GREAT PLAINS INSTITUTE

September 2021

Photovoltaic Stormwater Management Research and Testing (PV-SMaRT)

Potential Stormwater Barriers and Opportunities

Photo from Great Plains Institute by Katharine Chute

Acknowledgments

PV-SMaRT Project Team

- Aaron Hanson, University of Minnesota
- Brian Ross, Great Plains Institute
- David Mulla, University of Minnesota
- Jennifer Daw, National Renewable Energy Laboratory
- Megan Day, National Renewable Energy Laboratory
- Rob Davis, Fresh Energy

Water Quality Task Force Members

- Andrew Nelson, Westwood Professional Services
- Britta Hansen, Emmons Olivier Resources
- Dave Gasper, New York Department of Environmental Resources
- David Morley, American Planning Association
- Gavin Chase Meinschein, Engie North America
- Greg Hoffman, Center for Watershed Protection
- Jake Janski, Minnesota Native Landscapes
- Jason Bernagros, US Environmental Protection Agency Office of Research and Development
- Peter Parkinson, AES Distributed Energy
- Robert Goo, US Environmental Protection Agency Office of Wetlands, Oceans, and Watersheds
- Seth Brown, National Municipal Stormwater Association
- Sybil Sharvelle, Colorado State InTERFEWS Director
- Veronica Craw, Georgia Department of Natural Resources

Additional comments were provided from regulators and stakeholders in non-case study states.

Disclaimer

This material is based on work supported by the US Department of Energy Office of Energy Efficiency and Renewable Energy under the Solar Energy Technologies Office Award Number DE-AC36-08GO28308 .

Introduction

The Photovoltaic Stormwater Management Research and Testing (PV-SMaRT) project seeks to develop and disseminate research-based, solar-specific resources for estimating stormwater runoff at ground-mounted PV facilities as well as stormwater management and water quality permitting best practices. In this document, the Great Plains Institute (GPI) identified existing permitting practices and standards for solar development in the five PV-SMaRT case study states (New York, Georgia, Minnesota, Colorado, and Oregon) and other states across the nation. GPI then completed a “barriers and opportunities” assessment of existing practices to identify opportunities for reducing solar development soft costs and compliance costs, while maintaining or improving water quality outcomes. A “best practices” document will follow this report.

Case Study States

New York
Georgia
Minnesota
Colorado
Oregon

Photo from Great Plains Institute by Katharine Chute

Summary of Findings

The first step in developing best practices for protecting and improving water quality on PV facilities is to understand how existing water quality permitting practices affect the solar development process. It’s also key to understand the potential inadvertent barriers in existing practices that increase soft and hard costs of solar development. Soft costs, as described by the Department of Energy,[1] are the non-hardware costs of solar construction that include permitting, financing, and installation costs. These soft costs include the time spent addressing water quality regulatory standards, stormwater engineering and modeling, additional maintenance and operations expenses associated with managing stormwater, and the time delays in project completion due to addressing permitting uncertainty. Hard costs include the installation costs of stormwater infrastructure and additional land purchase or leasing costs for stormwater infrastructure.[2]

The PV-SMaRT team conducted substantial research and review of stormwater and water quality permitting practices. The team also engaged solar development and water quality stakeholders in multiple state and local jurisdictions. We identified potential barriers in existing development and permitting practices that can create inconsistent or unpredictable consequences and added costs for solar development in meeting water quality permitting standards. These barriers fall into four general categories across the landscape of water quality permitting:

1. **Most existing water quality standards and best practices were not designed or tested for solar installations.** Permit standards and the portfolio of stormwater best management practices (BMPs) were developed for non-solar projects such as housing and commercial projects, and do not account for the unique three-dimensional nature of solar development.
2. **Different post-construction and construction permit goals lead to suboptimal water quality results.** The inability of developers to take regulatory credit for the full range of water quality benefits of green stormwater infrastructure, low-impact development, perennial and habitat/pollinator-friendly ground cover in the stormwater construction general permit (CGP) permit process creates a potentially significant barrier to market adoption of optimal water quality design standards and discourages designs that optimize co-benefits.
3. **Solar projects face varying expectations and standards across jurisdictions, both state and local.** Assessments of water quality and stormwater risks vary across jurisdictions. This has led to sometimes substantially different permitting standards and practices, requiring changes in solar design and consequently stormwater BMPs cost across jurisdictions, even for virtually identical circumstances.
4. **Lack of consistent, data-driven best practices about array design, layout, and site standards that can minimize water quality risks and maximize benefits.** PV system design affects stormwater runoff, and neither regulators nor developers have data on designing to minimize stormwater runoff or assess cost-effectiveness of design decisions. Modeling to identify mitigation requirements by authorities having jurisdiction (AHJs) or development teams typically do not account for all design features that affect runoff.

Creating permitting best practices for these four categories of barriers (and opportunities for improvement) offer an opportunity to increase consistency and transparency of water quality permitting and reduce solar development costs. These resources are necessary to assist both developers and permit authorities to plan, design, and evaluate array design features that reduce runoff. The PV-SMaRT field research and modeling will provide the data-driven foundation to resolve barriers and support the creation of permitting and development best practices. These best practices can reduce permitting uncertainty and create consistency in the permitting process, limit unnecessary infrastructure investment, expedite array development, improve water quality outcomes, and may reduce solar development costs.

Methodology

To identify barriers to solar development, the team conducted research on existing permitting and stormwater practices. The team also interviewed stakeholders on barriers and opportunities for lowering permitting soft costs and reducing uncertainty, and assessed permit standards, regulations, and ordinances across a dozen states. Activities include the following:

- Reviewed the CGP of each case study state and selected additional states (reviewing a total of 12 state CGPs and associated guidance materials). Non-case study states, as shown in table 2, focused on states that have adopted or published guidance on stormwater for solar development.
- Interviewed over two dozen federal, state, and local representatives or regulators in each case study state and the US Environmental Protection Agency on existing practices for large-scale ground-mount solar projects.
- Presented to and solicited feedback from non-case study state water quality staff and officials. Material presented included the PV-SMaRT project, methodology, and interim findings. The audience was comprised of approximately 90 state water quality staff across Indiana, Michigan, Pennsylvania, New Hampshire, and Wisconsin.

