Dean Moor
Solar Farm

Applicant Response to D4 Written Representations

on behalf of **FVS Dean Moor Limited**

25 November 2025
Prepared by: Stantec UK Ltd
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DEAN MOOR SOLAR FARM

APPLICANT RESPONSE TO D4 WRITTEN REPRESENTATIONS

PLANNING INSPECTORATE REFERENCE EN010155

PREPARED ON BEHALF OF FVS DEAN MOOR LIMITED

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Contents

1 Introduction

1.1.1 This document has been produced for FVS Dean Moor Limited (the 'Applicant') to support the application for a Development Consent Order (the 'DCO application') for Dean Moor Solar Farm ('the Proposed Development') located between the villages of Gilgarran and Branthwaite in West Cumbria (the 'Site'), which is situated within the administrative area of Cumberland Council ('the Council').

1.1.2 This Applicant Response to Deadline 4 ('D4') Written Representations (ARWR-4) [**D5.6**] is a response to the Written Representations (WR) made by Interested Parties (IP), primarily but not entirely in response to the Examining Authority's (ExA) Written Questions 2 (ExQ2) [**PD-012**]. This document provides responses to D4 WR from:

- Cumberland Council [**REP4-030**];
- the Lake District National Park Authority (LDNPA) [**REP4-031**];
- Keystone Law on behalf of 12 Property FE Limited ('12 Property FE') [**REP4-032**]; and
- Local resident Mr. B. Blackett [**REP4-029**].

1.1.3 An Additional Submission (AS) from Mr James Howell was published on 12 November 2025 [**AS-023**] setting out Mr. Howell's feedback on matters discussed in the Issue Specific Hearing. While not a D4 submission, the Applicant has elected to respond to this WR within this document.

1.1.4 The Applicant notes that the Council and the LDNPA re-affirmed their positions on some of the matters listed below within the Issue Specific hearing, a recording of which is available at **EV9-001**. Fully agreed and signed-off Statements of Common Ground (SoCGs) have been submitted at D5 with both the Council [**D5.18**] and the LDNPA [**D5.24**].

1.1.5 In this document, the Applicant has responded where the Applicant believes that a response is required, for example if the WR includes a request for further information or clarification or where the Applicant considers that it is appropriate for the ExA to have the Applicant's comments on a matter raised by the IP in its response.

1.1.6 Where an issue raised within a WR has been dealt with previously by the Applicant, for instance within one of the documents submitted to the Examination, a cross reference to that response or document is provided to avoid unnecessary duplication. The information provided should, therefore, be read in conjunction with the material to which cross references are provided.

1.1.7 The Applicant has sought to respond to all material points by copying them directly or summarising them in the table below. A lack of response should not be treated as the Applicant accepting or agreeing with the point raised. If the ExA or any party considers that a material point has not been addressed, they may raise this in their response to this document, and the Applicant will consider the merits in making a direct response.

2 Response to the Council D4 Written Representation

Table 2.1: Applicant Response to Cumberland Council's D4 WR

Cumberland Council ExQ 2 Responses	
Q2.1.3: *Paragraph 12.45 of the Applicant Response to the Local Impact Report [REP3-008] indicates a legal agreement could be pursued in relation to monitoring. Is the Council satisfied with the applicant's response, which relies on control documents and the draft Development Consent Order (dDCO) requirements, as opposed to a legal agreement?* **Council Response:** *The Council consider that it is crucial to ensure a suitable monitoring arrangement is in place for the lifetime of the development. Any monitoring fee would need to be secured by appropriate means.* *The Applicant has set out that the requirement for monitoring would be undertaken and secured by the DCO Requirements which include the production of a CEMP, OMP, LEMP and DMP which are to be substantially in accordance with the outline versions which set out the proposed monitoring measures.* *The Council notes that the OLEMP secures the regular monitoring of habitats and planting within the Site throughout the operational phase. It is noted that the Applicant has agreed to make monitoring data available to the Council upon request, as well as sharing the outcomes of the repeat surveys and correctional management measures on submission of the LEMP.* *The Council would require that the LEMP is updated every five years to assess the progress towards the desired habitat conditions set out in the OLEMP. The Council are satisfied that this would place a legal obligation on the Applicant to undertake the monitoring for the duration of the Proposed Development (including construction, operational and decommissioning phases).* *The Council is in agreement with the Applicant that the monitoring regime as set out in the OLEMP, and particularly the requirement for regular updates based on annual monitoring which will be submitted to the Councilfor approval, provide security on the delivery of the LEMP and a mechanism of oversight by the Council.* *On this basis the Council is prepared to accept that it would not be necessary to enter into a separate legal agreement to undertake this monitoring.*	The Council's agreement on this matter is noted.

Cumberland Council ExQ 2 Responses	
Q2.3.2: *Please clarify whether you are satisfied with the applicant's updated appraisal of relevant schemes to be considered cumulatively as set out in appendix A (cumulative assessment note) of the applicant response to Cumberland Council's response to ExA's first written questions [REP3 008], and the associated documents.* **Council Response:** *The Council identified an additional 31 schemes that it considered raised potential cumulative impacts, and which required review. These schemes have now been assessed by the Applicant and the conclusions were set out in the Cumulative Assessment Technical Note submitted by the Applicant as Appendix A of the ARLIR (REP3-008).* *The Council has considered the additional appraisal work undertaken and agrees with the conclusions of the Technical Note. The Council is satisfied that these additional cumulative schemes do not result in further significant cumulative effects. The Council's consider that the conclusions reached by the Applicant are reasonable and robust given the location and nature of the additional schemes that have been assessed.* *It has been agreed with the Applicant that further clarity in relation to cumulative effects will be included in the updated version of the dSoCG under LPA.7.*	The Council's confirmation of agreement on this matter is noted. The language at LPA.7 of the D4 dSoCG [**REP4-015**] was updated to reinforce this shared position.
Q2.3.3: *Please respond to the applicant's response to the local impact report [REP3-008]. It may be more efficient to include separate sections within the dSoCG, if you are able to agree with the applicant, which addresses each of the points in the local impact report. Otherwise please provide a response in tabulated form.* **Council Response:** *The Council and the Applicant have had positive engagement throughout the process relating to a number of environmental and planning matters. Further detailed discussions have recently taken place following the Applicants response to the Councils Local Impact Report.* *This has resulted in an update to the dSoCG to reflect the areas where there is agreement between the Council and the Applicant. The updated dSoCG will be submitted at D4.* *The following summary sets out the current position on the key topic areas:* ***Planning Policy -** The Council note the Applicants response to the requirements of the relevant planning policies and accepts the conclusions made.* ***Ecology and Biodiversity -** The outcome of discussions are reflected in the dSoCG (REP3-019) which was submitted at D3.*	The Applicant agrees with the Council's summary as it relates to the Applicant's Response to the Local Impact Report (ARLIR) [**REP3-008**] and the progress made since D2 leading to the D4 dSoCG [**REP4-015**] and D5 final version [**D5.18**]. All comments are noted, and no further response is provided except where the Applicant considers a point needs to be specifically addressed or where a matter is relevant to D5 submissions. On the topic of Landscape & Visual Impact the Applicant would like to

