Submission by Mallard Pass Action Group (MPAG)

– unique ID ref. 20036230

Deadline 9

Appendices

APPENDICES

MPAG's responses to deadline 8 submissions by the Applicant

- Deadline 8 Submission - 9.47 Applicant's Response to Deadline 7 Submissions (REP8-019)
- Deadline 8 Submission - 9.49 Applicants Response to ExA's Rule 17 Request for further information (REP8-021)

Appendix 1 - Landscope, Land & Property's response to the Applicant's comments at deadline 8 (REP8-019)

Appendix 2 - Extracts and associated comments from MPAG from the ADAS report written for the Welsh Government titled: The impact of PV sites on agricultural soils and land quality, 2023.

Appendix 3 - The full ADAS report written for the Welsh Government: The impact of PV sites on agricultural soils and land quality, 2023.

Appendix 4 - Historic England: Piling and Archaeology – Guidance and Good Practice

APPENDIX 1: Comments from Landscope on the Applicant's response to their soil report (REP7-060) on behalf of MPAG.

Black text denotes the Applicant, blue text denotes Landscope comments.

1. INTRODUCTION

1.1 MPAG's written summary of oral case item 4 "BMV" also references and appends a new document,

Appendix 2, which is a "Critique of ALC" by Landscope. Both are responded to in this document.

1.2 There is implicit and explicit criticism of the Applicant's approach and methodology. This document provides a succinct response to the matters in the following section order:

(2) summary of MPAG's position;

(3) ALC methodologies and sampling densities;

(4) expected ALC results;

(5) preliminary results and Natural England's comments;

(6) additional survey carried out;

(7) impacts on soils and ALC grade, and the robustness of the results;

(8) the Landscope Field 2 survey and matters raised;

(9) comments on Landscope's analysis and where that leaves the EIA conclusions;

(10) what do Landscope's conclusions mean?;

(11) land use;

(12) enhancement of soils; and

(13) conclusions.

2 SUMMARY OF MPAG'S POSITION

2.1 MPAG's written statement is at [REP7-057]. The Appendix 2 Landscope Critique of ALC is [REP7-060]. The following key points are raised by MPAG and Landscope:

- the ALC survey is not robust. The requirement is that there is one auger boring taken per hectare (REP7-057/4.0.3);
- additional sampling was only undertaken on instruction from Natural England (REP7-057/4.0.5);
- the Applicant's information has been selective (REP7-057/4.0.8);

• Landscope conclude that across the whole Site there is around 50% Subgrade 3a and a small amount of Grade 2 (REP7-060/7.3).

• this adds 10 – 15% of BMV to KCC's second stage ALC results (REP7-057/4.0.14). If Landscope's results are extrapolated it is likely that over the whole site there is more than 50% BMV (REP7-060/1.6).

3 ALC METHODOLOGIES AND SAMPLING DENSITY

3.1 There is considerable criticism of the sampling density. MPAG [REP7-057] at 4.0.3 state that Natural England "requires 1 auger boring every hectare".

3.2 That is not the case. There is no sampling density set out in the 'Agricultural Land Classification of England and Wales: revised guidelines and criteria for grading the quality of agricultural land' (MAFF, October 1988), which is the methodology used for ALC.

Para 6.3 of government 'Guidance to assessing development proposals on agricultural land, Feb 2021' clearly outlines the following:

https://www.gov.uk/government/publications/agricultural-land-assess-proposals-for-development/guide-to-assessing-development-proposals-on-agricultural-land

6.3 Survey requirements

For a detailed ALC assessment, a soil specialist should normally make boreholes:

every hectare on a regular grid on agricultural land in the proposed development area up to 1.2m deep using a hand-held auger. They should:

- dig small inspection pits by hand to a minimum depth of 1m to add supporting evidence to the borehole data
- dig pits where there's a change in main soil type and ALC grade to provide a good depiction of the site
- combine the survey results with local climate and site data to plot on an Ordnance Survey (OS) base map
- use a base map at an appropriate scale for detailed work, such as 1:10,000 scale

Extract from TIN049

Natural England's TIN049 clearly outlines the survey guidance for ALC surveys. This was not followed to the full extent even after some more detailed surveys at stage 2. This will be explained further below.

New field survey

Digital mapping and geographical information systems have been introduced to facilitate the provision of up-to-date information. ALC surveys are undertaken, according to the published Guidelines, by field surveyors using handheld augers to examine soils to a depth of 1.2 metres, at a frequency of one boring per hectare for a detailed assessment. This is usually supplemented by digging occasional small pits (usually by hand) to inspect the soil profile. Information obtained by these methods is combined with climatic and other data to produce an ALC map and report. ALC maps are normally produced on an Ordnance Survey base at varying scales from 1:10,000 for detailed work to 1:50 000 for reconnaissance survey

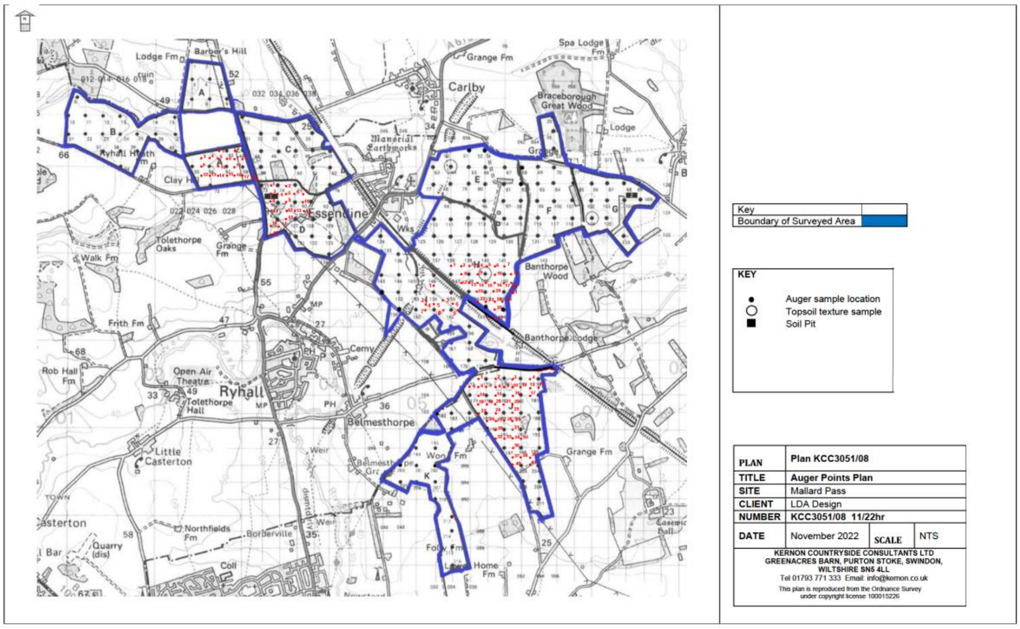
3.3 To describe a survey as a detailed survey, one auger per hectare is the normal practice. This is stated in, for example Natural England's TIN049 where it says surveys are "undertaken at a frequency of one boring per hectare for a detailed assessment" (TIN049, 2012, page 3). It is not a requirement of the methodology, however, that every survey has to be a detailed assessment. This is recognised in, for example, the Welsh Government "Agricultural Land Classification: Frequently Asked Questions" document (May 2021) in respect of the same ALC methodology, which advises that "depending upon the type of development, location, scale, purpose of the survey, availability of existing ALC data etc, less detailed surveys (or sometimes more detailed) may be undertaken, but expert advice must be sought from a soil scientist or other practitioner experienced in undertaking ALC survey work".

This development does not come under the auspices of the Welsh government. Wales has a very different approach to ALC and BMV on account of the fact that there is much less BMV in Wales.

Also Natural England said many times that the Applicant should do a detailed survey, that was also the recommendation of Stantec.

3.4 The semi-detailed ALC provided baseline data, and was submitted with the Preliminary Environmental Information Report (PEIR). This was reviewed by Reading Agricultural Consultants (on behalf of Rutland County Council) at PEIR stage, and the semi-detailed and detailed ALC subsequently submitted with the ES, has been reviewed by Natural England throughout the project development.

The ES did not contain the semi-detailed map layout of ALC grades from the PEIR, therefore there was no comparison between detailed and semi-detailed results. Therefore it would have been impossible to identify all the areas that changed (downgraded) that were not sampled at a detailed level. The plan map of auger bore points in Appendix 12.4 (APP-091) are quite small and of poor quality, making identification difficult. Landscope used the grid references in the KCC test results to overlay their map requiring 30 auger samples.



3.5 Despite MPAG's comments, Landscope do not state that the ALC was completed incorrectly. Indeed at 1.3 [REP7-060] Landscope state "our findings across the site broadly indicate that the KCC report is correct in that it presents the ALC grades in accordance with the guidelines". Therefore it is not clear on what basis Landscope and MPAG consider the grading to be incorrect in the areas surveyed.

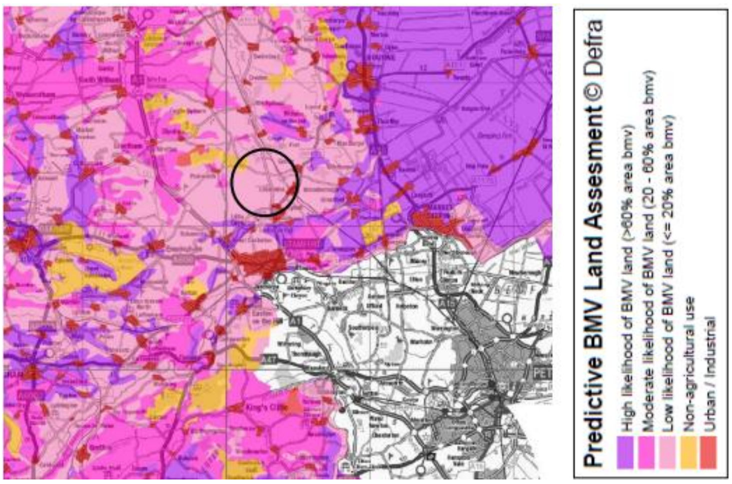
Landscope is not critical of the findings made by KCC, but even in the areas surveyed such as Field 2 the density of survey was not in compliance with TIN049, in that there were 24 and not 30 boreholes. Where Landscope did survey we found sufficient discrepancies or difference with the KCC report to suggest that there is or could be more BMV than the surveys of KCC.

4 EXPECTED ALC RESULTS

4.1 The Applicant is confident that the ALC provides sufficient detail for the Examining Authority to assess the effects. There is agreement [RR-0823] from Natural England that the installation of the panels does not result in loss, by sealing or downgrading, of land quality, subject to good management. Therefore, a detailed level of survey across all of the Site should not be necessary, as the agricultural land will not be sealed or downgraded (ie lost).

MPAG's report was not commissioned primarily to check whether the installation of panels results in a loss, by sealing or downgrading, of land quality. However since the Landscope report, MPAG has identified a report[1] commissioned recently by ADAS suggesting there could be quite a few reasons why areas of a PV site could be downgraded. (This report is in Appendix 2 and 3 after this, as soil report assessment.) Natural England's feedback never took into account the potential impact of a 60 year life span of the development and the fact that all the panels will have to be replaced, as well as other electrical infrastructure, fencing and the piles, causing undue trafficking, compaction, potential mixing and disturbance of the soil. Piles are not expected to last 60 years and when corroded can snap off when retracted, making removal an intrusive activity and disturbance to the soil.

4.2 Based on the Likelihood of BMV Land maps produced in 2017 by Natural England, the Site was predicted to be in the low likelihood of BMV. The following is a copy of Insert 12.4 from the ES Chapter 12 [APP042], which is an extract from Natural England's plan.



1 ADAS: The Impact of solar photovoltaic (PV) sites on agricultural soils and land, work package 3, March 2023.

4.3 A high proportion of BMV was not, therefore, expected for this site. That formed a starting point for the survey. True, but despite this, KCC found over 40% of site to be BMV which is more in line with Moderate Likelihood. The Landscope report suggests that that figure could be as high as 50% BMV. The fact that more BMV was found than the Predictive Maps suggested should be an indicator of need to undertake additional surveys to better understand the amounts of BMV.

4.4 The installation of the solar PV arrays does not result in the sealing or downgrading of agricultural land.

The ALC land will be neither lost nor downgraded. This is noted in Natural England's response of 2nd March[RR-0823]. It is noted in the decision at Little Crow (EN010101) (Secretary of State's decision letter of 5thApril 2022, paragraph 4.50). In cases where the land will not be lost, and the ALC grade will not be affected, the level of detail of the survey can be reduced to reflect that position.

The substation is regarded as permanent and lost and was not subject to a detailed survey, yet was downgraded following publication in the PEIR documents. Further to the Landscope report, it is noted the Applicant has now changed their position in the latest oSMP (REP08a-005) and stated a fully detailed survey will take place for the substation if the scheme is consented and they are no longer claiming the sub grade of the substation area to be 3b.

Given the above ADAS report it may be the case the Applicant's statement is considered open to challenge. Little Crow is nearly ¼ of the size compared to Mallard Pass Solar Farm and only has a lifespan of 35 years compared to 60 years for this scheme. Aside from other variables the Applicant cannot therefore assume the same conclusion would be drawn.

5 PEIR RESULTS AND NATURAL ENGLAND'S COMMENTS

5.1 The PEIR set out the findings of the initial semi-detailed ALC. A PEIR is a preliminary assessment. It is entirely appropriate that it sets out the results of the survey to the level of detail that had been completed at that time, which was at an early stage in the design process.

5.2 Following the PEIR review and comments, the main areas for additional survey were discussed with Natural England and additional survey was carried out.

5.3 The installation of solar PV arrays does not cause the ALC grade to change. This is an assumption, there is no evidence as no solar sites have reached decommissioning and been retested to see if ALC grade has changed. The ADAS report sheds sufficient doubt identifying the conditions under which soil is likely to be downgraded. MPAG's starting point is that the GEMP does not provide sufficient guarantee the grassland will be sown, giving it a clear 12 month period to establish, and importantly sowing and trafficking it only when the soil conditions are right. Additionally there is the concern about the soil disturbance during the replacement of any part of the site e.g. panels, inverters, piles, fencing etc. This could lead to soil compaction and soil mixing.

Accordingly, given the nature of the Proposed Development, the ALC results provide a robust and adequate level of information. Some 334 samples were taken across the 817ha of land within the Site, mostly in the Solar PV Site and field margins area. This gives an appropriate level of information about the ALC resource, which will not be sealed or downgraded. It provides sufficient information to inform the soil management plan, an outline of which is an application document [REP6-017], and to inform the future SMP (which may include areas for additional survey prior to construction).

6. ADDITIONAL SAMPLING

6.1 The additional sampling identified areas where the ALC pattern was more complex, as would be expected with additional sample results. Overall, however, the general pattern of the land quality identified was not significantly altered.

It was altered from 53% to 41% overall. The areas of BMV were altered following the findings of the second survey, but mostly on areas not surveyed in more detail.

7 CONTEXT OF THE RESULTS

7.1 The land quality will not be affected, because the land will not be sealed or downgraded by the installation of the Solar PV Site. 7.2 There will be areas used for tracks, solar stations and the Onsite Substation and these have been recorded.

There is no final design yet for solar panel layout, tracks, solar stations, cable routing etc, so how did the Applicant arrive at their ALC grades for these areas? They have not correctly reflected the BMV of field 19 which houses the substation and will be an area which is permanent.

The ES took a precautionary approach and assessed these areas as though they may not be returned to the same ALC grade. As the oSMP was expanded and developed during the Examination it was possible to conclude that the information was now available to allow the conclusion that these areas will be restored to the same ALC grade and that therefore there will be no loss of land or ALC downgrading.

This may be a desire but with soils being stripped and stored in bunds for 60 years Landscope do not consider that the Applicant can say with certainty that the land quality will not be downgraded at restoration.

7.3 As discussed above, undertaking additional survey work to refine the ALC grades across the Solar PV Site will not alter the assessment conclusions from a soils and land quality perspective because the land quality will not be affected. The question then becomes simply whether the change in land use of agricultural land, of the different qualities identified, is acceptable.

The Landscope report was commissioned primarily to look at the impact on Land Use and expectation that lower grade land should be selected for development, as per NPS EN3 and NPPF policy.

8 THE LANDSCOPE SURVEY

8.1 The Landscope report sets out in 1.3 that “our findings across the site broadly indicate that the KCC report is correct in that it presents the ALC Grades in accordance with the guidelines”.

For MPAG, the Landscope report was about checking the robustness of some of the data and methodology, it was never intended to be a detailed survey. MPAG could only obtain access to certain areas as landowners had entered into option agreements. Fields 2 and 3 were made available by the landowner, which allowed a survey. Field 2 was also a good example as it was 1 of 4 areas re-surveyed by KCC at a more detailed level, but still Landscope found various anomalies in that area.

8.2 The Landscope survey focuses mainly on one field. As Landscope record in paragraph 1.5 [REP7-060] KCC have sampled 24 auger points over the 30ha field. In 1.6 it is stated that “we consider that a full ALC survey across the whole site is justified to determine more precisely the quantity of BMV land”. This implies that 24 points over 30ha is not considered to be enough.

That is correct, especially as grade 2 land was also involved. Given that KCC would want to demonstrate accurately their findings that the land should be downgraded from the preliminary findings, then it would seem appropriate for the full 30 auger samples to have been taken. Landscope found differences and when looking in the Grade 2 area and found even more Grade 2.

8.3 Landscope then report the field survey that they have carried out. As identified in section 5, a total of 8 samples were taken over the 30ha field. Field 2 is a variable field, as shown on the aerial photograph set out in the Landscope report.

8.4 Based on those 8 sample points, Landscope consider that the KCC ALC results (based on 24 sample points) can be re-graded as below. In so doing the ALC boundaries are changed in parts of the field where Landscope has not taken samples, yet KCC has.

The ALC map only changed in the areas where Landscope surveyed.

KCC ALC Landscope ALC

8.5 Landscope then extrapolate their findings. The conclusion in 7.1 is that not all the BMV has been identified on the site (the implication is that they are referring to the whole Site not just field 2). Yes It is stated that areas of Subgrade 3b that were not resurveyed (i.e. detailed survey) may contain some 3a or higher.

This was a distinct possibility. Since the KCC findings place the Likelihood of BMV into the ‘Moderate Likelihood’ rather than the expected ‘Low Likelihood’, it demonstrates that there is a reasonable chance of more BMV across the site. KCC don’t know, because they did not re-survey the areas they previously identified as 3b.

8.6 From that it is extrapolated (1.6) that “it is likely that there is more than 50% BMV on the site overall”.

Landscope identified that some areas had been downgraded without re-survey, presumably based on the detailed surveys elsewhere on the site. On that basis KCC extrapolated ‘down’ the grade, whilst Landscope extrapolated ‘up’. Landscope considered 3 individual fields as part of the exercise and found different results from KCC, sufficient to suggest that there is more BMV on site than stated by KCC and in Landscope’s view sufficient to justify a full survey of the site.

The overall comment in 7.3 is that "the land remains mostly BMV, with around 50% of the site Grade 3a and a small quantity of Grade 2."

That is correct.

8.7 Questions are also raised about some boundary changes between the semi-detailed and detailed ALC mapping. These are considered in Attachment A.

9 COMMENTS ON LANDSCOPE'S ANALYSIS

9.1 Landscope have sampled 8 points in Field 2, and 3 points in Field 3. From those 11 points they extrapolate that over 50% of the entire Site is BMV, which MPAG consider represents a 10 – 15% increase in BMV across the Site than is reported in the ES [REP7-057 paragraph 4.0.14].

Landscope also dug four soil pits to substantiate these findings whereas KCC dug none; despite KCC's report identifying at least five different soil types in Field 2 <u>and</u> four different land Grades. The guidance indicates that soil pits should be dug where there are clear differences in soil types.

9.2 It is stated in MPAG's D7 ISH4 document [REP7-057] that sampling should be carried out at one per hectare (4.0.3, 4.0.4) and Landscope state that a full ALC survey is justified [REP7-060], paragraph 1.6. Yet based on only 8 sample points Landscope have concluded that the distribution of ALC grades across the whole 30ha of Field 2 can be altered, as set out in the comparison above, and from that small number of samples in small parts of two fields they conclude that over half the entire Site is BMV.

