Stephen Fox

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Interested Party Reference number: FA3AE8AE5

The Examining Authority

The Planning Inspectorate

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By Email

14th September 2009

One Earth Solar Farm Project: A Comprehensive Analysis of the Hydrological and Environmental Implications of a Large-Scale Photovoltaic Array on a Floodplain

Dear Sirs

Following a detailed analysis of the available scientific literature, I have prepared a comprehensive report on the hydrological and environmental implications of a large-scale solar project on a floodplain. A copy of this report is attached for your review.

My research raises two critical questions regarding the proposed development and its mitigation strategy, which I believe should be put to the relevant statutory bodies: the Environment Agency, Lincolnshire County Council, and Nottingham County Council, as the Lead Local Flood Authorities (LLFAs).

First, I ask that you request that both the Environment Agency and the two LLFAs state whether they currently have the necessary expertise and resources to supervise the design, installation, and maintenance of the proposed mitigation systems for a project of this scale and complexity.

Second, I ask that you also ask these same bodies to confirm if they have assessed the full implications of the attached report in arriving at their conclusions as stated in their local impact reports and Statements of Common Ground for the One Earth Solar proposal.

Your consideration of these matters is of paramount importance to ensure the long-term viability and safety of the proposed project and the surrounding communities.

Sincerely,

Stephen Fox

A Comprehensive Analysis of the Hydrological and Environmental Implications of a Large-Scale Photovoltaic Array on a Floodplain

1. Executive Summary

This report provides a multi-faceted analysis of the proposed 3,500-acre solar farm on a floodplain. The core finding is that the hydrological and ecological impact of the project is not inherent to the solar panels themselves but is a direct function of the site-specific design, land management, and construction practices. The work by Baiamonte et al. (2015, 2023) and supporting research confirms that while solar farms can create adverse effects like increased runoff and erosion if poorly managed, they can also deliver net positive environmental outcomes by preserving soil health and promoting biodiversity if designed with nature-based solutions.

The analysis also reveals a significant lack of comprehensive empirical data on the hydrological impacts of large-scale solar farms, particularly on floodplains, which makes such a project a high-stakes undertaking. Mitigation for such a project is not a simple calculation. It is a complex, data-intensive, and interdisciplinary process that requires sophisticated hydrological modeling, extensive due diligence, and robust stakeholder engagement. Consequently, correcting a miscalculation is not a quick fix. Remediation is a long-term, multi-phased process defined by a hierarchy of measures (avoidance, minimization, compensation) that can span years or even decades. The timeline for correction is influenced more by institutional, regulatory, and legal processes than by the speed of physical remediation. The project's success and long-term viability are contingent upon a proactive and comprehensive approach to environmental and hydrological management from the earliest planning stages.

2. The Foundational Science: An Analysis of Land-Use Change and Hydrological Processes

This section establishes the scientific basis for the report by examining two distinct but related bodies of research: the macro-scale effects of broad land-use changes and the micro-scale, project-specific hydrology of solar farms.

2.1. The Macro-Scale View: Implications of Baiamonte et al. (2015) and the Principle of Land-Use Change

The 2015 study by Baiamonte et al. used the Hydrological Simulation Program-FORTRAN (HSPF) model to analyze the impact of land use changes in the Gap-Cheon watershed. The findings revealed that a shift in land use, specifically a reduction in urban areas and a corresponding increase in wetlands and urban green spaces, had a beneficial effect on hydrological processes. This change resulted in a decrease in surface runoff and nutrient loads, while evapotranspiration and water absorption were enhanced[1]. The research underscored the critical role of urban green spaces, forests, and wetlands as natural mitigators of human impacts on watersheds. They function as natural sponges, regulating water balance, improving soil permeability, and reducing peak flows and erosion[1].