Cumberland Council ExQ 2 Responses	
Landscape and Visual Impact - *The outcomes in relation to landscape have been referenced as appropriate within the dSoCG as matters which have been agreed. The dSoCG does highlight where there are minor differences in judgements between the relevant Landscape professionals. The Council agrees that these do not affect agreement on the overall conclusions.* ***…*** *The Council made recommendations for further detail to be provided. Following discussions with the Applicant the dSoCG has been updated to explain when that information would be made available. This includes the heights of landscape planting which would be included in the LEMP. … The Council would wish to provide feedback as part of the detailed design considerations so that it had an input into the preparation of the documents that are submitted to discharge Requirements.* ***Cumulative Effects*** *This position will be included in an update to the dSoCG which is to be submitted at D4.* ***Residential Amenity*** *This position will be included in an update to the dSoCG which is to be submitted at D4.* ***Archaeology and Heritage -*** *All issues were addressed within the dSoCG submitted at D2* ***Environmental Health*** *All issues have been addressed. An update to the issue of statutory nuisance has been provided by the Applicants which has been reviewed and agreed by the Councils EHO. This position will be included in an update to the dSoCG which is to be submitted at D4.* ***Transport and Access*** *All issues were addressed within the dSoCG submitted at D2* ***Flood Risk and the Water Environment*** *All issues were addressed within the dSoCG submitted at D2* ***Ground Conditions and Minerals*** *All issues were addressed within the dSoCG submitted at D2* ***Employment and Skills*** *The Council is still involved in discussions with the Applicant on the issues of employment and skills. The Council notes the Applicant's intention to submit an updated OCEMP and OOMP at D4 which would include additional commitments in relation to local employment and skills. The principle of these have been discussed with the Applicant. The Council intends to review these updated commitments and it is anticipated that an updated position on this matter can be included within the next iteration of the dSoCG, which will be submitted at D5.* ***Summary -*** *Overall, subject to the issues set out above, the Council is broadly in agreement with the Applicant's statements. This position is reflected in the updated version of the dSoCG which is to be submitted at D4.*	clarify its understanding of the following: '*The Council made recommendations for further detail to be provided.* The Applicant believes this reflects a mutual understanding that the Council will expect feedback from the Examination phase to be taken on board by the Applicant for the preparation of the final LEP (Requirement 6) and LEMP (Requirement 7) for approval by the Council, who will scrutinise those applications on this basis. The Council and the Applicant agreed in-principle on the Applicant's approach to addressing education, employment, and skills via existing control documents before D4, and a final agreed position is established following the revisions to the OCEMP [**D5.14**] and OOMP [**D5.13**], as per the D5 SoCG [**D5.18**].
Q2.3.4: *Please clarify whether you are satisfied with the applicant's overall approach/methodology and conclusions regarding the potential impact of the scheme on the living conditions of occupiers of properties (i.e. residential amenity).*	The Applicant welcomes the Council's review of all topics relevant

Cumberland Council ExQ 2 Responses	
Council Response: *The Council has reviewed the Applicants methodology and assessment of the potential impacts on residential amenity. … The Council has undertaken detailed discussions with the Applicant on a number of issues that are likely to affect residential amenity. In response to this the Applicant has provided some clarification, and in some instances the submission of additional details to set out its approach to the consideration and assessment of these matters. … The matters where there is agreement between the Council and the Applicant are set out in the dSoCG. An updated version of this document is to be submitted at D4 to provide clarity on the current position. … The Council has considered impacts on residential amenity for both the construction and operational stages of the proposed development. …The key considerations are set out below to inform the ExA of the Councils stance.* ***Glint and Glare*** *Although the Council acknowledge that any final layout for the proposed development has not been set, there are a number of residential properties which lie in close proximity to the site, and these may be affected by the effects of glint and glare. … The Applicant has undertaken an assessment of glint and glare. Long term mitigation proposed relates to the addition of planting. The Council notes that the Applicant has acknowledged that planting may take time to mature and so some temporary mitigation is proposed in the form of green mesh barriers until the planting proposed matures to a sufficient height. … Whilst the provision of temporary mitigation is welcome the Council will require full details of the temporary measures, including their specific location and details of the time periods that the barriers will be maintained in place to be submitted and agreed by the Council. … The Council is satisfied that such measures can be controlled through the control documents secured through the DCO Requirements, including the CEMP, LEP, LEMP and OOMP. It is important that the Council is allowed sufficient opportunity to scrutinise these as part of the DCO discharge process. … The Council would also suggest that provision is made to agree a protocol or methodology to deal with any unexpected effects from glint and glare that are experienced once the solar farm is constructed and operational. This could be similar in nature to the provision made for any substantiated complaint made in relation to noise. Such a measure would provide additional reassurances to ensure that residential amenity is adequately protected.* ***Residential Visual Amenity*** *The Council has been involved in detailed discussions with the Applicant in relation to the potential visual effects of the Proposed Development. This followed on from the review of the Landscape and Visual Impact that was commissioned by the Council to allow a thorough assessment of the potential impacts. These discussions have focussed mainly upon the effects on the residential receptors at Wythemoor Sough, Dean Cross Cottage, Jackie Hill and Colligate. … Whilst there is a difference between the Applicants LVIA and the Councils LVIA Review the Council acknowledge that these reflect reasonable differences in professional opinion. There is no major disagreement on the outcomes which undermine the conclusions reached by the Assessment. The minor effects identified can be overcome by agreement to the detailed layout of the proposals, the type and location of the*	to residential amenity and agrees with the Council's summary. All comments are noted, and no further response is provided except where the Applicant considers a point needs to be specifically addressed or where a matter is relevant to D5 submissions. **Glint and Glare (G&G)** – The Applicant notes the suggestion of a methodology to deal with any unexpected effects from glint and glare. The OOMP [**D5.13**] has been updated to reflect a protocol as recommended by the Council which has been agreed and is affirmed in updated row CC.LPA.6 of the final SoCG [**D5.16**]. **Residential Visual Amenity** – The Applicant understands that the Council's feedback here is an acknowledgement that in-principle the LSP [**REP2-046**] and OLEMP [**D5.16**] provide an appropriate foundation for the future LEP (Requirement 6) and LEMP (Requirement 7) with respect to the use of landscaping as a form of

Cumberland Council ExQ 2 Responses	
landscaping proposed and the mitigation measures proposed as set out in the OLEMP. … The Council has requested additional woodland planting along the west of Branthwaite Edge Road to provide visual screening for both static residents and from the transient views of road users. The Council would expect the Applicant to have regard to its feedback in the preparation of the final LEP and LEMP ahead of the submission to discharge the DCO Requirements. … The Agreed position between the Council and the Applicant on these matters is set out in the updated dSoCG … at D4. ***Traffic*** *The Council is satisfied with the assessment of the impact of traffic on amenity that has been undertaken. The Highway Authority has been consulted and has had an input into the details set out in the OCTMP. --- The Council as the Highway Authority is satisfied with the content of the OCTMP.* ***Dust, Dirt, & Air Quality*** *The Councils EHO has been in active discussion with the Applicant on the content of the OCEMP. The EHO has confirmed agreement to the approach taken by the Applicant on this topic.* ***Noise*** *The Councils EHO has agreed that the construction OCTMP and OCEMP will provide measures to suitably address noise effects and provide suitable mitigation subject to the Council's review of the final CTMP and CEMP which are to be provided as a DCO Requirement. … In terms of the operational phase of the development the Council is satisfied that the use of a Noise Impact Assessment (NIA) based on a 'worst-case' operational noise effects scenario is an appropriate level of assessment to consider noise and vibration effects. The Requirement for an updated NIA to be submitted to and agreed by the Council is also welcome. This will provide a mechanism to consider the impacts and agree the mitigation that is to be implemented. … In addition to the DCO Requirement 12, the Council welcomes the opportunity to scrutinise the final OMP in relation to detailed noise attenuation measures being provided which requires maintenance and secures the provision of a means by which the Council can ensure acceptable operational noise effects. --- The Councils EHO is satisfied that the Application's approach to noise assessment and mitigation is appropriate to deal with the adverse noise impacts that may affect the amenity of the occupiers of nearby dwellings.* ***Statutory Nuisance*** *The Council is pleased to note that the Applicant has prepared a Statutory Nuisance Statement to justify provisions within the draft DCO relating to Statutory Nuisance. --- The Council agrees that the Applicant has proposed the appropriate embedded and additional mitigation measures identified in the ES and set out in the relevant control documents. These will prevent impacts which have a potential to result in statutory nuisance under Section 79 of the EPA. The Council note that these measures are secured by requirements within the draft DCO.*	mitigation for landscape and visual effects on proximate residential receptors. The Council's recommendations will be considered for the for the final LEP and LEMP to be submitted for the Council's approval. **Noise** – The Council summarises the position based on the commitments made in the Applicant Response to Issue Specific Hearing Agenda Items Annex A (ARISH-A) [**REP3-015**] (item 9(a)) at D3. This led to updates to the NIA [**REP4-017**] to include additional information provided in response to questions and to reinforce the operational noise management requirements of Table 4.1 in the OOMP [**D5.13**] with additional measures relating to noise mitigation and the provision of a Noise Verification Report (NVR). It is the Applicant's understanding that the Council consider the combination of DCO Requirement 12 and the OOMP will provide the detail the Council requires to be certain there will be no significant noise effects. It also allows the