Landscope were conducting checks where they had the opportunity to do so. The fact Landscope found this many differences in Field 2, with just 8 boreholes and 2 soil pits - what is the likelihood that across the whole site there are going to be a lot more differences? Landscope are not suggesting that the whole site is BMV or that the BMV is substantially better grades than KCC identified, just that there is more of it.

9.3 Landscope do not challenge that the KCC ALC survey was carried out according to the guidelines. Indeed, at 1.3 they explicitly acknowledge that the KCC results are in accordance with the guidelines. The Rutland County Council commissioned review of the PEIR and Natural England's review of the ES both reach the same conclusion on the validity of the survey findings.

KCC broadly followed the right process but the report commissioned by Stantec on behalf of RCC and SKDC at PEIR stage highlighted a number of issues and mistakes such that is raised alarm bells with MPAG in the first place. That was compounded by some of the anomalies identified at stage 2. It is clear KCC did not undertake either enough auger samples or enough soil pits to support their findings, particularly with the soil variability that was found across the site.

This level of auger sampling is unprecedented due to there being so few NSIPs prior to Mallard Pass, this may be the reason Stantec (via Reading Agricultural Consultants) was more sympathetic to accepting quite a high level of errors, noted by the traffic light system with a high degree of orange and red colour codings.

9.4 Accordingly Landscope's conclusion that, based on 8 sample points they are able to remap the ALC of the whole field, including regrading areas graded by detailed survey by KCC, must be wrong.

Landscope do not have the data to remap the ALC across the field. Therefore, the Landscope regrading cannot be accepted as accurate.

Landscope utilised its own data where obtained, but kept the KCC data from elsewhere on the site where it was present. Bearing in mind that 6 auger points were missing and they dug no soil pits to verify the KCC findings the Landscope map is reliable. Landscope's map is an attempt to show the impact.

9.5 It follows that there is no factual basis for then extrapolating those conclusions to apply to the whole of the Site, which Landscope have not surveyed.

KCC have extrapolated their findings to the whole site without a comprehensive survey. Landscope has done some testing checks, used that data, reviewed other areas of the site that were downgraded without retesting and consider that there is a higher level of BMV than the ES would suggest.

9.6 The results set out in the ES are based on 334 samples over the 817ha Site, and are recorded as detailed in places and semi-detailed on other parts of the site and have been undertaken at an appropriate level for the size of the site.

Natural England (reviewing the communications from the FOI request) clearly never gave approval of the detailed survey areas before the activity took place. As the Applicant said, they didn't object because Natural England never answered their request for clarification on the proposed detailed sampling areas. KCC just carried out the survey and didn't pursue getting the answer. Natural England should also have picked up the fact the substation area was not being covered at a detailed level.

Retrospective to the 2nd survey taking place in a later version of the Statement of Common Ground, Natural England finally/latterly agreed the detailed sampling was fine until they saw the Landscope report and MPAG's objections. Acquiescence by Natural England should not be taken as acceptance or agreement of a methodology/approach. KCC were basically not looking for BMV in their re-testing; they were looking for Grade 3b and found it in some instances and extrapolated it into others.

9.6 A small sample of 11 points from two fields is not a scientific basis to reclassify any areas beyond the areas sampled. It is not a scientific basis for making comments that there is 10-15% more BMV across the entire Site than is assessed from the samples submitted with the application. Therefore, the Landscope survey should not be relied upon.

Landscope's findings that the whole site could have more BMV was based partly on the soil survey work undertaken and partly on the KCC changes to the ALC maps without resurvey taking place. It is an estimate, but considered to be realistic.

10 WHAT DO THE CONCLUSIONS MEAN?

10.1 The conclusion by Landscope and MPAG is that there is likely to be more than 50% BMV across the Site as a whole.

10.2 MPAG conclude that Landscope's analysis allows them to extrapolate that there is 10 – 15% more BMV across the Site than assessed in the ES (42%, see Table 12-1 in Chapter 12 of the ES [APP-042]). As set out above, the Applicant does not accept this premise.

10.3 However, even if the conclusions were accepted, the obvious question to ask is "so what?"

10.4 If it was considered (which the Applicant does not accept) that the Landscope results are robust and the ALC of the whole Site can therefore be adjusted, it would change the proportion of BMV from about 40 –42% (solar PV Site and field edges or Order limits), to about or just over 50%.

Following the Landscope report and taking all the data from Stage 1 and stage 2 survey provided, Landscope have more information to arrive at their conclusion than KCC did at the time of completing their resurvey work. Also to be noted Landscope had additional data from the landowner not used to calculate the ALC but to help verify their findings. Landscope never expected that the amount of BMV would move to something like 80%, but given the Low Probability of BMV projections being more than doubled by the preliminary KCC survey, it is not unreasonable to consider this could be replicated across the site bearing in mind the similar geology and soils.

The point is that KCC had assumed from the predictive mapping that the BMV would be a lot lower, so when they got their first results it wasn't what they expected. So whilst being prompted to do more detailed surveys, it also gave them an opportunity to alter some of the gradings. MPAG and Landscope completely disagree with the approach of only resampling areas of BMV land rather than detailed surveys across the whole of the site. That is a very subjective approach.

10.5 That land quality will not be adversely affected. There is no commentary or conclusion in the Landscope report that the land will be downgraded as a result of the Proposed Development.

This point is very much open to question and there is not enough scientific evidence either way to say that ALC grade won't change. However with a 60 year life and full replacement of all elements of the solar PV, there is a real possibility of the Soil Management Plan being breached, resulting in soil compaction, disturbance and mixing of soils.

The loss of land from arable farming would be significant and this loss will be for 60 years. It's a reflection that at site selection, even after the PEIR results showed 53% BMV, that the Applicant did not to try to find land with a lower level of BMV.

10.6 Accordingly this really is a question of a land use assessment and the acceptability of using that increased amount of BMV from agriculture to agriculture and solar. Increased amounts of BMV does not result in losses of BMV, since the resource is not lost. Hence changes to the percentage of BMV does not affect an assessment of the protection of the BMV resource.

In the context of 60 year lifetime it does result in lost food production not just for 60 years but the additional time the land is out of use for construction, decommissioning and restoration of the land to arable farming.

The agricultural use of the land under panels is restricted to essentially one type of farming – grazing sheep. An outbreak of foot and mouth, or blue tongue disease could render the site unusable for grazing. It is not practicable to take hay crops or graze cattle and so the type of agriculture is highly restricted. Possible sheep grazing is no substitute for wheat production.

11 LAND USE

11.1 Landscope set out in 6.4 [REP7-060] that the loss of productive agricultural land "should be avoided, wherever possible". MPAG [REP7-057] consider this to be a "key issue", and the food production loss "has potentially huge implications" (4.0.5).

11.2 The layout was amended during the design stage to minimise the placement of panels on Grade 2 land.

That land would have always been mitigation as it was too close to villages, conservation areas and residentially sensitive receptors and Burghley House. The fact it was Grade 2 gave the Applicant limited options – to put those areas in mitigation. Additionally in reality Grade 2 land is particularly flexible land (being Very Good Quality, for say horticulture), Grade 3a and 3b is less flexible and more suited to dairying and combinable crops - where our primary food security is based.

The areas within the proposed Solar PV Site are almost all mixed grade fields, which affects the ability to exploit different ALC grades separately.

At site selection maybe that demonstrates that the proposed development could be in the wrong area, sites of Grade 3b and 4 should be the priority. This statement also simply confirms that a detailed survey of the whole site is much more likely to identify more BMV as the fields are so variable, that where a reconnaissance survey has been undertaken BMV may well have been missed.

11.3 This land is generally suitable for cereals and break crops. The difference in yield between Grades 3a and 3b is often, in practice, minimal. There would be limited difference in overall production if the subgrade 3a was retained for farming, and panels moved to subgrade 3b land elsewhere, which is the important question if the focus is on land use. The Applicant also notes its submissions in chapter 12, in respect of the land use within the Order limits, in this regard.

Government policy is clear about protecting BMV land wherever possible. Given that 25% of England is considered to be Grade 3b quality, this should provide plenty of opportunity for the Applicant.

11.4 Neither document provides a reference to any planning policy or initiative that discusses food security or the use of agricultural land for food production. MPAG cross refer to their D2 submission [REP2-090], but no policy document requiring or encouraging food production on farmland is referenced.

The UK Food Security Report 2021 provides a useful reference for UK food security and is an important document providing context and crucial information for those proposing projects that take significant productive land from production, yet is not referenced in MPSF's application documents (REP2-090). Information has been drawn from this document to help set the scene.

The recent House of Lords Inquiry on Land Use in England (published 13 December 2022) also raised a concern regarding the development of solar farms on BMV which is also relevant. The key paragraph is in respect of Para 132, which sets out the conclusions of the committee regarding solar farms on BMV land:

"Although there are provisions within the NPPF to dissuade the development of solar farms on Best and Most Versatile land, from the evidence received we are concerned that too many exceptions are being made. We believe that a consistent policy toward encouraging the installation of solar panels on industrial, commercial and domestic buildings is needed and would negate the need for large-scale ground mounted solar farms. Alongside that, we would like to see stricter regulations put in place to prevent the development of solar farms on BMV land. We also believe onshore wind turbines still have a crucial role to play in achieving national energy self-sufficiency".

11.5 The most recent Statement by Government was the Press Release of 6th December 2022, attached as Attachment B. This document makes clear that the UK has a highly resilient food supply chain and a high degree of food security.

12 ENHANCEMENT OF SOILS

12.1 Landscope comment in 6.3 [REP7-070] that recent studies have shown there are more efficient ways of sequestering carbon (non-tillage farming and rock dust) than (the Applicant assumes) through conversion of arable land to grassland.

Establishing grassland for low level and likely intermittent grazing is not a good substitute for arable farm production. Grassland is expensive to establish and costly to maintain during the early years of establishment, whereas no-tillage farming on existing arable land is a cheap, swift and proven method of carbon sequestration whilst maintaining good agricultural productive capacity.

12.2 The comment is in stark contrast to the British Society of Soil Science "Science Note: Soil Carbon" [APP094] which states at the top of the fifth page:
"Soil carbon stocks can be increased by either increasing inputs (eg crop residues, cover crops, use of organic materials, inclusion of grass leys in arable rotations) or decreasing losses (ie reducing oxidative losses to CO2 or particulate and dissolved organic content) via improved management such as reduced intensity tillage. Significant long-term land use change (eg conversion of arable land to grassland or woodland) has by far the biggest impact on soil organic carbon …" [Referenced in Chapter 12 of the ES, paragraphs 12.4.64 and 12.4.65, APP-042].

The BSSS document also states "Significant long-term land use change (e.g. conversion of arable land to grassland or woodland) has by far the biggest impact on SOC, but is unrealistic on a large scale because of the continued need to meet food security challenges." And as the Proposed Development is not permanent, it is a known fact that Soil Organic Matter (SOM) is more rapidly lost than it is accumulated (Freibauer et al, 2004), the carbon benefit is lost. So BSSS both acknowledge the importance of food security set against the fact the SOM will be lost. It goes on to say "moreover, the process of soil C sequestration is often misunderstood, and can lead to an overestimation of the climate change mitigation achievable by using this route". However it does acknowledge that soil carbon stocks can be increased "via improved management such as reduced intensity tillage".

SOM is not part of the ALC criteria, nor will grazing sheep do anything to enhance arable crop production, or dairy production – our staple foods. Whereas using minimal tillage for arable farming can sequester carbon and maintain agricultural production at the same time.

In addition, no baseline survey of soil organic matter across the site has been undertaken against which the stated 'improvements under panels' can be assessed.

The BSSS document, which states "*Furthermore, the implications of land use change for food security need to be considered.*"

13 CONCLUSIONS

13.1 The Landscope survey takes 10 samples mostly from one field. That is used to extrapolate different results across the whole Site. The survey is not robust and does not enable the conclusion that 10 – 15% more BMV exists across the Site than has been mapped from the semi-detailed and detailed ALC results.

13.2 Even if there was more BMV, that land would not be sealed or downgraded. The impact is not increased.

But the loss of BMV itself is increased. The land will still be lost to arable farming and therefore it is locked out of food production for the not inconsiderable 60 year life of the project. Wherever BMV is 'locked out' it is a loss, even if there are environmental or energy benefits.

Therefore, the consideration is one of land use, not of land loss. Yes that was the objective but there is no evidence either to prove the land will retain its ALC grade especially after 60 years and if there are any substandard soil management practices from day 1, the land grade may be changed.

13.3 There is no policy or initiative to enable the conclusion that the change in farming practices from arable to grassland based, which could occur at any time without needing permission or without penalty, is a significant adverse effect of the proposals.

ATTACHMENT A - ANALYSIS OF BOUNDARY CHANGES

This Attachment reproduces the comparison from the Landscope report, then explains any changes. Circles added are for ease of reference.

Further clarification is provided below which challenges the Applicant's retrospective explanation for the downgrading on land that was not re-surveyed.

You may want to print the Auger Points Plan from Appendix 12.4 p79 to aid clarification.

https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010127/EN010127-000163-Appendix%2012.4%20ALC%20Survey.pdf

LANDSCOPE A

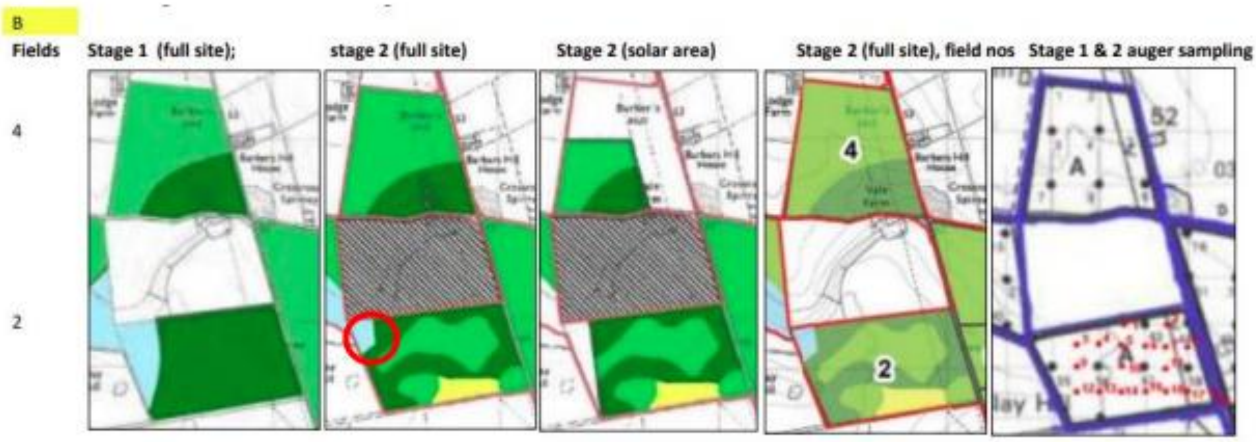
Comment: these plans all show the same area, bar a small area of Grade 2 (circled). That was mapped originally right up to auger point 27, which was a 3b position. The Applicant changed the boundary to match the field boundary. The area involved is about 0.5 ha.

The change: the RHS of filed 3 is mitigation as is the bottom of field 1

No red line boundaries have been changed here, just the boundaries between solar PV and mitigation areas. The solar PV boundary of field 1 has not changed. The solar boundary of field 3 has changed between stage 1 and stage 2 but so has the corner of the 3a triangle (highlighted yellow) in the middle bottom part of field 3 (1st drawing) where the grade has also been changed from 3a to 3b.

LANDSCOPE B

The bottom field was subject to an additional 18 auger points following the semi-detailed survey, meaning there are 25 points in that area. That changed the boundaries. The Grade 2 to the west (circled) is not proposed for Solar PV arrays, and the Applicant did not therefore carry out additional sampling in all of that area. However, following a walk-over survey, it was clear that the field had very different characteristics over short distances, and that the Grade 2, taken in the redder soils, was not evenly spread across the field. The boundary was therefore amended. As noted, no panels are proposed for this field. The variability is shown in the following photographs and aerial image.



This was the very reason Landscope tested that west corner of field 2 as it had not been tested, it may not be part of the solar area but it is part of the Order limits and the original grade 2 should have remained unless further auger sampling took place. Landscope's auger survey confirmed that the area was Grade 2. The Applicant cannot criticise the detailed survey work in field 2 and then say a walkover survey is sufficient to change the grading map.

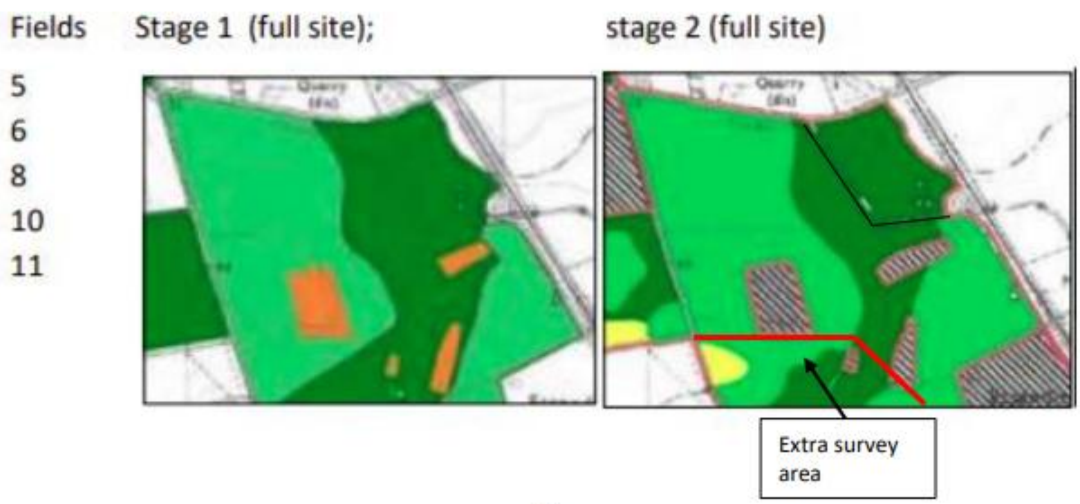
The 2nd drawing (stage 2 full site clearly shows a reduction in grade 2 with no substantiated data. As Natural England said **all BMV areas** should have been fully tested, that white triangle shown in drawing 3 is now mitigation but it will comprise a hard core track to enable access to field 1 and on to field 3. Therefore there is a high chance if the track area on this grade 2 land is not managed carefully that the ALC grade will not be recovered.

Given all the variability in field 2, this is all the more reason why the Applicant should have fully tested it.

LANDSCOPE C

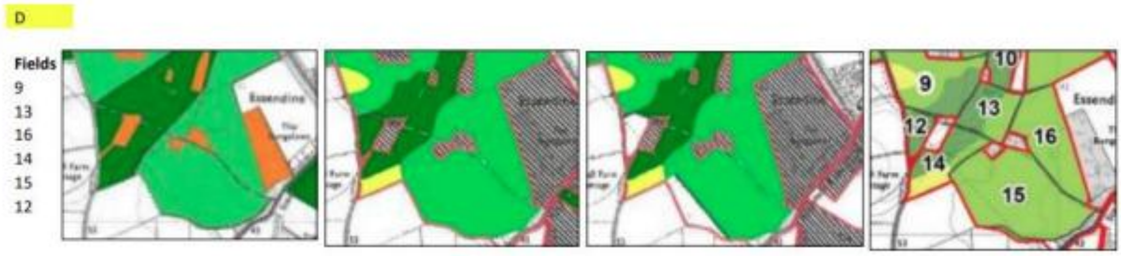
Part of this area, as below, was subject to additional surveys, changing the boundaries. The rest is not significantly changed. The woodland area was increased to match Google Earth. The small change to the boundary, to the east of the two woodlands, is a cartographic error, circled.

The 3a downgraded to 3b identified is NOT in the area where additional auger samples were taken, hence why no auger sampling map is shown in the charts above. Their own map below proves that point. We are talking about changes where field 11 meets 10 and 8. KCC don't explain how the cartographic error affects the grading!!