This finding is particularly significant because it presents a counter-narrative to a broad body of research that overwhelmingly links land-cover change, particularly urbanization, to increased flood frequency and severity[2],[3]. The core distinction is that the *type* of land-use change, not the change itself, is the primary determinant of hydrological impact. The implication for a 3,500-acre solar farm is that its outcome is not predetermined. While it represents a large-scale land-use conversion, its impact will be entirely dependent on whether its design mimics the beneficial "de-urbanization and greening" model or the detrimental "standard impervious development" model. By consciously designing the site to increase and maintain vegetative cover, soil health, and water absorption, the project could function as a net-positive environmental change, rather than a new source of hydrological risk.

2.2. The Micro-Scale View: Insights from Baiamonte et al. (2023) and Solar Farm Hydrology

The 2023 work by Baiamonte et al. focuses specifically on the hydrological effects of solar farms, with a key finding that the solar panels themselves have no significant effect on runoff volumes, peaks, or times to peak[4],[5]. This conclusion is supported by other research that found the introduction of panels on a small plot had minimal effect on runoff and peak flow[4]. The research emphasizes that the dominant factor is the ground cover beneath and between the panels[4],[5]. A ground surface of gravel or bare soil, whether due to design or a lack of maintenance, can lead to a significant increase in peak discharge, requiring extensive stormwater management[5]. Conversely, a well-maintained perennial vegetative cover promotes infiltration and prevents erosion, making the overall impact negligible[6].

A central paradox of a solar farm is that it is a large-scale, man-made intervention that, from a hydrological perspective, can behave more like a natural landscape than a traditional development. This is due to the "disconnected impervious surface" nature of solar arrays[4],[7]. While the panels themselves are impervious, the pervious soils beneath and between them are critical for infiltration[7]. Traditional stormwater permits often treat solar farms as fully impervious surfaces, which leads to a substantial overestimation of runoff[4],[7]. However, the kinetic energy of the concentrated water draining from the panels is greater than that of rainfall, which poses an erosion risk at the drip line and can lead to the formation of channelized flows if not managed correctly[5],[8]. This necessitates a custom, sophisticated modeling framework, such as the one proposed using the US EPA Storm Water Management Model (SWMM), to accurately predict the hydrological response[7]. The accuracy of the initial assessment is directly tied to the complexity and appropriateness of the modeling approach, as standard engineering assumptions are insufficient for these unique systems.

2.3. The State of Empirical Research and the Scale Problem

The user's question highlights a critical issue: the lack of comprehensive, large-scale empirical studies on the hydrological impacts of solar farms. While some studies have been conducted, they are often on a small scale, and their findings do not necessarily scale linearly to a 3,500-acre project.

- A study on a small array of 30 panels found that runoff increased by a minimal 0.35% and peak discharge by a mere 0.31%[4,8].
- Another study, based on rainfall simulation experiments on small plots, concluded that the installation of solar panels did not significantly affect runoff or peak flow[4,23].
- While some research has used models to show that runoff with solar arrays present can increase by 14%[7], these are simulations rather than real-world, large-scale empirical measurements. As one review of the existing research notes, there is a lack of research answering this question for net increases in stormwater runoff on large solar farms[24].

The lack of extensive empirical data on large-scale solar farms, combined with their placement on a sensitive floodplain, does indeed make such a project a high-stakes undertaking. The project's success is not a foregone conclusion; it is entirely dependent on the design, management, and long-term oversight.

The "gamble" is rooted in the following core risks:

- **The Compounded Effect:** The research indicates that while a single solar panel may have a minimal effect on hydrology, the cumulative impact of 1.5 million panels on a 3,500-acre site is a significant risk[8]. The aggregation of many small, localized runoff issues could overwhelm natural or poorly designed drainage systems, leading to a major, systemic problem affecting downstream areas[8].
- **The Erosion Hazard:** The water draining from solar panels has a higher kinetic energy than natural rainfall, which can cause significant erosion at the drip line and create channelized flows if not managed correctly[4,5,8]. This requires a robust and enforceable land management strategy to maintain healthy vegetation and avoid the use of bare ground or gravel, which can lead to a significant increase in peak discharge[5,8,9,25].
- **Modeling and Mitigation Uncertainty:** The process of calculating and designing mitigation is not a simple equation. It is a complex process of "environmental due diligence" that requires detailed hydrological modeling to account for the unique "disconnected impervious surface" nature of solar farms[7,15]. A miscalculation can stem from flawed input data, as demonstrated by a case where a critical data error in a climate study massively skewed its findings[17]. Furthermore, some researchers note that different models can produce conflicting outputs, and that a model's credibility is not just about technical accuracy but also about its legitimacy and acceptance by regulators and stakeholders[16].
- **A Slow Timeline for Correction:** If a miscalculation does occur, correcting it is neither simple nor quick. Remediation is a long-term process that is more dependent on institutional, regulatory, and legal processes than on the speed of physical work[20,21]. For example, a floodplain restoration project in France was abandoned after seven years of negotiation and conflicts between stakeholders[22]. A failure of mitigation would not be a short-term fix but a multi-year, multi-phased endeavor[20,21].

3. Impact Analysis: The 3,500-Acre Solar Farm on a Floodplain

This section applies the scientific principles from Section 2 to the specific project scale and location. It analyzes the compounded risks and opportunities that arise from a project of this magnitude on a sensitive floodplain.

3.1. Scalability, Compounded Runoff, and Off-site Effects

While the hydrologic impact of a single solar panel may be minimal, its effects do not scale linearly. A study found that over a small array of 30 panels, the runoff increased by only 0.35%[8]. However, the cumulative effect of 1.5 million panels on 3,500 acres could be significant. The aggregation of minor, localized effects could overwhelm natural or poorly managed drainage systems at the watershed level. The core risk is not the localized runoff but the systemic, compounded effect on downstream areas and beyond[8]. Poor land management and the creation of drainage channels can significantly increase discharge rates and volumes[8,9].

The literature highlights that the effects of land-use change on floods are most pronounced at a small scale and for frequent flood magnitudes, but the combined, gradual effects of large-scale changes can be severe[2]. This emphasizes a fundamental challenge of large-scale projects: the accumulation of minor, localized effects into a major systemic problem. A project of this magnitude demands a comprehensive hydrological model that extends beyond the site boundary to incorporate a watershed-level analysis to accurately predict impacts on the surrounding area and downstream communities.

3.2. Floodplain-Specific Hazards and Mitigation

Siting a solar farm on a floodplain introduces specific, non-negotiable safety requirements. The project has the potential to block or obstruct flood flow, necessitating a permit and a detailed assessment of the impacts of all project components, including supporting posts and fencing[10,20]. Panels must be properly anchored with flood-resistant materials and installed at or above the flood protection grade, which is typically 2 feet above the Base Flood Elevation (BFE)[9,10]. This height requirement also applies to all electrical systems and the lowest tilt position of the panels[9,10].

This safety requirement can create a fundamental conflict with other environmental benefits. While the literature suggests that the shade from panels can help retain soil moisture and support vegetation, promoting ecological health[6,11], elevating the panels to meet flood protection grades may reduce this beneficial shading effect[12]. Therefore, there is a direct trade-off between the height required for flood safety and the shade benefits that promote soil health and biodiversity. A project cannot be designed to achieve one objective without considering the implications for the other. This demands a careful, integrated design that balances safety with ecological goals.

3.3. Environmental and Ecological Trade-offs

The project is not an inherent environmental hazard but a land-use conversion with both significant risks and significant opportunities. Construction can lead to land grading, soil compaction, and a loss of topsoil[6,13]. Water and wind erosion are major concerns, as bare, disturbed soil is left exposed during and after construction[6]. Conversely, a well-managed solar farm can enhance local flora and increase plant and animal biodiversity by creating beneficial microclimates and wildlife corridors[11,14]. Research shows that well-planned solar farms can increase plant diversity by up to 90% and overall biodiversity by up to 95% compared to traditional agricultural land[11].