Cumberland Council ExQ 2 Responses	
Light Pollution *The Council's EHO has been consulted on the relevant control documents. --- The Council agree that the use of lighting within the Proposed Development can be acceptable subject to appropriate design and controls to ensure that it is operated in a sensitive way. --- The Council agree that the final CEMP (for construction) and LEMP/OMP (for operation) are appropriate means by which to control the use of lighting on the site. The Council will review the documents provided as a DCO Requirement to agree any final lighting designs.* ***Ground Conditions*** *The main issue relating to amenity with regards to ground conditions is the stability of the ground resulting from the former mining activities within the area. These matters have been subject to discussion and agreement with the Mining Remediation Authority. The Council accepts the technical input and conclusions of the MRA on this matter.* ***Contamination*** *The Councils EHO is satisfied with this approach and the measures proposed to deal with potential contamination to limit the potential effects on residential receptors as set out in the OCEMP. …The Council will review the final details that are submitted for the discharge of the DCO.* ***Flood Risk*** *The main potential effects to residential receptors resulting from the construction of the development would be a potential increase in off-site flood risk. … The Council as LLFA is satisfied with the Applicant's approach to the assessment and control of flood risk during construction. … The Council is satisfied that the requirement for the measures set out in the OCEMP can be fully considered in association with the discharge of DCO Requirement 4. … This provides additional reassurance that flood risk can be mitigated and will not have adverse impacts on residential receptors. … The Council as LLFA supports. the proposed landscape-led drainage strategy for the development.*	Council to scrutinise the Applicant's operational noise mitigation associated with the detailed design as part of the discharge of Requirements process. The Council's affirmation of the Applicant's approach to noise impact assessment and mitigation is provided in the final SoCG [**D5.18**] at row CC.EHO.14.

3 Response to LDNPA's D4 Written Representation

Table 3.1: Applicant Response to LDNPA's D4 WR

LDNPA's Response to the ExQ2	Applicant Response
Q2.4.1: *The LDNPA state that there would be 'minor harm' with regards visual effects as set out in paragraphs 4.1 and 4.3 [REP3-028]. The currently agreed position as set out in the SoCG [REP3-017] is that there would be no significant landscape impacts on the LDNPA.* *The ExA seeks additional clarification on this point in the context of section 11A National Parks and Access to the Countryside Act 1949 (as amended). The SoCG should set out whether the 'minor harm' asserted by the LDNPA is a position which is agreed/disagreed between the parties. It should also set out the implications of this identified harm in the context of the National Planning Policy Framework's requirement to give 'great weight' to conserving and enhancing landscape and scenic beauty (para 189). It should identify whether there would be residual harm to the landscape and conflict with the National Park's statutory purposes.* *In carrying out the above exercise, and if there is a finding of residual harm to the landscape, then the benefits and mitigation measures should be weighed clearly and properly against the statutory purposes in order to help the ExA determine whether the scheme seeks to further the statutory duties as required by the Act.*	
Section 11A - *Section 11A National Parks and Access to the Countryside Act 1949 imposes to a responsibility on any 'relevant authority' to seek to further the purposes of National Parks. This responsibility applies to the Lake District National Park Authority and the ExA as relevant authorities exercising their roles as interested party and decision maker in respect of the scheme.*	Noted.
NPPF189: Great weight *Paragraph 189 of the NPPF states that 'Great weight should be given to conserving and enhancing landscape and scenic beauty in National Parks, the Broads and National Landscapes which have the highest status of protection in relation to these issues'. A finding of minor harm to the scenic beauty of the Lake District National Park should therefore be given great weight in the consideration of this development proposal.* *This presents the decision maker with a tilted balance where the adverse visual effect on the National Park gain great weight and the benefits on the other side of the scale may have normal weight. That great weight has to have regard to the magnitude of the effect and be weighed against the benefits arising. Giving great weight to a very low magnitude of effect will not necessarily result in a balance that tips against the development.*	Noted. Discussion of compliance with NPPF paragraph 189 is set out in section 6.6 of the Planning Statement (PS) [**AS-010**] which includes the Applicant's assessment of the Proposed Development, as it relates to planning policy, considering the impacts and benefits relevant to a planning balance, with reference to local policy, the NPPF, and the relevant NPSs across PS sections 6 and 7. The Applicant and LDNPA are in agreement as to the conclusions as to the nature of effects arising from the Proposed Development as set out in ES Chapter 7 –

LDNPA's Response to the ExQ2	Applicant Response
Where there are large or numerous benefits on the other side of the scale, the decision maker may conclude that the benefits outweigh the harm identified.	Landscape and Visual [**REP2-032**] and its associated appendices as per the agreed (final) SoCG [**D5.24**].
Minor harm to visual amenity *The magnitude of the effect from the identified views from the fells would be 'very low' having regard to the small number of locations where views would be located, that the development would be visible as part of a wide sweep of view and the distance of the site from the viewpoints, notwithstanding the size of the development.* *The sensitivity of users of the areas where views are available will be high since these will predominantly be recreational users visiting the high fells for quiet enjoyment, including the appreciation of the available views.* *It should be noted that the minor harm results from a very low magnitude of effect combined with a high sensitivity.* *The LDNPA and the applicant agree that the development would result in 'minor harm' to the visual amenity of the Lake District National Park for the lifetime of the development.*	Noted. The Applicant and LDNPA are in agreement on this matter as reflected in the conclusions of ES Chapter 7 – Landscape and Visual [**REP2-032**] and its associated appendices (See Appendix 7.3 Schedule of Visual Effects [**REP2-036**] and Appendix 7.2 Schedule of Landscape Effects [**D5.15**]) and as per the SoCG [**D5.24**]. (see rows LDNPA.2, 4 and 5).
Residual harm *This minor harm is the residual effect once mitigation measures have been taken into account, over the lifetime of the development.* *The development is proposed to have a 40-year lifespan. After decommissioning as proposed, the harm would be reversed, and once the panels are removed and the site restored, there would be no adverse residual effect.* *For the lifespan of the development there would therefore be minor harm to the visual amenity (the appreciation of natural beauty) of the Lake District National Park.*	Noted. The Applicant and LDNPA are in agreement on this matter as reflected in the conclusions of ES Chapter 7 – Landscape and Visual [**REP2-032**] and its associated appendices (See Appendix 7.3 Schedule of Visual Effects [**REP2-036**] and Appendix 7.2 Schedule of Landscape Effects [**D5.15**]) and as per the SoCG [**D5.24**]. (see rows LDNPA.2, 4 and 5). The Applicant and the LDNPA have also affirmed the differences in methodology used by both parties in response to the Rule 17 Letter [**PD-015**] request for further information on this topic (see Applicant Response to the Rule 17 Letter [**D5.26**], which was discussed and agreed with the LDNPA on 20 November 2025.

LDNPA's Response to the ExQ2	Applicant Response
Weighing against statutory purposes of National Park *National Park Purposes are:* *(a) of conserving and enhancing the natural beauty, wildlife and cultural heritage of the areas specified in the next following subsection; and* *(b) of promoting opportunities for the understanding and enjoyment of the special qualities of those areas by the public."* *The development would not have an adverse effect on the wildlife of the National Park. It would not have an adverse effect on the cultural heritage of the National Park, except in regard to the effect on the English Lake District World Heritage Site attribute of Outstanding Universal Value relating to the extra-ordinary beauty and harmony, that mirrors the effect on visual amenity. The development would not have an effect on the opportunities for the public to access the special qualities of the National Park.P The development would, for the period of its construction, operation and decommissioning, have a minor adverse effect on visual amenity of certain views that translate into an adverse effect on natural beauty, and the enjoyment of that natural beauty by the public. The magnitude of such effects would be very low.* *Having regard to Section 11A of the 1949 Act the ExA needs to weigh this effect against the benefits of the scheme in delivering carbon savings, energy security, reliability and affordability and the other local enhancements proposed. The very low magnitude of effect, even with the great weight to be afforded to the effect, would appear capable of being outweighed by the nature and amount of benefits described.*	Noted. The Applicant and the LDNPA agree that the Proposed Development does not conflict with the statutory purposes of the National Park, and any residual visual impacts to the LDNP are capable of being outweighed by the benefits of the Proposed Development as 'Critical National Priority' infrastructure for which there is an urgent need. The Applicant supports the conclusions advanced by the LDNPA's judgment as to '*the benefits of the scheme in delivering carbon savings, energy security, reliability and affordability and the other local enhancements proposed. The very low magnitude of effect, even with the great weight to be afforded to the effect, would appear capable of being outweighed by the nature and amount of benefits described'.*

