Best Management Practices to Minimize Impacts of Solar Farms on Landscape Hydrology and Water Quality

STAC Workshop Report
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STAC Publication 24-001

About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the Watershed. For additional information about STAC, please visit the STAC website at http://www.chesapeake.org/stac.

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Executive Summary

As solar energy becomes a lower cost and more efficient source of renewable energy, major utility-scale solar panel installations, or solar farms, are being proposed and installed around the Mid-Atlantic region. These solar farms constitute a major land transformation. This transformation is particularly of interest because there can be substantial alteration of land characteristics in the development process, and solar farms also create a unique land cover with impervious surface over pervious surface, generating potential changes in hydrologic and water quality processes. There is currently wide variability in guidance and understanding of best practices relating to the land development and management of solar farms in the Chesapeake Bay region. Thus, a STAC-led workshop gathered speakers and participants from universities, industry, non-governmental organizations, and multiple levels of government across the Chesapeake Bay watershed to address the following questions in April 2023: 1) What is the state of science on how solar farms impact hydrology and water quality under a range of site and management conditions and project scales? 2) What are current best management practices and policies, and where in our region are there opportunities for improving recommendations and/or policies? 3) What are the key gaps with respect to research needs to better answer understand the implications of utility scale solar development.

The workshop kicked off by setting the stage on the scale of solar farm development and the associated land use transition in the region. A session on the state of the science revealed limited field research on solar farmland management in our region, and highlighted development of a new runoff calculator tool called Photovoltaic Stormwater Management Research and Testing (PV-SMaRT). Panels were also held featuring regulatory and industry representatives, who shared their experiences, insights, and recommendations on solar farm management practices.

In a final set of breakout sessions, workshop participants synthesized the workshop discussions and drew upon personal expertise to address the following questions: 1) What are key gaps in the current science that is informing best practices? 2) What are key gaps in the current regulatory/development process or guidance? 3) Where are there opportunities for better sharing knowledge/insights/approaches to achieve the best outcome for all?

These presentations and discussions yielded the following identification of key science gaps, best management practices, and recommendations to address gaps. Key science gaps include:

- A comprehensive understanding of how solar farms, as implemented in the Chesapeake Bay watershed region, impact hydrology, water quality, soil health, vegetation, and associated ecosystem services.
- Management practices that can successfully minimize impacts of solar farms on landscape hydrology across the diverse landscape types in our region.
- Solar farm-specific runoff modeling approaches that are validated for our region, to support design of best management practices.

Despite these needs, there is a consensus that key best management practices emerging in our region include:

- Incentivize selection of optimal sites for solar implementation.
- Support soil health through minimizing soil disturbance and removal during solar farm construction process.
- Implement appropriate erosion and sediment control measures during construction, and oversight to ensure compliance.
- Facilitate rapid establishment of perennial vegetation, with consideration of opportunities for other co-benefits (e.g. habitat provision) in the vegetation selection process.

Recommendations to address existing gaps fall under the umbrella of **supporting new field and modeling research on solar farms** as well as **improving information-sharing and coordination** in this space. Specific recommendations are:

- Funding allocation and other means of support for new field and modeling research that is region and state specific, and practitioner relevant.
- Testing and customization of the PV-SMaRT solar farm runoff calculator and other appropriate tools for our region.
- Integration of a solar farm specific land use in the Chesapeake Bay Model.
- Continued industry, academic, governmental, and community collaboration and information-sharing, including a centralized hub for sharing information and data related to solar farm planning, function, and management in our region.
- Demonstration solar farm site(s) with best management practices showcased, opportunities for integrated research, and ability for interaction and/or visibility from the public.

Introduction

As solar energy becomes a lower cost and more efficient source of renewable energy, major utility-scale solar (USS) panel installations, which generate 10 megawatts (MW) or more, are being proposed and installed around the Mid-Atlantic region. Many smaller community-scale systems (< 10 MW) are also being developed; both types are commonly called "solar farms" (US Energy Information Administration (EIA), 2020). As of 2023, there are approximately 6,440 existing major solar projects across the US, with existing installations generating 104 gigawatts (GW), and projects under construction or in development that will generate > 100 GW (Solar Energy Industries Association, 2023). In the Chesapeake Bay watershed, there are already hundreds of existing or proposed projects (Figure 1) with over 140 active sites permitted in Virginia alone.

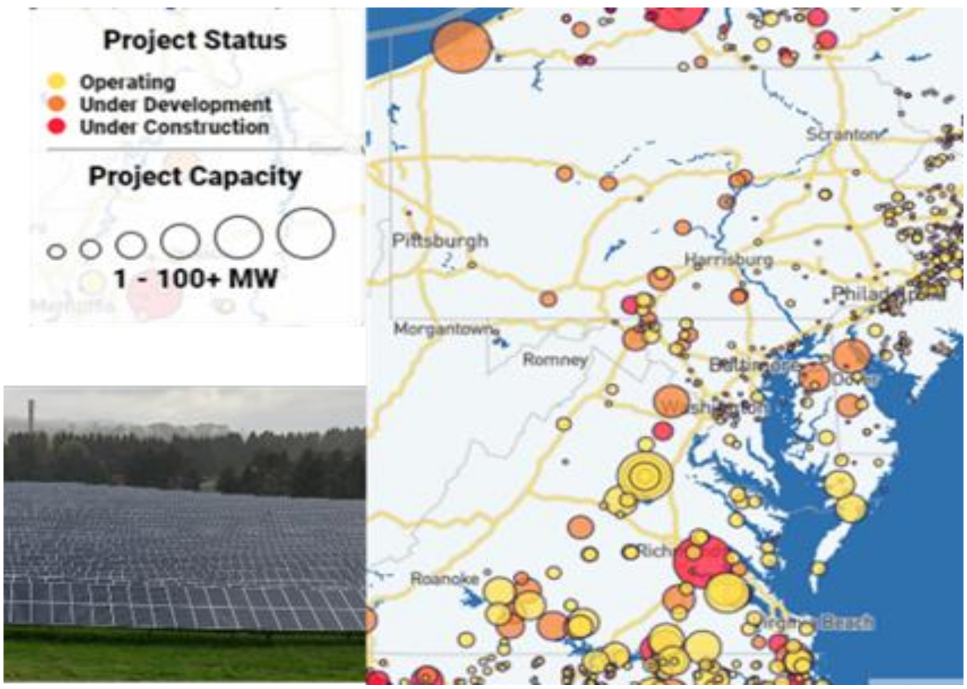

Figure 1. *Map of existing and proposed major solar projects in the mid-Atlantic region (source: Solar Energy Industries Association) with example photo of a utility-scale solar facility.*

Solar farms cover large areas of land (i.e., from tens of acres to greater than 1000 acres). Typical USS sites under review and development in Virginia range from ~20 to >100 MW in projected output. It generally takes ~ 7 to 10 acres of land per MW to fully encompass panel arrays, perimeter buffers, stormwater Best Management Practices (BMPs), access and service roads, and other infrastructure for internal transmission and connection to the grid. Many community-scale systems will affect smaller footprints (tens of acres) in more urbanized areas. The combination of the growing number of USS sites, along with the size of these sites leads to a substantial footprint; total area affected by USS in Virginia alone is expected to range from 150,000 to > 350,000 acres by 2045 (VA DEQ).

USS developments can entail substantial land transformation, often for an extended period of time. Some portion of each USS site will experience soil disturbance during the development process, ranging from ~10% by area to nearly the entire site, depending on site characteristics and developer preferences. This disturbance can lead to changes in soil health, resulting in infiltration and erosion changes, and challenges in establishing vegetation. Following initial development and revegetation/stabilization, most sites are maintained in a conventional herbaceous/forage cover for 25+ years, and then will undergo another round of extensive soil disturbance when the infrastructure is removed. This results in a widely varying extent of fundamentally altered site/soil conditions with respect to predicting and managing actual site responses.

Ground-mounted solar panels also create a unique set of conditions with impervious surfaces elevated over pervious land. As such, there is potential to alter natural hydrologic and water quality processes, including runoff generation and erosion (Hernandez et al., 2014). These changes could have direct implications for the ability to achieve the Total Maximum Daily Load (TMDL) reductions required to meet Chesapeake Bay estuary water quality standards. The extent of these impacts is dependent on prior land use (e.g. agricultural land, forest), site-specific terrain and soil conditions, site development/grading and stabilization practices, and long-term operation and management strategies.

Current guidance on BMPs for minimizing negative environmental impacts of solar farms is highly variable across the Chesapeake Bay states. Only some states within the Chesapeake Bay watershed currently have USS-specific guidance for stormwater management, to our knowledge, this includes Maryland and Pennsylvania (Maryland Department of Environment, 2013; PA Dept of Environmental Protection (DEP), 2021). Virginia is currently developing regulations (via VA House Bill 206) for sites < 150 MW that would affect > 10 acres of prime farmland or 50+ acres of contiguous forest that will be implemented by late 2024. Due to strong market conditions and an increased focus on reducing carbon footprint, some states (e.g. Virginia) have implemented expedited permits-by-rule (PBR) regulations for this activity. This has caused opposition in some local communities and environmental groups.

