergraduate student workers and we have budgeted for supplies, travel, and contractual labwork as needed. All travel and other expenditures will conform to Commonwealth of Virginia protocols and limitations.

As detailed in Table 1, we also have received cash support commitments from several sponsors. Assuming we are successful with this proposal with DEQ, those funds will be administered via separate contracts with each firm, but their expenditures will be connected directly to this project and reviewed periodically with DEQ and our sponsors.

Industry Support

Our group has been working extensively with the USS consulting support community for over three years now. We will take advantage of those connections to assist in this study and to solicit important input on various modeling parameters and assumptions utilized at our research sites.

As documented in Table 1 and Appendix 1, we have firm commitments of sites for consideration and/or combined in-king and cash support for our proposal from AES, Dominion, Energix, and Urban Grid. At this point, we collectively will have access to approximately 7 sites for consideration under Scenario A (established sites) and 13 sites for Scenario B (pre-development).

It is important to note that some of the sites that our cooperators have proposed for Scenario B are not yet fully permitted and approved and we are therefore listing them by approximate location and size only at this time. However, we have reviewed specific location details for the majority of these sites and deemed them as suitable for the initial site review phase of our program.

Additionally, we have total in-kind support commitments of at least $250,000 along with direct cash match commitments of $338,000 that will be contracted separately and allocated as described earlier in the proposal to amplify our monitoring and research efforts. We are also open to adding additional cooperators and sites to this overall study if sufficient matching resources are offered.

Deliverables

We will provide the following deliverables:

- Twenty-four quarterly stakeholder meetings including meeting materials;
- Six mid-year and six annual reports (i.e., 12 reports); and
- One final program report.

As discussed in the "Data Quality Assurance, Confidentiality, and Related Issues" section, we will provide data and interpretation to collaborating USS companies. Project results will likely form the basis of multiple student theses and dissertations, as well as peer-reviewed journal articles.

Project Timeline

Our project will have the following timeline. We assumed that the proposed project would initiate on April 1, 2023 (Q2 of 2023) and would conclude on March 31, 2029 (Q1 of 2029), which may or may not be achievable based on how quickly DEQ is capable of reviewing and approving proposals.

Determining Impacts of Utility-Scale Solar on Stormwater Runoff and Soil and Water Quality and Providing Design Criteria		2023			2024				2025				2026				2027				2028				2029	
		Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
TASK A: Identify and Establish Study Sites																										
A.1	Evaluate Potential Study Sites	■																								
A.2	Develop Monitoring Scenarios	■	■																							
TASK B: Determine Lab Protocols; Collect Data																										
B.1	Deploy Field Staff		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
B.2	Evaluate and Determine Lab Protocols		■	■	■	■																				
B.3	Perform Laboratory Analyses		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
TASK C: Write Handbook																										
C.1	Communicate Data to DEQ		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
TASK D: Evaluate and Calibrate Models																										
D.1	Develop Modeling Scenarios			■	■	■																				
D.2	Run Models					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
D.3	Calibrate Models							■	■	■	■	■	■	■	■	■	■	■	■	■	■					
TASK E: Report Findings																										
E.1	Convene 24 Quarterly Meetings		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
E.2	Prepare Mid-Year and Annual Reports			■		■		■		■		■		■		■		■		■		■		■		
E.3	Prepare Final Report																						■	■	■	

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