4 Response to 12 Property FE Written Representation

Table 4.1: Applicant Response to 12 Property FE's D4 WR

12 Property FE Limited's Response to the ExQ2	Applicant Response
Q2.5.1: *The ExA requests that this affected person, in relation to the purported freehold land interest, clarify the following: -* *- The extent and specifics of the land interest and rights held.* *- How the proposed development, having regard to the specifics of the works proposed within those plots, would interfere with the interests held.* **12 Property FE Ltd Response:** *In response to the first element of the question, 12 Property FE Limited is the owner of the freehold mines and minerals and mineral substances other than coal and mines of coal present at works plots 1-26, 1-33, 1-35, and 1-38. This is accepted by the promotor as demonstrated by my client's interest being listed in the book of reference in respect of those relevant plots.* *With regards to the second element of the ExA's question, my client is not in a position to provide any further detail than that already provided by the Applicant in response to written question 12.0. Further information has been sought from the Applicant although they claim not be in a position to confirm these details. This includes being unable to clarify the depths to which they will be required to excavate*	The Applicant notes the statement and confirms that 12 Property FE Limited (12FE) is noted in the Book of Reference [**APP-016**]. The ExA will note that, owing to the incorporation of the Minerals Code in the draft DCO, mines and minerals are automatically excluded from the scope of compulsory powers except where directly impacted. The Applicant is unaware of the depth of any 12FE interest and understands that 12FE does not hold this information. The Applicant has clearly set out the maximum depth for each work in the Design Parameters Document [**APP-028**]. Although the Applicant considers its works are unlikely to interfere with 12FE interests, compulsory powers are necessary to ensure the Proposed Development can be implemented without hindrance, In accordance with the relevant guidance including the Planning Act 2008[1]: procedures for the compulsory acquisition of land: '...*Parliament has always taken the view that land should only be taken compulsorily where there is clear evidence that the public benefit will outweigh the private loss.'* (see para 13). In the Applicant's view, there is compelling evidence that the public benefits that would be derived from this limited compulsory acquisition, will outweigh the private loss that

[1] Planning Act 2008 c 29

12 Property FE Limited's Response to the ExQ2	Applicant Response
to. In discussions with the Applicant's solicitor the potential for a "no dig" approach was raised although no details provided.	would be suffered. The Applicant recommends the ExA consider the strong policy support for the Proposed Development, as summarised in the Planning Statement [**AS-010**]. A fuller response to all matters relating to 12FE interests is in the Applicant Response to CAH Action Points [**D5.11**].

5 Response to Mr. B. Blackett D4 Written Representation

Table 5.1: Applicant Response to B. Blackett's D4 WR

Mr. Blackett's WR	Applicant Response
Has the developer considered, or made provision to attenuate, the increased rate of rainfall run off which will be experienced by the installation of Solar Panels and associated Ancillary Equipment on Dean Moor? *Rainfall Run Off from Dean Moor enters Lostrigg Beck which passes through my Property and also the Properties of my neighbours.* *An increased rate of rainfall run off from the development has the potential to cause flash flooding in Lostrigg Beck and cause damage to bridges and culverts which, as the sole means of access to the Properties in question, would cause serious disruption to our everyday lives.* *What assurances can the developer provide that should this concern be realised there would be funding available to reinstate the access structures crossing Lostrigg Beck?*	The Applicant welcomes this WR and the opportunity to provide reassurance on flood risk and surface water runoff. The starting point for understanding the potential flood risk associated with the Proposed Development is in the ES Appendix 2.4 – Flood Risk Assessment (FRA) and Outline Drainage Strategy (ODS) [**REP4-025**], which assesses the potential impacts and establishes mitigation requirements to be taken forward into the operational phase via the final Drainage Strategy (DS) which is secured by DCO Requirement 8. While the FRA and ODS is the lead information source for this topic, a helpful overview is also provided in the Planning Statement (PS) [**AS-010**] at section 6.8 The conclusions of the FRA and ODS, which are evidence-backed by research and established best practice, are affirmed in the agreed SoCG with the Council [**REP4-015**] and the Environment Agency (EA) [**REP4-009**] This hopefully provides assurance that the potential for effects and proposed mitigation has been scrutinised by the relevant technical experts, which has led to revisions that include additional hydraulic analysis modelling (FRA Appendix D) and additional mitigation necessary to ensure the Proposed Development meets EA standards. A high-level summary of the FRA and ODS outcome is that the Site is generally at very low risk of flooding (Zone 1) with fluvial (rivers) and pluvial (surface water) flooding primarily concentrated along watercourses including the Lostrigg Beck and other small streams and field drains, all of which will have buffers from development secured by the Work Plans [**APP-007**] and with additional protections secured by relevant control documents such as the Outline Construction Environmental Management Plan (OCEMP) [**REP4-021**] and Outline Soil Management Plan (OSMP) [**REP4-023**]. It is also established that solar farms are not generally associated with an increase in flood risk provided certain conditions are met, and this is demonstrated to be the case for the Proposed Development. This is because, even though solar panels cover a large area, they are not a single façade, and vegetation is able to grow underneath and between the rows. As such, they do not represent the introduction of new hardstanding that prevents the infiltration of rainfall into the ground.

Mr. Blackett's WR	Applicant Response
	The ODS is designed to ensure that all features which are capable of being new hardstanding are appropriately mitigated (e.g. all access tracks will be of permeable construction, and all ancillary buildings will have targeted sustainable drainage (SuDS). The final DS will provide data that demonstrates the Proposed Development will maintain existing greenfield characteristics and will not negatively affect runoff rates. The final DS must be in accordance with the ODS. To help better understand the Applicant's approach to SuDs, a copy of the research carried out by Cook and McCuan (2013)[2] on this topic, is provided as Appendix A of this ARWR-4. This confirms that *'the change in runoff characteristics from solar farm sites is likely to be insignificant and that ground cover has a highly significant control over runoff*.' It also notes that '*the addition of solar panels over a grassy field does not have much of an effect on the volume of runoff, the peak discharge, nor the time to peak'* if grass cover is located underneath panels and between rows, concluding that this is true for a range of return periods and storm durations. The core component of the Proposed Development's SuDS strategy is to ensure grass cover is maintained on the ground under and around the solar PV arrays, which is secured by the Outline Landscape Environmental Management Plan [**D5.16**]. The vegetated ground cover during the operational phase is expected to be better quality (more dense/less patchy) than the existing heavily grazed grass and will be coupled with the new and improved boundary vegetation (hedgerows, trees, scrub). Together this will help to slow runoff and provide improved opportunities for infiltration, evaporation, and transpiration, with a reasonable expectation of betterment for surface water flood risk on and off-Site compared to the existing scenario in intensive agricultural use. In addition to this landscape-led (nature-based solutions) drainage strategy being confirmed by the LLFA and EA it also has the support of Natural England (SoCG [**REP4-011**] at NE.8).

[2] Cook, L. M., & McCuen, R. H. (2013). Hydrologic Response of Solar Farms. Journal of Hydrologic Engineering, 18(5).

Mr. Blackett's WR	Applicant Response
	In summary, the Applicant considers that the Proposed Development has fully assessed the potential for the Proposed Development to increase flood risk and has ensured that embedded and additional mitigation are secured to wholly prevent risks to road infrastructure (including existing culverts), or nearby residential properties.

