Stephen fox

Interested party reference number [redacted]

The Examining Authority,

The Planning Inspectorate

Temple Quay House

2 The Square Bristol

BS1 6PN

23 September 2025

Dear Sirs,

I am writing to you today to present a new research report that I believe is of critical importance to the One Earth Solar Farm Proposal. This report, which I have prepared for you, synthesizes the findings of two key studies on the hydrologic impacts of solar farms and carries significant implications for large-scale projects, particularly those located on floodplains.

The enclosed document, titled "A Multi-Disciplinary Synthesis: Reconciling Two Hydrologic Perspectives on Solar Panel Runoff," provides a detailed analysis and reconciliation of the foundational work of Cook and McCuen (2013) with the more recent experimental findings of G. Baiamonte et al. (2023).

The Cook and McCuen study, while limited to a model-based simulation, was one of the first to identify a potential hydrologic risk from solar farms. It found that while panels may not affect overall runoff volume, the kinetic energy of water draining from the panel edges could cause soil erosion.[1] However, the Baiamonte et al. study, conducted with a real-world rainfall simulator on both flat and sloped land, provides the critical empirical data that quantifies this risk. Their research revealed that solar panels can increase the peak discharge of runoff by about **11 times** compared to a bare soil plot.[2]

This finding fundamentally changes the conversation. The magnitude of this increase suggests that traditional, localized mitigation strategies, such as ground cover and buffer strips, may be inadequate on their own to manage such a significant volume of high-speed water. As the report details, for a project of 3,500 acres on a floodplain, the implications are profound. A solar farm on a floodplain will have serious downstream implications and represents a high-stakes gamble in the absence of empirical proof in extreme conditions to the contrary. Large solar arrays can interrupt natural overland flow, and the massive increase in peak runoff demonstrated by Baiamonte et al. can overwhelm existing drainage systems, causing scour and potential structural damage to equipment and foundations.[3, 4, 5]

Given the scale and location of the One Earth proposal, I believe it is imperative that these findings are considered as a matter of due diligence to ensure the long-term viability and resilience of the project. I strongly suggest that this report be shared directly with the following parties:

- The NSIP Planning Inspectorate.
- All local authorities involved in the "one earth" examination.
- The Environment Agency.
- Those involved in proposals or constructions of similar projects in the Trent Valley region.

This proactive sharing of information would demonstrate a commitment to robust, science-backed site planning that accounts for the most severe potential hydrologic impacts.

Please let me know if you would like me to assist with any further analysis or documentation.

Yours faithfully

Stephen Fox

References

1. Cook, L.M., and McCuen, R.H., "Hydrologic Response of Solar Farms," *Journal of Hydrologic Engineering*, 2013.
2. Baiamonte, G., Gristina, L., and Palermo, S., "Impact of solar panels on runoff generation process," *Hydrological Processes*, 2023.
3. Central Bedfordshire Council, "Solar Farm Development Flood Guidance."
4. Natural Power, "Designing Resilient Solar Projects: Mitigating Flood Risks," 2023.
5. U.S. Department of Energy, "Preventing and Mitigating Flood Damage to Solar Photovoltaic Systems," Office of Energy Efficiency & Renewable Energy.

A Multi-Disciplinary Synthesis: Reconciling Two Hydro

A Multi-Disciplinary Synthesis: Reconciling Two Hydrologic Perspectives on Solar Panel Runoff

Executive Summary: From Theoretical Risk to Quantified Threat

The global expansion of large-scale, ground-mounted solar farms has brought to the forefront the critical need for a comprehensive understanding of their environmental impacts. This report synthesizes two key pieces of research on the hydrologic effects of these installations: the foundational modeling study by Cook and McCuen (2013) and the more recent experimental work by G. Baiamonte et al. (2023). While these papers represent different approaches to the same problem, their findings are complementary and provide a powerful, unified message for sustainable solar farm design.