PV-SMaRT Water Quality Task Force Members

Andrew Nelson
Britta Hansen
Dave Gasper
David Morley
Gavin Chase Meinschein
Greg Hoffman
Jake Janski
Jason Bernagros
Peter Parkinson
Robert Goo
Seth Brown
Sybil Sharvelle
Veronica Craw

- Interviewed water quality advocates and engineering professionals, both PV-SMaRT Water Quality Task Force members and others. We also engaged solar industry representatives at conferences and webinars.
- Reviewed local water quality and associated standards that affect solar projects, including zoning, stormwater, and environmental standards in all the case study states and in other states (primarily in the Midwest and eastern US).

The PV-SMaRT Water Quality Task Force provided substantial information and feedback to the barriers investigation, including participating in the interviews, referring the PV-SMaRT team to other professionals, and reviewing and providing feedback on draft barrier categories.

Potential Water Quality Permitting Barriers

Barrier Categories

1) Barrier - Existing stormwater standards and best practices were not designed or tested for solar installations. All large-scale PV installations are subject to standards outlined in each state's stormwater construction general permit (CGP).[3] Additional state water quality standards (from either federal Clean Water Act [CWA] requirements typically administered by the state, or state standards that work in parallel to CWA standards) also affect many PV installations.[4] Most local stormwater standards use the same tools or methods that were developed as part of these CWA programs and permit standards.[5] All of these standards, however, were designed for traditional construction and development activity and only a few jurisdictions have re-examined them for applicability to solar land uses and designs.[6]

The PV-SMaRT Team identified potential barriers to and increased costs for solar development. The team also identified barriers to achieving water quality outcomes that resulted from applying existing standards not designed or tested for solar applications to the special circumstances of solar development. The identified barriers are as follows:

- Definitions used for "impervious surface" in post-construction requirements are frequently not defined in the context of solar development projects. In some cases, landscape covered by PV arrays are considered impervious surfaces.
- Definition of "final stabilization" of a site inadvertently discourages use of native or deep-rooted vegetation that makes optimal use of the disconnected pervious area between and under the arrays in a large-scale PV development.
- Permit officials sometimes relied on non-solar runoff coefficients or ground cover categories to guide the extent of required post-construction BMPs.[7]
- A few states developed solar-specific stormwater standards and guidance for local governments to implement, but used a narrative standard with different treatments of disconnected pervious ground and generally no distinction for types of ground cover.[8]

Consequences: The lack of solar-specific standards and modeling leads to increased uncertainty in permitting, increased soft costs, and suboptimal water quality outcomes:

1. Because standards were developed for land uses with different characteristics than solar, solar projects frequently face a higher site-specific burden for demonstrating best practices and quantifying risk. Simply using Natural Resource Conservation Service curve numbers as a proxy for the lack of solar-specific runoff coefficients can over-estimate runoff by an inch or more on design storm calculations.[9]
2. Permit officials lack science-based evidence that proposed solutions will mitigate water quality and quantity risks.
3. Local permit officials have limited capacity to document or model new or solar-specific BMPs.

Case Study: Variation in, or lack of definition of, "impervious surface" in post-construction requirements

Most jurisdictions, including the US Environmental Protection Agency's standards, do not clarify in rules or guidance how to treat solar panels in calculations of impervious surface.[10] Solar development therefore faces an uncertain set of standards that can vary by permit official or jurisdiction and need clarification or negotiation in each instance. Solar developers reported different treatment of solar panels by state and local officials (even within the same state). They report the need to spend much more time justifying the submittal of modeled stormwater impacts or incorporate additional stormwater BMPs that require unanticipated engineering, construction, and additional consumption of land.[11] Several solar industry interviewees described one state that had solar-specific guidance, but discounted the infiltration benefit of disconnected vegetated ground. "They negotiate, and show some flexibility, but we always end up with a token stormwater pond," one industry representative noted. The representative added, "we don't think it's needed, but we can live with it to get the project completed."

Solar development is unique in the three-dimensional flow of stormwater; stormwater both flows along the impervious panel surface and simultaneously can infiltrate under the panel on pervious ground cover. This unique disconnection changes some of the basic assumptions about accounting for impervious surfaces and designing stormwater and water quality mitigation strategies. No research, prior to PV-SMaRT, has established runoff coefficients for ground-mounted PV as a land use, leading to permit officials applying existing curve numbers or runoff coefficients developed for non-solar land uses. This can lead to either unnecessary requirements for BMPs, or to inadequate BMPs for some site conditions, depending on the standard chosen by the permit agency or the applicant.[12] Three of the five case study states (GA, CO, OR) do not provide explicit guidance for how solar panels should be treated in meeting final stabilization or post-construction standards.

- Colorado's CGP is designed for arid environments, does not include post-construction requirements, and does not provide any explicit guidance for solar development.[13] This combination diminishes the importance of how to account for solar panel imperviousness.
- Minnesota defines solar panels as impervious while the vegetated area beneath and between solar array is pervious.[14] All roads and hardscape add to the amount of impervious surface on the project site, and the sum total of impervious surface requires post-construction mitigation. Minnesota's standards credit projects for disconnection of the panel runoff onto pervious vegetated ground cover, and calculates required treatment based on a solar-specific spreadsheet model that uses a pre-settlement baseline.[15]
- New York allows case-by-case exemption from the post-construction stormwater control plan requirement in the CGP if a permittee demonstrates that the project will result in minimal impervious changes from existing (pre-project) land use, but does not provide guidance on whether solar arrays count as impervious.[16]
- North Carolina defines the vegetated area beneath and between solar arrays as pervious but allows the arrays to be exempted from calculations for post-construction BMP requirements only if certain

conditions are met for ground cover, separation between arrays, and slope.[17] The Stormwater Manual promotes and encourages a pollinator-friendly ground cover but does not modify treatment of impervious surfaces relative to the type of vegetative cover.

2) Barrier - Different post-construction and construction permit goals lead to suboptimal water quality results. This barrier is specific to the habitat- or pollinator-friendly ground cover best practice for solar project ground cover. Existing non-solar-specific runoff standards for ground cover show that deep-rooted vegetation, such as a native meadow, provides better water quality outcomes than turf grass or equivalent.[18] Improved infiltration and diminished runoff volumes apply to post-construction CGP standards and to other water quality goals of other permit processes.