6 Response to Mr Howell Additional Submission – 12 November 2025

Table 6.1: Applicant Response to Mr Howell's Additional Submission – 12 November 2025

Mr. Howell's Additional Submission	Applicant Response
As Mr. Woodward has called a recess on specific issues. Could I just give some further feedback on the interesting commentary about historical and aesthetic visual issues. I do understand the mechanisms in the assessment but they have fundamental flaws, which too [redacted] *was copious to examine. The flaws are made worse when there is little knowledge of the locality*	These comments reflect matters raised in Mr. Howell's previous written responses and at the Open Floor Hearing (OFH). A separate 'Applicant Response to the OFH Actions' [**D5.12**] has been provided, which aims to respond to new matters raised in that hearing and provide references to previous responses on other topics.
1) No mention is referenced to the Solway Firth Area of Outstanding Beauty, which the Scottish Authorities ignored so gracefully when they planted a wind farm in the middle of it some 2 km distance from Europes most important wildfowl reserve. Also causing "actual" harm to the ecology to the seabed disturbing the shrimp fishery and laying off 30 shrimping boats as a result. There are perspectives from that viewpoint across to the World Heritage Site or the entirety of the landscape. Workington is an additional historical site of the steel industry. And sets well in the landscape.	Noted. Responses on this matter have previously been provided within the Applicant Response to Relevant Representations [**REP1-002**] (see Table 4.6). The Solway Firth Special Protection Area (SPA) (an ecological designation) is approximately 5km west of the Site, and the Solway Coast is a National Landscape (formerly Area of Outstanding Natural Beauty), and is located approximately 12.1 miles to the northwest. Due to the distance of the designated landscape and intervening topography, it is considered unlikely that there would be any visual impacts on the Solway Coast, which sits beyond the agreed ES study area. No factors were identified by the Council, Natural England (NE), or other consultees requiring it to be scoped-in. However, the Solway Firth SPA was scoped-in and is assessed in ES Chapter 8 – Biodiversity [**REP2-058**] and in the Shadow Habitats Regulations Assessment [**APP-156**]. It is confirmed that there will be no adverse effects on the site integrity of the Solway Firth SPA from the Proposed Development alone, or in-combination with other developments; this is affirmed in the NE SoCG [**D5.20**]. With respect to the Lake District National Park (LDNP) as a designated landscape and a World Heritage Site (WHS) the Applicant considers it has provided previous

Mr. Howell's Additional Submission	Applicant Response
	responses to Mr. Howell on this topic. The Applicant's position as previously conveyed is also in alignment with relevant consultees as reflected in their SoCGs including the LDNPA [**D5.24**], Historic England [**D5.19**], the Council [**D5.18**] and NE [**D5.20**].
2. The World Heritage Site achieved status mostly through the landscape photography that started from local initiative even independent from the formal application. You may quote when I say that any view point from the Lake District National Park Authority when I say it is hardly relevant because they are so badly managed and have so little understanding of what they are doing. There are several viewpoints from the nearby National Park I know them all and have listed the landscapes in photographs as " unspoilt England" . imagine 30 million hand mirrors being flashed into sun at only a few miles.	Noted. The Applicant appreciates Mr. Howell's passionate interest in the LDNP. The most relevant assessments for the matters raised are ES Chapter 6 – Cultural Heritage [**REP2-027**], Chapter 7 – Landscape and Visual [**REP2-032**]. The Applicant can confirm that representative view locations for photography from the LDNP for the purposes of the assessment of landscape and visual effects was agreed in advance with the LDNPA. The methodology of the assessment and its outcomes are affirmed by the agreed SoCG with the LDNPA submitted at D5 [**D5.24**]. The Applicant can also refer Mr. Howell to the Glint and Glare Assessment [**REP3-011**], which confirms that the potential glint and glare effects of solar panels are less than that of a white concrete building or a still body of water. Solar PV technology operates by absorbing light and the technology has significantly advanced to minimise solar reflectivity compared to earlier generations of the technology in use 10-15 years ago which were more associated with glint and glare effects. This is why solar PV is now regularly installed even along airport runways and busy motorways which have high safety standards to consider. The Applicant can also assure Mr. Howell that the Proposed Development is using standard fixed solar arrays and not 'Concentrated Solar Power' (CSP) which involves the use of mirrors and is more traditionally used in remote desert locations, but not in the UK.

Mr. Howell's Additional Submission	Applicant Response
3. Also what "expertise" would the LDNPA be demonstrating in their assessment if this was put too the World Heritage authorities they are already in trouble with.	Noted.
I can send -photos as examples demonstrating the substantive visual harms. I have been careful in. Choosing the word substantive	Noted.

Appendix A Cook, L. and McCuen, R. (2013) Hydrologic Response of Solar Farms

Hydrologic Response of Solar Farms

Lauren M. Cook, S.M.ASCE[1]; and Richard H. McCuen, M.ASCE[2]

Abstract: Because of the benefits of solar energy, the number of solar farms is increasing; however, their hydrologic impacts have not been studied. The goal of this study was to determine the hydrologic effects of solar farms and examine whether or not storm-water management is needed to control runoff volumes and rates. A model of a solar farm was used to simulate runoff for two conditions: the pre- and postpaneled conditions. Using sensitivity analyses, modeling showed that the solar panels themselves did not have a significant effect on the runoff volumes, peaks, or times to peak. However, if the ground cover under the panels is gravel or bare ground, owing to design decisions or lack of maintenance, the peak discharge may increase significantly with storm-water management needed. In addition, the kinetic energy of the flow that drains from the panels was found to be greater than that of the rainfall, which could cause erosion at the base of the panels. Thus, it is recommended that the grass beneath the panels be well maintained or that a buffer strip be placed after the most downgradient row of panels. This study, along with design recommendations, can be used as a guide for the future design of solar farms. **DOI: 10.1061/(ASCE)HE.1943-5584.0000530.**

CE Database subject headings: Hydrology; Land use; Solar power; Floods; Surface water; Runoff; Stormwater management.

Author keywords: Hydrology; Land use change; Solar energy; Flooding; Surface water runoff; Storm-water management.

Introduction

Storm-water management practices are generally implemented to reverse the effects of land-cover changes that cause increases in volumes and rates of runoff. This is a concern posed for new types of land-cover change such as the solar farm. Solar energy is a renewable energy source that is expected to increase in importance in the near future. Because solar farms require considerable land, it is necessary to understand the design of solar farms and their potential effect on erosion rates and storm runoff, especially the impact on offsite properties and receiving streams. These farms can vary in size from 8 ha (20 acres) in residential areas to 250 ha (600 acres) in areas where land is abundant.

The solar panels are impervious to rain water; however, they are mounted on metal rods and placed over pervious land. In some cases, the area below the panel is paved or covered with gravel. Service roads are generally located between rows of panels. Although some panels are stationary, others are designed to move so that the angle of the panel varies with the angle of the sun. The angle can range, depending on the latitude, from 22° during the summer months to 74° during the winter months. In addition, the angle and direction can also change throughout the day. The issue posed is whether or not these rows of impervious panels will change the runoff characteristics of the site, specifically increase runoff volumes or peak discharge rates. If the increases are hydrologically significant, storm-water management facilities may be needed. Additionally, it is possible that the velocity of water draining from the edge of the panels is sufficient to cause erosion of the soil below the panels, especially where the maintenance roadways are bare ground.

The outcome of this study provides guidance for assessing the hydrologic effects of solar farms, which is important to those who plan, design, and install arrays of solar panels. Those who design solar farms may need to provide for storm-water management. This study investigated the hydrologic effects of solar farms, assessed whether or not storm-water management might be needed, and if the velocity of the runoff from the panels could be sufficient to cause erosion of the soil below the panels.

Model Development

Solar farms are generally designed to maximize the amount of energy produced per unit of land area, while still allowing space for maintenance. The hydrologic response of solar farms is not usually considered in design. Typically, the panels will be arrayed in long rows with separations between the rows to allow for maintenance vehicles. To model a typical layout, a unit width of one panel was assumed, with the length of the downgradient strip depending on the size of the farm. For example, a solar farm with 30 rows of 200 panels each could be modeled as a strip of 30 panels with space between the panels for maintenance vehicles. Rainwater that drains from the upper panel onto the ground will flow over the land under the 29 panels on the downgradient strip. Depending on the land cover, infiltration losses would be expected as the runoff flows to the bottom of the slope.

To determine the effects that the solar panels have on runoff characteristics, a model of a solar farm was developed. Runoff in the form of sheet flow without the addition of the solar panels served as the prepaneled condition. The paneled condition assumed a downgradient series of cells with one solar panel per ground cell. Each cell was separated into three sections: wet, dry, and spacer.