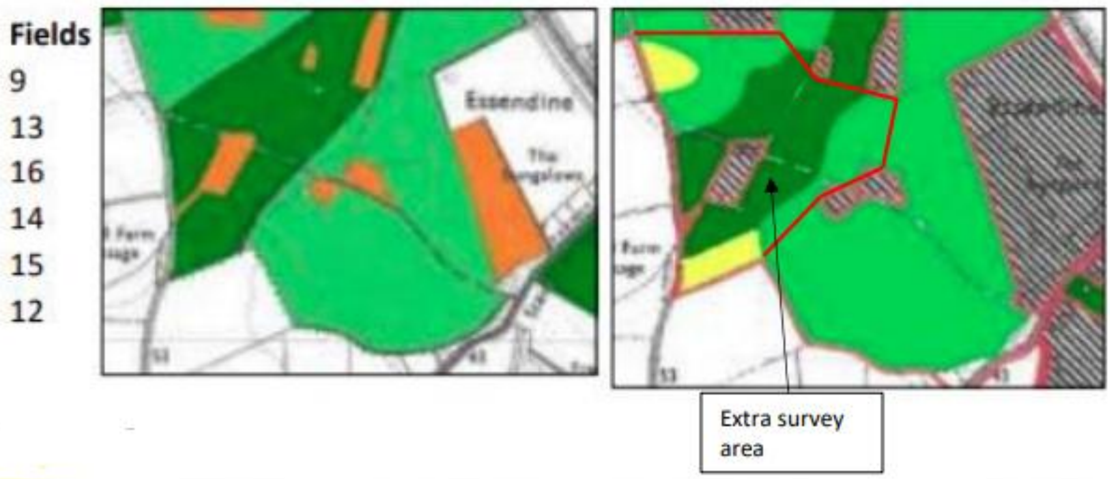


LANDSCOPE D

Part of this area was subject to additional sampling, as below. Otherwise the boundaries are not altered.



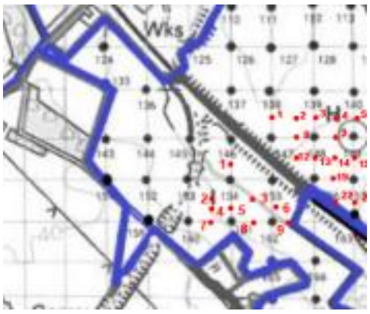
Part of this area was subject to additional sampling, as below. Otherwise the boundaries are not altered.



There is still a small area above/outside the 'extra survey area' in field 9 and 10 that has been downgraded.

LANDSCOPE E

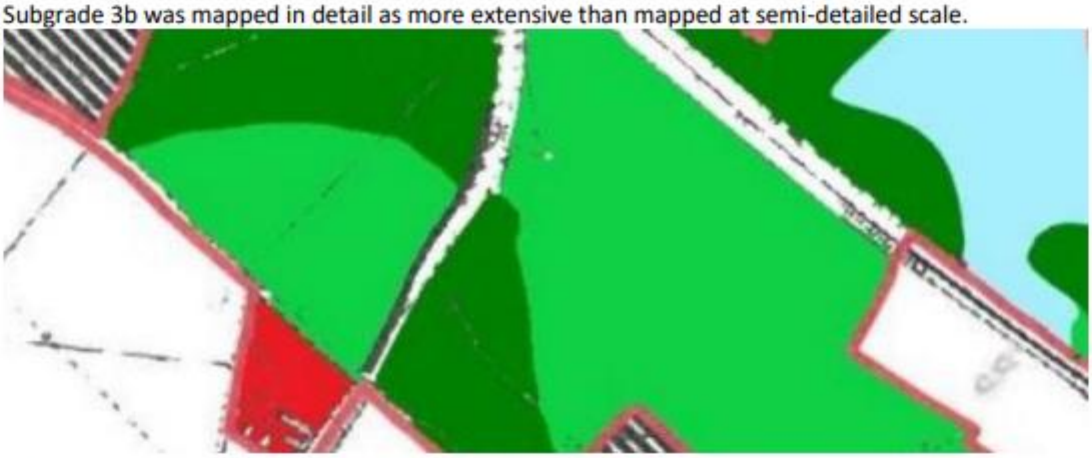
This area is adjacent to an area subject to additional surveying. Having completed additional auger sampling in the adjacent field, and reviewing 2020 Google Earth imagery, it was concluded that the 3b boundary was slightly further north. This area will be subject to further sampling as part of the final Soil Management Plan once the Onsite Substation position is fixed. See circled section, which involves approximately 1.5 ha. Subgrade 3b was mapped in detail as more extensive than mapped at semi-detailed scale.



The adjacent resurveyed field is separated by the dismantled railway line and not exactly butting up to field 19 and/or 18. The substation, due to the permanent nature of the installation, should have been fully resurveyed at a detailed level as requested by Natural England who had thought that had taken place. It should not have relied on a field close by which was fairly randomly sampled in the first place and strangely some of the auger samples were in the flood plain area where no solar was ever going to be located. KCC has not been consistent in their approach to resurvey BMV land within the Order Limits or just within the solar area. There seems to be a mix of both approaches.

Effectively they have extrapolated the data for one of the most sensitively scrutinised areas of the site.

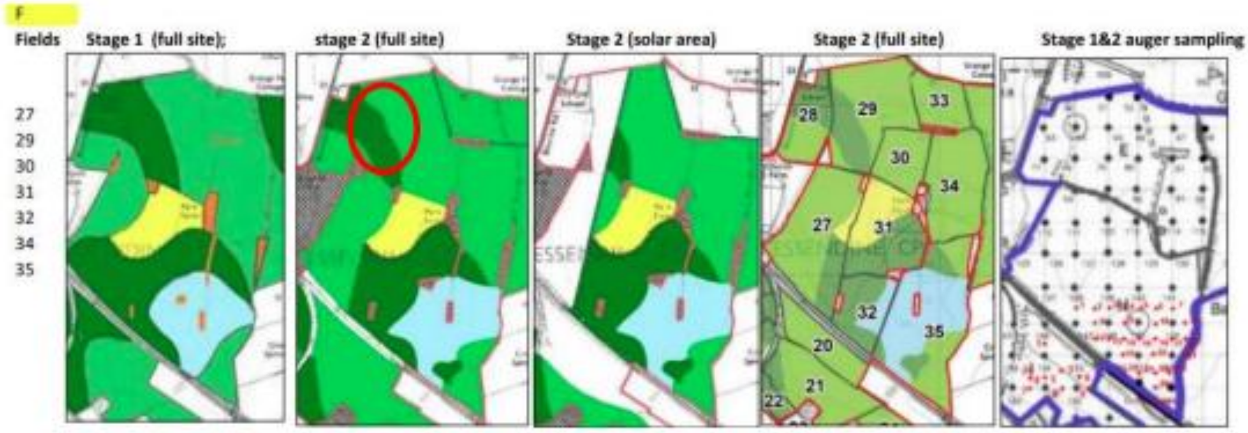
Subgrade 3b was mapped in detail as more extensive than mapped at semi-detailed scale.



Landscope are not sure these aerial pictures give any justification for not doing detailed survey at the substation.

LANDSCOPE F

There is a slight change to the boundary of the Grade 3a land in the north-west of the area shown above (circled). The Applicant tried to match the boundary to the evident change in soil on the aerial below, but the difference has not significantly altered the qualities of different grades.



Landscope is unclear about the point the Applicant is making here. Why again did KCC rely on aerial shots rather than extra auger samples and soil pits? The Applicant states that all the fields are variable with mixtures of Grades. The only way to clearly ID the BMV is by detailed survey.

LANDSCOPE G

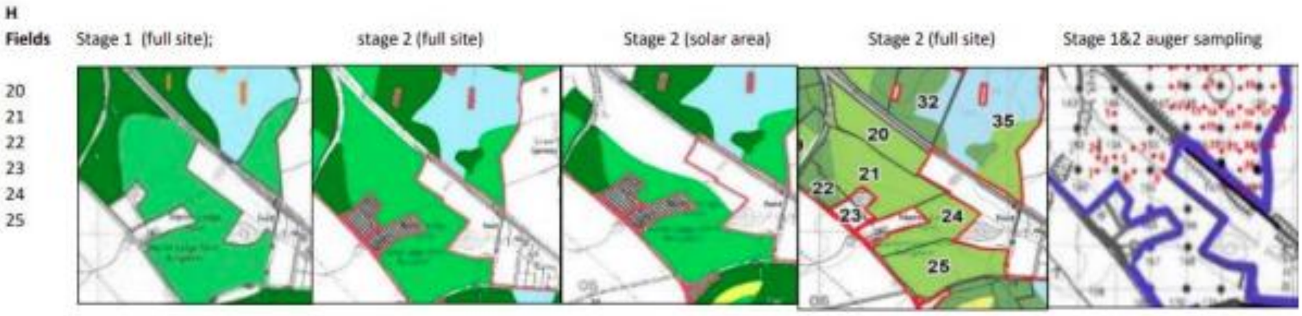
The big change here is the tongue of subgrade 3a which was reduced as circled. The reason for this was that Reading Agricultural Consultants, who carried out a technical review of the PEIR for Stantec, on behalf of Rutland County Council, concluded that auger points 69 and 83 should have been graded as 3b, not 3a. Therefore this 76 area was remapped (Reading Agricultural Consultants also downgraded 179 from 3a to 3b, 198 from 2 to 3a, and 203 from 3a to 3b).

It appears KCC has changed some grades without retesting them themselves. If KCC took on board the points from the RAC report as indicated above, why did they not rectify them during stage 2 resurvey. RAC stated *"Further work could be carried out to address the deficiencies identified above, in particular where observations are borderline to soil textures and grading."* They might have mentioned some areas might be downgraded but they also clearly said there were areas that likely needed upgrading too. This all points to doing a comprehensive detailed survey with all the points being addressed that RAC raised i.e. closing the gaps and deficiencies in the data collected.

The RAC report for Stantec on behalf of RCC and SKDC is appended at the back of this report and the detail assessment is worth reading. There were many areas deemed a 'concern' and 'unsatisfactory'.

LANDSCOPE H

The only changes were due to additional sampling. LANDSCOPE I The only changes were due to additional sampling.



Landscope would argue that is not the case if you overlay the auger plan. The auger samples do not run sufficiently close to the dismantled railway line and the main railway line to chop off a section of 3a, the extra sampling appears quite random.

LANDSCOPE I

The only changes were due to additional sampling.

Again Landscope do not see this to be the case if you overlay the auger plan. As an example, look at field 45, there is no additional sampling in that area and the land is downgraded.

July 2022

Stantec UK Limited

Mallard Pass Solar Farm
Project Reference: 33848/A5

Peer Review of the Agricultural Land and Soils PEIR Chapter and Appendix prepared by LDA Design

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Contents

1 Introduction

1.1 Reading Agricultural Consultants Ltd (RAC) is instructed by Stantec UK Limited on behalf of Rutland County Council and South Kesteven District Council to undertake a technical review of the Agricultural Land and Soils chapter of the Preliminary Environmental Information Report (PEIR) and the technical appendix produced in support of the application for the Mallard Pass Solar Project.

1.2 The technical appendix (Appendix 13.1) comprises an Agricultural Land Classification (ALC) report prepared by Kernon Countryside Consultants Ltd (KCC). The report details the site and soil conditions and classifies the agricultural land based on the findings of a semi-detailed survey. In total, 217 observations were made across the site area of 906ha, giving an observation density of approximately one per four hectares. The survey classified approximately half of the land (415ha or 47%) as Subgrade 3b, a large portion (320ha or 36%) as Subgrade 3a, around one-fifth (110ha or 12%) as Grade 2, and around 10ha or 1% as Grade 4.

1.3 The report comprises:

- Section 1, Introduction;
- Section 2, Methodology;
- Section 3, Known and Predictive Land Quality;
- Section 4, Factors Affecting Land Quality;
- Section 5, ALC Grading of the Site
- Annex 1, Natural England Technical Information Note TIN049[1];
- Annex 2, Available ALC from www.magic.gov.uk;
- Annex 3, Soil Profile Log;
- Annex 4, Description of Soil Pits;

[1] **Natural England (2012).** *Technical Information Note 049 - Agricultural Land Classification: protecting the best and most versatile agricultural land*, Second Edition. http://publications.naturalengland.org.uk/file/4424325

- Annex 5, Certificate of Analysis;
- Plan KCC3051/01A Auger Point Plan; and
- Plan KCC3051/02A Agricultural Land Classification Plan.

1.4 In addition, a review has been undertaken of Appendix 13.2, Agricultural Land Use Assessment Methodology; and Chapter 13, Agricultural Land and Soils of Volume 1 of the PEIR.

2 Background to Agricultural Land Classification

2.1 Guidance for assessing the quality of agricultural land in England and Wales is set out in the Ministry of Agriculture, Fisheries and Food (MAFF) revised guidelines and criteria for grading the quality of agricultural land[2], and summarised in Natural England's TIN049.

2.2 Agricultural land in England and Wales is graded between 1 and 5, depending on the extent to which physical or chemical characteristics impose long-term limitations on agricultural use. The principal physical factors influencing grading are climate, site conditions and soil which, together with interactions between them, form the basis for classifying land into one of the five grades.

2.3 Grade 1 land is excellent quality agricultural land with very minor or no limitations to agricultural use. A very wide range of agricultural and horticultural crops can be grown, and yields are high and less variable than on land of lower quality.

2.4 Grade 2 is very good quality agricultural land, with minor limitations which affect crop yield, cultivations or harvesting. A wide range of agricultural and horticultural crops can usually be grown but there may be reduced flexibility due to difficulties with the production of the more demanding crops. The level of yield is generally high but may be lower or more variable than Grade 1.

2.5 Grade 3 land has moderate limitations which affect the choice of crops, timing and type of cultivation, harvesting or the level of yield, and is subdivided into Subgrade 3a (good quality land) and Subgrade 3b (moderate quality land).

2.6 Subgrade 3a land is capable of consistently producing moderate to high yields of a narrow range of arable crops or moderate yields of a wide range of crops. Subgrade 3b is land capable of

[2] **MAFF (1988).** *Agricultural Land Classification of England and Wales. Revised guidelines and criteria for grading the quality of agricultural land*. http://publications.naturalengland.org.uk/publication/6257050620264448

producing moderate yields of a narrow range of crops or lower yields of a wider range of crops or high yields of grass.

2.7 Grade 4 land is poor quality agricultural land with severe limitations which significantly restrict the range of crops and/or level of yields.

2.8 Grade 5 is very poor quality land, with severe limitations which restrict use to permanent pasture or rough grazing.

2.9 Land which is classified as Grades 1, 2 and 3a in the ALC system is defined in Annex 2 of the National Planning Policy Framework[3] (NPPF) as best and most versatile (BMV) agricultural land.

2.10 As explained in Natural England's TIN049, the whole of England and Wales was mapped from reconnaissance field surveys in the late 1960s and early 1970s, to provide general strategic guidance on agricultural land quality for planners. This Provisional Series of maps was published on an Ordnance Survey base at a scale of One Inch to One Mile (1:63,360). The Provisional ALC map shows the site undifferentiated Grade 3. However, TIN049 explains that:

> *"These maps are not sufficiently accurate for use in assessment of individual fields or development sites, and should not be used other than as general guidance. They show only five grades: their preparation preceded the subdivision of Grade 3 and the refinement of criteria, which occurred after 1976. They have not been updated and are out of print. A 1:250 000 scale map series based on the same information is available. These are more appropriate for the strategic use originally intended …"*

2.11 TIN049 goes on to explain that a definitive ALC grading should be obtained by undertaking a detailed survey according to the published guidelines, at an observation density of one boring per hectare. The site had not previously been surveyed.

[3] **Ministry of Housing, Communities & Local Government (2021).** *National Planning Policy Framework.* https://www.gov.uk/government/publications/national-planning-policy-framework--2

3 Technical Review of the ALC Survey Report

3.1 The data, report and conclusions have been reviewed, as summarised in Table 1 below. The review has concentrated on the methodology and approach used in the survey, the quality and consistency of data with published data, and the interpretation of the data in the light of the ALC guidelines. The review has had regard to the British Society of Soil Science Guidance Document 1 on assessing ALC surveys[4].

Table 1: Technical Review of ALC Survey Report

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
General and Background Data		
Have the correct ALC guidelines been referenced and used?	G	The report makes reference to the MAFF 1988 ALC guidelines, and follows the methodology within the guidelines.
Has the survey been undertaken at the correct observation density?	C	The survey was carried out at a semi-detailed scale of one observation per 4ha. This does not accord with Natural England's TIN049 recommendation of one observation per hectare for detailed surveys. Although TIN049 does not comment on semi-detailed surveys, it is common practice on very large sites such as this to reduce the observation density as ALC surveys are time consuming and expensive. However, it is often advisable within the survey to increase the observation density in those parts of the site where BMV land is found in order to define the extent of BMV land accurately. It is noted in paragraph 5.2 that "*the soils within the Site are … quite variable spatially over short distances… This leads to a quite complex pattern of ALC Grade*". The survey was generally undertaken on a regular 200m x 200m grid pattern and so may have missed

[4] Assessing Agricultural Land - Jan 2022 (soils.org.uk)

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
		localised variability that has been acknowledged to exist.
Is the site description correct?	G	Generally Yes but with some minor comments and inconsistencies: • The site extends to 906ha (as in paragraph 1.1) but the classification in Table 5 (including non-agricultural/other land and urban land) is of 889ha. • The description of topography is very brief, yet across the site is variable. The maximum and minimum elevations above Ordnance Datum are not consistent with paragraph 3.2.1 of Volume 1 of the PEIR. • Paragraph 4.9 states that "*there are no records (data) to show that agricultural land in any part of the Site is limited by flooding*". There is clear photographic evidence that parts of the site within the West Glen River valley are affected annually by flooding (see Appendix 1).
Has existing ALC data been taken into account?	G	The report references and provides extracts from the Provisional ALC, the Predictive BMV and the available detailed ALC maps. In all cases, the site boundaries are not shown on the extract maps, despite the supporting text, and so it is not easy to immediately follow the findings in the text.
Has the correct geology been identified?	G	Mostly, although the Lower Lincolnshire Limestone Member of the Lincolnshire Limestone Formation is also present in the north-west of the site; and superficial glacial head deposits are also mapped. The appendix describes the geological formations, whereas paragraph 3.9.1 of Volume 1 describes the main geological groups (of formations). An

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
		explanation of the relationship between groups and formations, or a consistent approach to description, would be helpful.
Has the correct mapped soil association been identified, and the correct map referenced?	G	Yes, correct soil associations have been identified. However, no soil association or soil type map is provided which would be helpful to understand the distribution of the five soil associations within the site. The Sherborne association is repeatedly referred to as the "*Sherbroune association*".
Has the correct climate data been used?	G	The three climate data sets given have been verified.
Technical Data		
Does the soil described correspond with the mapped data?	U	The report contains no description of the main soil types found or an indication of their distribution.
Are the full soil profile logs available and described?	C	209 profile logs are appended to the report; six are omitted. No reason given. 46 soil profiles are not logged to a full depth of 120cm due to increasing stoniness/limestone in the subsoil. The soil profile logs in Annex 3 are set out for 11 'sites' which, as explained in paragraph 2.4, were established for the purposes of organising and managing the ALC survey. These sites bear no relation to the development proposals (e.g. areas proposed for solar panels, areas for mitigation etc) and the presentation of data in this format is not particularly helpful to the reader or for cross-referencing with other parts of the PEIR.
Do the soil profile logs look credible?	G	There is variability between the profiles, as would be expected in a natural soil. The soil profile logs

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
		are generally consistent with the mapped soil descriptions.
Were any soil pits dug?	C	Two pits were dug. More pits would be expected in a site of this size (over 900ha) and with five soil associations mapped. There should be a soil pit per main soil type identified but, as the report is silent on the number of soil types actually identified during the survey, the number of pits that should have been dug is unknown. Annex 4, Description of Soil Pits includes two recording sheets for the soil pit data. One of the two is incomplete (no ALC grade given; topsoil shown as borderline medium clay loam/heavy clay loam (not verified by laboratory analysis); the log notes limestone at 30cm but it is not noted whether the limestone is solid, fragmented or very stony).
Has the correct Wetness Class (WC) been identified?	G	Mostly – all but six profiles. In the absence of further explanation: • Profile 92 should be WC II not WC III; • Profile 131 should be WC I not WC II; • Profile 137 is not strictly gleyed until 65cm depth – WC could be II; • Profile 124 should be WC I not WC II; • Profile 135 should be WC I not WC II; • Profile 162 should be WC II not WC III (the SPL is <15cm thick)
Has the topsoil texture been verified with laboratory analysis?	C	Three samples were analysed and demonstrate a range of textures (heavy clay loam, sandy silt loam, clay) but this is a low number to cover approximately 900ha of land.