Existing guidance in some states addresses water quality problems by minimizing compaction during the construction process, stipulating the amount of space needed between panel rows to facilitate infiltration, specifying optimal vegetation characteristics and management, and determining if post-construction structural stormwater management is required. The diversity of landscapes in which solar farms could be installed and nascent BMP recommendations governing such installations limits our ability to understand and model the net effect of USS expansion on downstream water quality in the Chesapeake Bay watershed over the full three-phase lifecycle of USS projects (i.e., construction, operation, decommissioning). While existing erosion & sediment control and stormwater management regulations in the states are presumed to be effective when applied to USS sites, local enforcement and compliance varies by state and locality.

There is a small but rapidly growing body of research addressing the question of how USS impacts landscape conditions and processes. Existing field measurements from a few locations indicate redistribution of soil moisture around solar farms; thus, soils under the solar panels may be very dry, while soils right under the solar panel edge can be very wet after rain events (Choi et al., 2020; Hassanpour Adeh et al., 2018; Lambert et al., 2021). Net impacts on runoff and erosion are less clear, and existing work largely comes from unvalidated modeling efforts (Cook & McCuen, 2013; Nair et al, 2023). There is a growing body of research focused on coupling USS with agriculture as 'agrivoltaics', which may include crop agriculture or sheep grazing. Solar farms with cultivated crops such as lettuce have demonstrated reduced evaporative water losses and reduced crop stress due to panel shading. However, runoff and water quality implications of agrivoltaics, particularly in more humid and less sunnier climates, are not clear (Marrou et al., 2013). As noted above, the land transitioned to this new use is growing rapidly within the Chesapeake Bay watershed, with hundreds of thousands of acres needed to meet renewable energy goals over the next two decades. Thus, conversion of existing agricultural and forested lands to USS is likely to be the major land use change for rural areas. Therefore, it is critical that we adequately understand the implications of this transition on hydrology and water quality, and how to best manage this transition to minimize adverse environmental impacts. There could be opportunities to prioritize certain types of land for conversion to USS that minimizes nutrient and runoff losses.

There are many questions about USS impacts under various conditions, such as the conversion of conventional agricultural land with soils rich in legacy nutrients. The scale of parcels being converted to solar farms is also of great importance and uncertainty. Current erosion and stormwater control guidelines are not well adapted for the massive scale of some USS projects, and it is unclear how impacts vary with scale.

This workshop sought to address issues and provide guidance under the Chesapeake Bay Program's Management Strategies of Clean Water (e.g. Healthy Watersheds) and Conserved Lands (e.g. Land Use Methods and Metrics Development). More information on the 2014 Chesapeake Bay Watershed Agreement (amended October 5, 2022), including program goals and outcomes for the restoration of the Bay, see the Chesapeake Bay Program's website.

Rationale for workshop

2023 was a pivotal time to convene experts to address the impact of USS given the increasing push to transition to renewable energy. Presently, there is very little knowledge on the potential impact of this land use conversion for the Chesapeake Bay watershed, and our ability to meet TMDL and other related water quality management goals. Current BMP recommendations are varied across the watershed, with only some states providing solar-specific stormwater management guidance. There is a need to ascertain the state of the science on solar farms and environmental quality that will inform field research and modeling in the Chesapeake Bay region. Given that the state of science in this area is rapidly evolving and relevant research is ongoing and not-yet-published, a facilitated discussion with experts provided an important initial step towards establishing what is known, what needs further research, and options exist to better manage USS water quality impacts.

Focal questions for the workshop include:

1. What is the state of science on how USS impact hydrology and water quality under a range of site and management conditions and project scales?
2. What are current USS best management practices and policies, and where in our region are there opportunities for improving recommendations and/or policies?
3. What are the key gaps and research needs to better answer questions 1 and 2?

Session 1: Setting the Stage

Scale of Development and Transition

There are over 5,300 major solar projects across the nation, with existing installations generating 74 GW, and projects under construction or in development generating 70 GW. In the Chesapeake Bay watershed, there are already over 900 existing arrays and approximately 40 GW of proposed additional solar production in the interconnection queue. This first workshop session focused on the current and future scale of solar development and the timeline of that occurrence. Two presentations, one on the factors affecting solar development and one on predicting solar buildout, set the stage for discussion.

Determining the extent and timing of utility scale solar development is governed by numerous factors, including grid proximity and injection suitability, land use site conditions, sensitivity and ecological considerations, permits, zoning and ordinances, and public support. Any of these factors can potentially derail a given project. Therefor predicting when and where utility scale solar development will occur is an area of increasing interest. Retrospective analysis of where utility scale solar has been built forms the basis for a better understanding of where it is likely to be placed in the future. Building on historical trends, additional analysis incorporates machine learning to predict future development potential in the Chesapeake Bay watershed.

Potential Extent of Future Solar Farm Implementation – *David Murray (American Clean Power)*

- Link to Presentation Slides

The siting of utility scale solar energy is dependent on several factors outside of a developer's control, most notably, transmission and interconnection. Not only does a solar facility need to be proximate to high voltage transmission lines, but the lines need to have sufficient injection capacity to cost-effectively convey the power onto the regional electric grid. The regional grid operator, PJM, analyzes the technical and economic feasibility of interconnection; this process requires several years of study. Additional factors dictating successful solar development include topography, land availability, landowner interest, the presence of sensitive species and ecosystems, local ordinances and land use decisions.

Thus, predicting where solar facilities will be constructed in Virginia is challenging, as no entity can assume how the above factors will affect the success of a potential project. That said, one can look at the PJM interconnection queue for clues. The queue-based process reveals where in the interconnection process a solar project (or any energy generator) sits, indicating what counties are most attractive for potential development. Due to the fluid nature of the electric grid, many projects are speculative. Ultimately, all projects are affected by the success or failure of generators ahead of them in the queue, as well as a myriad of other factors that influence the complex dynamics of the regional electric grid.

Footprint and Land Use of Existing Solar Farms in the Chesapeake Region – *Michael Evans (Chesapeake Conservancy)*

- Link to Presentation Slides

The Chesapeake Conservancy has developed an Artificial Intelligence (AI) model that automatically maps ground-mounted solar arrays in satellite imagery. With this AI system, the Chesapeake Conservancy created annual maps of all solar arrays within the District of Columbia, Delaware, Maryland, Pennsylvania, New York, Virginia, and West Virginia from 2017 to 2022.

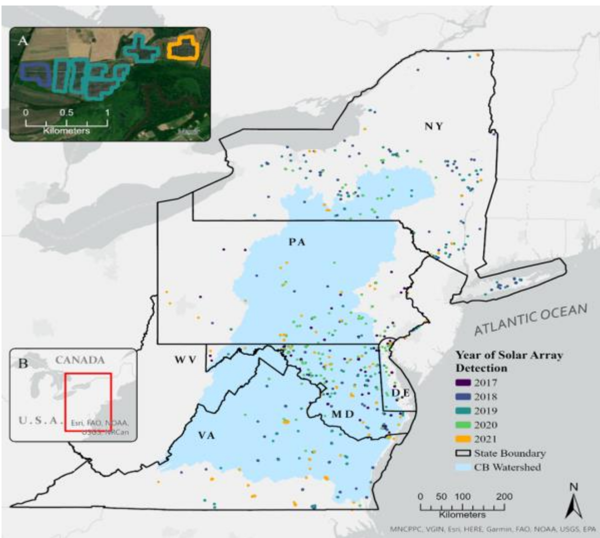

Figure 2. *Polygons representing ground-mounted photovoltaic arrays present in 2021 mapped by a U-Net image segmentation model using Sentinel-2 satellite data. Arrays were mapped in each of six states overlapping the* Chesapeake Bay watershed *(blue). Colors indicate the year in which arrays were constructed. Map insets show (A) the detailed solar array polygons generated by the U-Net model, and (B) the location of the study area in the United States. Full size image available for download. Note. Reprinted from "Predicting patterns of solar energy buildout to identify opportunities for biodiversity conservation" by Evan, M.J.E., et al. 2023, Biological Conservation, 283*.

This dataset is the first of its kind, and polygons are available in an Open Science Framework repository. This data has been used to understand the rate of solar energy growth in the region, associated land use transitions, and future trends. From the model, results show that 7 states have been adding solar at different rates, with West Virginia having no large installations and Virginia adding solar acreage most rapidly.

State	*Solar area* (km^2)	Size ± σ (km^2)	Δ 95% CI (km^2/yr)	*β* 95% CI
DE	0.90 (1.79e-4%)	0.029 ± 0.05	**7.29e-5 – 2.08e-4**	-1.25e-3 – 4.66e-3
MD	8.91 (3.54e-4%)	0.043 ± 0.07	**4.35e-4 – 5.68e-4**	-1.25e-3 – 2.47e-3
NY	9.97 (0.82e-4%)	0.038 ± 0.05	**3.91e-5 – 2.26e-4**	-6.54e-4 – 2.32e-3
PA	3.75 (0.32e-4%)	0.039 ± 0.07	-7.05e-6 – 1.30e-4	-4.57e-4 – 3.85e-3
VA	27.42 (2.69e-4%)	0.086 ± 0.13	**5.57e-4 – 6.95e-4**	-8.06e-4 – 2.06e-3

Table 1. *Characteristics of solar arrays within each state. Table displays the total area and proportion of each state occupied by solar arrays, mean array size, 95% credible interval around rate of increase (Δ) and biodiversity selection (β) coefficients. Bold text indicates credible intervals that did not overlap zero.*
Note. Reprinted from "Predicting patterns of solar energy buildout to identify opportunities for biodiversity conservation" by Evan, M.J.E., et al. 2023, Biological Conservation, 283.