Solar farms are different from most types of development in regard to the effect of vegetative ground cover choices for water quality outcomes. The substantial amount of pervious ground cover available on a solar farm is far larger than on other forms of development that create buildings and parking lots. The ability of the project to disconnect flows to pervious vegetated areas creates a water quality opportunity somewhat unique to solar development.

CGP permit standards for post-construction mitigation of stormwater impacts are typically designed to meet a minimum performance standard on the construction site for different design storms (2-, 10-, 100-year frequency storms).[19] Once the standard is reached, the developer has no incentive to improve on the water quality performance of that site (the standard is a minimum, not an optimal target). Some states encourage use of BMPs that go beyond the minimum standard, but there is no mechanism within the permit process to benefit the developer.[20] In contrast, other permit standards such as total maximum daily load standards for impaired waters are designed to meet a quality standard in the receiving waterbody rather than considering individual sites that discharge to that waterbody.[21] Improving a particular site beyond the minimum CGP standard allows the full benefit of improvements to that site to be recognized and credited to the project and the permitted local jurisdiction.[22] Jurisdictions that have water quality trading systems may be able to capture this potential benefit for monetary benefit to the solar project owner and regulatory benefit to the local jurisdiction.[23]

Photo from Great Plains Institute by Katharine Chute

Consequences: The inability of developers to benefit from the full range of water quality benefits of habitat- and pollinator-friendly ground cover in the CGP process creates a potentially significant barrier to market adoption of optimal water quality design standards and discourages designs that optimize co-benefits. If, as existing research and measurement indicate, a habitat-friendly ground cover creates better water quality outcomes for the local waterbodies, the CGP standards may be leaving water quality opportunities on the table. One water quality designer who worked with solar developers on stormwater mitigation noted, “Sometimes it’s easy to lose track of the end goal. Setting the bar for doing what’s right rather than doing just enough, can make all the difference.” [24]

Recognizing water quality benefits of different types of ground cover in the permit process may also benefit the solar development. If the extra infiltration capacity of habitat or pollinator ground cover allows more closely spaced arrays, the developer can increase productive capacity on the site.[25]

Case Study: Final stabilization standards create inadvertent barrier to use of best management vegetation practices that improve stormwater infiltration

Pennsylvania has a specific pathway to meeting post-construction standards for solar farms that recognizes the benefits of native and naturalized ground covers.[26] However, native and naturalized ground covers take approximately three years before they are self-sustaining.[27] Turf grass, which has a significantly higher runoff coefficient than native grasses and pollinator habitat, can be established much more quickly and can meet CGP final stabilization requirements.[28] The establishment time creates an additional barrier in the Pennsylvania pathway, as the final stabilization establishment threshold for the native/naturalized BMP was at 90% density rather than the typical 70% density.[29]

The solar developer had committed to using a pollinator-friendly standard for purposes other than meeting permit requirements but could not close their construction stormwater permit until the native vegetation was established at the 90% density standard. Rather than leaving CGP coverage open for what could be another year, the developer chose to stabilize the site with turf grass to establish final stabilization and close out the stormwater construction permit. Then, after closure of permit coverage, the developer reseeded and established pollinator-friendly vegetation.[30]

Other developers and subcontractors to the engineering procurement construction contractor also reported higher soft costs from final stabilization requirements associated with habitat- or pollinator-friendly practices.[31] Stakeholders reported that waiting for 70% establishment for native or naturalized pollinator ground cover can affect the length of time temporary stabilization measures must be maintained, the risk of having to install redundant stormwater BMPs, and the willingness of financiers to proceed with sales of the project to management entities. One stormwater engineer noted, “the financiers are sometimes looking more closely at the details than the regulators.” Avoiding perception of financial risk, he noted, can be a tougher standard than meeting the design storm.[32]

Photo from Great Plains Institute by Jenna Greene

3) Barrier - Solar projects face varying expectations and standards across jurisdictions. Although the federal Clean Water Act is the foundation for most of the stormwater and water quality permitting across the nation, solar projects face a wide variety of permitting standards and requirements. The National Pollutant Discharge Elimination System (NPDES) permit system is overseen by the US Environmental Protection Agency, but authority for managing the system is frequently delegated to states, which then, in many instances, delegate administration of the permit to local government.[33] Each cross-jurisdictional delegation creates an opportunity for both interpretation differences and additional standards or requirements to be incorporated into the permit that are specific to the delegated authority.

Jurisdictional variations occur at both the state and the local level. Variations create uncertainty about the modeling assumptions for determining stormwater impacts in permit submittals and the type and scale of BMPs that will be needed for stormwater mitigation.

One engineer working in the solar industry noted, “we see a lot of variation in expectations in different states, and have spent time helping stormwater permit officials understand solar development.” The engineer also noted, however, that familiarity with solar among state level officials had improved significantly, but “local governments are where the real problems lie.” [34]

Table 1: Differences in water quality standards and guidance for case study states

State	Permanent Stabilization	CGP Post-Construction Standards	Statewide Stormwater Manual	Local Land-Use Permitting Authority	State Model Solar Ordinance
Colorado	Uniform vegetative cover, individual plant density of 70% of pre-disturbance level	No	No	Always	No
Georgia	Uniform permanent vegetation, 70% density	No	Yes	Always	Yes
Minnesota	Uniform (90%) perennial vegetation, 70% density of native background cover	Yes	Yes	< 50 MW	Yes
New York	Uniform perennial vegetative cover, 80% density	Yes	Yes	< 25 MW	Yes
Oregon	Established, uniform perennial vegetation, 70% coverage	No	No	Always	Yes

Both state regulators and solar industry stakeholders noted the importance of making local permitting standards consistent with best practice standards:

1. Local governments are the primary land use regulator in many (but not all) states for large-scale PV development.[35]
2. Local governments also sometimes have authority for CGP standards (local governments that are designed as Municipal Separate Storm Sewer System permittees).
3. Finally, local jurisdictions sometimes have independent water quality or water protection standards that drive BMPs and solar site design decisions.

Consequences: The lack of consistency across jurisdictions in assessing water quality and stormwater risks have led to sometimes substantially different permitting standards and practices, requiring changes in solar design and BMP cost across jurisdictions even for virtually identical circumstances.