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
		Furthermore, the samples are not distributed evenly across the site but are all from the east. Neither of the pit locations was sampled which is surprising given that the texture is described as borderline medium clay loam/heavy clay loam which could influence grading. Profile 119 is shown in Table 2 as a medium sandy silt loam (based on the laboratory analysis) but recorded and assessed as a medium clay loam in Annex 3. If this sample was used as a typical example of a soil texture found on site, it is possible that many other profile logs shown as medium clay loam should be described as sandy silt loam, which again could influence grading, potentially over large areas of the site. There are no profile logs in Annex 3 shown with a sandy silt loam topsoil.
Has the correct grade been allocated?	U	As above, profiles that could have sandy silt loam topsoils (on the basis of laboratory analysis) but classified on the basis of medium clay loam topsoils may not be correctly graded (and could be upgraded). Similarly, those profiles borderline to medium and heavy clay loam as found in one of the soil pits, may not be correctly graded. Profiles logged as being limited by droughtiness to Grade 4 may not be graded correctly. If the limestone is soft or fragmented/fissured, the limitation would be less severe to Subgrade 3b. Similarly, deeper profiles with fewer stones listed as Subgrade 3b could improve to Subgrade 3a. See Appendix 2 for a comparison of the calculations for the applicable profiles.

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
		Only one profile (201) is noted as having a topsoil stone limitation. Several profiles have undeclared topsoil stone limitations equal to the reported most limiting factor (wetness or droughtiness) but based on the percentages of stone larger than 2cm and 6cm, a more severe limitation is applicable to: • Profile 69 to Subgrade 3b (currently 3a); • Profile 83 to Subgrade 3b (currently 3a); • Profile 179 to Subgrade 3b (currently 3a); • Profile 198 to Subgrade 3a (currently 2); • Profile 203 to Subgrade 3b (currently 3a).
Have photographs been included in the report?	U	For completeness, photographs should be included, particularly to illustrate the structures identified from the soil pits and the nature of the underlying limestone.
Is there any reason to doubt the robustness of the survey and/or report conclusions?	C	Overall, whilst there are a number of mostly minor errors, inconsistencies and uncertainties, and areas where clear improvements could be made, the survey is considered to be adequate to describe the agricultural land quality of a very large site. Further work could be carried out the address the deficiencies identified above, in particular where observations are borderline to soil textures and grading.

4 Review of PEIR Chapter and Impact Assessment

Introduction and Background

4.1 The Agricultural Land and Soils Chapter considers the effects of the Proposed Development on agricultural land and businesses through the construction, operation and decommissioning phases.

4.2 The review in Table 2 follows the structure of Chapter 13 for ease of cross-referencing, with the main section headings shown in bold.

Table 2: Review of Chapter 13 Agricultural Land and Soils

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
Introduction	G	No comments.
What might be affected by the Proposed Development?	C	The section identifies three key receptors; agricultural land quality, soil structure and local farm businesses. Soil structure is a very specific receptor, and it would be more commonplace to assess the effects of a development on a soil resource. Perhaps the most obvious effect of removing approximately 900ha of agricultural land from agricultural production for a period of 40 years is the effect on food production but this effect has not been addressed in the assessment.
• Agricultural Land Quality	C	Paragraph 13.2.4 indicates that the ALC survey undertaken has made it possible to map the distribution of land quality and soil types. No map showing the distribution of soil types has been presented in Appendix 13.1. Table 13.2 presents the ALC grades for a larger area than the current proposal for the solar PV area which is 463ha (in paragraph 3.1.4). The ALC of the current proposal is not stated (and presumably therefore not assessed).
• Soil Integrity, Structure and Environmental Benefits	C	Not the same receptor as identified in 13.2.1. 13.2.8 states that the soils identified in the survey were grouped into the five associations – but this is not evident from the survey report. The five mapped soil associations are described in the survey report but the actual observed soil profiles

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
		are not described outside the survey logs, let alone grouped into associations. Paragraph 13.2.11 states that "*the better quality land has soils least susceptible to damage from construction traffic*". This statement is not strictly true: there are profiles of Subgrade 3a quality with heavy clay loam or clay topsoil, and profiles of Subgrade 3b quality with medium clay loam topsoil. As well as reporting what might be affected, this section explains how soils would be affected, how effects would be mitigated and what further consultation will take place.
• Agricultural Businesses	C	The section lacks specific data on the four farm businesses occupying the site, other than they are mostly arable. The section also summarises the assessment (only a proportion of the wider farm holdings, no key infrastructure affected).
How have we assessed the effects relating to this topic?	G	Reference made to Appendix 13.2 which relies to a large extent on IEMA guidance for land and soil.
• Agricultural Land Quality	C	The IEMA guidance is quite prescriptive and its use in this particular instance leads to a number of questions as to its widespread application. All BMV land is assessed in the guidance as being of high or very high sensitivity, such that any impact above a negligible impact (more than 5ha of permanent sealing, for example) will lead the assessor to identify a significant effect on agricultural land. That does not seem a helpful approach to take for the decision maker in this case where potentially 900ha of land is affected and the ES identifies that BMV land is not a rare resource nationally

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
		(paragraph 13.3.6) or regionally (paragraph 13.4.11), and where policy is that BMV land should be avoided "*where possible*" but "*should not be a predominating factor in determining the suitability of the site location*." The use of this guidance therefore suggests that the sensitivity of the land has been overstated, leading to results that do not differentiate in any helpful manner between different levels of effect on the resource.
• Soil Integrity, Structure and Environmental Benefits	U	The soil sensitivity criteria in Appendix 13.2 and paragraph 13.3.11 concentrate on 'high clay soils' which is not a known soil category description. Paragraph 13.3.11 identifies the high sensitivity soils in the wetter regions but this is of no relevance to this assessment which is concerned with soils in a dry region. There is no indication of which soils on the site are of high sensitivity. The section does not describe how the magnitude of impact on the soil resource has been assessed. Table 13.4 identifies the sensitivity of soils as mostly medium, without explanation, and the magnitude of impact as minor, without explanation.
• Agricultural Businesses	C	The agricultural business criteria include a category for non-agricultural land which is not a relevant receptor, and otherwise appear a little simplistic in dividing all farm businesses between full-time (medium sensitivity) and part-time (low sensitivity) holdings, with no businesses being high or very high sensitivity. Clarity is required as to whether the assessment of "*the productivity and economic implications*" in

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
		paragraph 13.3.13 will include an assessment of the effect on food supplies from removing approximately 900ha of land from agricultural production for the duration of the project.
Study Area	G	No comments
Assumptions and Limitations	G	No comments
What are the potential environmental effects?		
• Construction	C	The section identifies that the effect on agricultural land is expected to be adverse moderate or large. The effect during construction on soil resources does not appear to have been assessed (the summary Table 13.4 says slight adverse effect but there is no text to support this). The assessment in paragraph 13.4.3 that the magnitude of effect on farm businesses will be moderate adverse seems overstated, given the definition in Appendix 13.2. The only impact identified – "*closure or severance of field accesses at key times of the farming year*" – does not equate to "*The impact of the development would require significant changes in the day-to-day management of a full-time agricultural business, or closure of a part-time agricultural business.*" Table 13.4 identifies the magnitude as minor adverse, giving rise to a slight adverse effect, which is not consistent with the text but seems more appropriate.
• Operation	U	The assessment of agricultural land used during the operation of the solar farm refers to Table 3.2 which is not correct for the current proposal of 463ha of land for solar PV arrays.

Review Item	Good/Concern/ Unsatisfactory	Explanation and Comments
		There is no assessment of the consequential effects on food supplies of taking nearly 900ha out of arable production for a period of 40 years other than an unsubstantiated comment in paragraph 13.4.11 that *"the removal of the Solar PV Site from agricultural production is considered to be insignificant in a regional context"*.
• Decommissioning	G	All effects on decommissioning are identified as adverse but there could be beneficial effects from bringing land that has laid fallow for 40 years back into food production.
How would we mitigate the environmental effects?	G	No comments, other than careful management and soil handling in the CEMP does not mitigate the effect on agricultural land loss/sealing.
What environmental effects would remain?	C	Given that agricultural land loss/sealing is not mitigated by careful soil handling, it is not clear how a moderate or large adverse effect on agricultural land can be reduced to a slight adverse residual effect in Table 13.4.
In-combination effects		No substantive text on which to comment.
Conclusions and Next Steps		
• Land Quality and Soil Resources	C	ALC assessment not consistent with previous text that identified a moderate or large adverse effect on BMV agricultural land (that is not mitigated by a CEMP).
• Agricultural Businesses	C	Paragraph 13.8.5 is finally a recognition that the potential to use approximately 900ha of land for arable or livestock uses will be reduced as a result of the proposal. The conclusion is *"that is neither a policy not an environmental impact"* appears too much of a throwaway comment for a very clear consequential effect of the proposal.

5 Conclusions

5.1 The site of the proposed Mallard Pass Solar Farm was subject to a semi-detailed ALC survey in winter 2021. Other than the scale, the survey followed the established guidelines and methodology for classifying agricultural land. The survey work was undertaken by competent surveyors, each with decades of experience.

5.2 Although spread out across multiple sections within the technical appendix, the background data is all present and correct. The report includes the profile logs, results of laboratory analysis and pit descriptions which are all required in best practice.

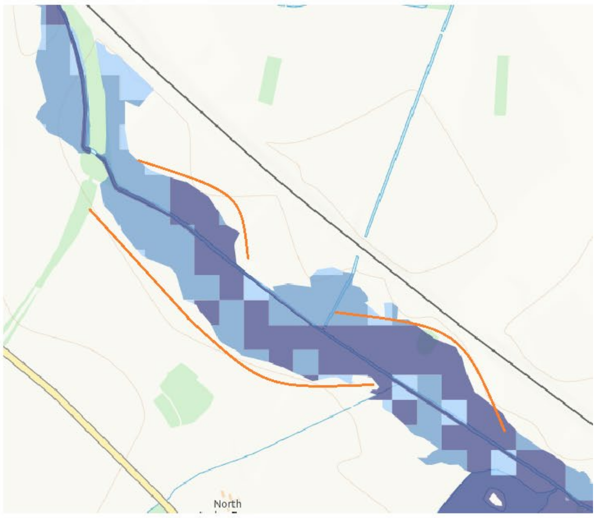
5.3 There are a few mistakes in the WC allocations in the profile logs but, given the volume of data, some minor errors are to be expected.

5.4 However, many profiles were not assessed to a full depth of 120cm. As demonstrated, depending on what was below the assessed depth, profiles currently assessed as Grade 4 may all be upgraded to Subgrade 3b, and a small number of profiles in Subgrade 3b will upgrade to Subgrade 3a. This will affect grade boundaries. Other limitations have been identified during the process of the peer review that are not stated in the report.

5.5 Although pits were dug and samples were submitted for laboratory analysis, there are too few to constitute a fully robust assessment considering the size of the site. Where BMV land was identified, the observation density should ideally have been increased.

5.6 Overall, the quality and clarity of the assessment in the Agricultural Land and Soils PEIR Chapter could be much improved. The chapter does not assess the up-to-date proposal for the solar PV arrays as set out in Chapter 5 but a previous iteration of the scheme which does not inspire confidence. The assessment methodology and criteria need consideration if the conclusion is reached that the loss of less than 5ha of BMV agricultural land from soil sealing is a moderate or large adverse effect (which incidentally cannot be mitigated by careful soil handling, as claimed in the chapter) but the consequential effect of removing approximately 900ha of agricultural land from food production for a period of 40 years is not even assessed.

Appendix 1: Flood Risk



Environment Agency (2022) *Mapping of long term flood risk*. https://check-long-term-flood-risk.service.gov.uk/map?easting=505135&northing=313942&map=RiversOrSea

Applicable areas of the site are outlined in orange.

Satellite imagery clearly showing the effects of flooding where the flood risk is mapped (outlined in orange).

Bing Maps (2022), https://www.bing.com/maps

Satellite imagery clearly showing the effects of flooding where the flood risk is mapped (outlined in orange).

Google Maps (2022), maps.google.co.uk

Appendix 2: Droughtiness Calculation Comparisons

Profiles with site numbers coloured black are as the original profile; profiles with site numbers coloured green are recalculations assuming soft/fragmented/rubble limestone at the base. Grades according to droughtiness are colour coded for ease.

Site No.		Depth cm		Texture	stone% hard	stone% Soft Lstone	Struct-ure	APwheat mm	AP potato mm
78	T	0	28	C	30			34	34
		28	40	C	50			10	10
		40	60	C	50			13	17
		60	120	Rock				0	0
							Total	**57**	**61**
							MB	-60	-50
					Droughtiness grade (DR)			4	3b
78	T	0	28	C	30		-	34	34
		28	40	C	50			10	10
		40	60	C	50			13	17
		60	120	Lstone				18	4
							Total	**75**	**65**
							MB	-42	-46
					Droughtiness grade(DR)			3b	3b
80	T	0	25	C	50		-	23	23
		25	30	C	50			4	4
		30	50	C	70			11	11
		50	120	Rock				0	0
							Total	**38**	**38**
							MB	-79	-73
					Droughtiness grade(DR)			4	4
80	T	0	25	C	50		-	23	23
		25	30	C	50			4	4
		30	50	C	70			11	11
		50	120	Lstone				21	8
							Total	**59**	**46**
							MB	-58	-65
					Droughtiness grade(DR)			4	4
132	T	0	30	C	30		-	37	37
		30	40	C	30			12	12
		40	60	C	50			13	17
		60	120	Rock				0	0
							Total	**61**	**65**

						MB	-56	-46
						Droughtiness grade(DR)	4	3b
132	T	0	30	C	30	-	37	37
		30	40	C	30		12	12
		40	60	C	50		13	17
		60	120	Lstone			18	4
						Total	**79**	**69**
						MB	-38	-42
						Droughtiness grade(DR)	3b	3b
142	T	0	30	C	35	-	34	34
		30	40	C	30		12	12
		40	60	C	50		13	17
		60	120	Rock			0	0
						Total	**58**	**63**
						MB	-59	-48
						Droughtiness grade(DR)	4	3b
142	T	0	30	C	35	-	34	34
		30	40	C	30		12	12
		40	60	C	50		13	17
		60	120	Lstone			18	4
						Total	**76**	**67**
						MB	-41	-44
						Droughtiness grade(DR)	3b	3b
112	T	0	28	mCL	15	-	43	43
		28	35	mCL	30		8	8
		35	60	mCL	80		8	10
		60	120	Rock			0	0
						Total	**60**	**61**
						MB	-57	-50
						Droughtiness grade(DR)	4	3b
112	T	0	28	mCL	15	-	43	43
		28	35	mCL	30		8	8
		35	60	mCL	80		8	10
		60	120	Lstone			18	4
						Total	**78**	**65**
						MB	-39	-46
						Droughtiness grade(DR)	3b	3b
113	T	0	30	mCL	15	-	46	46
		30	33	mCL	30		3	3
		33	60	mCL	80		9	11
		60	120	Rock			0	0
						Total	**59**	**61**
						MB	-58	-50
						Droughtiness grade(DR)	4	3b

113	T	0	30	mCL	15	-	46	46
		30	33	mCL	30		3	3
		33	60	mCL	80		9	11
		60	120	Lstone			18	4
						Total	**77**	**65**
						MB	-40	-46
				Droughtiness grade(DR)			3b	3b
125	T	0	30	hCL	20	-	44	44
		30	35	SCL	50		4	4
		35	60	SCL	50		17	20
		60	120	Rock			0	0
						Total	**65**	**68**
						MB	-52	-43
				Droughtiness grade(DR)			4	3b
125	T	0	30	hCL	20	-	44	44
		30	35	SCL	50		4	4
		35	60	SCL	50		17	20
		60	120	Lstone			18	4
						Total	**83**	**72**
						MB	-34	-39
				Droughtiness grade(DR)			3b	3b
127	T	0	25	C	25	-	33	33
		25	35	C	50		9	9
		35	60	C	50		17	21
		60	120	Rock			0	0
						Total	**58**	**62**
						MB	-59	-49
				Droughtiness grade(DR)			4	3b
127	T	0	25	C	25	-	33	33
		25	35	C	50		9	9
		35	60	C	50		17	21
		60	120	Lstone			18	4
						Total	**76**	**66**
						MB	-41	-45
				Droughtiness grade(DR)			3b	3b
128	T	0	25	hCL	25	-	34	34
		25	35	C	30		12	12
		35	60	C	80		8	10
		60	120	Rock			0	0
						Total	**54**	**56**
						MB	-63	-55
				Droughtiness grade(DR)			4	4
128	T	0	25	hCL	25	-	34	34

		25	35	C	30		12	12
		35	60	C	80		8	10
		60	120	Lstone			18	4
						Total	**72**	**60**
						MB	-45	-51
					Droughtiness grade(DR)		3b	3b
165	T	0	25	C	15	-	37	37
		25	30	C	10		7	7
		30	35	C	50		4	4
		35	60	C	80		8	10
		60	120	Rock			0	0
						Total	**56**	**58**
						MB	-61	-53
					Droughtiness grade(DR)		4	3b
165	T	0	25	C	15	-	37	37
		25	30	C	10		7	7
		30	35	C	50		4	4
		35	60	C	80		8	10
		60	120	Lstone			18	4
						Total	**74**	**62**
						MB	-43	-49
					Droughtiness grade(DR)		3b	3b
167	T	0	25	C	15	-	37	37
		25	35	C	15		14	14
		35	45	C	50		9	9
		45	65	C	80		5	8
		65	120	Rock			0	0
						Total	**64**	**67**
						MB	-53	-44
					Droughtiness grade(DR)		4	3b
167	T	0	25	C	15	-	37	37
		25	35	C	15		14	14
		35	45	C	50		9	9
		45	65	C	80		5	8
		65	120	Lstone			17	2
						Total	**80**	**69**
						MB	-37	-42
					Droughtiness grade(DR)		3b	3b
171	T	0	30	C	20	-	41	41
		30	60	C	50		21	26
		60	120	Rock			0	0
						Total	**63**	**67**
						MB	-54	-44
					Droughtiness grade(DR)		4	3b

171	T	0	30	C	20	-	41	41
		30	60	C	50		21	26
		60	120	Lstone			18	4
						Total	**81**	**71**
						MB	-36	-40
					Droughtiness grade(DR)		3b	3b
173	T	0	25	hCL	35	-	30	30
		25	50	C	50		21	21
		50	120	Rock			0	0
						Total	**51**	**51**
						MB	-66	-60
					Droughtiness grade(DR)		4	4
173	T	0	25	hCL	35	-	30	30
		25	50	C	50		21	21
		50	120	Lstone			21	8
						Total	**72**	**59**
						MB	-45	-52
					Droughtiness grade(DR)		3b	3b
192	T	0	25	hCL	50	-	24	24
		25	50	C	50		21	21
		50	120	Rock			0	0
						Total	**45**	**45**
						MB	-72	-66
					Droughtiness grade(DR)		4	4
192	T	0	25	hCL	50	-	24	24
		25	50	C	50		21	21
		50	120	Lstone			21	8
						Total	**66**	**53**
						MB	-51	-58
					Droughtiness grade(DR)		4	4
210	T	0	30	C	25	-	39	39
		30	40	C	25		12	12
		40	60	C	80		6	8
		60	120	Rock			0	0
						Total	**57**	**59**
						MB	-60	-52
					Droughtiness grade(DR)		4	3b
210	T	0	30	C	25	-	39	39
		30	40	C	25		12	12
		40	60	C	80		6	8
		60	120	Lstone			18	4
						Total	**75**	**63**
						MB	-42	-48
					Droughtiness grade(DR)		3b	3b

130	T	0	28	C		2	-	47	47
		28	40	C		20		16	16
		40	60	C		40		17	22
		60	80	C		50		11	10
		80	120	Rock				0	0
							Total	**91**	**96**
							MB	-26	-15
							Droughtiness grade(DR)	3b	3a
130	T	0	28	C		2	-	47	47
		28	40	C		20		16	16
		40	60	C		40		17	22
		60	80	C		50		11	10
		80	120	Lstone				12	0
							Total	**103**	**96**
							MB	-14	-15
							Droughtiness grade(DR)	3a	3a
162	T	0	28	C	8		-	44	44
		28	60	C	0			43	51
		60	70	SCL	50			5	8
		70	90	SCL	50			11	0
		90	120	Rock				0	0
							Total	**103**	**103**
							MB	-14	-8
							Droughtiness grade(DR)	3a	2
162	T	0	28	C	8		-	44	44
		28	60	C	0			43	51
		60	70	SCL	50			5	8
		70	90	SCL	50			11	0
		90	120	Lstone				9	0
							Total	**112**	**103**
							MB	-5	-8
							Droughtiness grade(DR)	3a	2
177	T	0	25	hCL	15		-	39	39
		25	35	hCL	10			15	15
		35	55	hCL	15			25	28
		55	60	hCL	70			2	3
		60	80	hCL	70			7	6
		80	120	Rock				0	0
							Total	**86**	**89**
							MB	-31	-22
							Droughtiness grade(DR)	3b	3a
177	T	0	25	hCL	15		-	39	39
		25	35	hCL	10			15	15
		35	55	hCL	15			25	28

55	60	hCL	70		2	3
60	80	hCL	70		7	6
80	120	Lstone			12	0
				Total	**98**	**89**
				MB	-19	-22
			Droughtiness grade(DR)		3a	3a

APPENDIX 2

Extracts and associated comments from MPAG on the ADAS report written for the Welsh Government titled:

"The impact of PV sites on agricultural soils and land quality, 2023".