Thus far, solar arrays have primarily replaced cultivated areas including agricultural fields, pasture, and managed forest lands, while avoiding more natural land cover like deciduous forests and wetlands. Agriculture was both the most frequently converted land use in terms of total area and showed the highest strength of selection in terms of area converted to solar in proportion to available area. The Chesapeake Conservancy suggested that the conversion of agriculture to solar presents a unique win-win opportunity to restore biodiversity and ecosystem services in the watershed, while mitigating climate change impacts.

Finally, the observed rates and site characteristics of past solar buildout were utilized to forecast and identify the areas within the watershed most likely to be developed for solar. At each observed solar array, a suite of geospatial covariates including slope, protected status, percent open/forest/impervious/cultivated landcover, distance to road, distance to transmission line, housing density, median census tract income, population, and agricultural suitability were recorded. These covariates were measured at 5,000 randomly distributed non-solar locations. Time to solar development was modeled at these locations as a Weibull process in a hierarchical Bayesian framework, with rate of solar development a function of covariates and acceleration a function of the state (e.g., Delaware, Maryland, etc.). Observations showed that solar was more likely to be developed in places previously cultivated and closer to roads, had low agricultural suitability, and less likely to be developed in areas that were steep, protected, and had high tree cover. Rate estimates indicated accelerating rates of development in Delaware, Maryland, Pennsylvania, and Virginia. Using these estimated coefficients, the Chesapeake Conservancy projected the relative time to development at 30 m resolution across all 7 states (excluding West Virginia) which can be visualized through a public web application, Chesapeake Bay Watershed Solar Arrays. In combination with regulatory and grid capacity data, this 30 m resolution heatmap can help anticipate the impacts of future growth and inform synergistic siting (Evans et al., 2023).

Session 2: State of the Science

There is very limited research worldwide that provides understanding about how solar farms affect landscape hydrological processes and characteristics such as runoff generation and soil health; as of 2022, there were 13 field studies and 7 modeling studies published in peer-reviewed literature (Yavari et al., 2022). These studies primarily focused on the western United States, Europe, and China. Thus, there is a need for a deeper understanding of how solar farms affect landscape processes in the Chesapeake Bay Region. Additionally, there is a need to determine what management practices are most effective in mitigating any potential negative impacts and generating further ecosystem benefits. Accessible, science-based guidance on how to best design and implement these management practices is paramount. There are several ongoing field and modeling studies in the midwestern and mid-Atlantic US that provide some additional insights. Highlights are summarized below from three of these researchers that presented at the workshop.

Insights from the PV-SMaRT Project – *David Mulla (University of Minnesota)*

- Link to Presentation Slides

An innovative spreadsheet-based Photovoltaic Stormwater Management Research and Testing (PV-SMaRT) Runoff Calculator has been developed to estimate stormwater runoff from ground-mounted solar photovoltaic (PV) sites for pre-construction as well as post-construction site-specific conditions.

This software tool allows for estimation of stormwater runoff curve number (CN) and runoff by considering factors such as rainfall hitting solar panels, generating concentrated runoff at a drip-edge, and the subsequent infiltration of this water downslope in a pervious sunlit area having a wide range of surface conditions, as well as in a pervious area beneath the adjacent downslope row of solar arrays that are themselves impervious to rainfall.

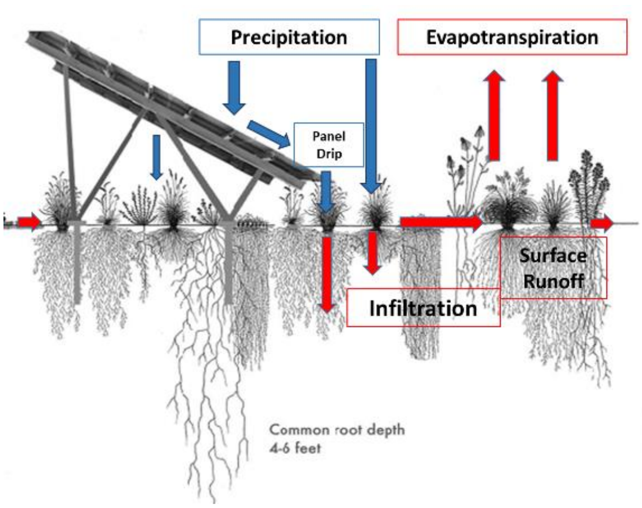

***Figure 3**. Schematic of a ground- mounted solar panel and surrounding vegetation and soils, with key hydrologic processes highlighted.*

These factors are currently ignored by other stormwater calculators, which either assume that the entire surface is either pervious or impervious, or that it has a level of imperviousness that is calculated by averaging the area of arrays and the area of pervious surfaces between arrays. The runoff calculator is based on extensive field testing and calibration/validation of a 2-D numerical model (Hydrus). The Hydrus model was field tested at five experimental sites in the states of Colorado, Georgia, Minnesota, New York, and Oregon. Based on comparison to experimental data from these sites, the model was able to accurately estimate runoff across a range of ground solar PV site conditions.

The runoff CN and runoff calculator has been developed to estimate stormwater CN and runoff at USS sites based on comprehensive simulation for a wide range of site-specific factors accounting for: 1) Soil and topographic characteristics (soil texture, soil depth, soil bulk density, slope); 2) Surface cover (row crop, turf, pollinator habitat, etc.); 3) Disconnected impervious surfaces associated with various solar panel designs (panel width, spacing and orientation along slopes); and 4) Climatic factors (precipitation).

The PV-SMaRT Runoff Calculator quickly estimates runoff CN for pre- and post-construction scenarios. Users can then input the 24-hr design storm depth of interest, and the calculator will estimate actual depth of runoff. If the user wishes, runoff CN values for different soils or slopes at a given site can be used as area weighted inputs for other hydrologic models such as TR-55, SWMM, FLO-2D or HydroCAD. The PV-SMaRT Runoff Calculator and User Manual are available at the following URL: https://license.umn.edu/product/pv-smart-solar-runoff-calculator-version-30.

Soils and Hydrology of Solar Farms in Midwestern United States – *Sujith Ravi (Temple University)*

- Link to Presentation Slides

Vegetation types and management on USS can have major implications for ecosystem benefits. Using a combination of sensor data analysis and laboratory measurements, research was completed to investigate the role of site-specific conditions on the environmental co-benefits and trade-offs between USS and underlying vegetation. Field investigations examined the microclimatic modifications and the soil properties under solar arrays at multiple utility scale solar sites in the midwestern US with different land management practices (bare soil, pollinator friendly vegetation, vegetation with managed sheep grazing) and compared those to adjacent undisturbed areas. Results indicate heterogeneity in soil moisture distribution based on panel orientation, and significantly lower soil total carbon and total nitrogen in the soils from the bare sites compared to those of the vegetated solar sites (Choi et al., 2020). The compounding effect of photovoltaic arrays and underlying vegetation can homogenize soil moisture distribution (leading to less likelihood of runoff issues), improve soil properties, and provide a greater soil temperature buffer against extreme temperatures, as compared to USS sites with bare soils or minimal vegetation. Thus, co-locating native vegetation and managed grazing on USS sites can be an effective climate mitigation strategy on agricultural areas with carbon debt along with revitalizing soils, improving water quality outcomes, generating income streams from fallow land, and providing pollinator habitats, seen in Figure 4. However, some of the co-benefits including vegetation cooling effects on electricity generation are rather site-specific and depend on the background climate and soil properties. Overall, findings provide data for site preservation along with the need for targeting site-specific co-benefits.

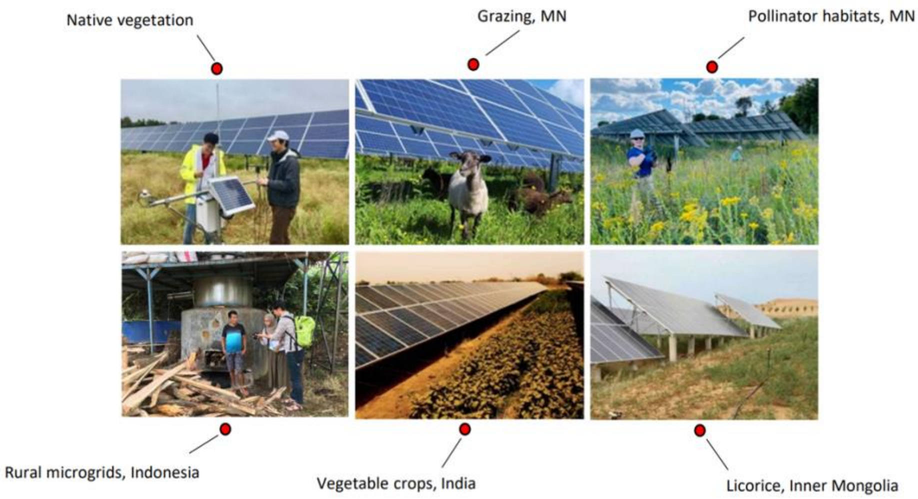

Figure 4. *Over the past ten years, we studied the co-location of solar energy with crops/biofuels, grazing and/or pollinator-friendly native plants at multiple sites around the world, and the highlighted the environmental and socio-economic co-benefits. (Ravi et al 2012, 2014, 2015, 2016, Choi et al, 2020, 2021, Bertel et al 2021, Towner et al 2021; Macknick et al., 2022.)*

Hydrology of Solar Farms in Central PA – *Lauren McPhillips (Penn State)*

- Link to Presentation Slides

Most existing research on the landscape processes occurring on solar farms is focused on most ideal sites, particularly those with low slopes and well-drained soils. There is a clear need for understanding best management practices for solar farm implementation on more marginal sites, particularly with respect to minimizing runoff generation, and maximizing ecosystem services.