Local governments, which generally have the fewest resources and least capacity for addressing new and evolving forms of development, are the implementers and have the final say on water quality permits and associated land use regulation. Solar projects face great uncertainty on how local officials will interpret CGP best practices relative to solar development.

Here are examples of differences across jurisdictions and the consequences for water quality permitting of large-scale solar development:

- Water quality or resource protection policies and standards can vary significantly between jurisdictions (state and local). Some communities prioritize natural resource protection and ecosystem function in local comprehensive and master plans, while others do not. These differences can lead to community-specific protection thresholds and variability in required BMPs.
- Local capacity for managing permit processes and knowledge of modeling and best practices innovations. For an unfamiliar land use or land uses for which little guidance is available from national or state authorities, permitting can be slow and uncertain.
- Overlapping local jurisdictions, such as states that enable separate regulatory authority for watershed districts or drainage districts that overlap with county or city land use authority. Jurisdictional uncertainty contributes to permitting uncertainty and project risk.
- Some states lack centralized guidance or assessment tools for local regulators, leading to a wider variety of interpretations, particularly with new land uses and water quality circumstances as with solar development.
- Unfamiliarity with large-scale solar as a land use leads to perceptions that the community should limit its deployment and assign a higher risk to solar than other more familiar land uses.[36]

Case Study: Local treatment of solar panels in coverage and impervious surface standard

In New York, local jurisdictions typically follow the state's CGP guidance when regulating large-scale PV developments.[37] New York has centralized guidance for stormwater permitting under the CGP (with no solar-specific guidance) and a model solar ordinance identifying best practices for large-scale solar installations. However, solar projects still face substantially different standards across local jurisdictions.

In Long Island, NY, one solar project was required by the jurisdiction to treat the PV panels as impervious, regardless of the disconnection provided by the vegetated ground cover. This decision required a stormwater basin that used approximately 50 percent of the site area.[38] The project is built and still seeking final approvals.

Several towns in upstate New York adopted similar language in their zoning standards to set lot coverage standards for solar farms.[39] While the ordinance language was common across all three communities, the actual dimensional standards were substantially different. One community set the maximum lot coverage at 50%, another at 35%, and a third at 20%. A solar project that needed 5 acres per MW under the 50% standard would need approximately 11.5 acres per MW under the 20% standard.

Lot coverage is a basic zoning standard (rather than stormwater permitting). However, coverage is typically associated with limiting the amount of impervious surface on a lot and consequently with protecting water quality. How land use regulation interacts with stormwater permitting is one of the cross-jurisdictional variations increasing the soft costs that solar projects face.

Table 2: States with solar-specific stormwater guidance or policy

State	Location of Standard	Type of Standard	Regulatory Method	Varies by Conditions
Minnesota	Stormwater Manual, FAQ	Spreadsheet model, evaluating entire site	Calculated treatment need	Slope, soils
Pennsylvania	FAQ Guidance	Performance standard, based on array size and infiltration area	Disconnection design	Slope
New Jersey	Statute	Statute exempting solar panels from impervious surface standards	Statutory pervious designation	Pinelands area exempt
North Carolina	Stormwater Manual	Performance standard, based on array size and infiltration area	Disconnection design	Slope, spacing, racking
Maryland	Stormwater Manual	Performance standard, based on array size and infiltration area	Disconnection design	Slope
Connecticut	CGP solar guidance	Performance standard (array and infiltration area), and modeling	Disconnection design, calculated treatment	Slope, soils, compaction
Massachusetts	Guidance document	Policy-based	None	Slope, soils, cover
Ohio	NPDES Post-Construction Guidance	Performance standard, based on array size and infiltration area	Disconnection design	Slope, soils, tracking array

4) Barrier - Lack of consistent, data-driven best practices about array design, layout, and site standards to minimize water quality risks and maximize benefits. A wide variety of system design decisions can affect the volume and velocity of water at the drip edge of the panel, the ability of the disconnected ground cover to infiltrate the runoff, and the ability of the site to retain design storm runoff on site. There are several design variations that affect stormwater flows, including the following:

- Tracking or fixed racking systems
- Spacing of arrays (disconnection area)
- Connected collector surface (surface area of array)
- Solar panels mounted in portrait or landscape (disconnection within array)
- Interaction of topography and array layout
- Construction practices (grading, soil compaction, soil removal)
- Height of panel drip edge

The solar industry continually innovates to reduce costs, recognizing the interplay of design decisions on cost, such as maximizing productive capacity of the site in array layout and minimizing labor costs through racking and panel design decisions. But industry stakeholders and regulators indicated that stormwater mitigation costs or water quality permitting issues were rarely, if ever, part of the cost assessment.[40] Initial results of field testing and modeling indicate that array spacing can significantly affect the required capacity of stormwater BMPs for post-construction stormwater mitigation, and therefore also affect project costs.[41]

From the water quality perspective, post-construction BMPs are typically based on modeled results of the site design submitted by the CGP applicant.[42] Additional water quality or stormwater standards at the state or local jurisdictional level (that focus more exclusively on post-construction performance) will address water quality via modeling or sometimes simply by exclusion.(add endnote "Local governments will sometime simply exclude certain types of development such as large-scale solar where water quality is a high priority.") In either case, permit officials do not have data-driven evidence of how design elements affect stormwater runoff, such as the effect of disconnecting panel surfaces within the array, and have no basis for offering that as a BMP for mitigating runoff.



Three examples of internal array disconnection (none, one, and three breaks)
Photo credits left to right: Brian Ross, Great Plains Institute; Dr. David Mulla, University of Minnesota; Brian Ross

Consequences: PV system design affects stormwater runoff, and neither regulators nor developers have data on designing to minimize stormwater runoff or assess cost-effectiveness of design decisions. Modeling to identify mitigation requirements by authorities having jurisdiction (AHJs) or development teams typically do not account for all design features that affect runoff. The resulting permit standards may fail to select or credit design opportunities that could decrease costs or improve water quality outcomes, or both. BMPs that are required to mitigate post-construction stormwater impacts may be unneeded or more expensive than alternatives that are incorporated into site design, array design, or layout.