The absence of agricultural chemicals and reduced mechanical maintenance can lead to improved soil health and increased organic carbon levels over time[11]. The key to achieving these benefits is the project's adherence to "low-impact" development principles, which involve retaining existing vegetation, designing around geomorphology, and preserving topsoil[6],[13]. This requires a robust, enforceable land and soil management plan[8],[9] that moves the project from a passive land occupation to an active form of ecological management, mitigating risks and realizing environmental opportunities.

4. Mitigation and Corrective Action: A Feasibility and Timeline Assessment

This section directly addresses the ease of calculating mitigation and the speed of correcting miscalculations, demonstrating that both are complex, multi-faceted processes.

4.1. The Process of Calculating Mitigation: "Easily Calculated?"

The "calculation" of mitigation is not a simple engineering equation but a dynamic, interdisciplinary process. The user's question implies a straightforward, quantitative answer, but research demonstrates this is a fundamental misconception. A solar farm application requires a detailed drainage strategy and a land management strategy from the earliest planning stages[8],[9]. This process, known as "Environmental Due Diligence," involves assessing environmental risks, determining mitigation measures, and estimating costs[15].

The hydrological models used in this process must be appropriate for the unique "disconnected impervious" nature of solar farms[7]. However, models can produce conflicting outputs and their credibility is not just about technical accuracy, but also about their transparency and acceptance by regulators and the public[16]. A simpler model that is easier to explain can sometimes gain more legitimacy, even if it gets results "right for the wrong reasons"[16]. Therefore, a miscalculation is not a simple numeric error; it is a failure of the entire due diligence process. Such a failure can stem from flawed input data, as demonstrated by a case where a critical data error in a climate study massively skewed its findings[17], or from a lack of institutional legitimacy. The process is complex because it is a function of data quality, model choice, and the complex, subjective process of stakeholder trust.

4.2. Correcting Miscalculated Mitigation: "How Quickly Can It Be Corrected?"

The user's use of "quickly" implies a reactive, short-term fix, but the research refutes this completely. The timeline for corrective action is not measured in weeks or months, but in years to decades, as it is more dependent on institutional, legal, and social factors than on the speed of physical remediation. Environmental mitigation is a hierarchy of measures: avoidance, minimization, and compensatory mitigation[18],[19]. When a miscalculation occurs, it typically means avoidance and minimization were insufficient, and compensatory measures must be applied[18].

This would trigger a new round of regulatory and legal processes[18],[19]. The physical work of remediation or restoration is itself a lengthy, multi-year process. For example, a groundwater remediation project in the San Fernando Basin was a six-year study just to plan the remediation[20]. Another large-scale remediation project took years to get a water license and land use permit before beginning full-scale work[21]. This is compounded by the fact that large-scale projects can fail due to institutional factors and stakeholder conflicts, with negotiations taking seven years and still ending in abandonment[22]. A miscalculation is not a simple technical repair; it is a new, high-stakes project in itself, with all the associated risks, timelines, and legal complexities. The "fix" is a multi-phased, long-term endeavor that demands foresight and institutional readiness.

Table 1: Key Project Characteristics and Their Hydrological and Mitigation Impacts