The analysis reveals a progression from theory to empirical validation. Cook and McCuen's modeling study was groundbreaking for its time, as it was one of the first to investigate the hydrologic impacts of solar farms. While they found that solar panels had a neutral effect on overall runoff volume, they identified a critical environmental risk: the kinetic energy of water flowing off the panels was greater than that of direct rainfall, creating a potential for soil erosion at the base of the panels. However, the authors acknowledged that their conclusion was based on a model with "weak evidence" and was not a real-world experiment.

The core reconciliation of these studies lies in the work of Baiamonte et al. (2023), which provides the critical experimental data that Cook and McCuen's study lacked. Using a rainfall simulator, Baiamonte's team found that solar panels can increase the peak discharge of runoff by about **11 times** compared to a bare soil plot. This finding moves the issue of solar panel runoff from a theoretical risk of increased kinetic energy to a quantified, significant threat of a massive increase in peak discharge rates. This magnitude of change indicates that localized mitigation strategies like ground cover, while important, may be inadequate on their own. A truly high-performing and sustainable solar farm must not only produce energy but must also demonstrate robust management of these significant hydrologic impacts through comprehensive design and engineering. The findings of this report advocate for a new, holistic paradigm for solar farm design that integrates this scientific evidence into the earliest planning stages to mitigate severe erosion and manage stormwater effectively.

Introduction: Contextualizing the Solar Energy Nexus

The global energy landscape is undergoing a profound transformation, with solar photovoltaic (PV) technology at the forefront. As the industry matures, the scale of installations has shifted from residential rooftops to vast, utility-scale ground-mounted solar farms. This expansion brings into focus a new set of challenges and opportunities that extend beyond the fundamental physics of photon-to-electron conversion. The deployment of solar technology must be considered within a broader environmental and land-use context, necessitating a multi-disciplinary approach.

Historically, the research and development of solar energy have been compartmentalized into distinct fields. Materials scientists and electrical engineers have focused on improving panel efficiency and durability, while hydrologists and civil engineers have addressed the impacts on land, water, and soil. This report aims to bridge this disciplinary divide by providing a detailed, comparative analysis of two key contributions to the literature: the hydrologic study by Cook and McCuen (2013) and the hydrologic experimental work by G. Baiamonte et al. (2023). The central objective is to synthesize their findings and establish a unified framework for sustainable and high-performing solar farm design.

Analysis of the Cook and McCuen (2013) Paper: A Foundational Study with Critical Limitations

The paper "Hydrologic Response of Solar Farms" by Lauren M. Cook and Richard H. McCuen is a foundational study that sought to determine the environmental effects of solar farms, specifically focusing on the need for stormwater management. Published in the

Journal of Hydrologic Engineering, the research represented one of the limited studies at the time on the hydrology of utility-scale ground-mounted solar PV sites.

Research Methodology and Scope

The study's core approach was based on a model-based simulation rather than a real-world, experimental setup. A hydrologic model of a solar farm was used to simulate runoff for two distinct conditions: the pre-paneled state and the post-paneled state. The model incorporated various parameters, including soil hydrologic groups to estimate runoff curve numbers (RCNs) and Manning's n values to estimate the velocity of runoff in response to different rainfall hyetographs. The model also performed sensitivity analyses, which revealed that factors such as the landscape slope and the panel tilt angle had minimal impact on runoff, a surprising finding at the time.

Key Findings and Recommendations

The primary conclusion of the study, based on its modeling, was that the solar panels themselves did not have a significant effect on the runoff volumes, peaks, or times to peak. This finding suggested that, in terms of total runoff volume, the presence of solar panels was largely neutral. The authors posited that this was perhaps due to the continued presence of grass and other plantings beneath and between the solar arrays, which enhanced infiltration.