Case Study: Impervious surface and disconnection in array design and placement

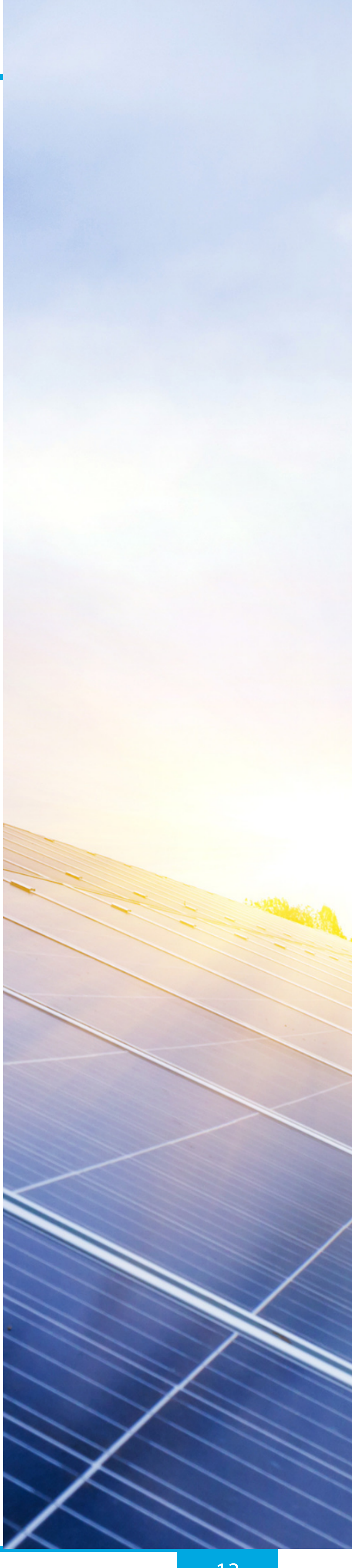
In the Array - Array designs have distinct differences in the level of disconnection between impervious panels and pervious vegetated ground cover. Arrays that have stacked panels that create a break along the sloped profile have more disconnection than arrays with a single panel along the slope.

Panels that are mounted on the arrays in landscape format may have as many as four breaks between the panels on a single array, which serve a disconnection function where stormwater may flow between panels to the ground beneath the array (verified by observational evidence from the PV-SMaRT field research team).

Portrait orientations may only have one break, or in a smaller tracking array may in fact be a single panel with no break. If the ground under the panels is vegetated, this disconnection distributes water infiltration and reduces volume at the lowest drip edge on the array.

Most of the solar standards examined in this study make no distinction for the additional disconnection. States with solar stormwater guidelines almost all follow the example of Minnesota or Ohio where the impervious measurement is either the horizontal width of the array or the length of the combined panels along the slope of the panel surface. Only the State of North Carolina recognizes the additional disconnection from spacing between panels.

Jurisdictions that do not have solar standards rely on the solar industry applicant to model post-construction



BMP needs. Whether the additional disconnection is included in the modeling or not depends largely on the person doing the modeling, and whether the AHJ accepts disconnection as a BMP.

Between the Arrays - Solar arrays within the site are typically spaced to minimize shadowing. Modeling programs used by developers take into account a variety of site conditions to maximize the site for solar production and minimize land costs.[43] However, array spacing, including consideration of vegetated ground beneath the arrays, can also affect water quality outcomes and the need for stormwater BMPs. Most states do not have stormwater guidance for ground-mount solar installations but require submittal of modeling by the applicant to determine the needed capacity of post-construction BMPs. A small separation between arrays, or lack of vegetative cover under the arrays, may result in increased need for additional BMPs. However, once the design is done the developer is unlikely to redo the array layout to improve water quality outcomes. States that have recognized the importance of disconnection of solar arrays in CGP guidance or stormwater manuals provide predictable pathways that can be incorporated into modeling (or in some cases eliminate the need for post-construction modeling). The State of Ohio recognizes this dynamic in its stormwater manual guidance for solar farms, allowing panels to be discounted as impervious surface if the spacing between the arrays is equal to the horizontal width under the array, and accounts for differences in slope (greater slope requires additional BMPs).

Conclusion

Stormwater permitting standards are intended to protect surface and ground waters from the effects of land development, which changes the flow and infiltration of stormwater from what occurs in an undeveloped or natural landscape. Removing native vegetation and increasing the amount of impervious surface can significantly change the functioning of the watershed, resulting in much higher levels of surface water flow and decreased infiltration or subsurface hydrology.

The science of stormwater regulation was not, however, developed with the unique characteristics of large-scale PV installations in mind. Permitting standards and processes can therefore be unpredictably variable for solar development, both increasing development costs (soft costs and infrastructure costs) and diminishing water quality outcomes.

Identifying inadvertent barriers to solar development that result from the lack of solar development-specific research and water quality standards is the first step in addressing this dilemma.

Creating permitting best practices for these four categories of barriers to appropriate permitting offers an opportunity to increase consistency and transparency of water quality permitting and reduce solar development costs. The PV-SMaRT field research and modeling will provide the data-driven foundation to resolve many of these barriers. This includes the development of solar-specific coefficients, lookup tables, or spreadsheet tools to allow for and support the creation of permitting and development best practices that reduce permitting uncertainty, limit unnecessary infrastructure investment, and improve water quality outcomes. These tools and best practices for permitting authorities and for solar projects will be listed on the PV-SMaRT website and disseminated in forums across the nation.