The dry section is that portion directly underneath the solar panel, unexposed directly to the rainfall. As the angle of the panel from the horizontal increases, more of the rain will fall directly onto

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the ground; this section of the cell is referred to as the wet section. The spacer section is the area between the rows of panels used by maintenance vehicles. Fig. 1 is an image of two solar panels and the spacer section allotted for maintenance vehicles. Fig. 2 is a schematic of the wet, dry, and spacer sections with their respective dimensions. In Fig. 1, tracks from the vehicles are visible on what is modeled within as the spacer section. When the solar panel is horizontal, then the length longitudinal to the direction that runoff will occur is the length of the dry and wet sections combined. Runoff from a dry section drains onto the downgradient spacer section. Runoff from the spacer section flows to the wet section of the next downgradient cell. Water that drains from a solar panel falls directly onto the spacer section of that cell.

The length of the spacer section is constant. During a storm event, the loss rate was assumed constant for the 24-h storm because a wet antecedent condition was assumed. The lengths of the wet and dry sections changed depending on the angle of the solar panel. The total length of the wet and dry sections was set equal to the length of one horizontal solar panel, which was assumed to be 3.5 m. When a solar panel is horizontal, the dry section length would equal 3.5 m and the wet section length would be zero. In the paneled condition, the dry section does not receive direct rainfall because the rain first falls onto the solar panel then drains onto the spacer section. However, the dry section does infiltrate some of the runoff that comes from the upgradient wet section. The wet section was modeled similar to the spacer section with rain falling directly onto the section and assuming a constant loss rate.

For the presolar panel condition, the spacer and wet sections are modeled the same as in the paneled condition; however, the cell does not include a dry section. In the prepaneled condition, rain falls directly onto the entire cell. When modeling the prepaneled condition, all cells receive rainfall at the same rate and are subject to losses. All other conditions were assumed to remain the same such that the prepaneled and paneled conditions can be compared.

Rainfall was modeled after an natural resources conservation service (NRCS) Type II Storm (McCuen 2005) because it is an accurate representation of actual storms of varying characteristics that are imbedded in intensity-duration-frequency (IDF) curves. For each duration of interest, a dimensionless hyetograph was developed using a time increment of 12 s over the duration of the storm (see Fig. 3). The depth of rainfall that corresponds to each storm magnitude was then multiplied by the dimensionless hyetograph. For a 2-h storm duration, depths of 40.6, 76.2, and 101.6 mm were used for the 2-, 25-, and 100-year events. The 2- and 6-h duration hyetographs were developed using the center portion of the 24-h storm, with the rainfall depths established with the Baltimore IDF curve. The corresponding depths for a 6-h duration were 53.3, 106.7, and 132.1 mm, respectively. These magnitudes were chosen to give a range of storm conditions.

During each time increment, the depth of rain is multiplied by the cell area to determine the volume of rain added to each section of each cell. This volume becomes the storage in each cell. Depending on the soil group, a constant volume of losses was subtracted from the storage. The runoff velocity from a solar panel was calculated using Manning's equation, with the hydraulic radius for sheet flow assumed to equal the depth of the storage on the panel (Bedient and Huber 2002). Similar assumptions were made to compute the velocities in each section of the surface sections.

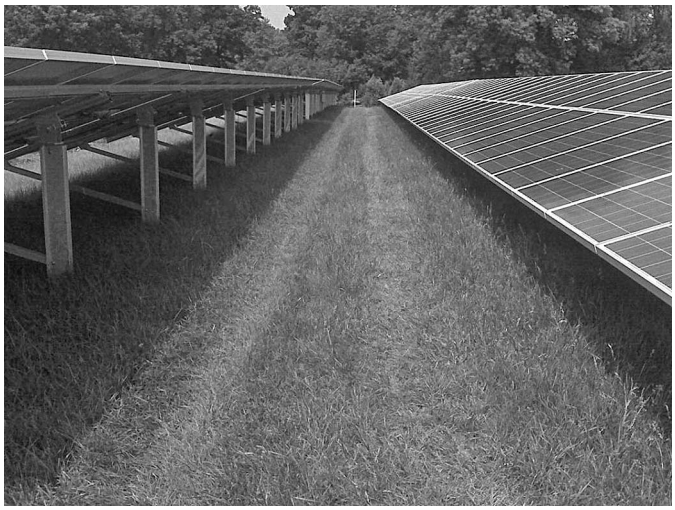

Fig. 1. Maintenance or "spacer" section between two rows of solar panels (photo by John E. Showler, reprinted with permission)

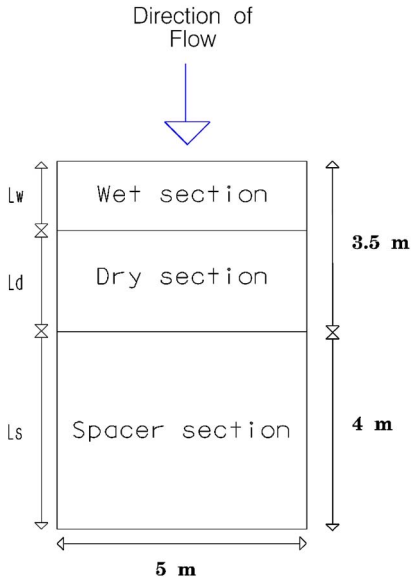

Fig. 2. Wet, dry, and spacer sections of a single cell with lengths *Lw*, *Ls*, and *Ld* with the solar panel covering the dry section

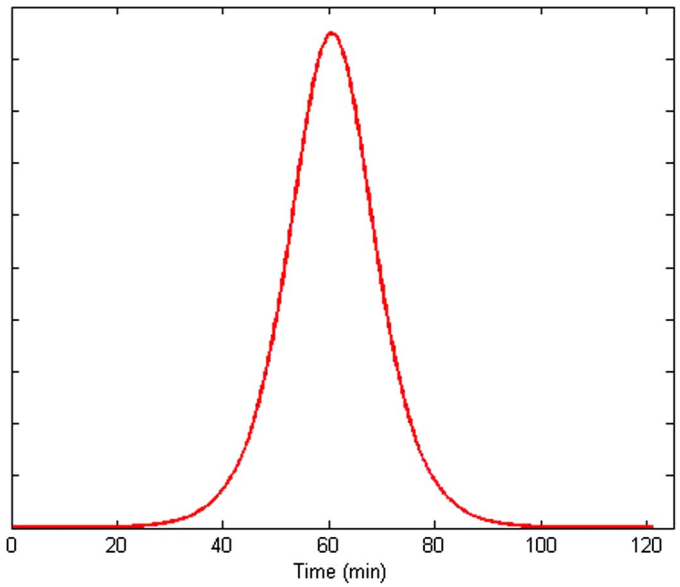

Fig. 3. Dimensionless hyetograph of 2-h Type II storm

Runoff from one section to the next and then to the next downgradient cell was routed using the continuity of mass. The routing coefficient depended on the depth of flow in storage and the velocity of runoff. Flow was routed from the wet section to the dry section to the spacer section, with flow from the spacer section draining to the wet section of the next cell. Flow from the most downgradient cell was assumed to be the outflow. Discharge rates and volumes from the most downgradient cell were used for comparisons between the prepaneled and paneled conditions.

Alternative Model Scenarios

To assess the effects of the different variables, a section of 30 cells, each with a solar panel, was assumed for the base model. Each cell was separated individually into wet, dry, and spacer sections. The area had a total ground length of 225 m with a ground slope of 1% and width of 5 m, which was the width of an average solar panel. The roughness coefficient (Engman 1986) for the silicon solar panel was assumed to be that of glass, 0.01. Roughness coefficients of 0.15 for grass and 0.02 for bare ground were also assumed. Loss rates of 0.5715 cm/h (0.225 in./h) and 0.254 cm/h (0.1 in./h) for B and C soils, respectively, were assumed.