Research is currently being conducted on solar farms in central Pennsylvania to help better understand hydrology, soil, and vegetation characteristics (Figure 5). This approach includes field evaluation at two solar farms in State College, Pennsylvania. The sites are characterized by meadow vegetation, and either variable or steep slopes. Both solar farms have engineered stormwater management features, including infiltration basins and infiltration trenches; at one site, structural stormwater management was added due to high slopes, and runoff calculations did assume modifications to impervious surface from the solar panels, while at the other site, stormwater features were added due to more stringent local ordinances. Ongoing field monitoring using soil moisture sensing indicates increased heterogeneity of soil moisture due to runoff from panels being concentrated at the dripline and direct rainfall not reaching the area under the panels, and reduced evapotranspiration under the panels. While there are periods of saturation and runoff generation at the dripline, it is also clear that infiltration is occurring in the interspace between the panels- meaning that most of the panel runoff is able to be absorbed into the soils. Existing structural stormwater management at these sites (i.e. infiltration basins or trenches) appears to be adequate to manage generated runoff. For example, measured water level in the infiltration basin at the base of one solar farm has never come close to exceeding capacity during the monitoring period. Despite much reduced solar radiation under the panels (~60-85% reduction compared to away from panels), there is still good vegetation cover under the panels.

While there is substantial diversity in vegetation in the interspace, there are still several species of plants (particularly grasses) present under the panels. Healthy vegetation is important for maintaining soil health and managing runoff, as well as providing other ecosystem services. Hydrologic model development is also being conducted in order to better represent processes on the sites that are more challenging to directly measure, as well as to generate potential scenarios for alternate management strategies. A model framework customized for the unique landscape of solar farms has been developed in using the EPA Storm Water Management Model (SWMM), a common stormwater modeling program (Nair et al. 2023). Further development is ongoing in OpenHydroQual, which will allow representation of unsaturated hydrology.

Overall, this work demonstrates that healthy vegetation and an adequate gap between solar panel rows is important for helping manage runoff. On more runoff-prone landscapes (e.g. poorly draining soils and higher slopes), it is particularly critical to have adequate structural stormwater management, like infiltration basins, to help prevent net increases in runoff from the solar farm.

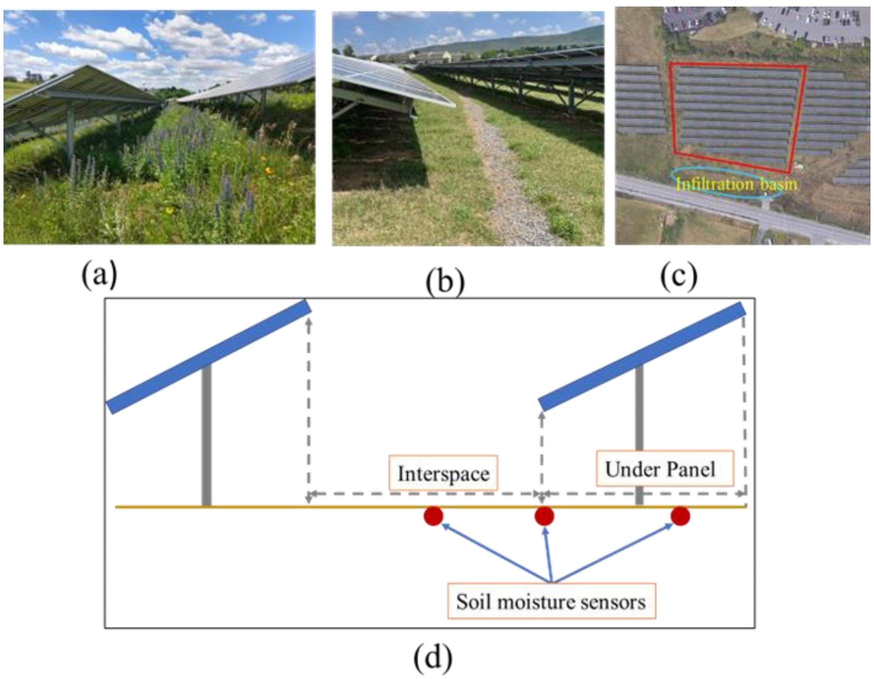

Figure 5. *Photos and schematic of the studied solar farms: (a) solar farm 1 (steep site); (b) solar farm 2 with infiltration trench; (c) infiltration basin at base of solar farm 1, and (d) schematic of key monitoring locations relative to solar panels.*

Session 3: Insights from Regulatory and Industry Sectors

Regulatory/Permitting Panel – moderated by Tony Buda (USDA)

- Link to Regulatory/Permitting Panel Recording (YouTube)

The regulatory panel sought to highlight a range of issues regarding USS development in the Chesapeake Bay watershed. Panel members included Mike Rolband from Virginia's Department of Environmental Quality (VA DEQ), Stewart Comstock from Maryland's Department of the Environment (MDE), and Andrew Foley from Pennsylvania's Department of Environmental Protection (PA DEP); workshop steering committee member, Tony Buda (USDA) moderated.

Specific input from the three panelists is summarized in the following sections. The panel addressed a series of questions about solar projects in their states:

1. What are some of the key solar-specific management considerations in your state?
2. What have been some of the challenges in developing current guidance for solar farms?
3. What can be learned from other states in the region?
4. Are current management practices for solar farms adequate, or are they too restrictive?
5. How can we promote solar projects on marginal sites while minimizing impacts on runoff?

Mike Rolband, Director, VA Dept of Environmental Quality

USS projects in Virginia have presented several interrelated issues relative to erosion and sediment control and stormwater management. While not all USS sites exhibit these problems, the scale of USS both proposed and underway highlights the significance of erosion and stormwater problems when they occur (Figure 6).

Figure 6. *Photos and schematic of the studied solar farms: (a) solar farm 1 (steep site); (b) solar farm 2 with infiltration trench; (c) infiltration basin at base of solar farm 1, and (d) schematic of key monitoring locations relative to solar panels.*

In March 2023, VA DEQ inspections of 39 different sites under their jurisdiction found that 69% (53/77 including others under consent orders) of USS under construction in Virginia exhibited compliance issues related to erosion and sediment control and stormwater management. Moreover, current projections for Virginia indicate the total land area for USS may exceed 300,000 acres, including 57,000 acres of impervious solar panel area. As such, guidance memoranda (effective February 2023) should address these issues for current and future USS projects. The key solar-specific management considerations in Virginia that must be addressed are:

1. Cut and fill excavation. This practice leads to site compaction from burying topsoil with fill materials. Site compaction needs to be eliminated or mitigated
2. Lack of vegetation. According to 9VAC25-840-40.1, “permanent or temporary soil stabilization shall be applied to denuded areas within seven days after final grade is reached on any portion of the site”
3. Curve numbers. Curve numbers used to estimate runoff must reflect specific aspects of solar development, including site compaction, land cover (worst case scenario), and panel imperviousness
4. Erosion and stormwater. Erosion and sediment controls and stormwater management practices must be installed properly and adequately maintained

USS sites that are well-vegetated and did not require cut-to-fill grading, burial of topsoil, and compaction do not appear to have significant erosion control and stormwater management problems. As an alternative to the costs of site grading practices that avoid these issues, USS sites on steeper or rolling terrain could benefit from dual-axis tracking systems or U-joints in drive shafts of single-axis tracker systems. Indeed, such practices could avoid or minimize soil grading and compaction and their attendant erosion and sediment control and stormwater management issues by “working with the in-situ terrain.” Minimizing runoff from solar farms could also involve the use of rain sensors, which could be used to trigger panel rotation to vertical during rainstorms.

Andrew Foley, Regional Permit Coordination Office, PA Department of Environmental Protection

Relative to Virginia and Maryland, Pennsylvania’s guidance on solar farms is more recent. Indeed, official guidelines on the permitting of utility-scale solar farms were introduced by PA DEP in 2019. These guidelines sought to balance the growing need for solar energy while protecting environmental resources. Currently, Pennsylvania’s guidance focuses on best management practices for stormwater, including erosion and sediment control and post-construction stormwater management. Similar to Maryland, the panels themselves are considered pervious surfaces provided specific stormwater management guidelines are followed. Notably, Pennsylvania’s experience with the natural gas industry helped to inform its approach to managing the solar industry. A key lesson learned with natural gas development in Pennsylvania was the need to regularly review and update stormwater guidance to keep pace with the industry.

Stewart Comstock, Chief, Permit Review Division, Stormwater, Dam Safety, and Flood Management Program, Maryland Dept of Environment

Utility-scale solar development in Maryland has resulted in many of the same issues as reported in Virginia. For instance, even though Maryland's Stormwater Management Guidelines require post-development hydrology to be restored to "woods in good condition", many solar farms still experience issues with soil compaction (Figure 7).