Appendix A: Definitions

- **Construction general permit (CGP):** A construction general permit regulates stormwater-related pollution during the construction process and establishment of permanent stabilization of disturbed soils. All large-scale, ground-mount PV solar projects must apply for coverage and meet the permit requirements of the CGP.
- **Design storm:** Design storm is the amount of rainfall in a 24-hour period at specific recurrent intervals, usually at 2-, 10-, or 100-year intervals.
- **Disconnection: "**Disconnection refers to the practice of directing runoff from impervious areas, such as roofs or parking lots, onto pervious areas, such as lawns or vegetative strips, instead of directly into storm drain." (Source: National Stormwater Calculator Web APP User's Guide – Version 3.2.0, EPA/600/R-19/076August 2019)
- **Final stabilization:** The CGP addresses stormwater-borne pollution during the construction phase of development. But this includes defining when construction activities cease, and a transition to ongoing management of the development. The CGP standards for "final stabilization" are the trigger that allows the project to close the permit.
- **Habitat- or pollinator-friendly solar: "**This program promotes the planting and management of wildlife habitat with an emphasis on pollinator, songbird, and gamebird benefits on solar projects. This effort was initiated to comply with Minnesota legislative requirements stating that "an owner of a solar site implementing solar site management practices may claim that the site provides benefits to gamebirds, songbirds and pollinators only if the site adheres to guidance set forth by the pollinator plan provided by the Board of Water and Soil Resources" (Minn. Stats. 216B.1642). "Local governments and other landowners, as well as solar developers, can work toward meeting the standards. Some municipalities are also requiring that ground mounted solar projects are meeting Habitat Friendly standards to help ensure that projects are providing multiple landscape benefits and are maintained for the lifespan of the project." (Source: Minnesota Board of Water and Soil Resources, https://bwsr.state.mn.us/minnesota-habitat-friendly-solar-program)
- **Lot coverage: "**Since Ground-Mounted Solar Energy Systems generally do not include much impervious surface, and since lot coverage requirements are designed, in large part, to reduce impervious surfaces and the run-off they create, this Model Law measures lot coverage for a Ground-Mounted Solar Energy System by its actual impervious footprint, which results in a smaller measurement than the square footage of the solar panels." (Source: New York Model Solar Ordinance)
- **Post-construction:** In some jurisdictions the CGP or related state regulation includes requirements for establishment of permanent stormwater management practices or infrastructure and demonstrating that these practices adequately manage stormwater runoff for the project's life. Such provisions are referred to as "post-construction" standards.
- **Pre-development condition:** When a requirement exists to match runoff rate or volume to "pre-development conditions," there is a range of options that could be applied to define land cover conditions. This range goes from pre-settlement, which assumes land is in an undeveloped condition, to the land use condition immediately prior to the project being considered, which assumes some level of disturbance in the natural landscape has already occurred. (Source: Minnesota Stormwater Manual, https://stormwater.pca.state.mn.us/index.php?title=Main_Page)
- **Stormwater best management practices: "**BMPs are structural, vegetative, or managerial practices used to treat, prevent, or reduce water pollution." (Source: Stormwater Management Best Practices, https://www.michigan.gov/documents/deq/ess-nps-savvy-bmp_209386_7.pdf)

Appendix B: Water quality permitting and standards affecting solar development

Existing practices

Large-scale[44] photovoltaic (PV) installations, similar to all other forms of development, are subject to a variety of land use and environmental standards and permitting processes administered by federal, state, or local regulatory authorities. Many of these permits are associated with protecting surface and ground water resources, and with the management of stormwater and associated federal Clean Water Act standards and permit requirements, as well as state and local water quality protections and associated permitting requirements.

Permits and standards that affect the infrastructure and soft costs of large-scale PV development include several categories of permits administered by different authorities having jurisdiction (AHJs), from federal to local jurisdictions. The categories are described below:

- **National Pollutant Discharge Elimination System (NPDES) Stormwater Construction General Permit (CGP)** – Regulates stormwater-related pollution during the construction process and establishment of permanent stabilization of disturbed soils. All large-scale ground-mount PV solar projects must apply for coverage and meet the permit requirements of the CGP.
- **Section 404 Dredge and Fill Permit** – Regulates impacts to waters of the US including wetlands and small streams. Many, but not all, solar projects need to meet these permit standards.
- **State-specific water permits** – State permits modify (are at least as stringent and often more stringent) federal permit processes or require permits for impacts to specific protected waters or water quality goals not addressed by the Clean Water Act. Solar projects are subject to these additional standards on a state-by-state basis.
- **Municipal separate storm sewer system (MS4) permits** – MS4 permits administered by local governments under the NPDES permit system incorporate state and local standards and additional federal standards under the Section 303(d) (impaired waters and total maximum daily load) standards. Solar projects located in MS4 jurisdictions are subject to these permit standards.
- **Local-specific standards** – Local standards are developed by AHJs to meet local water quality priorities, including permits, zoning, and environmental standards managed by cities, counties, watershed districts, drainage authorities, and other local AHJs. Solar projects are generally subject to these permits and standards, but there is substantial variability across states and local jurisdictions about whether the project needs to comply with this category of permits.

All of the above permit categories are affected by stormwater design and infrastructure choices made during the solar development process. Creating scientific, data-driven stormwater standards for ground-mounted PV installations will clarify risks and effectiveness of design decisions and stormwater management methods. Such standards will also open the door to improved permit consistency across jurisdictions and permit goals. Increased standardization of site design and permit administration will create more transparent and predictable permitting for solar projects, and improved water quality outcomes for all jurisdictional water quality priorities.

Clean Water Act

The Clean Water Act (CWA) has, since 1972, been the foundation for water quality protection across the nation. A primary permitting standard that stretches from federal to local jurisdictions is the NPDES stormwater permit system. Phase 1 of NPDES was launched in 1990 to ensure that nonpoint sources of pollution were meeting federal standards for discharges to the public waters of the US NPDES. Phase 2, implemented in 2003, expanded the scope of the NPDES system to include construction activities that disturb as little as one acre of land.

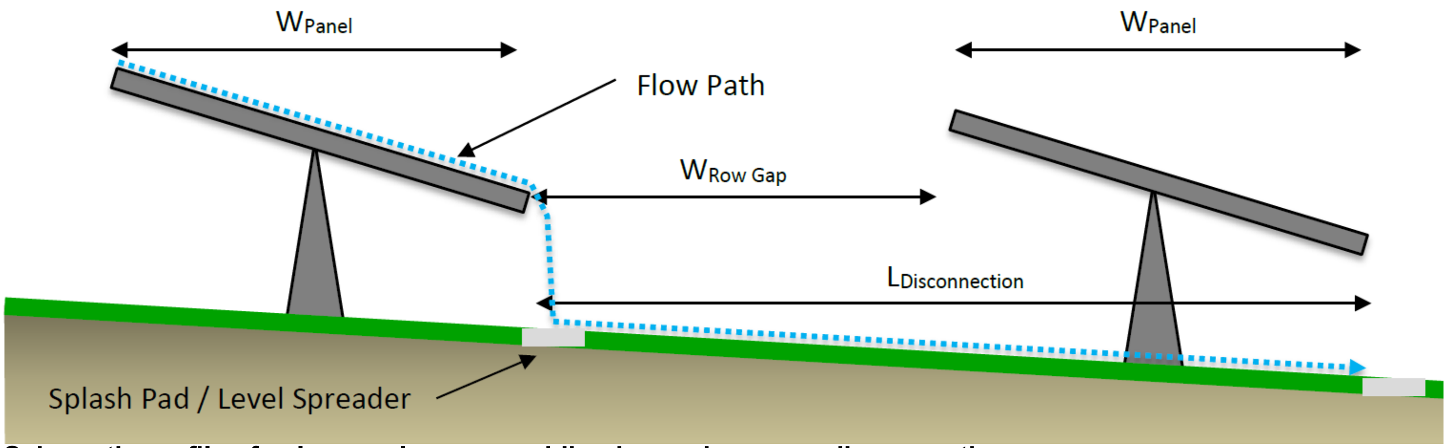
The US Environmental Protection Agency (EPA) has developed NPDES standards, permitting processes, and threshold definitions for managing construction activities and ensuring permanent stabilization to protect waters from unmanaged stormwater. These standards apply to all large-scale PV development in the nation, and guide state standards where the EPA has delegated authority to the state.[45] The foundational element of the NPDES program is the stormwater construction general permit (CGP).