The prepaneled condition using the 2-h, 25-year rainfall was assumed for the base condition, with each cell assumed to have a good grass cover condition. All other analyses were made assuming a paneled condition. For most scenarios, the runoff volumes and peak discharge rates from the paneled model were not significantly greater than those for the prepaneled condition. Over a total length of 225 m with 30 solar panels, the runoff increased by 0.26 m^3, which was a difference of only 0.35%. The slight increase in runoff volume reflects the slightly higher velocities for the paneled condition. The peak discharge increased by 0.0013 m^3, a change of only 0.31%. The time to peak was delayed by one time increment, i.e., 12 s. Inclusion of the panels did not have a significant hydrologic impact.

Storm Magnitude

The effect of storm magnitude was investigated by changing the magnitude from a 25-year storm to a 2-year storm. For the 2-year storm, the rainfall and runoff volumes decreased by approximately 50%. However, the runoff from the paneled watershed condition increased compared to the prepaneled condition by approximately the same volume as for the 25-year analysis, 0.26 m^3. This increase represents only a 0.78% increase in volume. The peak discharge and the time to peak did not change significantly. These results reflect runoff from a good grass cover condition and indicated that the general conclusion of very minimal impacts was the same for different storm magnitudes.

Ground Slope

The effect of the downgradient ground slope of the solar farm was also examined. The angle of the solar panels would influence the velocity of flows from the panels. As the ground slope was increased, the velocity of flow over the ground surface would be closer to that on the panels. This could cause an overall increase in discharge rates. The ground slope was changed from 1 to 5%, with all other conditions remaining the same as the base conditions.

With the steeper incline, the volume of losses decreased from that for the 1% slope, which is to be expected because the faster velocity of the runoff would provide less opportunity for infiltration. However, between the prepaneled and paneled conditions, the increase in runoff volume was less than 1%. The peak discharge and the time to peak did not change. Therefore, the greater ground slope did not significantly influence the response of the solar farm.

Soil Type

The effect of soil type on the runoff was also examined. The soil group was changed from B soil to C soil by varying the loss rate. As expected, owing to the higher loss rate for the C soil, the depths of runoff increased by approximately 7.5% with the C soil when compared with the volume for B soils. However, the runoff volume for the C soil condition only increased by 0.17% from the prepaneled condition to the paneled condition. In comparison with the B soil, a difference of 0.35% in volume resulted between the two conditions. Therefore, the soil group influenced the actual volumes and rates, but not the relative effect of the paneled condition when compared to the prepaneled condition.

Panel Angle

Because runoff velocities increase with slope, the effect of the angle of the solar panel on the hydrologic response was examined. Analyses were made for angles of 30° and 70° to test an average range from winter to summer. The hydrologic response for these angles was compared to that of the base condition angle of 45°. The other site conditions remained the same. The analyses showed that the angle of the panel had only a slight effect on runoff volumes and discharge rates. The lower angle of 30° was associated with an increased runoff volume, whereas the runoff volume decreased for the steeper angle of 70° when compared with the base condition of 45°. However, the differences (~0.5%) were very slight. Nevertheless, these results indicate that, when the solar panel was closer to horizontal, i.e., at a lower angle, a larger difference in runoff volume occurred between the prepaneled and paneled conditions. These differences in the response result are from differences in loss rates.

The peak discharge was also lower at the lower angle. At an angle of 30°, the peak discharge was slightly lower than at the higher angle of 70°. For the 2-h storm duration, the time to peak of the 30° angle was 2 min delayed from the time to peak of when the panel was positioned at a 70° angle, which reflects the longer travel times across the solar panels.

Storm Duration

To assess the effect of storm duration, analyses were made for 6-h storms, testing magnitudes for 2-, 25-, and 100-year return periods, with the results compared with those for the 2-h rainfall events. The longer storm duration was tested to determine whether a longer duration storm would produce a different ratio of increase in runoff between the prepaneled and paneled conditions. When compared to runoff volumes from the 2-h storm, those for the 6-h storm were 34% greater in both the paneled and prepaneled cases. However, when comparing the prepaneled to the paneled condition, the increase in the runoff volume with the 6-h storm was less than 1% regardless of the return period. The peak discharge and the time-to-peak did not differ significantly between the two conditions. The trends in the hydrologic response of the solar farm did not vary with storm duration.

Ground Cover

The ground cover under the panels was assumed to be a native grass that received little maintenance. For some solar farms, the area beneath the panel is covered in gravel or partially paved because the panels prevent the grass from receiving sunlight. Depending on the

volume of traffic, the spacer cell could be grass, patches of grass, or bare ground. Thus, it was necessary to determine whether or not these alternative ground-cover conditions would affect the runoff characteristics. This was accomplished by changing the Manning's n for the ground beneath the panels. The value of n under the panels, i.e., the dry section, was set to 0.015 for gravel, with the value for the spacer or maintenance section set to 0.02, i.e., bare ground. These can be compared to the base condition of a native grass ($n = 0.15$). A good cover should promote losses and delay the runoff.

For the smoother surfaces, the velocity of the runoff increased and the losses decreased, which resulted in increasing runoff volumes. This occurred both when the ground cover under the panels was changed to gravel and when the cover in the spacer section was changed to bare ground. Owing to the higher velocities of the flow, runoff rates from the cells increased significantly such that it was necessary to reduce the computational time increment. Fig. 4(a) shows the hydrograph from a 30-panel area with a time increment of 12 s. With a time increment of 12 s, the water in each cell is discharged at the end of every time increment, which results in no attenuation of the flow; thus, the undulations shown in Fig. 4(a) result. The time increment was reduced to 3 s for the 2-h storm, which resulted in watershed smoothing and a rational hydrograph shape [Fig. 4(b)]. The results showed that the storm runoff

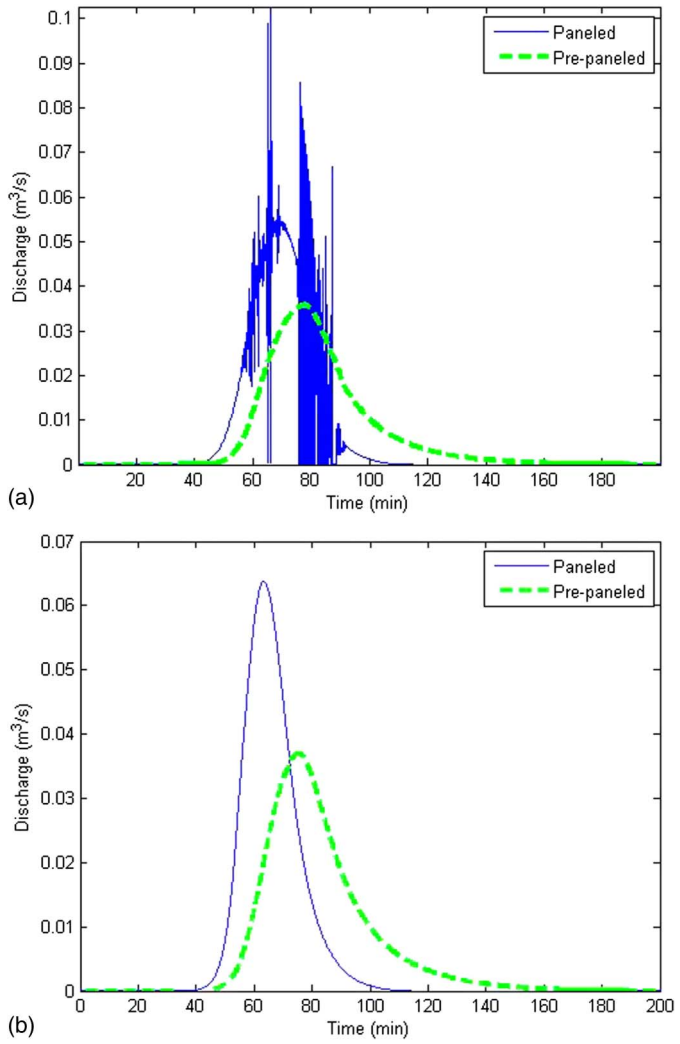

Fig. 4. Hydrograph with time increment of (a) 12 s; (b) 3 s with Manning's n for bare ground

increased by 7% from the grass-covered scenario to the scenario with gravel under the panel. The peak discharge increased by 73% for the gravel ground cover when compared with the grass cover without the panels. The time to peak was 10 min less with the gravel than with the grass, which reflects the effect of differences in surface roughness and the resulting velocities.