Figure 7. *Solar panel installation in Garrett County, Maryland.*

As such, there is an ongoing need for solar projects to incorporate environmental site design, including soil decompaction and soil restoration procedures, to reduce post-development stormwater runoff. Another issue relates to how solar panels are viewed regarding stormwater runoff. Unlike Virginia, where solar panels are now considered impervious, Maryland's Chapter 702 guidelines treat solar panels as a permeable land use, with only the foundation or base counting as impermeable surfaces. This creates challenges when trying to mimic pre-disturbance hydrology, which is the essence of Maryland's stormwater management guidance. A further challenge arises with climate change, as current design storms are unable to keep pace with increasingly intense rainfalls that produce larger amounts of runoff.

Panel Summary

In summary, all three panelists agreed that there is a need to encourage solar development in the Chesapeake Bay watershed while mandating best practices for stormwater management. The panelists felt that there is much to learn from interstate coordination, especially with regard to maintaining and updating regulations as solar development accelerates across the region. The panelists shared concerns about the conversion of forests and farmland to solar farms, and several highlighted alternatives to this pattern of development, including encouraging solar farm development on brownfields. Indeed, Virginia is overlaying brownfields areas with maps of transmission lines to steer the solar industry in this direction. Finally, panelists highlighted the importance of innovative research like the PV-SMaRT project, which aims to help the solar industry navigate stormwater and water quality challenges stemming from solar development.

Industry Panel – moderated by John Ignosh (VT), Siobhan Fathel (PSU)

- Link to Industry Panel Recording (YouTube)

The industry panel included Sterling Turner - Environmental Compliance Consultant of Dominion Energy, Tim Seldon - Senior Engineer of Geosyntec, Jordan Brooks - Solar Project Manager/Engineer of Kimley-Horn, and Virginia Brown - Director of Ecosystem Services of Lightsource BP; workshop steering committee members, John Ignosh (VT) and Siobhan Fathel (PSU) moderated.

The panel addressed a series of questions, indicated below. The session closed with an open question-and-answer period with attendees. A summary of responses from each panel speaker is described below.

Panel Questions:

- Based on your project experiences, what are some of your preferred practices and design approaches for erosion and sediment control and stormwater management for utility-scale solar sites in the Chesapeake Bay watershed? How do project economics and regulations inform these? Have these preferences and approaches evolved over time? If so, how so?
- Based on your project experiences, what are some of your biggest challenges or concerns regarding erosion and sediment control or stormwater management for utility-scale solar sites in the Chesapeake Bay watershed? Have these challenges or concerns evolved over time? If so, how so?
- Based on your project experiences, what (if any) research-based information do you believe is still lacking but needed to help better design utility-scale solar sites in the Chesapeake Bay watershed?
- Are potential opportunities for co-benefits (e.g., carbon sequestration, pollinator habitat, agrivoltaics (solar grazing, etc.)) with utility-scale solar considered in your project design work? If so, how and what type(s) of co-benefits? Have considerations for co-benefits evolved over time? If so, how so?

Sterling Turner, Environmental Compliance Consultant, Dominion Energy

Sterling Turner has been with Dominion Energy for five years, prior to his current role he worked in environmental consulting for two decades. Turner works to raise awareness on a variety of best management practices during the construction phase, both, amongst internal networks and with external vendors, to assure compliance with quality control regulations. Turner notes that when utility-scale solar started in the Chesapeake Bay area, many contractors were not from the same region, but came in with project experience from other areas (i.e., western US, Florida). This resulted in an adjustment period as designers and contractors gained knowledge and experience on factors unique to Virginia (e.g., geographic, weather, and regulatory factors).

Some common strategies include promoting site stabilization as early as possible, seeding and frequent re-seeding as needed to support vegetation establishment, efforts to minimize disturbance issues and address them when they emerge, applying thick mulch cover for erosion control, and layering these suites of practices as needed. Turner notes that there have been a lot of challenges in the early-construction phase of solar farms with perimeter controls to manage erosion and sediment; however, there have been fewer perceived challenges in implementing post-construction stormwater management. Additional efforts consist of defining resource protection areas and their required buffers across the site to comply with regulations, internal company requirements, and stakeholder acceptance. A large part of his work is translating environmental protection intent and regulations to inform construction processes and notes that there are opportunities for industry to further refine its understanding of best management practices for construction and post construction. However, he believes it is important to further streamline these processes to make the information related to specific construction requirements available and easy to understand.

Additional discussion explored the impacts and opportunities with site buffer areas as conserved open space, and associated water quality benefits, which he estimated may comprise one-third of average project areas. The size and location of these areas is often a function of the real estate deal and other site development considerations such as the geometry of the array. In considering opportunities with ecosystem service markets, Turner noted that the sector is open to exploring opportunities in ecosystem services markets that couple mutually beneficial land uses citing related opportunities with solar grazing and agricultural community engagement. Related, Turner shared a specific example of working with an environmental group to identify and remove old road culverts that were no longer needed within a solar site, to help improve fish habitat. Broadly, due to the land areas involved, Sterling sees opportunities to identify these types of land management synergies that are beneficial to the Chesapeake Bay and the local community.

Tim Seldon, Senior Engineer, Geosyntec

Tim Seldon shared that Geosyntec began as a geotechnical-civil engineering firm in the remediation sector. In the past 10-15 years, the firm began to work in solar project applications on landfills and other brownfields, while more recently they have been working in utility-scale solar. Geosyntec tries to take a bigger picture view first and go from outside then in when designing a solar site, trying to ensure that pre-development conditions are accurately assessed. For example, a large site might have many different flow paths for runoff, and land cover and subsurface conditions are important to assess, as this will all impact appropriate stormwater management strategies. Seldon also indicated the value of having an accurate understanding of runoff generation potential on solar farms, in order to appropriately design management practices, particularly when considering sites that can span hundreds to thousands of acres. Seldon noted that as sites become larger, and more challenging site locations are developed (e.g., steeper southwestern Virginia topography), the amount of re-grading and compaction of the landscape make the underlying assumptions used in site design more critical.

Regarding the construction process, Seldon described efforts to ensure that sites are properly stabilized with topsoil management, and making sure that all exposed soil has appropriate sediment control measures. They also try to leave temporary stormwater controls in place until upslope drainage areas are fully stabilized. However, they acknowledged challenges with project timelines to meet schedules related to the electricity interconnection; these schedule challenges can complicate site stabilization activities, such as less-than-ideal calendar windows for seeding vegetation, or premature removal of erosion and sediment controls. Seldon also shared perspectives on long-term erosion management at larger utility-scale solar sites. It was noted that development of concentrated flowpaths can create gullies, requiring installation of intermediate management practices intended to attenuate flow and capture sediment (e.g. infiltration berms). Seldon shared that some research needs include collecting site-level data to better understand the impact of USS on site hydrology, and incorporating soil testing to inform soil amendment use that can help improve site vegetation establishment. In general, clarity on these issues could help bring further consistency and consensus to a very fluid area of civil engineering.

Jordan Brooks, Solar Project Manager/Engineer, Kimley-Horn

Jordan Brooks described Kimley-Horn as a national civil engineering consulting firm, which she has been with for six years, where she leads a 10-person Richmond-based solar team. The firm's USS project experience ranges from 1 MW to over 500 MW, with 2,000 projects nationally.

Brooks indicated that some of the preferred erosion, sediment and stormwater practices include perimeter measures designed to be permanent whether required by regulations or not, such as permanent slope armoring to minimize erosion or limited site grading to preserve intact topsoil. Related to minimizing grading, having tracking solar panels (panels that track with the sun) can help work with existing site topography while still maximizing power production.

Brooks noted some challenges with existing options for erosion and stormwater control during construction on large USS sites (e.g. clogging of certain controls due to site mulching), but that her firm has been seeking out better performing options. Brooks noted that site stabilization is important, and the need for seeding at the right time and right mix during construction conditions is critical to maintain construction and post construction site compliance. Brooks indicated that typically they will dedicate existing areas as conserved forest or open space to meet water quality requirements and nutrient credit requirements. When speaking on economic considerations, she noted that large USS sites present a unique challenge compared to smaller commercial development, where USS sites of hundreds of acres can require dozens of sediment control or stormwater control ponds, and significant slope armoring, leading to questions of how to best minimize cost while choosing the practices that will best work on these large sites.

Regarding research needs and related opportunities, Brooks expressed interest in the outcomes from ongoing research, noting that models are useful but data from actual sites will be particularly helpful; it was noted that having data in hand can be useful for justifying regulatory requirements for use in discussion with clients, particularly for aspects that differ from state-to-state and represent additional costs for Virginia-based projects.