Several critical permitting elements embedded in NPDES and other CWA-based regulation are common across all levels of stormwater and water quality permitting.

The CGP is designed to address stormwater discharges to public waters during the construction process, and coverage is therefore terminated at the conclusion of construction activities. Coverage termination requires the project meets specific standards for permanent or final stabilization of the site. Final stabilization ensures that the site is at a stable state reflecting conditions and stormwater discharges matching baseline conditions of an undeveloped site in the area in which the project is located.

“Post-construction” standards require the project to demonstrate that permanent best management practices are installed that will mitigate stormwater impacts, as measured from a benchmark condition that varies across jurisdictions, for design storms after construction is completed.[46] Some, but not all, states have requirements for “post-construction” plans or meeting specific post-construction performance standards. Only five states include statewide post-construction standards in their CGP, and another nine require post-construction standards statewide under state regulation. For all states, local governments that are MS4s must include post-construction standards in their administration of the CGP.

Most, but not all, states appear to consider solar panels to be disconnected impervious surfaces in the administration of the CGP. Many states have not recognized “disconnection” as a stormwater best management practice; directing the flow off the impervious surface to vegetated ground where the flow is infiltrated rather than running off into a conveyance system or waterbody. Some states specifically identify disconnection as a form of green infrastructure, while others simply incorporate it into the stormwater modeling that is part of CGP or local ordinance submittal requirements.[47]



Schematic profile of solar panel array providing impervious area disconnection
Republished from Ohio EPA, Guidance on Post-Construction Storm Water Controls for Solar Panel Arrays, NPDES Construction General Permit (October 2019), figure 1.

Endnotes

[1] The range of stormwater infrastructure and additional land costs needed to meet permitting requirements is dependent on the jurisdiction and can be significant. However, solar developers have reported that the primary problem is the uncertainty of treatment that will be required, which can unexpectedly increase costs that were not included in the project formas, and show up after the project has been initiated.
[2] US DOE Office of Energy Efficiency and Renewable Energy, Soft Costs Technologies Office, https://www.energy.gov/eere/solar/soft-costs.
[3] See "EPA's 2017 Construction General Permit (CGP) and Related Documents," NPDES, US EPA, https://www.epa.gov/npdes/epas-2017-construction-general-permit-cgp-and-related-documents; NPDES, US EPA, 2017 CGP - Permit, as modified and applicable as of June 2019. Under the Clean Water Act NPDES stormwater program, all development projects that disturb a minimum of one acre of ground require permit coverage. The permit is administered by either the US EPA or the delegated state authority in which the project is located.
[4] For instance, Section 404 dredge and fill permits covering impacts to wetlands and other waters of the US, and parallel state regulation such as Minnesota's Wetlands Conservation Act.
[5] Other local land use and water quality standards and policies also were developed without considering solar land uses, and present similar barriers, as noted later in this document.
[6] The team identified eight states with solar-specific standards or guidelines for meeting construction general permit standards. Only one of the case study states has a solar-specific standard. Interviews conducted with federal and state permit officials identified no solar-specific validated research that contributed to these standards. All of the standards drew from non-solar research and modeling.
[7] PV-SMaRT field testing and modeling (forthcoming publication) demonstrate that non-solar runoff coefficients such as National Resource Conservation Service curve numbers overestimate runoff on solar sites.
[8] Some jurisdictions require site-specific modeling that can account for disconnected pervious area and alternative ground covers, but permit officials and developers must address these on a case-by-case basis, rather than established science or validated best practices.
[9] Unpublished results of PV-SMaRT field testing and modeling.
[10] In a review of existing state guidance for CGPs, we identified eight states with at least some guidance or policy on how to treat solar panels vis-à-vis addressing post-construction impervious surface calculations that dictate how much and what kinds of stormwater infrastructure is needed.
[11] Interviews of solar developers and engineering firms on stormwater permitting, conducted during PV-SMaRT. Feedback was provided at regional and national solar industry conference presentations. Differences were most acute among local AHJs, but solar industry representatives described both cross-state difference in CGP interpretations, and within states at the local level.
[12] The choice of curve number for proposed vegetated areas is sometimes left to the applicant, and in other instances is managed by the AHJ. An example in Wisconsin used a "meadow" curve number (39) for the final planned pollinator-friendly ground cover and a pre-development curve number for corn of 58. Other projects used other final land cover types with higher (less pervious) curve numbers (turf can be over 60), and Minnesota recommends use of a "pre-settlement" (curve number of 30) rather than "pre-development" baseline.
[13] Outside of Municipal Separate Storm Sewer Systems (MS4s) areas, where standards are determined by the local AHJ.
[14] "Minnesota Stormwater Manual," Minnesota Pollution Control Agency, https://stormwater.pca.state.mn.us/index.php?title=Main_Page. Stormwater management for solar projects and determining compliance with the NPDES construction stormwater permit.
[15] A pre-settlement baseline measures from what the runoff would have been prior to any development or agriculture (generally a prairie).
[16] New York State Department of Environmental Quality, *New York Construction General Permit* (January 20, 2020), Appendix B – Required SWPPP Components by Project Type, table 2, https://www.dec.ny.gov/docs/water_pdf/constgp020001.pdf.
[17] North Carolina Department of Environmental Quality, *Stormwater Design Manual* (revised January 13, 2018), E-6, Solar Farms, https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Stormwater/BMP%20Manual/2018-E-6--Solar-Farm-Manual.pdf.
[18] US Department of Agriculture National Resource Conservation Service, *Technical Release 55* (June 1986), https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf.
[19] US EPA Office of Water, Office of Wastewater Management Water Permits Division, *Summary of State Post Construction Stormwater Standards* (updated July 2016), https://www.epa.gov/sites/production/files/2016-08/documents/swstdsummary_7-13-16_508.pdf.
[20] North Carolina Department of Environmental Quality, *Stormwater Design Manual* (Revised August 2019) https://deq.nc.gov/about/divisions/energy-mineral-and-land-resources/stormwater/stormwater-program/stormwater-design. For instance, the North Carolina Stormwater Design Manual encourages use of pollinator-friendly ground cover in E-6 Solar