Project Feature	Hydrological Impact	Environmental Impact	Recommended Mitigation/Best Practice
Ground Cover Type	Well-maintained vegetation minimizes runoff, while bare ground or gravel can significantly increase peak discharge.	Bare ground leads to soil erosion and compaction. Healthy vegetation promotes biodiversity and soil health.	Maintain healthy, perennial vegetative cover[6]. Avoid bare ground or gravel beneath panels[5].
Panel Arrangement	Perpendicular arrangement to contours can create channelized flows, increasing runoff rate and volume.	Channelized flows intensify soil erosion and degrade soil structure.	Arrange solar panel rows parallel to the site's contours to reduce erosion[9].
Construction Practices	Heavy machinery use can cause soil compaction, reducing infiltration and increasing surface runoff.	Soil compaction destroys soil structure and reduces its ability to absorb water, impacting soil health and biodiversity.	Limit disturbance and compaction to necessary areas[6]. Chisel ploughing or similar methods to restore soil infiltration post-construction[9].
Drainage Design	Can interrupt overland flow routes, increase runoff, and create new channels.	Improper design can lead to erosion and sediment transport off-site.	Use SuDS features (swales, bunds, basins) to slow down, store, and infiltrate runoff[8]. Account for all impervious areas[9].
Location (Floodplain)	Potential to block or obstruct flood flow.	Can impede natural floodplain functions and impact wildlife corridors.	Anchor panels and use flood-resistant materials[10]. Install panels and electrical systems above flood protection grade[10].

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Table 2: Mitigation Corrective Action Phases and Timelines

Phase of Corrective Action	Key Activities	Responsible Parties	Estimated Timeline
Phase 1: Problem Identification & Assessment	Data collection, monitoring analysis, technical review of miscalculation, initial impact assessment.	Project sponsor, regulatory agencies, independent experts	6 months – 2 years
Phase 2: Re-evaluation & Planning	Re-modeling of hydrological impacts, design of new mitigation plans, expert consultation, and cost estimation.	Project sponsor, consulting engineers	1 year – 3 years
Phase 3: Legal & Regulatory Approvals	Re-application for permits, environmental review (e.g., NEPA), public hearings, stakeholder negotiations.	Regulatory agencies, legal counsel, community groups	2 years – 7+ years
Phase 4: Physical Remediation	Implementation of new earthworks, construction of drainage features, soil restoration, re-vegetation.	Contractors, project sponsor	1 year – 5 years
Phase 5: Long-term Monitoring	Ongoing data collection, reporting to regulatory authorities, adaptive management of the site.	Project sponsor, independent auditors	Ongoing for project life

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5. Conclusions and Actionable Recommendations

The proposed 3,500-acre solar farm on a floodplain presents a complex set of hydrological and environmental challenges and opportunities. The project's impact is not a foregone conclusion but a design outcome, a direct function of the strategies employed during its planning, construction, and operation. The principles from Baiamonte et al. and other research show that a solar farm can be either a source of compounded hydrological risk or an opportunity for ecosystem enhancement, depending on the management approach. The concept of a "disconnected impervious surface" is central to understanding this duality. Furthermore, the analysis confirms that the calculation and correction of mitigation are neither "easy" nor "quick" but a multi-disciplinary, long-term commitment that demands foresight and institutional readiness.

Based on this analysis, the following actionable recommendations are provided to ensure the project's long-term viability and to transform potential risks into tangible benefits:

- **Recommendation 1: Adopt a "Low-Impact" Development Framework.** Integrate the principles of low-impact solar development from the outset, focusing on the preservation of existing vegetation, minimizing soil disturbance, and active soil health management[6],[13].
- **Recommendation 2: Mandate a Sophisticated Hydrological Modeling Strategy.** Reject standard impervious-surface assumptions. Require a detailed, site-specific hydrological model that accurately represents the "disconnected impervious" nature of the solar array and its potential effects on the wider watershed[7]. This model should

also account for the kinetic energy of panel runoff and the potential for channelization[4,5,8].