Virginia Brown, Director of Ecosystem Services, Lightsource BP

Virginia Brown has a background in soil science, ten years of experience in construction, and five years of experience in USS development. Her firm, Lightsource BP, has completed projects across a wide range of project sizes up to 400 MW. Brown shared that at Lightsource BP, key goals are to focus on vegetation establishment as early as possible (even before solar array installation begins), use of designs that require less grading, and incorporate new single-axis solar panel tracking systems that can work with rolling contours of a site (and thus require less grading). In general, less grading reduces site vegetation challenges, as existing topsoil can be preserved. Brown also noted that assumptions made about soil before construction (which can impact stormwater runoff calculations) can be impacted by actual civil works and timing of these activities, resulting in models that do not capture post-construction site challenges. For example, topsoil removal and re-grading can impact soil hydrology due to compaction, among other factors. Brown commented that, unique to utility-scale solar, post-construction reclamation work can be particularly challenging. Early seeding of vegetation as part of site development can be a critical aspect of construction and post-construction erosion and stormwater management. It was noted that vegetation emergence can be better when seeding occurs before solar panels are even mounted, due to panel shading. Additionally, the vegetation has more time to establish, helping to meet site stabilization requirements during construction. In response to erosion and sediment control concerns, Brown described how construction time schedules often pose challenges in meeting requirements and using best practices related to soil management and vegetation establishment. In general, it was noted that topsoil management practices during the site construction phase are a persistent challenge.

Brown described Lightsource BP as community-focused and engaged, and noted that the firm has a corporate mandate to have net-biodiversity gain on projects (e.g. creating pollinator habitat), which, based on their experiences adds little additional cost to site development. Often Lightsource BP purchases land for the duration of the project which enables further improvements. Brown shared that some research needs include monitoring sites over time to characterize performance of native plants and pollinators. In particular, interest was expressed at better understanding vegetation establishment at larger utility-scale solar sites with extensive earth works (e.g., grading, cut and fill, compaction, etc.). In general, there is an interest in understanding whether assumed benefits associated with various site management practices are actually being produced.

Panel Summary

During this session, industry panelists shared their direct sector-specific experiences in utility-scale solar development from across the region. The speakers shared some of the preferred practices, biggest challenges, and research needs. The responses shared illuminated some common areas across project experiences, and also some differences in project experiences across the broader region. Attendees further engaged panelists with additional comments and questions regarding incentive structures, ecosystem services, among other areas.

Some of the consistently highlighted points across this panel included

- Challenges related to the large scale of these sites, and ensuring appropriate erosion and stormwater controls for such a large and sometimes variable site
- Getting vegetation rapidly established to help stabilize sites during construction
- Interest in having better information to support runoff calculations and appropriate management practices for this unique type of development

Considerations for Developing a Coordinated Effort for Understanding Best Management Practices to Minimize Impacts of Solar Farms on Landscape Hydrology and Water Quality in the Chesapeake Bay

In the final session, workshop participants were divided into breakout groups to synthesize workshop discussions, and leverage personal insights related to USS management and best management practices. Specifically, participants were asked to consider the following:

- What are key gaps in the current science that is informing best practices?
- What are key gaps in the current regulatory/development process or guidance?
- Where are there opportunities for better sharing knowledge/insights/approaches to achieve the best outcome for all?

A full list of outcomes from the breakout groups is in Appendix D.

After the breakout discussions and reports back to the group, a poll was populated with top recommendations pulled from all breakout group report-outs. The poll was administered to all attendees, requesting that participants rank solar farm management priorities and gaps for the future of solar as a whole (Figure 8).

Figure 8. *Summary of a poll administered to the workshop attendees asking them to rank solar farm management considerations. Selections by ranked choice are the following: 1st – Minimize land disturbance and utilize low impact development techniques; 2nd – Collect more field data on a range of site types at a range of scales; 3rd – Appropriate modeling for runoff from solar development to plan for necessary management practices; 4th – Incentivizing site selection; 5th – Greater focus on vegetation and soil post-development; 6th – Characterize soil conditions before and after development; 7th – Greater understanding of co-benefits, water hydrology; 8th – Incentivizing co-benefits; 9th – Clearinghouse of information; 10th – Communication/Outreach across levels/scales; 11th – Refine solar potential and suitability maps; 12th – Adding a climate mitigation goal.*

As seen from the Mentimeter poll results in Figure 8, the top USS management considerations identified by workshop participants were the following:

- Minimize land disturbance and utilize low impact development techniques
- Collect more field data on a range of site types at a range of scales
- Appropriate modeling for runoff from solar development to plan for management practices
- Incentivizing selection of optimal sites
- Greater focus on vegetation and soil post-development

Summary of High Priority Science Gaps and Associated Recommendations

The following **high priority science gaps** emerged from the workshop:

- A better understanding of how USS, as implemented in the Chesapeake Bay watershed impact during construction and through the lifetime of the solar farm.
    - hydrology (including evapotranspiration, infiltration, and runoff)
    - soil health (including physical, chemical, and biological properties)
    - vegetation and associated co-benefits (including habitat provision)

  There is a need for additional research to cover the full spectrum of physiography, prior land uses (e.g. crops versus meadow), and scale (i.e. solar farm site to catchment).

- Development and evaluation of management practices that can minimize impacts of USS on landscape hydrology and water quality across the diverse landscape types in our region
- Develop USS specific runoff modeling approaches that are validated for our region, to support design of best management practices

There was a consensus on some **key practices** emerging in our region as supporting sustainable development of USS. These practices include:

- Incentivizing selection of optimal sites for solar implementation- particularly considering ways to leverage existing impervious surface (e.g. parking lots, warehouse rooftops) and marginal lands (e.g. brownfields, marginal agricultural land)
- Supporting soil health through minimizing soil disturbance and removal during USS construction process
- Implementation of appropriate erosion and sediment control during construction, and oversight to ensure compliance
- Facilitating rapid establishment of perennial vegetation, with consideration of opportunities for other co-benefits (e.g. habitat provision) in vegetation selection process

Recommendations to Address the Science Gaps

Support of New Field and Modeling Research on Solar Farms

- Funding allocation and other means of support for new field and modeling research that is region and state specific, and practitioner relevant.
- Testing and customization of the PV-SMaRT solar farm runoff calculator tool for the Bay region.
- Integration of a solar farm specific land use in the Chesapeake Bay Model.

Improving Information Sharing and Coordination

- Continued industry, academic, governmental, and community collaboration and information-sharing. Potential venues include the Chesapeake Community Research Symposium, as well as other existing or new opportunities that bring together solar energy and watershed/ land planning discussions.
- A clearinghouse or platform for sharing information and data related to solar farm planning, function, and management in our region. Opportunities exist to leverage, improve, and elevate existing resources. State university Extension agencies offer a key means of disseminating information to the public relating to energy, water, and land management, though opportunities exist to further collaborate and share resources between states in our region. Key non-governmental agencies also play a key role in some data provision and sharing, such as Chesapeake Conservancy.
- Demonstration solar farm site(s) with best practices showcased, opportunities for integrated research, and ability for interaction and/or visibility from public. Several types of organizations are poised to develop demonstration solar farms, including regional universities and governmental and non-governmental organizations.

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Appendix A: Workshop Agenda

Chesapeake Bay Program's (CBP)
Scientific and Technical Advisory Committee (STAC)
Workshop

Best Management Practices to Minimize Impacts of Solar Farms on Landscape Hydrology and Water Quality

April 6-7th, 2023
George Mason University, Manassas VA
Beacon Hall 1017A
Workshop webpage

****Exact Times Are Subject to Change****
This meeting will be recorded to assure the accuracy of meeting notes.

Day 1, Thursday, April 6th

9:00 am **Coffee & Light Breakfast (Provided)**

Session 1: Setting the Stage

9:30 am **Workshop Overview & Objectives –** *Rachel Tardiff (Rachel Tardiff LLC), Meg Cole (CRC)*
Discuss the goals of the workshop and the expertise in the room. Workshop objectives that will be addressed over the 2-day workshop are the following:

- What is the state of science on how solar farms impact hydrology and water quality under a range of site and management conditions and project scales?
- What are current best management practices and policies, and where in our region are there opportunities for improving recommendations and/or policies?
- What are the key gaps with respect to research needs to better answer questions 1 and 2?

9:40 am **Setting the Stage: A brief review of published research and existing stormwater guidance** *– Lauren McPhillips (Penn State)*

9:50 am **Scale of Development and Transition**
Discussion of the existing and potential extent of planned solar fields in the Bay watershed based on the states' plans for renewable energy production.

- **Footprint and Land Use of Existing Solar Farms in the Chesapeake Region –** *Michael Evans (Chesapeake Conservancy)*
- **Potential Extent of Future Solar Farm Implementation –** *David Murray (American Clean Power)*

10:50 am **10-minute break**

Session 2: State of the Science

11:00 am ***Insights from the PV-SMaRT project*** *– David Mulla (University of Minnesota)*

11:45 am **Soils and Hydrology of Solar Farms in Midwestern US** – *Sujith Ravi (Temple University)*

12:05 pm **Hydrology of Solar Farms in Central PA** – *Lauren McPhillips (PSU)*

12:25 pm **Group Discussion** – *led by Steering committee member(s)*

1:00 pm **Lunch (provided)**

Session 3: Insights from Regulatory and Industry Sectors

2:00 pm **Regulatory/Permitting Panel –** moderated by *Tony Buda (USDA)*

Invited Bay state representatives will speak on a panel regarding current and considered regulatory and permitting processes and perceived challenges regarding solar farms. Panelists listed below:

- **Mike Rolband**, Director, Virginia Dept of Environmental Quality
- **Andrew Foley/Domenic Rocco**, Regional Permit Coordination Office, PA Department of Environmental Protection
- **Stewart Comstock**, Chief, Permit Review Division, Stormwater, Dam Safety, and Flood Management Program, Maryland Dept of Environment

Panel questions:

- What are some of the key solar-specific management considerations in your state?
- What have been some of the challenges in developing current guidance for solar farms?
- What can be learned from other states in the region? Are there opportunities to coordinate?
- Are current management practices for solar farms adequate, or are they too restrictive?
- How can we promote solar projects on marginal sites like those with steep slopes, poorly drained soils, floodplains, etc.? Can we do this while still minimizing impacts on runoff?