If maintenance vehicles used the spacer section regularly and the grass cover was not adequately maintained, the soil in the spacer section would be compacted and potentially the runoff volumes and rates would increase. Grass that is not maintained has the potential to become patchy and turn to bare ground. The grass under the panel may not get enough sunlight and die. Fig. 1 shows the result of the maintenance trucks frequently driving in the spacer section, which diminished the grass cover.

The effect of the lack of solar farm maintenance on runoff characteristics was modeled by changing the Manning's n to a value of 0.02 for bare ground. In this scenario, the roughness coefficient for the ground under the panels, i.e., the dry section, as well as in the spacer cell was changed from grass covered to bare ground ($n = 0.02$).The effects were nearly identical to that of the gravel. The runoff volume increased by 7% from the grass-covered to the bare-ground condition. The peak discharge increased by 72% when compared with the grass-covered condition. The runoff for the bare-ground condition also resulted in an earlier time to peak by approximately 10 min. Two other conditions were also modeled, showing similar results. In the first scenario, gravel was placed directly under the panel, and healthy grass was placed in the spacer section, which mimics a possible design decision. Under these conditions, the peak discharge increased by 42%, and the volume of runoff increased by 4%, which suggests that storm-water management would be necessary if gravel is placed anywhere.

Fig. 5 shows two solar panels from a solar farm in New Jersey. The bare ground between the panels can cause increased runoff rates and reductions in time of concentration, both of which could necessitate storm-water management. The final condition modeled involved the assumption of healthy grass beneath the panels and bare ground in the spacer section, which would simulate the condition of unmaintained grass resulting from vehicles that drive over the spacer section. Because the spacer section is 53% of the cell, the change in land cover to bare ground would reduce losses and decrease runoff travel times, which would cause runoff to amass as it

Fig. 5. Site showing the initiation of bare ground below the panels, which increases the potential for erosion (photo by John Showler, reprinted with permission)

moves downgradient. With the spacer section as bare ground, the peak discharge increased by 100%, which reflected the increases in volume and decrease in timing. These results illustrate the need for maintenance of the grass below and between the panels.

Design Suggestions

With well-maintained grass underneath the panels, the solar panels themselves do not have much effect on total volumes of the runoff or peak discharge rates. Although the panels are impervious, the rainwater that drains from the panels appears as runoff over the downgradient cells. Some of the runoff infiltrates. If the grass cover of a solar farm is not maintained, it can deteriorate either because of a lack of sunlight or maintenance vehicle traffic. In this case, the runoff characteristics can change significantly with both runoff rates and volumes increasing by significant amounts. In addition, if gravel or pavement is placed underneath the panels, this can also contribute to a significant increase in the hydrologic response.

If bare ground is foreseen to be a problem or gravel is to be placed under the panels to prevent erosion, it is necessary to counteract the excess runoff using some form of storm-water management. A simple practice that can be implemented is a buffer strip (Dabney et al. 2006) at the downgradient end of the solar farm. The buffer strip length must be sufficient to return the runoff characteristics with the panels to those of runoff experienced before the gravel and panels were installed. Alternatively, a detention basin can be installed.

A buffer strip was modeled along with the panels. For approximately every 200 m of panels, or 29 cells, the buffer must be 5 cells long (or 35 m) to reduce the runoff volume to that which occurred before the panels were added. Even if a gravel base is not placed under the panels, the inclusion of a buffer strip may be a good practice when grass maintenance is not a top funding priority. Fig. 6 shows the peak discharge from the graveled surface versus the length of the buffer needed to keep the discharge to prepaneled peak rate.

Water draining from a solar panel can increase the potential for erosion of the spacer section. If the spacer section is bare ground, the high kinetic energy of water draining from the panel can cause soil detachment and transport (Garde and Raju 1977; Beuselinck et al. 2002). The amount and risk of erosion was modeled using the velocity of water coming off a solar panel compared with the velocity and intensity of the rainwater. The velocity of panel runoff was calculated using Manning's equation, and the velocity of falling rainwater was calculated using the following:

$$V_t = 120\, d_r^{0.35} \tag{1}$$

where d_r = diameter of a raindrop, assumed to be 1 mm. The relationship between kinetic energy and rainfall intensity is

$$K_e = 916 + 330 \log_{10} i \tag{2}$$

where i = rainfall intensity (in./h) and K_e = kinetic energy (ft-tons per ac-in. of rain) of rain falling onto the wet section and the panel, as well as the water flowing off of the end of the panel (Wischmeier and Smith 1978). The kinetic energy (Salles et al. 2002) of the rainfall was greater than that coming off the panel, but the area under the panel (i.e., the product of the length, width, and cosine of the panel angle) is greater than the area under the edge of the panel where the water drains from the panel onto the ground. Thus, dividing the kinetic energy by the respective areas gives a more accurate representation of the kinetic energy experienced by the soil. The energy of the water draining from the panel onto the ground can be nearly 10 times greater than the rain itself falling onto the ground area. If the solar panel runoff falls onto an unsealed soil, considerable detachment can result (Motha et al. 2004). Thus, because of the increased kinetic energy, it is possible that the soil is much more prone to erosion with the panels than without. Where panels are installed, methods of erosion control should be included in the design.

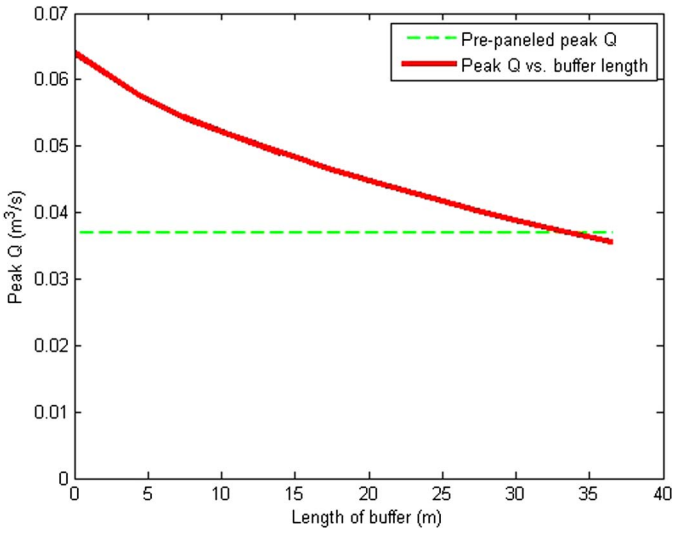

Fig. 6. Peak discharge over gravel compared with buffer length

Conclusions

Solar farms are the energy generators of the future; thus, it is important to determine the environmental and hydrologic effects of these farms, both existing and proposed. A model was created to simulate storm-water runoff over a land surface without panels and then with solar panels added. Various sensitivity analyses were conducted including changing the storm duration and volume, soil type, ground slope, panel angle, and ground cover to determine the effect that each of these factors would have on the volumes and peak discharge rates of the runoff.

The addition of solar panels over a grassy field does not have much of an effect on the volume of runoff, the peak discharge, nor the time to peak. With each analysis, the runoff volume increased slightly but not enough to require storm-water management facilities. However, when the land-cover type was changed under the panels, the hydrologic response changed significantly. When gravel or pavement was placed under the panels, with the spacer section left as patchy grass or bare ground, the volume of the runoff increased significantly and the peak discharge increased by approximately 100%. This was also the result when the entire cell was assumed to be bare ground.

The potential for erosion of the soil at the base of the solar panels was also studied. It was determined that the kinetic energy of the water draining from the solar panel could be as much as 10 times greater than that of rainfall. Thus, because the energy of the water draining from the panels is much higher, it is very possible that soil below the base of the solar panel could erode owing to the concentrated flow of water off the panel, especially if there is bare ground in the spacer section of the cell. If necessary, erosion control methods should be used.

Bare ground beneath the panels and in the spacer section is a realistic possibility (see Figs. 1 and 5). Thus, a good, well-maintained grass cover beneath the panels and in the spacer section is highly recommended. If gravel, pavement, or bare ground is

deemed unavoidable below the panels or in the spacer section, it may necessary to add a buffer section to control the excess runoff volume and ensure adequate losses. If these simple measures are taken, solar farms will not have an adverse hydrologic impact from excess runoff or contribute eroded soil particles to receiving streams and waterways.

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