APPENDIX 2

ADAS[1] report to the Welsh Government – " The impact of PV sites on agricultural soils and land quality"

Extracts from the report with MPAG comments

(Key: text copied from ADAS paper in ***blue italics***; MPAG comments in **black text**)

Executive Summary

"This report is part of an evidence-based assessment of the impact of solar photovoltaic (PV) sites on agricultural land and soil. The work, under the Welsh Government's Soil Policy Evidence Programme SPEP 2021-22/03, is to inform Welsh Government and Natural England specialists when dealing with solar photovoltaic (PV) planning applications.

The impacts on Best and Most Versatile(BMV) agricultural land from the construction, operational and decommissioning phases are reviewed, based on the findings of the earlier literature review (WP1), best practice and extensive experience of land restoration. The main impact of the three phases of development is deep soil compaction resulting in the loss of versatility of Best and Most Versatile agricultural land and in wetter parts of England and Wales the loss of Best and Most Versatile agricultural land. An assessment is made of the reversibility of the impacts. Soil compaction results mainly from trafficking and alleviation is reported to depths of 45cm. It can take many years for soils to recover from compaction and compaction may be permanent. Runoff from panels can result in rivulets, which can lead to soil loss by erosion."

The importance of this report cannot be underestimated in shining a light on the absolute fundamental importance of handling the soils appropriately from day 1 to protect the quality and ALC grading of the soil.

Para 2.4.2

"The number of piles required is determined by the site layout. One case study in WP2 gave the number of piles as 492 piles per ha. Many planning applications for solar PV sites usually include an elevation plan of the solar panel and give the number of PV panels as an illustration, ***but not the number of piles required (our emphasis)."***

The number of piles will directly affect the degree of land disturbance and potential ALC downgrading at decommissioning, particularly after 60 years when there will be a high degree of corrosion to the supports which in all likelihood will have to be dug out of the ground as corrosion will make it difficult to pull them out.

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[1] ADAS: Agricultural Development and Advisory Service. The UK's largest independent provider of agricultural and environmental consultancy, policy advice, and research and development

Para 2.4.4

During the operational life of a solar PV site there is likely to be minimal disturbance of the site. The wooden posts of deer/security fencing will require replacing through the lifetime of the development due to rot. Frequency of replacement will be greatest in wet or exposed sites. Excavation of the post hole will be required and ***then re-compaction of the soil leading to localised compaction around the hole and along the access track (our emphasis).”***

This is likely to be required every 15-20 years. Therefore a significant amount of compaction can be expected along the fence lines during the life (however long) of the development.

“There is likely to be some instances of run-off from the solar panels, which could result in the compaction of soils at the base of the panels (Choi et al,2020). Over time rivulets can form along the trailing edge of the panel with potential risk of soil erosion creating rills and gullies across the site.”

Figure 6: Channels created by panel runoff within 12 months of site operation commencing

This is of great concern. The above picture shows a situation where foliage has failed to develop which would be the case where grassland establishment takes place after construction (as indicated in the GEMP). If this is how it looks after 12 montsh then in 40 to 60 years time it will be much worse, and all the time water is finding its way more quickly into the rivers creating flash flood risk.

Para 2.4.5

“The extraction of the piles is likely to be more problematical than the initial installation (per. comm. P. Woodfield, Technik GS). *Pile extraction is undertaken typically with a 13-ton excavator and vibrating pile driver attachment, which removes one beam and then tracks to the next one (per. comm. I. Woolley, Twig Group). A vibrating plate shakes the soil at removal stage, to ensure that the soil stays in place with little disturbance as the H beam is lifted out of the ground, this reduces the risk of soil attaching to the H beam and resulting in a larger area lifting.”*

“In clay soils there will be softening and swelling to close the void overtime partially or wholly. ***Plugging can occur in clay soils where the soil may stick to the pile and be withdrawn with the pile, in effect pulling out a solid unit defined by the flanges and width of the pile.*** *The volume of the soil pulled out is greater than in sandy soils and can produce a local ground settlement as soil swells or collapses to fill the void unless measures are taken to fill the void at the time of withdrawal. The clay*

*or soil adhering to the pile can be cleaned off and returned to the hole and then the void is minimal as bulking takes up part of the volume**, but this may mix topsoil and subsoil unless carefully managed.”***

Again the risk of top & subsoil mixing which would lead to downgrading. Also a depression left where each post was could lead to localised wet areas (puddles) across the site which would also affect future ALC.

“There is no known reported experience of pile pull out within the solar industry in the UK. *A study of civil structures in Japan, where the ground is ‘soft’ and many structures use pile foundations, reported that ‘filling’ the void was effective in reducing ground subsidence and that the ‘filler’ must suit the ground conditions (Inazumi et al, 2017). At this stage in the life of the ground-mounted solar PV industry, the impact of pile pull-out on agricultural land and soil is a ‘grey’ area with few conclusions having been drawn to date.”*

Surely a precautionary approach should apply here? Sample piles could be extracted every so often, nearing the end of expected life, to assess the level of corrosion and ascertain when the cross over between pile ‘pulling’ and digging might be. In conjunction with the replacement of panels this could be a method of determining the lifespan of the site. Pile replacement does not seem to be factored in anywhere in the management plans, it should have been added alongside panel replacement.

Para 2.5

“The main cause of compaction is the compressive forces applied to the soil from the wheels or tracks of machinery. Hakansson (1985) found that an axle load of 10 tonnes increased soil bulk density to a depth of 50 cm. Compaction may be very persistent in the subsoil and possibly permanent (Hakansson et al 1988). Where there is ‘industrial compaction’ the depth of compaction can extend to depths of 1m (Spoor, 2006) and may persist for up to 30 years (Batey, 2009).”

Field identification of soil compaction includes evidence of waterlogging on the surface or in subsurface horizons, an increase in soil strength or bulk density, low visible porosity, poor structural conditions, soil colour and rooting pattern (Batey, 2009).

Techniques for loosening compacted soils to depths of about 45cm are established, but at lower depths correcting problems may not be effective and economic and engineering equipment is required. As well as the forces applied to the soil, the soil water content and bearing capacity are critical at the time the pressure is applied – this is true for both the instance of compaction and the alleviation of compaction.

The impact of soil compaction is well documented (Batey, 2009) and crop growth, yield and quality may be adversely affected. **There are also wider environmental implications relating to water and air quality.**

Wet soils can become anaerobic and in these situations methane is produced (reference to air quality). Methane is 80 times more potent than CO2 as a GHG. If the Applicant causes significant compaction leading to a slowly permeable layer (SPL) then the organic carbon cycling through the soil could be released as Methane.

Para 3.0

"The scenarios assume that unremediated (sub)soil compaction has resulted in a slowly permeable layer (SPL) at a shallower depth in the soil profile than was previously the case. The depth to a SPL is key to assessing soil water regime and ultimately ALC grade according to soil wetness. A SPL prevents the downwards movement of water in the soil profile and can lead to surface water perched at shallow depth for periods of the year, particularly autumn through to spring, and particularly problematic in wetter soil types or wetter areas of England and Wales. This can negatively impact the flexibility of agricultural land, potentially lowering quality and ALC grade."

Land sitting wetter for longer makes it less flexible and more problematic for cultivating hence the reduction in ALC grade.

"A similar set of scenarios could be made of the potential residual impact of unremediated (sub) soil compaction on ALC grade according to soil droughtiness. The assessment of soil droughtiness considers climate, soil texture and, again, soil structure, consistency and porosity."

A compacted layer will restrict plant rooting and therefore access to soil water (and nutrients) which will increase droughtiness and reduce ALC grade (common in potatoes when cultivations occur in slightly too wet conditions). See section 3.3

Para 3.2.2

"Several scenarios for 'undisturbed' soils are presented in Appendix 5 (Table B) to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land. For 'undisturbed' soils reference is made to soil colour (gleying), textural, structural and porosity characteristics for determining the soil wetness limitation."

Gleying is the reduction of iron in the absence of oxygen (ie in wet anaerobic soils) and produces a grey layer in the soil. The orange compounds associated with rusting are iron reduction in the presence of oxygen. Soil scientists will deduce that a grey layer in a soil indicates it has been wet for prolonged periods.

Several scenarios are presented where compaction has led to an SPL being present during the life of solar farm, and how this will affect ALC grading post decommissioning. MPAG are focussing on the scenario most relevant to the proposed development.

For 'undisturbed' soils reference is made to soil colour (gleying), textural, structural and porosity characteristics for determining the soil wetness limitation.

The scenario is a pre-construction soil profile placed in Wetness Class I, which has a medium textured topsoil:

"In a drier part of England, with an FCD of 125, where there is gleying present below a depth of 40cm and a slowly permeable layer starting between a depth of 35cm to 42cm the soil at decommissioning is placed in Wetness Class III and Subgrade 3a. Prior to commissioning the ALC grade is given as Grade 1, hence there is an impact on the versatility of the BMV land at decommissioning."

Para 3.25 Summary.

"To summarise on both disturbed and undisturbed land, the soil wetness assessment shows the impact of unremediated soil compaction leading to gleying in the soil and the introduction of a slowly permeable layer. The potential loss of BMV agricultural land or its versatility increases in wetter parts of England and Wales. In slightly drier parts of England and Wales there is loss of BMV agricultural land depending on the starting depth of the slowly permeable layer**. Loss of versatility of BMV agricultural land, for the soil textures considered, occurs in slightly drier parts depending on the interaction of the Wetness Class and the FCD of the location."**

Our reading of this is that the higher the ALC grade prior to construction, the greater the likely affect (downgrading) on the ALC grade post construction if compaction is caused during construction, operation or decommissioning. Appendix 5 of the ADAS report has much more detail.

Para 3.5

"One of the key impacts on BMV agricultural land is soil compaction, which can vary considerably from very minimal and short term to severe, which possibly cannot be rectified.

Compaction in the subsoil below about 45cm is unlikely to be practicable and economic to alleviate (Batey, 2009) and is unlikely to respond quickly to natural recovery through the freeze-thaw cycle. Where compaction is present at depth it is a long-term limitation and it is taken into account in the ALC Guidelines (MAFF, 1988) through reduced permeability in the wetness assessment and crop available water in soil droughtiness assessment. There will be compaction at the time of construction, which may remain for the lifespan of the development. Further compaction may result at the decommissioning phase."

"Business Wales (2018) and Froehlich et al (1985) reported that ***natural recovery of a compacted soil is complex and a slow process. Batey (2009) refers to 30 years for a compacted soil to recover****, where 'industrial' compaction extends to depths of 1m or more (Spoor, 2006). Hakansson (1988) reported that compaction may be very persistent in the subsoil and permanent."*

"A study undertaken by Defra (2016) considered compaction in grassland on 300 grassland fields. The study considered how grassland management may be used to influence soil compaction and how management can be targeted to alleviate or avoid compaction. ***The careful management of machinery use in terms of when and how many times soils are trafficked was a key influence on the level of soil compaction."***

As has been stated before compaction should be avoided at all costs, as once compacted the soil will stay compacted for a very long time, leading to all of the problems highlighted in previous submissions.

Para 4.2 Claimed benefits of topsoil carbon capture and soil structural improvements.

"Defra (2009) reported that the quantity of C that can be stored in any soil is finite. Following a change in management practice levels C can increase (or decrease) towards an equilibrium value at about 100 years depending on the soil type, land use and climate.

Maintaining an increased SOM level, due to a change in management practice, will be dependent on continuing that practice indefinitely. Only if land is taken permanently out of arable cultivation or *rotation will the benefits of C storage be realised over the long-term.* ***Soil organic matter is more rapidly lost than it is accumulated (Freibauer et al, 2004).***

A study by Gosling et al (2017) considered the potential for the conversion of arable cropland to grassland to sequester carbon in the short to medium term. The study reported no difference in soil organic carbon stocks in the top 30cm of the soil profile in grassland up to 17 years old and arable cropland at sites across the UK.

Key points from studies on land use changes and soil carbon include:

• The initial increases in the early years do not continue

• To maintain an increase in the level of soil carbon the land has to be taken permanently out of arable cultivation or rotation

• Soil organic matter is more rapidly lost than it is accumulated"

In short any carbon benefit attributed to soils in MP calculations should be zero.

Para 4.3 The influence of shading and microclimates beneath panels on soil microbial activity.

"Armstrong et al (2016) investigated the effects of solar PV arrays on microclimate and the consequences for carbon (C) cycling at Westmill Solar Park. The research found that ***PV arrays can cause both seasonal and diurnal variation in the ground-level microclimate such that there was an effect on terrestrial C cycling.*** *One of the conclusions of the project is that the effects of solar PV sites on plant–soil processes, which underpin key ecosystem services, is poorly understood.*

The microclimatic variability within a solar PV site arises from a lower temperature under the PV arrays. ***The above ground plant biomass was four times higher in the gap between arrays and the control areas compared to the biomass under the PV arrays.*** *The soil temperature is cooler under the PV arrays and between the PV arrays during the winter due to the interception of shortwave radiation by the solar PV arrays. The cooling is likely to be significant in terms of ecosystem function with the temperature differences affecting key plant-soil processes from productivity to decomposition (Marrou et al 2013).*

This confirms our fears that plant & soil processes will be significantly impeded underneath the panels and further underlines the nonsense of sowing grass underneath panels post construction as it will not grow (which is probably what happened in the figure 6 picture above).

Para 4.4 The influence of solar developments on soil loss and erosion.

"Runoff from solar panels has an influence on soil erosion. Water is known to run along the edge of the panels then fall to the ground at localised points and form rivulets. This has the potential to cause soil erosion, the risk of which is strongly influenced by slope and soil type. Choi (2020) reported erosion and one of the case studies in WP2a (Estuary Farm7) considered the possibility of runoff from solar panels causing compaction of soils at the base of the panels and resulting in rivulets forming along the edge of the rows of panels. While there may not be a significant increase in runoff, small channels will have formed with potential of soil loss. ***This problem is likely to be more severe in erodible soils such as sandy soils on slopes before a vegetation cover establishes.*** *However, the steepness of the slope would be an even stronger influence. The risks are repeated at the construction and decommissioning phases."*

This again underlines how critical it is to establish vegetation well before construction.

Para 5.2 Are solar PV sites reversible to Agriculture without residual impact? The evidence base.

"The key residual impact on the land is soil compaction. Defra (2016) reported that careful management of machinery use in terms of when and how many times soils are trafficked was a key influence on the level of soil compaction on grassland.

A review by Nawaz et al. (2021) refers to time scales of 5 to 18 years for soils to recover from compaction with the aid of agricultural machinery and for soil to recover from compaction naturally (without aid) 100 to 150 years."

Compaction must be avoided at all costs as it can take 15 to 18 years to sort out by mechanical means and up to 150 years without intervention.

Para 5.3 The main issues influencing reversion to agriculture.

"At decommissioning all materials are expected to be removed including the removal of piles from the soil. Most standard steel products corrode, particularly in the upper part of the pile and this may adversely affect the ability to extract the piles after 40 years. (Non-corrosive materials could be used but have cost implications). It may be that piles fracture and are difficult to extract without additional digging. An engineering solution, where extraction is adversely impacted, would be to partially cut down the piles and provide a capping layer of soil (per comm. P Woodfield, Technik GS). Any residual piles are likely to have a negative impact on whether the land is physically reversible to agriculture unless buried sufficiently deep to enable cultivations and drainage. Where residual piles could not be buried to a depth to allow cultivations the grading of the land would take into account the severity of the limitation. Land with severe or very severe limitations, which restrict the range of crops, is placed into either Grade 4 or Grade 5 in the MAFF Agricultural Land Classification system. To bury the piles to a sufficient depth would mean excavating to a depth of at least 1.0-1.2 metres. This would result in significant soil disturbance if many of the piles were affected in this way."

Piles are likely to corrode and be difficult to extract. They can either be dug out causing much soil disturbance and further trafficking & compaction; or cut off below ground which will limit how the land can be farmed and will thus reduce the ALC grade significantly.

There is some discussion as to the financing of decommissioning and how it may not be undertaken properly if the finance isn't in place to remove the entire infrastructure and revert the land to agriculture, often because the site will have changed hands more than once.

Para 9 deals with Whole lifetime planning conditions

Whilst the Applicant has requirements set out in the oSMP, oCEMP and oDEMP, it does not seem that they take account of the scenarios involved when replacing piles and fencing throughout the Operational phase and then at decommissioning. All the soil handling relates to larger movements of soil e.g. handling and storage of soil in respect of areas such as tracks and hard-standing for solar stations etc.

The soil disturbance when removing and replacing piles and fencing posts 1 to 2 times during the scheme life, and the associated trafficking of the soils combined with panel replacement activities, could have a huge impact on the quality and final ALC grade of the soils subject to the levl of disturbance to the soil. MPAG do not feel this has been properly acknowledged and considered by the Applicant. This report shines a light on the potential issues and effects.

Appendix 4 of the report, the images presented in figures 4 to 10 speak for themselves. The contractor (in this example of how not to construct a solar farm) appears to show no consideration for topsoil preservation and work proceeding during very wet conditions, resulting in wheel ruts, surface water ponding and slurrified soil in places. The photos give an idea of the soil disturbance that can occur during a solar PV site construction.

MPAG show these photos for the main reason that it seems commercial imperatives will take precedence over a) creating a robust grass sward in advance of any construction, b) not working on wet soils irrespective of time pressures. The Applicant uses words such as ‘where practicable’ and ‘if reasonably possible’.