However, a more nuanced and critical finding emerged from the analysis. While the overall *volume* of runoff might not change, the *nature* of the runoff was significantly altered. The study determined that the kinetic energy of the water flowing from the panels was greater than that of the rainfall itself. This concentrated, high-energy flow was identified as a potential cause of soil erosion at the base of the panels. Based on this discovery, the authors recommended that grass beneath the panels be well-maintained or that buffer strips be placed after the most downgradient row of panels to mitigate this erosive force.

Second-Order Insights and Methodological Critique

A careful review of the study's findings reveals a key distinction that redefines its primary contribution. The seemingly contradictory findings—that panels have a neutral effect on runoff volume but still cause a significant erosion risk—are not a failure of the model but a critical insight into the physical process. The model demonstrated that the total volume of water reaching the ground may be consistent, but the high kinetic energy of the concentrated flow from the panel edges is the true source of the problem. This redirects the focus of solar farm design from managing total runoff volume—a traditional hydrologic concern—to managing the specific, erosive force of concentrated water flow.

Furthermore, it is essential to acknowledge the study's limitations. The provided research material explicitly states that the study's conclusion of a neutral effect on runoff is based on "weak evidence" because it was a model-based simulation and not a "real-world experiment". A third-party analysis notes that no experimental measurements were collected to verify the model's performance and that the impacts of "concentrated drip edge runoff" were not considered in the model's development. Consequently, the paper's most significant contribution is not its definitive conclusion but its identification of a previously unexamined problem—drip-edge erosion—and its call for further field-based research to validate its findings.

Analysis of the Baiamonte et al. (2023) Paper: The Experimental Validation

The body of work associated with G. Baiamonte et al. (2023) directly addresses the hydrologic impacts of solar farms with an experimental approach, contrasting with the model-based methodology of the Cook and McCuen paper. The paper, titled "Impact of solar panels on runoff generation process," moves the scientific conversation from theoretical modeling to empirical data.

Research Methodology and Scope

In stark contrast to the simulation-based work of Cook and McCuen, Baiamonte et al. conducted a real-world experiment using a rainfall simulator. They performed runoff measurements on a controlled plot with a rainfall intensity of 56 mm/h. The study compared runoff from a bare soil reference plot to plots with solar panels arranged in different configurations. The experiment specifically considered panel arrangements on a field with a maximum slope direction, investigating both "cross slope" and "aligned slope" configurations. This indicates that the findings are applicable to a variety of terrains, from flat to sloped.

Key Findings and Implications

The quantitative results of the experiment provided a definitive and startling answer to the question of solar farm hydrology. The study found that solar panels increase the peak discharge of runoff by about **11 times** compared to a bare soil reference plot. A moderate effect was observed based on the panel arrangement, with the increase in peak discharge being 11.7 times higher for cross-slope panels and 11.5 times higher for aligned-slope panels.

This finding is a critical validation of the concerns raised by Cook and McCuen. While the Cook and McCuen model had a neutral finding on runoff volume but identified a risk from kinetic energy, the Baiamonte et al. experiment demonstrated a dramatic increase in peak discharge, confirming that runoff is not a "neutral" phenomenon. This directly addresses the "weak evidence" critique of the earlier paper and provides a robust, quantitative measure of the problem. The study also found that the time to runoff was significantly lower for the paneled plots, with the bare soil plot having the highest time to runoff. This suggests that not only is the peak flow higher, but it occurs much more quickly.

Synthesis and Reconciliation: Bridging the Disciplinary Divide

The core of this report is to bridge the gap between the two distinct but complementary hydrologic perspectives on solar panel performance. The papers by Cook and McCuen (2013) and Baiamonte et al. (2023) are not isolated pieces of research; they represent a progression of scientific understanding from theoretical risk to a quantified, severe threat.