3:00 pm **Industry Panel –** moderated by *John Ignosh (VT), Siobhan Fathel (PSU)*

Panel discussion with invited speakers from Lightsource BP, Dominion Energy, and Geosyntec. Questions considered will include site selection and management of solar projects. Panelists listed below:

- **Virginia Brown**, Director of Ecosystem Services, Lightsource BP
- **Sterling Turner**, Environmental Compliance Consultant, Dominion Energy
- **Tim Seldon**, Senior Engineer, Geosyntec Consultants
- **Jordan Brooks**, Solar Project Manager/Engineer, Kimley-Horn

Panel questions:

- Based on your project experiences, what are some of your preferred practices and design approaches for erosion and sediment control and stormwater management for utility-scale solar sites in the Chesapeake Bay watershed? How do project economics and regulations inform these? Have these preferences and approaches evolved over time? If so, how so?
- Based on your project experiences, what are some of your biggest challenges or concerns regarding erosion and sediment control or stormwater management for utility-scale solar sites in the Chesapeake Bay watershed? Have these challenges or concerns evolved over time? If so, how so?
- Based on your project experiences, what (if any) research-based information do you believe is still lacking but needed to help better design utility-scale solar sites in the Chesapeake Bay watershed?
- Are potential opportunities for co-benefits (e.g., carbon sequestration, pollinator habitat, agrivoltaics (solar grazing, etc.)) with utility-scale solar considered in your project design work? If so, how and what type(s) of co-benefits? Have considerations for co-benefits evolved over time? If so, how so?

4:00 pm **Group Discussion –** led by workshop facilitator, *Rachel Tardiff (Rachel Tardiff LLC)*

4:45 pm **Overview of Day 1 and Expectations for Day 2 –** *Siobhan Fathel (PSU), David Sample (VT)*

5:00 pm **Recess**

Day 2, Friday, April 7th

8:00 am **Breakfast (Provided)**

8:30 am **Introduction to Dominion Energy: Solar Projects –** *Sterling Turner (Dominion Energy)*
Sterling Turner (Dominion Energy) will provide an overview of Dominion Energy in advance of the workshop fieldtrip. This presentation will include details on the range of Dominion solar projects and context on how the Remington solar site fits into the broader Dominion Energy portfolio.

9:00 am **Field trip to Local Solar Operation:**
An optional fieldtrip is offered to interest participants to the Dominion Energy Remington Solar Power Facility. Those attending should be dressed appropriately and are required to wear closed toe footwear appropriate for walking around uneven terrain. Transportation to the site will be provided. The chartered bus will leave GMU at 9am.

12:00 pm **Lunch (provided)**

12:40 pm **Report-out on Morning Fieldtrip to Dominion Energy, Remington Solar Site**

12:50 pm **Review of Day 1; Objectives for Day 2** – *Rachel Tardiff (Rachel Tardiff LLC), Meg Cole (CRC)*

1:00 pm **Breakout Discussions: Identifying key gaps, needs, and points of coordination**
Questions considered during the breakout session are the following:

1. What are key gaps in the current science that is informing best practices?
2. What are key gaps in the current regulatory/development process or guidance?
3. Where are there opportunities for better sharing knowledge/insights/approaches to achieve the best outcome for all?

2:00 pm **15-minute break**
Participants will take a 15-minute break during the breakout session.

2:45 pm **Breakout Group Report-out**

3:25 pm **15-minute break**

3:40 pm **Group Discussion: Report recommendations**
Participants will draft and prioritize report recommendations resulting from Day 1 and Day 2.

4:30 pm **Workshop Wrap-up and Next Steps** – *Steering committee member*
The workshop steering committee will synthesize workshop findings and recommendations provided by participants.

4:45 pm **Workshop Adjourns**

Appendix B: Workshop Participants

Name	Affiliation
Aaron Berryhill	Virginia Department of Energy
Alexander Gunnerson	Chesapeake Research Consortium
Andrew Foley	Pennsylvania Department of Environmental Protection
Ann Jurczyk	Stakeholders' Advisory Committee
Brian Ross	Great Plains Institute
Charles Hegberg	Resource Environmental Solutions LLC
Cibin Raj	Pennsylvania State University
David Hirschman	Hirschman Water & Environment, LLC
David Mulla	University of Minnesota
David Murray	American Clean Power
David Sample	Virginia Tech
Domenic Rocco	Pennsylvania Department of Environmental Protection
Doug DeBerry	William & Mary
Efeturi Oghenekaro	District of Columbia Dept. of Energy & Environment
Emily Royce	Genesee/Finger Lakes Regional Planning Council
Gary Shenk	United States Geological Survey
Gregg Zody	County of Nottoway
Hanne Borstlap	University of Virginia
Jessica Forrest	Private Consultant
Joe Belmonte	Environmental Construction Solutions
John Ignosh	Virginia Tech
Jonah Fogel	University of Virginia
Jordan Brooks	Kimley-Horn
Kaitlyn Spangler	Pennsylvania State University
Kathy Gee	Longwood University
Kevin McGowan	Dominion Energy
Kristen Sadtler	Virginia Department of Environmental Quality
Larry Band	University of Virginia
Lauren McPhillips	Pennsylvania State University
Liz Engle	Aes Corporation
Mark Remsberg	Virginia Department of Environmental Quality
Meg Cole	Chesapeake Research Consortium
Meghan Mayfield	Virginia Department of Environmental Quality
Melanie Davenport	Virginia Department of Environmental Quality
Melissa Chatham	Maryland Department of the Environment
Michael Collins	American Climate Partners
Michael Evans	Chesapeake Conservancy
Mike Rolband	Virginia Department of Environmental Quality
Patrick Fanning	Chesapeake Bay Foundation
Peter Claggett	United States Geological Survey
Rachel Tardiff	Rachel Tardiff LLC
Rebeccah Rochet	Department of Environmental Quality
Rebeccah Rochet	Virginia Department of Environmental Quality
Siobhan Fathel	Pennsylvania State University
Sterling Turner	Dominion Energy
Stewart Comstock	Maryland Department of the Environment
Sujith Ravi	Temple University
Susan Minnemeyer	Nature Plus
Sushil Ghimire	Energix Renewables
Tahneen Jahan Neelam	Cornell University
Tim Seldon	Geosyntec Consultants
Tony Buda	United States Department of Agriculture
Tou Matthews	Chesapeake Research Consortium
Victoria Cecchetti	Hexagon Energy
Virginia Brown	Lightsource BP
W. Lee Daniels	Virginia Tech
Whitney Pipkin	Bay Journal
Zach Easton	Virginia Tech

Appendix C: Field trip pictures

Figure 9. Participants visited a solar site in Remington and were provided a tour of the project by Sterling Turner (Dominion Energy).

Appendix C: Breakout Group Discussions: Mentimeter Responses, Breakout Google Slide Decks, and Notes on Key Takeaways from Each Breakout Group