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

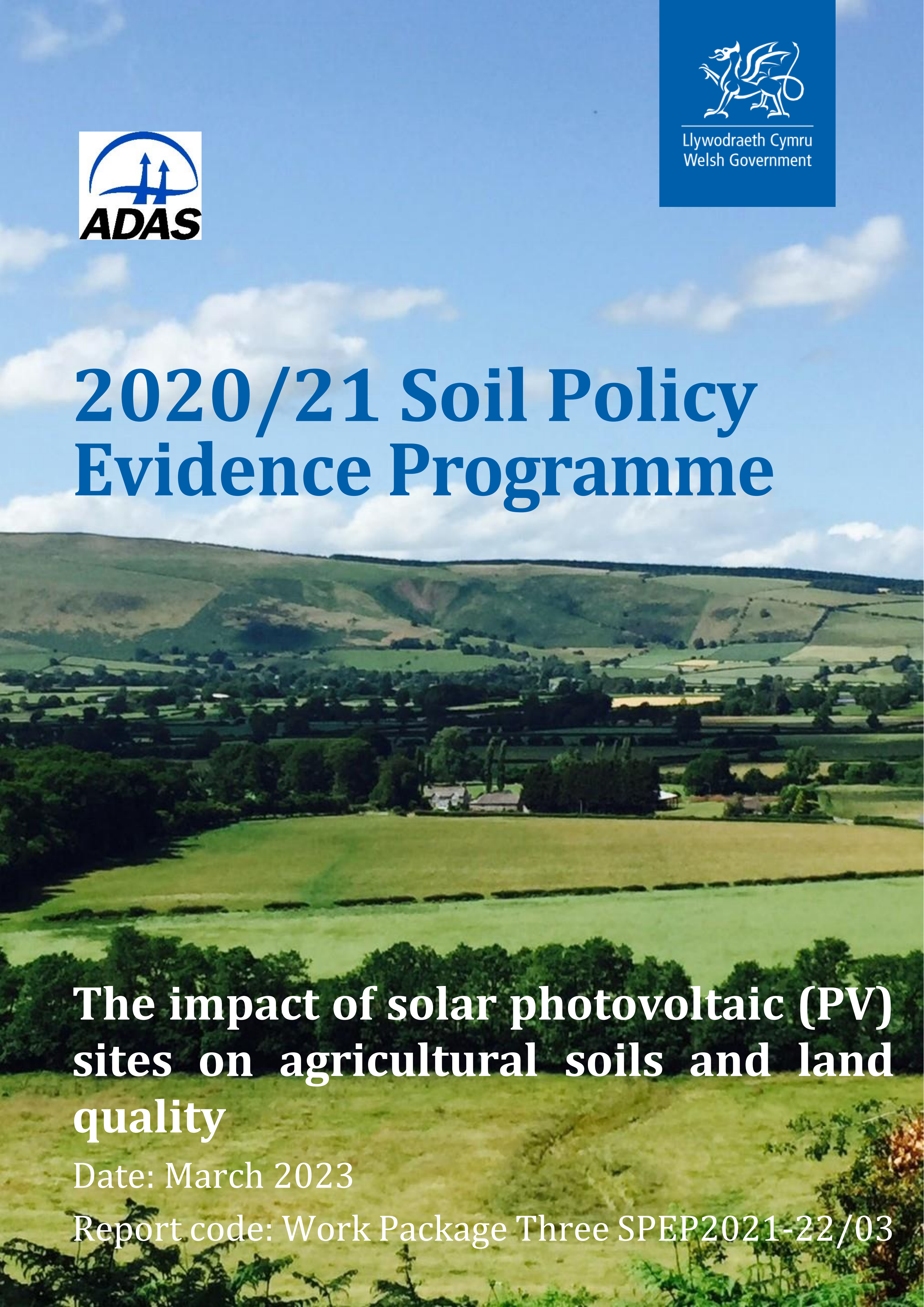
Figure 9

Figure 10

APPENDIX 3

The full ADAS report written for the Welsh Government titled:

“The impact of PV sites on agricultural soils and land quality, 2023”.



Llywodraeth Cymru
Welsh Government

ADAS

2020/21 Soil Policy Evidence Programme

The impact of solar photovoltaic (PV) sites on agricultural soils and land quality

Date: March 2023

Report code: Work Package Three SPEP2021-22/03

Welsh Government

The impact of solar photovoltaic (PV) sites on agricultural soils and land

Work Package Three: Review of Impacts

March 2023

ADAS

ADAS GENERAL NOTES

Project No.: 1010857-WP3

Title: The impact of solar photovoltaic (PV) sites on agricultural soils and land. Work Package Three: Review of Impacts

Client: Welsh Government

Date: 31/03/2023

Office: ADAS Rosemaund, Preston Wynne, Herefordshire, HR1 3PG

Status: Final v2

EXECUTIVE SUMMARY

This report is part of an evidence-based assessment of the impact of solar photovoltaic (PV) sites on agricultural land and soil. The work, under the Welsh Government's Soil Policy Evidence Programme SPEP 2021-22/03, is to inform Welsh Government and Natural England specialists when dealing with solar photovoltaic (PV) planning applications.

The impacts on Best and Most Versatile[1&2] (BMV) agricultural land from the construction, operational and decommissioning phases are reviewed, based on the findings of the earlier literature review (WP1), best practice and extensive experience of land restoration. The main impact of the three phases of development is deep soil compaction resulting in the loss of versatility of Best and Most Versatile agricultural land and in wetter parts of England and Wales the loss of Best and Most Versatile agricultural land. An assessment is made of the reversibility of the impacts. Soil compaction results mainly from trafficking and alleviation is reported to depths of 45cm. It can take many years for soils to recover from compaction and compaction may be permanent. Runoff from panels can result in rivulets, which can lead to soil loss by erosion.

The benefits of topsoil carbon capture and soil structural improvements are reported for grassland. Research on the impact of solar PV panels on microclimate beneath panels highlights the changes in temperature on vegetation growth.

The decommissioning phase involves the removal of the solar PV site infrastructure. The issues of 'pile pull out' are considered, including corrosion and fracture of the piles.

Good soil handling conditions may mitigate the threats to soil and land. Appropriate planning with a quality soil resource and management plan is essential at the planning application stage to ensure that conditions, as part of the planning process, are relevant and focussed on the restoration of the land to agriculture.

[1] Planning Policy Wales Paragraphs 3.58-3.59 Edition 11 February 2021 and National Planning Policy Framework

[2] Land classified as Grade 1, 2 and 3a. MAFF Agricultural Land Classification Guidelines. 1988

CONTENTS

1 BACKGROUND

This report is part of an evidence-based assessment of the impact of solar photovoltaic (PV) sites on Best and Most Versatile (BMV) agricultural land and associated soils. The work, under the Welsh Government's Soil Policy Evidence Programme SPEP 2021-22/03, is to inform Welsh Government and Natural England specialists when dealing with solar photovoltaic (PV) planning applications.

A detailed search of published research and industry experience has been undertaken to inform this report. The search concentrated on the impacts of solar PV sites on agricultural land and soils within the UK and internationally. There have been few studies of solar PV sites which have a focus on the impacts on agricultural land and soils. This is largely because solar PV sites are recent developments but also because in the early years sites were located on brownfield land or poorer quality agricultural land. The importance of achieving successful restoration of solar PV sites has increased in significance as the number, size and operational time frame of solar PV sites on BMV agricultural land has increased.

An overview study of the industry has been undertaken and informs this report. The distribution of solar irradiation (Huld et al,2019) across the UK ranges from approximately 900-1350kWh/m^2 per year, with the highest resource available in the South West. There has been a trend (BEIS, 2021) towards larger schemes (up to 50 MW and a typical land take of 50ha to 80ha), because of the ceiling for schemes dealt under the Town and Country Planning Act in England. There has also been a move to 'super large' solar PV schemes, generally over 300ha in size. Published sources of guidance for solar developers identified are limited and include several BRE publications (2013, 2014).

Solar Energy UK have prepared a 'best practice guide' (https://solarenergyuk.org/wp-content/uploads/2022/05/NCBPG-Solar-Energy-UK-Report-web.pdf), with much focus on the benefits for ecology and biodiversity and little consideration of the impact on soil. A virtual workshop was held on 2nd September 2021 with Welsh Government, Natural England and invited interested parties.

This report reviews the potential impacts to soil and land associated with solar PV site developments at the commissioning and decommissioning phases. The potential effects on soils during the operational phase of the site are considered and the physical reversion from low-maintenance grass to other agricultural uses typically associated with BMV agricultural land and non BMV agricultural land is undertaken.

This report follows the Technical Specification received from Welsh Government and the layout closely follows the points in the brief (Appendix 1).

ADAS gratefully received evidence from the trade body Solar Energy UK to inform this project and details of the evidence provided over December 2021 – January 2022 is provided in Appendix 2.

2 CONSTRUCTION, OPERATION AND DECOMISSIONING

2.1 Overview of Construction phase

At the time of the submission of the planning application, the solar PV developer will have prepared site outline plans showing details of all aspects of the proposed scheme. Each site is designed taking into account the site's technical assessment, landowner negotiation and grid connection. The solar PV site will typically include some key activities resulting in effects on soil and land, including:

1. Site levelling
2. Construction compound (either for operational life or the temporary during construction phase)
3. Site fencing and security
4. Access road/tracks
5. High voltage cabling
6. Low voltage cabling
7. String cabling
8. Earthing
9. Steel framing mounts and PV panels
10. Piles
11. Inverters and container bases
12. Substation

2.2 Overview of Operational Phase

Solar PV sites are usually unmanned once commissioned. Regular visits may be planned by operations and maintenance staff to undertake monitoring and site maintenance. Typical activities include grass cutting, if grazing does not keep the grass at the optimum height, management of landscaping works and panel washing. The visits will generally require a 4x4 vehicle. Grass on the site is often grazed by sheep, particularly in Wales.

2.3 Overview of Decommissioning Phase

Outline plans stating that decommissioning will be undertaken at the end of the operational life of the development are generally included in the planning application stage. A condition of planning permission is that a more detailed plan, usually about 6 months before the end of the operational life, is submitted to the planning authority. Decommissioning may be triggered by the end of the operational life of the development or by economic reasons or abandonment (Stantec, 2020).

Typical activities at the decommissioning phase may include:

1. Access roads may need to be reinforced to be able to carry traffic involved in the decommissioning phase
2. De-energise solar arrays
3. Dismantle panels and racking
4. Removal of piles from soil and reinstatement of soil into voids
5. Removal of frames and internal components
6. Removal of structural foundations and backfill sites
7. Removal of inverter stations and foundations
8. Removal of electrical cables and conduits
9. Removal of access and internal roads
10. Removal of substation.

2.4 Impacts on soil and land

2.4.1 Construction phase - overview

The construction of the solar PV site involves operations that necessarily impact on the soil and land. All activities at the construction phase involve trafficking by plant/machinery across the whole site, possibly following access tracks on parts of the site. Examples of the equipment used include excavators and dumper trucks for soil removal and storage, trenching machinery, piling rig and dumper trucks for the transportation of cabling, piles, mounts and panels on site.

The removal of a depth of soil is necessary to prepare the site compound, access roads and site tracks (where aggregate and geo textile membrane are used) and bases for inverters and substations. Site fencing, usually 2m high deer or security fencing, is placed around the site perimeter. Wooden supporting posts are often used, which do not require concrete foundations except at the corners and gateways. With typical spacings of 2.4m to 3m there are approximately 300-416 posts per 1000m run of fencing. The length of fencing varies according to the site layout and each post may be sunk at a depth of up to 1m below ground level. Metal fencing may be used where there is a risk of theft and will require concreting at every footing, which will be spaced at approximately 2m giving 500 posts per 1000m run.

2.4.2 Construction phase - piling

The PV panels are placed on frames which are attached to supporting piles. Most sites use H or I beams, driven into the ground by a piling rig (with a vibrating plate) to a depth of approximately 1.4m to 2m. The beams displace a volume of soil about equal to the volume of the pile. H beam piles are described as 'non-displacement', but soil is displaced as a soil plug forms between the flanges and moves down the pile as it is driven (Ahlvin et al, 1988).

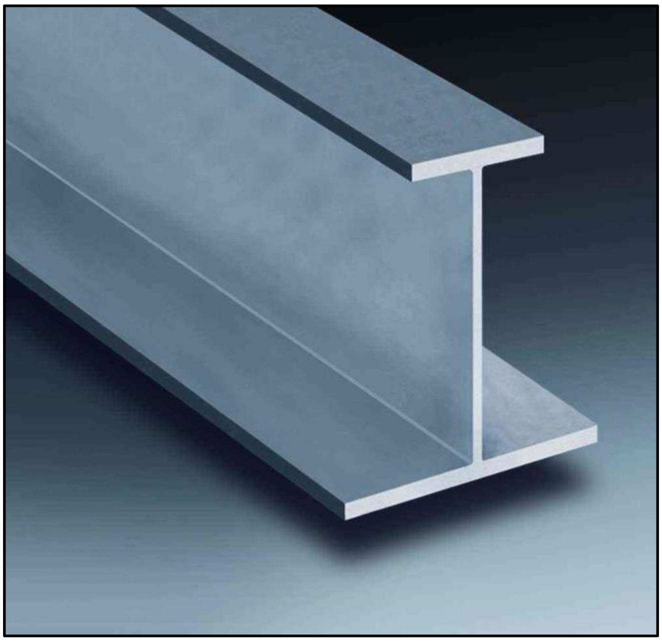


Figure 1: H beam (Sinosources)

H beams have wider flanges than I beams, which have tapered edges. In sandy soils the displaced volume results in compaction of the soil surrounding the pile. In clay soils displacement piles create high stresses in the soil. There is no spoil on the surface.

Helical piles or screws are cylindrical posts with a helix near the bottom of the post and the helix part resists being pulled out by creating a cone of soil above it. Helical piles are installed by digging an initial guiding hole and using a skid steer vehicle with a rotating attachment to spin the pile into place. Helical piles have a smaller surface and will embed with minimal soil disturbance.

Figure 2: Helical beams

Figure 3 Helical piles at depth (Goliathtechpro.com)

H beams are used on larger scale developments as they have a stronger load bearing and require fewer penetrations per rack compared to helical anchors or ground screws.

The number of piles required is determined by the site layout. One case study in WP2 gave the number of piles as 492 piles per ha. Many planning applications for solar PV sites usually include an elevation plan of the solar panel and give the number of PV panels as an illustration, but not the number of piles required.

Ballasted systems provide a non-penetrating foundation to support solar PV frames. The concrete bases can be used on land fill sites or where deep penetration from H beams may damage archaeological features.

2.4.3 Construction phase – soil movement

The development of solar PV sites requires the excavation of soils associated with construction compounds, access roads and trenching for cables. Soil removal is usually undertaken for construction of the site compound and access roads/tracks, where a geo-textile membrane may be placed over the subsoil and covered with a surface layer of aggregate. The depth of soil stripped for the compound and for the foundation of bases for inverters and substations should be determined by an assessment of soil resources on site. A review of the case studies (WP 2a) showed removal of soil to depths of up to 30cm i.e. typically topsoil, but excavation to this depth could mix in some subsoil if it is not stripped separately. Trenches created by a trenching machinery will require the removal of soil to a depth of typically up to 1.2m (i.e. a layer of topsoil and subsoil and on some sites overburden) and a width of up to 0.75m. The cables are placed in sand with a suitable backfill placed over. The amount of trenching and cabling is site specific, and one case (Estuary Farm WP2) reported a cabling requirement of approximately 2km on the site.

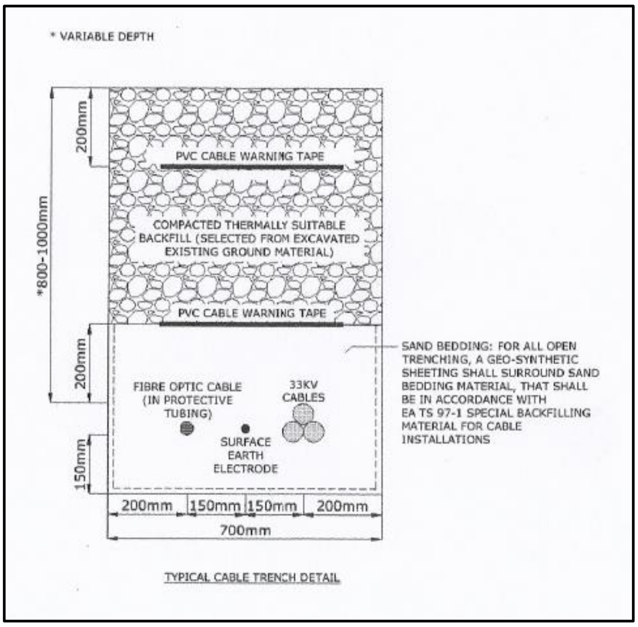


Figure 5: Typical cabling trench details

Site levelling works may be required depending on the site contours and on sites where tilting PV panels are used. Such an engineering operation will disturb the topsoil and it may be that some fill is required on site.

Damage to field drainage systems can occur as piles are driven into the ground, resulting in localised or widespread wet areas within the site.

2.4.4 Operational Phase

During the operational life of a solar PV site there is likely to be minimal disturbance of the site. The wooden posts of deer/security fencing will require replacing through the lifetime of the development due to rot. Frequency of replacement will be greatest in wet or exposed sites. Excavation of the post hole will be required and then re-compaction of the soil leading to localised compaction around the hole and along the access track.

Land between and underneath the PV panels is often grazed by sheep and where there are high numbers of sheep a solid compaction layer 2 cm to 6 cm over a wide area may result (Defra, 2021). There is likely to be some instances of run-off from the solar panels, which could result in the compaction of soils at the base of the panels (Choi et al,2020). Over time rivulets can form along the trailing edge of the panel with potential risk of soil erosion creating rills and gullies across the site. The sand bed could act as a drain, especially on heavy textured soils, leading to drainage discharges or wet patches at the down slope end of each trench.

Figure 6: Channels created by panel runoff within 12 months of site operation commencing

2.4.5 Decommissioning Phase

When the decommissioning phase is triggered at the end of the operational life of the solar PV site, operations to remove the physical infrastructure commence. Access roads and tracks may require reinforcing to be of a standard suitable for heavy machinery. Trafficking will again occur across the site on and off the site tracks as panels, frames and inverter cabins and substations are removed. Cabling may be removed from trenches and string cabling will be dismantled. Access roads, and construction compounds will have aggregate and the geo-textile membranes removed. Where the inverter cabins have been placed on an aggregate base or concrete plinth then this should be removed.

The extraction of the piles is likely to be more problematical than the initial installation (per. comm. P. Woodfield, Technik GS). Pile extraction is undertaken typically with a 13-ton excavator and vibrating pile driver attachment, which removes one beam and then tracks to the next one (per. comm. I. Woolley, Twig Group). A vibrating plate shakes the soil at removal stage, to ensure that the soil stays in place with little disturbance as the H beam is lifted out of the ground, this reduces the risk of soil attaching to the H beam and resulting in a larger area lifting. The volume occupied by the steel beam is the theoretical void. Where there are granular soils e.g. sands and gravel, the soil will fall into the void to occupy the space. The soils do this through a combination of gravity, flow if below the water table and the likely vibration effects while withdrawing the piles (per. comm. M. Wheeler, Binnies).

In clay soils there will be softening and swelling to close the void over time partially or wholly. Plugging can occur in clay soils where the soil may stick to the pile and be withdrawn with the pile, in effect pulling out a solid unit defined by the flanges and width of the pile. The volume of the soil pulled out is greater than in sandy soils and can produce a local ground settlement as soil swells or collapses to fill the void unless measures are taken to fill the void at the time of withdrawal. The clay or soil adhering to the pile can be cleaned off and returned to the hole and then the void is minimal as bulking takes up part of the volume, but this may mix topsoil and subsoil unless carefully managed. Widespread ground settlement is unlikely to occur, although there may be localised ground surface settlement at the point of the pile extraction. It is expected that any localised ground surface settlement would be removed at the time of cultivations on the site. There is no known reported experience of pile pull out within the solar industry in the UK. A study of civil structures in Japan, where the ground is 'soft' and many structures use pile foundations, reported that 'filling' the void was effective in reducing ground subsidence and that the 'filler' must suit the ground conditions (Inazumi et al, 2017). At this stage in the life of the ground-mounted solar PV industry, the impact of pile pull-out on agricultural land and soil is a 'grey' area with few conclusions having been drawn to date.