The Unifying Principle: The Panel as an Active Interface

The central thesis that unites these two studies is that the solar panel's surface is not a passive element. It is a dynamic interface that actively mediates the flow of both energy (light) and liquid (water). The Baiamonte et al. study provides the crucial experimental evidence that validates the warnings from Cook and McCuen's model-based work. The "potential" for erosion identified by Cook and McCuen is made concrete by Baiamonte et al.'s finding of an **11-fold increase in peak discharge**. This finding elevates the hydrologic impact of solar farms from a localized ground-cover issue to a significant, site-wide engineering challenge that must be addressed in a comprehensive manner. The magnitude of this increase suggests that traditional mitigation strategies may be overwhelmed, and any solar farm on a floodplain represents a high-stakes gamble in the absence of empirical proof in extreme conditions to the contrary.

A solar farm covering a large area, such as 3,500 acres, introduces unique risks, especially if it is located on a floodplain. Large-scale solar arrays have the potential to interrupt natural overland flow routes, which can exacerbate flood risk in surrounding areas. The 11-times increase in peak discharge observed by Baiamonte et al. demonstrates that the solar panels themselves can significantly contribute to these high-volume flows, overwhelming existing or natural drainage systems. This magnitude of runoff can cause scour, washing away soil and undermining the structural foundations of the solar arrays and electrical equipment. Therefore, the potential for catastrophic failure in flood-prone areas is a primary concern that must be addressed from the earliest stages of planning.

Performance Redefined: Efficiency and Environmental Stewardship

This interdependence necessitates a re-evaluation of what constitutes "solar farm performance." If a farm is efficient at converting sunlight but leads to severe soil erosion and requires expensive, large-scale stormwater management systems, its overall performance is compromised. The findings of Baiamonte et al. demand that the hydrologic impact be treated not as a secondary consideration but as a primary factor in solar farm viability and sustainability. This concept is closely related to the Water-Energy-Food-Ecosystem (WEFE) nexus framework mentioned in the provided literature.

Table 1: Comparative Analysis of Cook and McCuen (2013) vs. Baiamonte et al. (2023)

Feature	Cook and McCuen (2013)	Baiamonte et al. (2023)
Research Domain	Hydrologic Engineering	Hydrologic Engineering
Research Question	What are the hydrologic impacts of solar farms?	How do solar panels impact the runoff generation process?
Scale of Analysis	Macro-level (site-wide runoff simulation)	Experimental, plot-based (rainfall simulator)
Methodology	Model-based simulation	Experimental comparison (bare soil vs. paneled plots)
Key Finding	Panels have a neutral effect on runoff volume, but the kinetic energy of drip-flow is an erosion risk based on the model.	Panels increase peak discharge by about **11 times** compared to bare soil.
Key Limitation/Critique	Model-based, lacks real-world data, did not fully account for concentrated drip-edge runoff.	No stated limitations; provides a crucial empirical data point.

Export to Sheets

Strategic Recommendations for Holistic Solar Farm Design and Management

The synthesis of these two papers provides a clear framework for developing more sustainable and effective solar farms. The following recommendations are designed for policymakers, project developers, and researchers to adopt a holistic approach that moves beyond traditional disciplinary silos.

6.1. Ground Cover and Site Hydrology

Based on the findings of both studies, site design and ongoing maintenance must prioritize ground cover management. The significant increase in peak discharge identified by Baiamonte et al. reinforces the urgency of the recommendations from Cook and McCuen, but also suggests that they may be insufficient on their own. It is no longer a question of a minor risk, but a serious, quantified threat of increased runoff that requires more than just localized mitigation. While maintaining dense, well-maintained grass or implementing buffer strips is a necessary first step, these measures must be part of a much larger, comprehensive site drainage plan to manage the severe increase in peak discharge.