Farms, Recommendation 5. The draft Indiana CGP emphasizes use of green infrastructure with native vegetation as BMPs and provides some regulatory leeway on final stabilization for establishing native vegetation.

[21] Unless a particular site or facility is allocated a portion of the total load via a separate permit.

[22] Local jurisdictions with MS4 permits are required to address total maximum daily load and impaired waters in their portfolio of stormwater management tools, including administration of the CGP.

[23] Example jurisdictions that have used water quality trades include, Washington D.C., and the states of Oregon, Wisconsin, and Minnesota.

[24] Interview with solar industry engineering procurement and construction (EPC) contractor

[25] Array layout is driven by shading issues; ensuring that the arrays are not so close together as to create shading issues.

[26] Pennsylvania Department of Environmental Protection, Chapter 102 Permitting for Solar Panel Farms, Frequently Asked Questions (FAQ) (revised April 30, 2021), version 1.1, http://files.dep.state.pa.us/Water/BPNPSM/StormwaterManagement/ConstructionStormwater/Solar_Panel_Farms_FAQ.pdf.

[27] Michiana Council of Governments, *Technical Guide: Establishment and Maintenance of Pollinator-Friendly Solar Projects* (January 2020), http://macog.com/docs/sustainability/solar_energy/Pollinator-Friendly-Solar-Guide-Version-1-1.17.2020.pdf.

[28] Interviews of EPC landscaping and stormwater contractors.

[29] The FAQ notes this explicitly, explaining that since the ground cover BMP may be the only management tool in place, the importance of it being established before terminating permit coverage needed a higher establishment threshold than basic vegetation standards.

[30] Interview of solar developer and EPC contractor.

[31] As reported in interviews of solar developers, landscape and water quality engineers, and EPCs.

[32] Interviews of solar developers and EPC contractors.

[33] Delegation to local governments occurs when the local government is also under a NPDES permit requirement for MS4s.

[34] Water Quality Task Force interviews.

[35] For instance, in three of the five case study states, all large-scale solar projects must meet local land use approvals. For two states (New York and Minnesota), large-scale solar projects larger than 25 MW and 50 MW are exempt from local land use authority.

[36] Team review of local zoning treatment of large-scale solar land uses across multiple states demonstrates a restrictive, rather than enabling, stance toward large-scale solar. Water quality concerns are one component of restrictions imposed in ordinance or as part of land use permits. Communities in Minnesota and Wisconsin, for instance, prohibit solar farms in the state-designated shoreland areas around lakes due to uncertainty about riparian and water quality impacts.

[37] Interviews of New York state permit staff and of two solar industry businesses.

[38] Interview of solar developer.

[39] All the communities used a fairly unique definition of coverage: “The area beneath ground-mounted and freestanding solar collectors shall be included in calculating whether the lot meets maximum permitted lot building coverage and lot surface coverage requirements . . . notwithstanding that the collectors are not ‘buildings.’” Example from Town of Hyde Park, New York zoning ordinance, 130-6 I.

[40] As reflected in interviews of solar industry and regulator stakeholders, as a part of the Water Quality Task Force feedback.

[41] Unpublished results of 1-d modeling, PV-SMaRT Team.

[42] Team assessment of CGPs, guidance documents, stormwater manuals, and interviews with state and EPA permit officials. Most state jurisdictions do not list these design elements as BMPs, and some design elements are not included in the minimum modeling assumptions required or recommended by the state. A few exceptions to this have been noted earlier.

[43] S. Sánchez-Carbajal and P. M. Rodrigo, “Optimum Array Spacing in Grid-Connected Photovoltaic Systems considering Technical and Economic Factors”, *International Journal of Photoenergy,* Volume 2019: 1-14.

[44] For the purpose of this project, large-scale is defined as any ground-mounted PV system that is subject to stormwater or water quality permitting. This would include all community and utility-scale PV development, from less than 1 MW to hundreds of MWs.

[45] US EPA 2017 CGP - Permit as modified and applicable as of June 2019. The permit is administered by either the US EPA or the delegated state authority in which the project is located.

[46] *Summary of State Post Construction Stormwater Standards*, US EPA Office of Water, Water Permits Division, July 2016, https://www.epa.gov/sites/production/files/2016-08/documents/swstdsummary_7-13-16_508.pdf.

[47] For instance, Pennsylvania references specific disconnection BMPs in the Stormwater Manual for use with solar farms, while Minnesota incorporates disconnection into its spreadsheet solar stormwater manual but does not include disconnection as a listed BMP.

ABOUT THE GREAT PLAINS INSTITUTE

GREAT PLAINS INSTITUTE

Better Energy. Better World.

A nonpartisan, nonprofit organization, the Great Plains Institute (GPI) is transforming the energy system to benefit the economy and environment. Working across the US, we combine a unique consensus-building approach, expert knowledge, research and analysis, and local action to find and implement lasting solutions. Our work strengthens communities and provides greater economic opportunity through creation of higher paying jobs, expansion of the nation's industrial base, and greater domestic energy independence while eliminating carbon emissions.

www.betterenergy.org

To learn more about the PV-SMaRT project, and to stay up to date on the research and analysis, visit https://www.nrel.gov/solar/market-research-analysis/pv-smart.html.