2.5 Risks to agricultural land quality

During the construction and decommissioning phases there will be soil movement and soil handling on site. During the commissioning, operational and decommissioning phases there will be trafficking by a range of machinery, including dozer, tracked excavator, wheeled backhoe loader, hydraulic hammer rig and rotary bored piling rig, vibrating plates, which can result in soil compaction. The main cause of compaction is the compressive forces applied to the soil from the wheels or tracks of machinery. Hakansson (1985) found that an axle load of 10 tonnes increased soil bulk density to a depth of 50 cm. Compaction may be very persistent in the subsoil and possibly permanent (Hakansson et al 1988). Where there is '*industrial compaction'* the depth of compaction can extend to depths of 1m (Spoor, 2006) and may persist for up to 30 years (Batey, 2009).

Low ground pressure tyres and tracked machinery may reduce the impact of compaction. Tracked vehicles can reduce rut depth by up to 40%, compared to extra wide or soft tyre options (Bygden etc al, 2003). The weight on tracked machinery is concentrated beneath the idlers and the bogies (the wheels within the tracks).

Field identification of soil compaction includes evidence of waterlogging on the surface or in subsurface horizons, an increase in soil strength or bulk density, low visible porosity, poor structural conditions, soil colour and rooting pattern (Batey, 2009).

Techniques for loosening compacted soils to depths of about 45cm are established, but at lower depths correcting problems may not be effective and economic and engineering equipment is required.

As well as the forces applied to the soil, the soil water content and bearing capacity are critical at the time the pressure is applied – this is true for both the instance of compaction and the alleviation of compaction.

Soil compaction can occur and be unrelated to mechanical forces, for example finely aggregated soil 'tumbling' down from the surface when cracks are open and wide (Batey,2009). There is potential for soil falling into the voids created when piles (e.g. H-beams) are removed.

The impact of soil compaction is well documented (Batey, 2009) and crop growth, yield and quality may be adversely affected. There are also wider environmental implications relating to water and air quality.

The extent of trafficking and soil disturbance can cover a substantial proportion of a solar PV site. Satellite imagery of three solar schemes is included in Appendix 3 to this report. This imagery shows:

- 1) Hunstpill Level Solar Farm, Sedgemoor District – pre-construction
- 2) Hunstpill Level Solar Farm, Sedgemoor District – during-construction
- 3) Lamby Way Solar Farm, Cardiff – pre-construction
- 4) Lamby Way Solar Farm, Cardiff – early-construction
- 5) Lamby Way Solar Farm, Cardiff – mid-construction
- 6) Lamby Way Solar Farm, Cardiff – post-construction
- 7) Afon Llan Solar Farm, Swansea – pre-construction
- 8) Afon Llan Solar Farm, Swansea – during construction

The imagery is taken from Google Earth Pro (historical imagery), Google Earth and Bing Aerial.

A number of developers have published videos on the YouTube.com showing phases of solar farm construction in the UK. Some videos appear to show construction during good ground conditions, with suitable access tracks constructed to support the field work. Other videos, however, appear to show no consideration for topsoil preservation and work proceeding during very wet conditions, resulting in wheel ruts, surface water ponding and slurrified soil in places. Extracts from two of these videos are provided in Appendix 4. Whilst care must be taken when drawing conclusions from such limited evidence from any given site, the videos give an idea of the soil disturbance that can occur during a solar PV site construction.

On all sites there is the potential impact on soils from the spillage or leakage of fuel and oil. Contaminants only affect agricultural land classification grading where they have or are likely to have a detrimental long-term effect on the physical condition of the soil (MAFF,1988), the yield, cropping and the stocking rates. It is likely that the impact on solar PV sites will be minimal, as bio-oils are widely used and incidents managed through control of contaminants and action.

The supporting information for solar PV sites indicates that galvanised aluminium or steel posts are used to support the frame. Galvanising involves a coating of zinc with thickness ranging from 0.3mm to 3.5mm. The impact on soil and land from the zinc coating is unknown. Defra's code for using sewage sludge (Defra,2018) gives thresholds for zinc in soils of 200 – 300mg/kg; these levels are very unlikely to be achieved from the presence of piles in the soil, although the base level of zinc could influence the threshold. Research on agricultural land has shown that zinc in soils diminishes biological activity (Moffett et al, 2003).

The maintenance of on-site ditches will be key to ensuring that surface water is managed on site. Should maintenance not be undertaken, there is a potential impact of flooding on land. Many solar PV site planning applications consider surface run-off within a management strategy.

3 AGRICULTURAL LAND QUALITY

This section of the report looks specifically at agricultural land, and the risk of residual impacts of solar PV sites on agricultural land quality and Best and Most Versatile (BMV) agricultural land.

The Agricultural Land Classification (ALC) system is used in England and Wales to determine agricultural land quality. The ALC system provides '*a framework for classifying land according to the extent to which its physical or chemical characteristics impose long-term limitations on agricultural use*'. The main factors influencing agricultural production and therefore agricultural land quality are climate, site and soil. These three factors and the interactions between them form the basis of classifying agricultural land into one of five grades, as described in Table 1 below.

Table 1: Agricultural Land Classification Grades

Agricultural Land Classification Grades
Grade 1 – excellent quality agricultural land Land with no or very minor limitations to agricultural use. A very wide range of agricultural and horticultural crops can be grown and commonly include top fruit, soft fruit, salad crops and winter harvested vegetable. Yields are high and less variable than on land of lower quality.
Grade 2 – very good quality agricultural land Land with minor limitations which affect crop yield, cultivations or harvesting. A wide range of agricultural and horticultural crops can usually be grown but on some land in the grade there may be reduced flexibility due to difficulties with the production of the more demanding crops such as winter harvested vegetables and arable root crops. The level of yield is generally high but may be lower or more variable than Grade 1.
Subgrade 3a – good quality agricultural land Land capable of consistently producing moderate to high yields of a narrow range of arable crops, especially cereals, or moderate yields of a wide range of crops including cereals, grass, oilseed rape, potatoes, sugar beet and the less demanding horticultural crops.

Agricultural Land Classification Grades (continued)
Subgrade 3b – moderate quality agricultural land Land capable of producing moderate yields of a narrow range of crops, principally cereals and grass or lower yields of a wider range of crops or high yields of grass which can be grazed or harvested over most of the year.
Grade 4 – poor quality agricultural land Land with severe limitations which significantly restrict the range of crops and/or level of yields. It is mainly suited to grass with occasional arable crops (e.g. cereals and forage crops) the yields of which are variable. In moist climates, yields of grass may be moderate to high but there may be difficulties in utilisation. The grade also includes very droughty arable land.
Grade 5 – very poor quality agricultural land Land with very severe limitations which restrict use to permanent pasture or rough grazing, except for occasional pioneer forage crops.

Agricultural land of Grade 1, 2 and Subgrade 3a is considered to be the best and most versatile (BMV) agricultural land in England and Wales.

Two of the principal limitations to agriculture, considered by the ALC system, are soil wetness and soil droughtiness. Soil wetness limits the flexibility of agricultural land by reducing the number of days available for safe cultivations and harvesting. The greater the soil wetness limitation the fewer days available. Soil wetness is influenced by climate (i.e. rainfall v evapotranspiration) and soils (primarily the soil water / drainage regime and topsoil clay content). Soil droughtiness limits the capacity of agricultural land to economically support certain crops. The greater the soil droughtiness limitation the less crop available water there is during the growing season and the less economically viable certain, or in the worst cases all, crops become. Soil droughtiness is influenced by climate (e.g. rainfall v evapotranspiration) and soils (primarily soil structure, soil depth, soil stone content and soil texture).

An assessment of soil wetness and droughtiness can demonstrate the residual impact of solar PV sites on agricultural land quality.

3.1 'Disturbed' and 'Undisturbed' Agricultural Soils / Land

In areas of a solar PV site, including the compound, access tracks, bases for inverters/substations, the soil will be stripped during the construction phase, stored and then replaced at the time of decommissioning. In areas of cable trenching the soil will be stripped, placed close to the trench and then reinstated once the cable is in place. In this report these areas are considered to be *'disturbed'*.

For this report areas in which soils are not stripped or reinstated and remain in situ are considered to be *'undisturbed'* land. These areas of 'undisturbed', soils may still be impacted during the various construction phases, via trafficking.

The ALC system recognises the classification of 'disturbed' land, which has different criteria for classifying land from 'undisturbed land'. Therefore the two are assessed differently:

- the agricultural quality of *'disturbed'* land is assessed with reference only to the soil textural, structural and porosity characteristics.
- the agricultural quality of '*undisturbed'* land is assessed with reference to soil colour (gleying[3]), textural, structural and porosity characteristics for determining the soil wetness limitation.
- the assessment of soil droughtiness for both 'disturbed' and 'undisturbed' land considers the soil texture, structure, organic matter and stone content.

3.2 Agricultural Land Classification Grade Scenarios

In the following sections several scenarios are outlined to indicate the potential residual impacts of solar PV sites on agricultural land quality. The scenarios concentrate on the residual impact of unremediated soil compaction on agricultural land, specifically relating to ALC grade according to soil wetness and soil droughtiness.

The assessment of ALC grade according to soil wetness (MAFF ALC Guidelines Section 3.4 and Appendix 3) considers climate, soil water regime and soil texture. Soil water regime is influenced by climate plus subsoil structure, consistency and porosity – each of which will be impinged by unremediated compaction.

The scenarios assume that unremediated (sub)soil compaction has resulted in a slowly permeable layer (SPL) at a shallower depth in the soil profile than was previously the case. The depth to a SPL is key to assessing soil water regime and ultimately ALC grade according to soil wetness. A SPL prevents the downwards movement of water in the soil profile and can lead to surface water perched at shallow depth for periods of the year, particularly autumn through to spring, and particularly problematic in wetter soil types or wetter areas

[3] A greyish, pale and ochreous colouring indicative of waterlogging.

of England and Wales. This can negatively impact the flexibility of agricultural land, potentially lowering quality and ALC grade.

A similar set of scenarios could be made of the potential residual impact of unremediated (sub) soil compaction on ALC grade according to soil droughtiness. The assessment of soil droughtiness considers climate, soil texture and, again, soil structure, consistency and porosity.

Several scenarios have been prepared to demonstrate the impact on soils using Field Capacity Days covering a range of hypothetical climates across England and Wales. Field Capacity Days (FCD) is a theoretical climatic model of the number of days in a typical year that accumulated precipitation exceeds accumulated evapotranspiration. It is based on historical climatic data in England and Wales, and wetter, cooler areas have higher FCD (e.g. >300 FCD in Welsh hills) than warmer, drier areas (e.g. 100 FCD in SE Cambridgeshire). It corresponds with the soil concept of Field Capacity, is the water content of a soil after gravitational drainage over approximately a day.

As is standard with the ALC system, the scenarios assume that soils have or could have an appropriate underdrainage system and the assumption is made that such a system will be in place at the end of the solar PV site decommissioning phase.

Several examples are presented to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) and the interaction with the climate variable Field Capacity Day (FCD) on BMV agricultural land. A summary of the scenarios is given below and detailed tables are in Appendix 5.

3.2.1 Scenario 1: Wetness Class I Medium-Textured Soils (Disturbed Land)

Several scenarios for 'disturbed' soils are presented in Appendix 5 (Table A) to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land.

The following summary demonstrates the potential impact on land during the lifetime of a solar PV site. The pre-construction soil profile belongs to Wetness Class I[4] and has a medium-textured topsoil. During the construction phase the soil is stripped and stored in soil bunds.

[4] Wetness Class (WC) I = freely-draining soil. WC II = moderately freely-draining. WC III = imperfectly-draining. WC IV = poorly-draining. WC V = very poorly-draining. WC VI = permanently waterlogged.

- in an area with a FCD of 230 the impact of an introduced slowly permeable layer at a depth of between 25cm and 60cm would place the reinstated soil profile in Wetness Class IV and the agricultural land classification grade of Subgrade 3b. The agricultural land classification grade before commissioning would be Subgrade 3a, hence there is an impact at decommissioning on BMV land.
- in a drier part of England, with a FCD of 125, with an introduced SPL at a depth of between 35cm and 60cm, the reinstated profile is placed in Wetness Class III and the resultant ALC grade is Subgrade 3a. Prior to commissioning the ALC grade is given as Grade 1, hence there is an impact on the versatility of the BMV land at decommissioning.

3.2.2 Scenario 2: Wetness Class I Medium-Textured Soils ('Undisturbed' Land)

Several scenarios for 'undisturbed' soils are presented in Appendix 5 (Table B) to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land. For 'undisturbed' soils reference is made to soil colour (gleying[5]), textural, structural and porosity characteristics for determining the soil wetness limitation.

The scenario is a pre-construction soil profile placed in Wetness Class I, which has a medium-textured topsoil:

- in an area with a FCD of 230, where there is an introduced slowly permeable layer at a depth of between the surface and a depth 80cm with gleying present below a depth of 40cm, the soil at decommissioning is placed in Wetness Class III and an ALC grade of Subgrade 3b. Prior to commissioning the ALC grade is given as Grade 3a, hence there is an impact at decommissioning on the BMV land.
- in an area with a FCD of 230, where an introduced slowly permeable layer is present at a depth of 25cm and gleying is present in the soil profile above 40cm the soil is placed in Wetness Class V and Grade 4. There is an impact at decommissioning on the BMV land.
- in a drier part of England, with an FCD of 125, where there is gleying present below a depth of 40cm and a slowly permeable layer starting between a depth of 35cm to 42cm the soil at decommissioning is placed in Wetness Class III and Subgrade 3a.

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[5] A greyish, pale and ochreous colouring indicative of waterlogging.

Prior to commissioning the ALC grade is given as Grade 1, hence there is an impact on the versatility of the BMV land at decommissioning.

3.2.3 Scenario 3: Wetness Class II Light-Textured Soils (Disturbed Land)

Several scenarios for 'disturbed' soils are presented in Appendix 5 (Table C) to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land. The pre-construction soil profile belongs to Wetness Class II[6] and has a light-textured topsoil. During the construction phase the soil is stripped and stored in soil bunds.

The following summary demonstrates the potential impact on land during the lifetime of a solar PV site:

- in an area with a FCD of 225 the impact of an introduced slowly permeable layer at a depth of between 25cm and 60cm would place the reinstated soil profile in Wetness Class IV and the agricultural land classification grade of Subgrade 3b. The agricultural land classification grade before commissioning would be Grade 2, hence there is an impact at decommissioning on BMV land.
- in a drier part of England, with a FCD of 125, with an introduced SPL at a depth of between 35cm and 60cm, the reinstated profile is placed in Wetness Class III and the resultant ALC grade is Grade 2. Prior to commissioning the ALC grade is given as Grade 1, hence there is an impact on the versatility of the BMV land at decommissioning.

3.2.4 Wetness Class II Light-Textured Soils ('Undisturbed' Land)

Several scenarios for 'undisturbed' soils are presented in Appendix 5 (Table D) to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land. The pre-construction soil profile belongs to Wetness Class II and has a light-textured topsoil.

- in an area with a FCD of 225 the impact of an introduced slowly permeable layer at a depth of between 35cm and 61cm and gleying present above 40cm would place the profile in Wetness Class IV and the agricultural land classification grade of

[6] Wetness Class (WC) I = freely-draining soil. WC II = moderately freely-draining. WC III = imperfectly-draining. WC IV = poorly-draining. WC V = very poorly-draining. WC VI = permanently waterlogged.

Subgrade 3b. The agricultural land classification grade before commissioning would be Grade 2, hence there is an impact at decommissioning on BMV land.

- in a drier part of England, with a FCD of 125, with an introduced SPL at a depth of between 35cm and 61cm and gleying above 40cm, the profile is placed in Wetness Class III and the resultant ALC grade is Grade 2. Prior to commissioning the ALC grade is given as Grade 1, hence there is an impact on the versatility of the BMV land at decommissioning.
- in areas with a FCD of 170 or lower with a light-textured soil changes in the Wetness Class and resultant grade may have minimal impact on BMV land (Appendix 5 Table D). However the introduction of a slowly permeable layer may influence the available water holding capacity of the soil profile and soil droughtiness may have an impact on the BMV land.

3.2.5 Summary

To summarise on both disturbed and undisturbed land, the soil wetness assessment shows the impact of unremediated soil compaction leading to gleying in the soil and the introduction of a slowly permeable layer. The potential loss of BMV agricultural land or its versatility increases in wetter parts of England and Wales.

In slightly drier parts of England and Wales there is loss of BMV agricultural land depending on the starting depth of the slowly permeable layer. Loss of versatility of BMV agricultural land, for the soil textures considered, occurs in slightly drier parts depending on the interaction of the Wetness Class and the FCD of the location.

3.3 Soil Compaction and Soil Droughtiness

Section 3.4 and Appendix 4 of the MAFF ALC Guidelines (1988) outline the methodology for assessing the soil droughtiness. Soil droughtiness indicates the degree to which a shortage of soil water may influence the range of crops grown and the yields achieved. Droughtiness is more likely to be a limitation to crop growth in areas of relatively low rainfall or high evapotranspiration. The interaction of the climate, soil texture, soil stoniness, subsoil structure, subsoil porosity and subsoil consistency influences the degree of the severity.

On solar PV sites both disturbed and undisturbed land at decommissioning may be affected by the introduction of unremediated soil compaction. This could reduce the crop available water of the soil profile, changing the ALC grade in the soil droughtiness assessment and may result in downgrading and /or loss of BMV.

The change in the grade may arise from a change in the soil profile characteristics, particularly soil consistence (the resistance to crushing) leading to changes in the available water holding capacity in the subsoil. The following scenario shows the impact of a change in the available water capacity of a subsoil on BMV land:

- Location – south east England
- Climatic moisture deficit for wheat is 122mm and potatoes 118mm
- ***Prior to commissioning***: the profile subsoil has a good structural condition with the resultant crop adjusted water capacity for wheat of 110mm and for potatoes of 89mm.

  The moisture balance limits place the profile in Subgrade 3a

- ***At decommissioning***: the profile subsoil has a moderate structural condition with the resultant crop adjusted water capacity for wheat of 106mm and for potatoes of 85mm.

  The moisture balance limits place the profile in Subgrade 3b.

In more severe cases unremediated soil compaction may prevent root penetration. Occurring at shallow depth this may have a significant impact on crop available water which may result in downgrading by more than one ALC grade. The depth of root penetration can only be assessed by the examination of soil pits.

3.4 Soil Mixing

Soil mixing may occur in the construction and decommissioning phases and is identified in Section 3.3 of the ALC Guidelines (MAFF,1988) as a potential limitation to grade. A study of the effects of golf course development on high quality agricultural land (MAFF,1995) considered the impact of soil mixing on the reversibility of high quality agricultural land. Where mixing of very different soils e.g. sands with clays occurred subsequent agricultural management was potentially difficult. The severity of the impact will depend on the amount of mixing- the ratio of different soil textures and other soil properties such as soil structure, stone content and organic matter content. It is difficult to assess the impact on BMV agricultural land from soil mixing but where it causes significant management problems, post-decommissioning, an independent assessment would be required – both to quantify and to remediate.

3.5 Reversibility or otherwise of the impacts on BMV agricultural land

One of the key impacts on BMV agricultural land is soil compaction, which can vary considerably from very minimal and short term to severe, which possibly cannot be rectified. Compaction in the subsoil below about 45cm is unlikely to be practicable and economic to alleviate (Batey, 2009) and is unlikely to respond quickly to natural recovery through the freeze-thaw cycle. Where compaction is present at depth it is a long-term limitation and it is taken into account in the ALC Guidelines (MAFF, 1988) through reduced permeability in the wetness assessment and crop available water in soil droughtiness assessment. There will be compaction at the time of construction, which may remain for the lifespan of the development. Further compaction may result at the decommissioning phase.