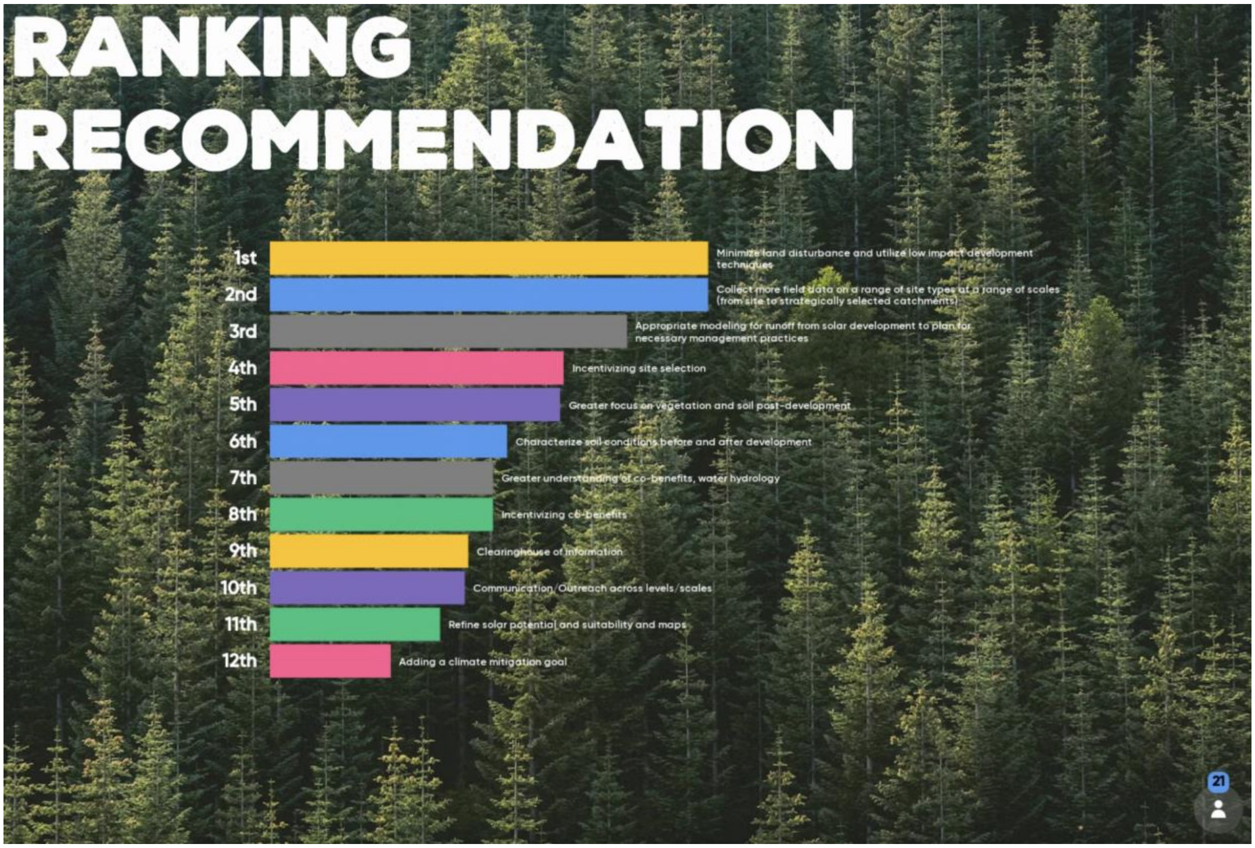
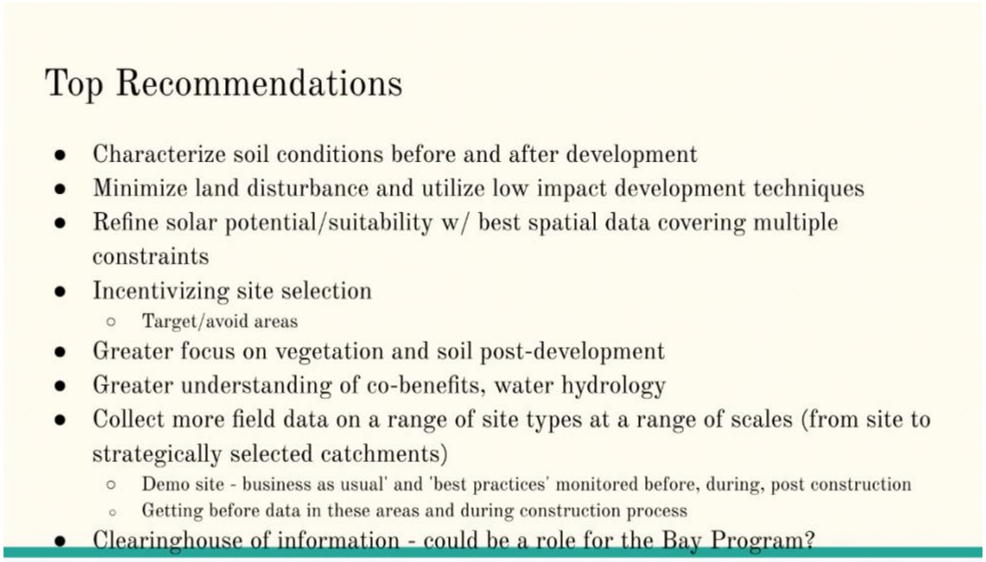


Figure 8. *Summary of a poll administered to the workshop attendees asking them to rank solar farm management considerations.*

Breakout Google Slide Decks

Figure 10. *Example responses gathered from the virtual breakout group using Google Slides. In-person and virtual breakouts were requested to answer three prompts and record feedback using preloaded Google Slides: What are key gaps in current regulatory/development process or guidance?; Where are there opportunities for better sharing knowledge/insights/approaches to achieve the best outcomes for all?; What are key gaps in the current science that is informing best practices?*



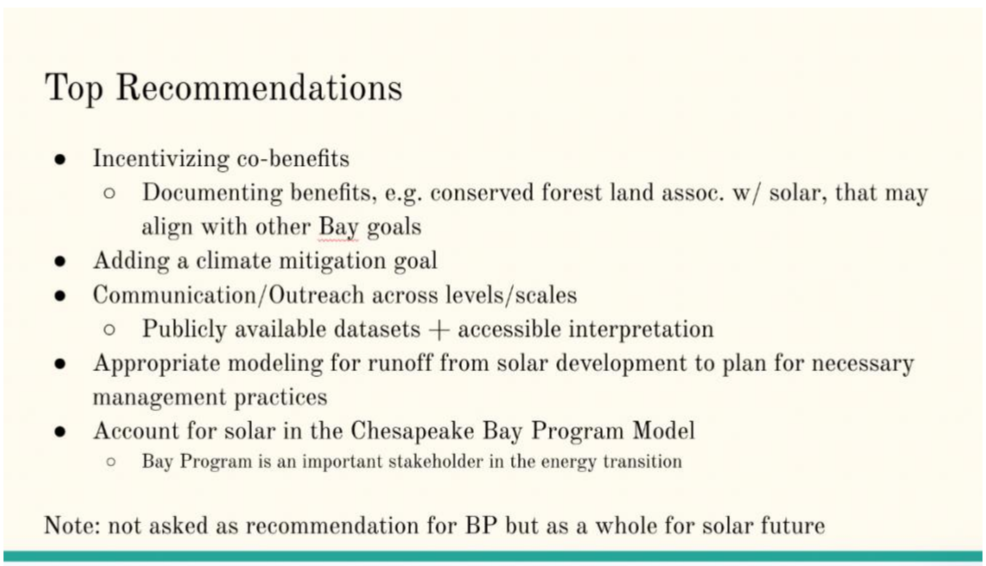


Figure 11. *Top recommendations collected from a report-out of all participant breakout, in-person and virtual. This collection of top recommendations was used to inform the high priority science gaps and associated recommendations.*

Breakout Group Summary Notes

Identified Key Gaps, Needs, and Points of Coordination

Participants were split randomly into four breakout groups and asked to consider the following questions.

What are key gaps in the current science that is informing best practices?

More field studies on solar sites

- Different size systems, under different prior land use conditions (forests, agriculture) in different physiographic provinces (coastal plain, valley-ridge, Piedmont) and with different construction practices
- Data collection during the construction phase + long-term monitoring of sites
- Watershed-scale monitoring of solar farm impacts
- Soil health monitoring
- Runoff monitoring
- Understanding of changes over time (e.g. relating to vegetation and soils)
- Understanding optimal vegetation across different regions and environments
- What are the co-benefits/trade-offs expected for diff types of sites/ management practices (e.g. carbon, pollinators)?

Spatial analysis to support utility scale solar (USS) siting

- Systems map to support better siting USS (include current land use, interconnection analysis, solar irradiance, slope, etc.)
- Optimal siting for who? Important to consider multiple perspectives
- Leverage AI
- Understand implications for forecasting as footprint increases

Watershed-scale understanding of solar farm impacts- what are impacts to loads at CBW modeling scale (noting that we also should evaluate impacts at a smaller scale)

Understand agriculture and solar interactions- is it an issue of competition or are there more synergies possible?

Necessity of region-specific runoff calculations and associated best practices- acknowledging that even within the Chesapeake Bay watershed region there is a range of environments (e.g., coastal plain, Piedmont, etc.)

What is the appropriate maintenance to ensure ongoing benefits?

What are key gaps in the current regulatory/development process or guidance?

Opportunities in the construction process

- Ensure adequate, comprehensive soil health testing at the site, before and after development

- Check best erosion and sediment practices are being used (i.e. also providing adequate enforcement and oversight)
- Minimize soil disturbance in development process (cut and fill/grading)
- Provide better training to construction personnel on solar farms, with respect to minimizing land impacts

Post-construction stormwater management

- Current guidance can be variable- consistency in stormwater regulations across the Bay watershed could help, where possible
- Should provide enough guidance to ensure good practices, but leave enough flexibility to ensure that the best solutions can be implemented, esp. on more complex sites
- Lag time to create and implement guidance

General policy recommendations

- Alignment between public policy objectives; for example, land conservation and renewable energy development-related policies
- Requires sufficient data to inform policy
- Better accounting for nitrogen, not just phosphorus in water quality considerations (somewhat Virginia-specific)

Better incentivizing solar on land uses other than prime agriculture and forest

- Leverage existing/new impervious surface to reduce ground solar footprint
- Incentivize solar on brownfields

Holistic consideration of co-benefits (like soil microbes, carbon sequestration) during design, siting, and construction

Where are there opportunities for better sharing knowledge/insights/approaches to achieve the best outcome for all?

In general, need to continue to share best practices amongst the Chesapeake Bay region

Make sure to get relevant information down to localities that can help them connect between state regulations and local zoning, ordinances etc. In general, need closer collaboration between state and local levels

Leverage Cooperative Extension in land-grant universities

Incentivize good stewardship and share experiences

Develop strong, mutually beneficial relationships between researchers, industry, and regulators

Standard practice of making data publicly available in well-known repositories

Facilitate learning exchange through demonstration sites with best practices showcased

Greater interface between the Chesapeake Bay Program and purchasers of electric power

Address shortage of expertise on soil and vegetation management relative to construction aspect

Higher level assessment to target more marginal lands for solar farms, and reduce clash with prime agriculture

Appendix D: Figures

Appendix E: Tables