- **Recommendation 3: Implement a Robust, Long-Term Land Management Plan.** Develop an enforceable plan for the lifetime of the project that includes vegetation management (e.g., native grasses, pollinator-friendly species), erosion control measures (e.g., swales, bunds), and regular, documented inspections to proactively address issues before they escalate[8,9].
- **Recommendation 4: Acknowledge and Plan for Remediation Complexity.** Recognize that a miscalculation of mitigation is not a simple engineering fix. Establish a framework for adaptive management and long-term monitoring, and budget for potential multi-year, multi-million-dollar remediation efforts, should they become necessary. This foresight is critical for managing the long-term legal, financial, and reputational risks[15,17,20,21,22].
- **Recommendation 5: Model a Catastrophic flood event resulting from sustained mitigation failure.**

Footnotes

1. {

   https://pmc.ncbi.nlm.nih.gov/articles/PMC11835984/}

2. {

   https://www.researchgate.net/publication/11351680_Land-use_change_and_floods_What_do_we_need_most_research_or_management}

3. {

   https://www.researchgate.net/publication/387602106_Flood_Hazard_Assessment_Due_to_Changes_in_Land_Use_and_Cover}

4. {

   https://www.researchgate.net/publication/276982541_Hydrologic_Response_of_Solar_Farms}

5. {

   https://www.sandiegocounty.gov/content/dam/sdc/pds/ceqa/JVR/AdminRecord/IncorporatedByReference/Appendices/Appendix-I---Drainage-Report/1_HydrologicResponseOfSolarImpacts.pdf}

6. {

   https://www.nrcs.usda.gov/sites/default/files/2024-03/Conservation_Considerations_Solar_Farms.pdf}

7. {

https://www.researchgate.net/publication/372648103_A_Framework_to_Model_the_Hydrology_of_Solar_Farms_Using_EPA_SWMM}

8. {

https://www.essexdesignguide.co.uk/suds/further-guidance/solar-array-development/}

9. {

https://www.doncaster.gov.uk/Documents/DocumentView/Stream/Media/Default/Environmental/Solar%20Farm%20Drainage%20Strategy%20Advice.pdf}

10. {

https://www.in.gov/dnr/water/files/wa-water-FAQ-solar-panel.pdf}

11. {

https://www.residentialsolarpanels.org/environmental-impact-and-sustainability/solar-farms-are-transforming-local-ecosystems-heres-how-it-affects-you/}

12. {

https://energy.gov/femp/preventing-and-mitigating-flood-damage-solar-photovoltaic-systems}

13. {

https://www.kgs.ku.edu/Publications/OFR/2025/OFR2025-20.pdf}

14. {

https://www.residentialsolarpanels.org/environmental-impact-and-sustainability/solar-farms-are-transforming-local-ecosystems-heres-how-it-affects-you/}

15. {

https://energy-base.org/wp-content/uploads/2020/03/2.EDD-Solar-Photovoltaic-Energy-Systems.pdf}

16. {

https://pmc.ncbi.nlm.nih.gov/articles/PMC9291984/}

17. {

https://illuminem.com/illuminemvoices/this-climate-study-made-a-big-error-one-piece-of-data-was-to-blame}

18. {

https://www.epa.gov/cwa-404/types-mitigation-under-cwa-section-404-avoidance-minimization-and-compensatory-mitigation}

19. {

https://dot.ca.gov/programs/environmental-analysis/biology/mitigation}

20. {

https://www.ladwp.com/community/construction-projects/other/groundwater-remediation}

21. {

https://www.rcaanc-cirnac.gc.ca/eng/1663177205830/1663177367439}

22. {

https://www.researchgate.net/publication/271923257_A_floodplain_restoration_project_on_the_River_Rhne_France_analyzing_challenges_to_its_implementation}

23. {

https://www.researchgate.net/publication/276982541_Hydrologic_Response_of_Solar_Farms}

24. {

https://iee.psu.edu/news/blog/maximizing-hydrological-and-environmental-benefits-solar-farms}

25. {

https://www.doncaster.gov.uk/Documents/DocumentView/Stream/Media/Default/Environmental/Solar%20Farm%20Drainage%20Strategy%20Advice.pdf}

26. {

https://www.researchgate.net/publication/372648103_A_Framework_to_Model_the_Hydrology_of_Solar_Farms_Using_EPA_SWMM}