6.2. The New Paradigm: Integrated Design and Research

The most critical recommendation is to establish a new paradigm for solar farm development that mandates a joint analysis of energy output and environmental hydrology from the earliest design phases. Decisions regarding panel tilt angles and spacing should be made in tandem with a site's specific hydrologic conditions to optimize for both energy output and environmental stewardship. This requires a shift in mindset from treating these issues as separate challenges to recognizing them as interdependent facets of a single, complex system. The **11-fold increase in peak discharge** observed by Baiamonte et al. necessitates that comprehensive downstream drainage system reviews be an integral part of solar farm planning, as localized ground cover and buffer strips alone are unlikely to be able to accommodate such a significant change in flow. For projects on floodplains, such as a 3,500-acre solar farm, this means going beyond FEMA maps and conducting site-specific floodplain studies and hydrological modeling to simulate water flow and identify potential inundation areas. This would involve a full review and potential overhaul of the site's hydrologic plan to ensure long-term stability and prevent catastrophic erosion and structural damage.

Table 2: Integrated Design Recommendations for Sustainable Solar Farms

Recommendation	Derived from	Benefit/Rationale
Implement Robust Ground Cover	Cook and McCuen (2013), and validated by Baiamonte et al. (2023)	Mitigates severe erosion caused by high-volume, high-kinetic-energy runoff and enhances infiltration.
Conduct Integrated Hydrologic Analysis	Synthesis of both papers	Ensures a holistic approach that considers both energy output and environmental impact from the outset of a project.
Prioritize Comprehensive Drainage System Reviews	Baiamonte et al. (2023)	The 11-fold increase in peak discharge requires site-wide engineering solutions beyond localized mitigation.
Require Site-Specific Floodplain Studies	Synthesis of both papers, with data from Baiamonte et al.	Essential for large-scale projects on floodplains, as the magnitude of runoff can overwhelm traditional drainage and increase flood risk.
Prioritize Real-World Field Experiments	Critique of Cook & McCuen (2013)	Validates theoretical models and provides actionable data on the long-term effects of panel coatings on hydrology.

Conclusion: Towards a Holistic Framework for Solar Sustainability

The papers by Cook and McCuen (2013) and Baiamonte et al. (2023) are not simply disparate studies from different domains. They are critical pieces of a single, complex puzzle. The analysis presented in this report demonstrates that the physical interface of the solar panel is a dynamic system where material properties and hydrologic engineering are intrinsically linked. The initial theoretical concerns about erosion from Cook and McCuen's modeling work are now strongly validated and quantified by the experimental findings of Baiamonte et al., which showed an **11-fold increase in peak discharge**. The future of solar energy development hinges on moving beyond disciplinary silos and embracing a holistic, multi-faceted approach. Any solar farm on a floodplain will have serious downstream implications and represents a high-stakes gamble in the absence of empirical proof to the contrary.

The magnitude of the hydrologic impacts discovered by Baiamonte et al. changes the conversation from simple ground-cover recommendations to a fundamental reassessment of site planning and infrastructure. For a project as large as a 3,500-acre solar farm, especially on a floodplain, the design must account for the potential for significant increases in peak runoff, which requires comprehensive drainage systems and site-specific flood risk assessments. A sustainable and high-performing solar farm is one that successfully optimizes for both energy yield and environmental integrity. This requires an integrated design framework that considers the interplay between energy, water, and land from the initial planning stages. Continued research, particularly in real-world settings, is essential to further validate and quantify the causal links identified in this report, paving the way for a more responsible and truly sustainable solar future.

References

1. Cook, L.M., and McCuen, R.H., "Hydrologic Response of Solar Farms," *Journal of Hydrologic Engineering*, 2013.
2. Baiamonte, G., Gristina, L., and Palermo, S., "Impact of solar panels on runoff generation process," *Hydrological Processes*, 2023.
3. Central Bedfordshire Council, "Solar Farm Development Flood Guidance."
4. Natural Power, "Designing Resilient Solar Projects: Mitigating Flood Risks," 2023.
5. U.S. Department of Energy, "Preventing and Mitigating Flood Damage to Solar Photovoltaic Systems," Office of Energy Efficiency & Renewable Energy.
6. Harbinger Land, "Understanding Flood Risk Assessments for Solar Farms: An In-Depth Tutorial."