The timescale for reversibility is undefined but is taken in this report as the point at which decommissioning is completed. The time taken for a soil with compaction to recover depends on the severity of the compaction and the soil type. Business Wales (2018) and Froehlich et al (1985) reported that natural recovery of a compacted soil is complex and a slow process. Batey (2009) refers to 30 years for a compacted soil to recover, where ‘industrial’ compaction extends to depths of 1m or more (Spoor, 2006). Hakansson (1988) reported that compaction may be very persistent in the subsoil and permanent. Nawaz et al (2012) presented a review of research and concluded that soil compaction is rapid and easy to create with agricultural machinery but it can be years before the soil is recovered. Keller at al (2017) noted that knowledge regarding soil compaction rates is ‘sketchy’ with experimental evidence of recovery periods from a few months to years and decades. Differences in laboratory and field experiments highlight the ‘partial and incomplete’ knowledge of the key processes involved in soil structure recovery.

Keller et al (2021) undertook research at the Swiss Soil Observatory to quantify and monitor short-term recovery after prescribed compaction. After 2 years it was noted that different soil physical properties follow different recovery paths and rate. Bulk density and air permeability had not fully recovered to pre-compaction values in the topsoil and subsoil. Post compaction recovery rates decreased with soil depth and differed between soil properties.

A study of soil compaction on golf courses (MAFF, 1995) reported that the inappropriate handling of soils resulted in severe compaction and a deterioration of soil structure. In the period 1988 to 1993 construction work, such as soil stripping and trafficking, was undertaken on a number of golf courses during the winter months. A finding of the report was that if soil stripping had been carried out in a more controlled way parts of golf courses might have been practically reversible to an agricultural land quality closer to the pre-construction quality.

A study undertaken by Defra (2016) considered compaction in grassland on 300 grassland fields. The study considered how grassland management may be used to influence soil compaction and how management can be targeted to alleviate or avoid compaction. The careful management of machinery use in terms of when and how many times soils are trafficked was a key influence on the level of soil compaction.

Current techniques for alleviating compaction above depths of 45cm, particularly in drier parts of England and Wales, indicate that some reversibility of the impact on BMV agricultural land is possible. However not all soils respond and silty soils, where there is structural instability, may be problematic.

Where deep compaction occurs in soil the reversibility of the impacts on BMV agricultural land are given in scenarios (sections 3.2.1 to 3.2.4 and Appendix 5). The impact of compaction on disturbed soils and undisturbed soils are assessed separately. In the case of disturbed soils there may not be any compaction if the soils associated with cable trenching are replaced in an unconsolidated condition. There are many unpredictable factors, such as soil strength and prevailing moisture content, that will affect the level of compaction and the potential to successfully alleviate damage.

In the case of compacted soils and the pre-construction Wetness Class I soil, reversibility involves the removal of the slowly permeable layer within 80 cm at decommissioning. The ALC Guidelines (MAFF,1988) consider that '*where significant compaction occurs below 35cm… it may be difficult or impossible to ameliorate practically or economically. Such compaction is therefore a long-term limitation which is taken into account through reduced permeability and water capacity in the wetness and droughtiness assessments*'.

Batey (2009) reports that techniques for loosening compact soils operating to depths of about 45cm are established. In the case of a soil profile in Wetness Class II it may be that the impact on BMV agricultural land is reversible and some loss of versatility is reversed. For example, in the drier parts of England with a FCD of 125 where there is compaction close to a depth of about 45cm and gleying present below a depth of 40cm, then the impact of compaction on BMV agricultural land is normally reversible, with the Wetness Class moving from Wetness Class III to Wetness Class II.

Any soil mixing may impact on BMV agricultural land but each site will have individual characteristics and it is difficult to prescribe for a potential impact. Small amounts of soil mixing should be reversible as the subsoil and topsoil are mixed by cultivation and soil biota but where significant soil mixing does occur the reversibility of the impact on BMV agricultural land becomes increasingly challenging.

4 POTENTIAL IMPACTS (POSITIVE AND NEGATIVE) ON SOILS DURING THE OPERATIONAL PHASE

4.1 Introduction

During the operational phase of the solar PV site there are minimal activities on site and the site is usually unmanned. Routine maintenance at the site may include grass cutting, if grazing does not keep the grass at the optimum height, landscape management (e.g. hedge trimming) and an annual PV panel wash. The electrical systems may be monitored monthly and a grazier to manage stock grazing may access the site. Access is typically by 4x4 vehicles and it is unlikely that any heavy machinery will be required.

Grazing of grassland by sheep required careful management. Excessive stocking rates and / or grazing on soils susceptible to damage during wet weather, may negatively impact the soil during the operation phase and may pose environmental issues such as increased surface water runoff.

4.2 Claimed benefits of topsoil carbon capture and soil structural improvements

Much guidance (BRE, 2013 and 2014a) and many planning applications promote the benefits to biodiversity of solar PV sites.

Agricultural land use change, often from arable use, on BMV agricultural land to low-maintenance grassland, has been cited by developers in planning applications as a benefit arising from solar PV sites. Soil carbon, mainly derived from carbon fixed by plants, is stored in soils in the form of soil organic matter (SOM). SOM is the cornerstone of soil health; it is beneficial to soil structure, the resistance of the soil to erosion, plant / crop available water, plant / crop available nutrients, earthworm numbers, soil microbiology and biodiversity etc. Furthermore, as a carbon store it is of particular importance today and in the future.

Reports of changes in soil carbon resulting from land reversion are reported by Conant et al (2001). More recently Connant et al (2017) have studied data since 2001 and confirm their earlier conclusions that improved grazing management, fertilization, sowing legumes and improved grass species and conversion from cultivation all tend to lead to increased soil carbon (C).

Defra (2009) reported that the quantity of C that can be stored in any soil is finite. Following a change in management practice levels C can increase (or decrease) towards an equilibrium value at about 100 years depending on the soil type, land use and climate. The relatively ‘high’ annual rate of C storage reported in the early years following a land use change from arable use to a grassland use does not continue and the rate of accumulation will decline until a new equilibrium is reached. Where the land use change is from long term grasslands it is expected that the initial properties at commissioning of the solar PV site would be different from short term grassland and arable land.

Maintaining an increased SOM level, due to a change in management practice, will be dependent on continuing that practice indefinitely. Only if land is taken permanently out of arable cultivation or rotation will the benefits of C storage be realised over the long-term. Soil organic matter is more rapidly lost than it is accumulated (Freibauer et al, 2004).

A study by Gosling et al (2017) considered the potential for the conversion of arable cropland to grassland to sequester carbon in the short to medium term. The study reported no difference in soil organic carbon stocks in the top 30cm of the soil profile in grassland up to 17 years old and arable cropland at sites across the UK.

The conversion of tillage to grassland resulted in an increased carbon storage in the range 1.1 to 7.0 CO_2e/ha/year (Dawson and Smith, 2006). Conversion of grassland to tillage cropping was estimated to result in carbon losses in the range 2.2 to 6.0 CO_2e/ha/year. It was also reported that converting areas of farmland to grass buffer strips and hedges/shelter belts would enhance soil organic matter and increase C storage on a smaller scale. The baseline soil reference values prior to commissioning are key to understanding any change in SOM over the lifetime of the solar PV site. The land use and factors, such as the changes in management practices e.g. reduced tillage operations, at each site prior to commissioning impact on the baseline soil reference values and potential level of change in SOM.

The relationship between increased SOM and improved soil structure is documented (Cranfield, 2001) and recognised in land management practices with minimum tillage or no tillage operations (Game and Wildlife Conservation Trust, 2020). It is also recognised that reverting arable agricultural land to low-maintenance grassland will improve soil structure. The term soil structure refers to the shape, size, orientation, degree of development, porosity and consistency of aggregates of soil particles. Structure influences the movement of air, water, carbon, nutrients, roots and microorganisms within soil. An improved soil structure is beneficial to many of the key ecosystem services performed by soils, including regulation of air and water, carbon capture and support of plants.

Choi et al (2020) undertook a study in Colorado USA on the effects of revegetation on soil physical and chemical properties in solar PV infrastructure over a 7- year period. The study found that soils at the solar PV site contained significantly less carbon than the reference soil. This was likely to be caused by the removal of topsoil during the array's construction. The ability of the soil on the site to sequester carbon was diminished relative to reference soils. The study suggested mitigation in the adoption of minimum topsoil disturbance during construction.

Key points from studies on land use changes and soil carbon include:

- The initial increases in the early years do not continue
- To maintain an increase in the level of soil carbon the land has to be taken permanently out of arable cultivation or rotation
- Soil organic matter is more rapidly lost than it is accumulated.

There is limited evidence specifically relating to solar PV sites to confirm the benefits to soil health. Baseline site specific soil reference values are required with long-term monitoring to provide evidence of the changes and legacy in the soil health at a solar PV site over a typical lifetime of 40 years.

Factors such as the disturbance of the soil at the construction phase may impinge the development of benefits through the operation phase. Even in the most successful cases (of soil carbon capture, health and structure improvement), improvements are likely to be only temporary and decrease with disruption at decommissioning and again at the return to arable cropping.

The physical presence of solar PV arrays on land is known to cause seasonal and diurnal variations in air and soil microclimate (Armstrong et al, 2016). The work by Alona Armstrong and her team at Lancaster University, particularly the work of Carvalho et al (2021), is looking at the effect of solar PV sites on soil specific factors, including soil organic carbon, nutrients and pH, bulk density, above ground biomass, soil microbial community etc. The work is in its early stages but managed to survey 35 solar PV sites in England and Wales in 2021 and will survey more sites in 2022. This and further such work could be very instructive.

In summary, further evidence is required to substantiate the benefits of SOM at solar PV sites and the claims cited by developers in planning applications.

4.3 The influence of shading and microclimates beneath panels on soil microbial activity

While the increased levels of SOM are recognised in grassland systems, the full impact of the physical presence of solar PV arrays on grassland management is open for discussion. Armstrong et al (2016) investigated the effects of solar PV arrays on microclimate and the consequences for carbon (C) cycling at Westmill Solar Park. The research found that PV arrays can cause both seasonal and diurnal variation in the ground-level microclimate such that there was an effect on terrestrial C cycling. One of the conclusions of the project is that the effects of solar PV sites on plant–soil processes, which underpin key ecosystem services, is poorly understood.

The microclimatic variability within a solar PV site arises from a lower temperature under the PV arrays. The above ground plant biomass was four times higher in the gap between arrays and the control areas compared to the biomass under the PV arrays. The soil temperature is cooler under the PV arrays and between the PV arrays during the winter due to the interception of shortwave radiation by the solar PV arrays.

The shadow cast by the PV arrays varied from under 2 m in the month of June to just under 11 m in the month of December. The cooling is likely to be significant in terms of ecosystem function with the temperature differences affecting key plant-soil processes from productivity to decomposition (Marrou et al 2013). Thomas et al (2020) expected rising soil temperatures on site would increase soil organic carbon losses due to the increased rates of microbial decomposition.

Recent work in the Netherlands has considered the design of the site layout and the impact on soil (van Aken et al 2021). A comparison of the amount of ground irradiance in terms of intensity and distribution between two south-facing solar park configurations and east-west orientated panels was made. Two variants were made- one with standard solar panels and another with semi-transparent solar panels and bifacial panels. A 77% coverage with semi-transparent and bifacial panels ‘performed better on soil quality’ with a more even distribution of light on the soil than standard panels with a 53% coverage. The study recommended the establishment of criteria for ground radiation under and between panels.

4.4 The influence of solar developments on soil loss and erosion

Soil loss can occur during the construction phase as soil is stripped for the construction of a compound, bases for inverters and substation, and access tracks. Many solar PV site layouts do not plan space for soil storage bunds and propose to spread the soil in thin layers alongside the access track. This leaves the stripped soil barely visible in the landscape and difficult to reclaim at the restoration phase. This approach is likely to contribute to soil loss, as the soil will not be recovered to its original volume at the decommissioning phase.

Across a solar PV site disturbance can cause the loss of the surface vegetation (see Appendices 3 and 4) and this will leave a site far more vulnerable to soil loss from erosion.

Runoff from solar panels has an influence on soil erosion. Water is known to run along the edge of the panels then fall to the ground at localised points and form rivulets. This has the potential to cause soil erosion, the risk of which is strongly influenced by slope and soil type. Choi (2020) reported erosion and one of the case studies in WP2a (Estuary Farm[7]) considered the possibility of runoff from solar panels causing compaction of soils at the base of the panels and resulting in rivulets forming along the edge of the rows of panels. While there may not be a significant increase in runoff, small channels will have formed with potential of soil loss. This problem is likely to be more severe in erodible soils such as sandy soils on slopes before a vegetation cover establishes. However, the steepness of the slope would be an even stronger influence. The risks are repeated at the construction and decommissioning phases.

4.5 A summary of claimed benefits to soil from previous cases (WP 2a case studies)

The case studies referred to in WP 2a have been reviewed for any claimed benefits to soil within the supporting documentation.

- **Tyddyn Cae Solar Farm Gwynedd**[8] – there is reference to a reduction in nutrient input to the land as a result of changing from an arable use to grassland. The statement is made that 'soil health is essential for long term sustainability of farming, and solar farms could play an important role by resting soils through the life of the solar farm, allowing soil nutrients to restore naturally, without the need for regular use of fertilizers.' and reference is made to BRE (2014a).

[7] https://www.west-norfolk.gov.uk/planning_and_development Ref: 21/01432/FM

[8] https://amg.gwynedd.llyw.cymru/planning/index.html?fa=getApplication&id=24205 Ref: C14/0885/33/LL

- **New Works Solar Farm Telford**[9] – the site falls outside BMV agricultural land. There is no reference to claimed benefits to soil. Reference is made to the Solar Energy UK's publication 'The Natural Capital Value of Solar'.
- **Estuary Solar Farm, King's Lynn**[10] – there is no reference to claimed benefits to soil. The proposal is to use an 'under-utilised area of agricultural land' and enhance the 'once arable habitat' with wildflowers and species diverse grassland.

The case studies do not give any site-specific detail on benefits to soil in the supporting documents for the planning application.

[9] https://secure.telford.gov.uk/planning/pa-applicationsummary.aspx?applicationnumber=TWC/2021/0737 Ref: TWC/2021/0737

[10] https://www.west-norfolk.gov.uk/planning_and_development Ref: 21/01432/FM

5 ARE SOLAR PV SITES REVERSIBLE TO AGRICULTURE WITHOUT RESIDUAL (NEGATIVE) IMPACT?

5.1 Introduction

A brief review and summary of the hypothesis: '*that solar PV sites are physically reversible to agriculture without residual (negative impact) in the BMV and Non-BMV context*' is presented. The evidence base to support this hypothesis and the main issues influencing reversion to agriculture are identified.

5.2 Evidence Base

The key residual impact on the land is soil compaction. Defra (2016) reported that careful management of machinery use in terms of when and how many times soils are trafficked was a key influence on the level of soil compaction on grassland.

Current techniques on alleviating soil compaction are effective in the topsoil and upper subsoil, generally above a depth of 45cm (Batey, 2009). The depth of the uppermost compacted layer (e.g. after remediation) may be the determining factor in the realisation of potential agricultural use. Keller et al (2021) provide evidence that the recovery of soil from compaction was longer than 2 years. Compaction may be very persistent in the subsoil and possibly permanent (Hakansson et al 1988). Where there is 'industrial' compaction the depth of compaction can extend to depths of 1 m (Spoor, 2006) and may persist for up to 30 years (Batey, 2009). A review by Nawaz et al. (2021) refers to time scales of 5 to 18 years for soils to recover from compaction with the aid of agricultural machinery and for soil to recover from compaction naturally (without aid) 100 to 150 years.

At the point of decommissioning there is likely to be a residual impact of soil compaction across solar PV sites. The impact may affect the agricultural use of the land and decisions about cropping and yields.

Soil mixing has been reported by Choi (2020) where there was a greater fraction of coarse particles in the study solar PV site soil than the reference soil. It was considered that the difference arose during the construction phase, when the topsoil was disturbed and fine soil particles were lost by water erosion. Soil mixing has potential to occur at other stages in the life of a solar PV site, such as pile extraction.

5.3 The main issues influencing reversion to agriculture

At decommissioning all materials are expected to be removed including the removal of piles from the soil. Most standard steel products corrode, particularly in the upper part of the pile and this may adversely affect the ability to extract the piles after 40 years. (Non-corrosive materials could be used but have cost implications). It may be that piles fracture and are difficult to extract without additional digging. An engineering solution, where extraction is adversely impacted, would be to partially cut down the piles and provide a capping layer of soil (per comm. P Woodfield, Technik GS). Any residual piles are likely to have a negative impact on whether the land is physically reversible to agriculture unless buried sufficiently deep to enable cultivations and drainage. Where residual piles could not be buried to a depth to allow cultivations the grading of the land would take into account the severity of the limitation. Land with severe or very severe limitations, which restrict the range of crops, is placed into either Grade 4 or Grade 5 in the MAFF Agricultural Land Classification system. To bury the piles to a sufficient depth would mean excavating to a depth of at least 1.0-1.2 metres. This would result in significant soil disturbance if many of the piles were affected in this way.

Where galvanised beams are used zinc is present in the galvanised coating. There are two methods of galvanising used- 'continuous galvanising' and 'batch hot dip galvanising' (per. comm. A Whalley, Milestone Communications). Continuous galvanising (DIN EN 10327) gives a thinner coating, so the expected life is lower. If the beams are batch hot dip galvanised then standard ISO14713-1 applies, which includes reference to exposure to soil. Corrosion in soil is dependent on the soil's mineral content, the nature of the minerals and organic components and the water and oxygen contents. The impact of any interaction between the piles and the soils and potential loss of zinc coating over 40 years and whether there is any residual impact may need to be considered (per. comm J Williams, ADAS). Guidance from Defra (2018) on the use of sewage sludge on land states that the maximum quantity of zinc that can be applied per ha is 150kg over 10 years. Potentially any loss of zinc from piles could be well within this limit, but there is no supporting evidence. There is also evidence that high zinc levels in soils affects the soil biological activity (Moffett et al, 2003).

Handling soil in suitable conditions has an influence on the reversion of land to agriculture. Different soil textural classes have more resilience to structural damage and are more responsive to remediation during soil handling. Light textured soils e.g. sand, loamy sand, sandy loam and sandy silt loam have a higher resilience to structural damage than medium texture soils e.g. soil with 18-27% clay content. Silt loam soils and heavy soils with >27% clay content have a low resilience to damage. Soil should only be handled or trafficked when as dry and as friable as is practicable. If handled or trafficked in adverse conditions damage to the soil structure can easily occur.

The period available for soil handling and trafficking on a solar PV site can influence the impact on the soil, the resultant structural damage and reversion to agriculture. The Institute of Quarrying (2021) has prepared a map of England and Wales showing climatic zones when vegetated mineral soils may be in a sufficiently dry condition according to their geographic location, depth of soil and clay content. When the clay content is between 10% and 27% in the topsoil in Wales, the South West and North of England the indicative on-average period when soils may be in a sufficiently dry condition for handling is generally late May to early October. For similar soils in central parts of England it is generally late April/early May to early November, while in the East of England it is generally late April to early December. The location of the proposed solar PV site and susceptibility of a soil type to structural damage should be considered at the design stage to ensure timeliness of soil handling and trafficking. A soil in West Wales with a medium clay loam texture and clay content of 24% will have a shorter window for soil handling and trafficking than the same soil in East Anglia. The impact of climate and climatic zones should be built into the design statement at the pre-planning stage of a site.

A research study into end of life decision making for solar farms (Windemer,2021) reported that there may be changes in ownership of the solar PV site with a change in the priorities for the site. The study considered finance for decommissioning, reporting that bonds are not always used in the solar sector as it is 'felt that decommissioning will not present a challenge'. The study found that some developers considered that decommissioning may be self- funding through the resale value of equipment and materials from the site. A sample decommissioning plan (Solar Energy UK, 2022) refers to the provision of a decommissioning fund either through a surety bond, an irrevocable standby letter of credit or other financial security.

Developers may consider that the scrap value of the panels etc on site will cover the costs of decommissioning. There are few contingency plans in place and should operators encounter financial instability and the economics of solar PV change during the project life and trigger early decommissioning then this may influence the reversion of the site to agriculture and other changes of land use may be sought.

Finances available for decommissioning are part of the responsibility of the operator or landowner or both and can influence the reversion to agriculture. It is the responsibility of the planning authority to ensure that the developer or landowner has secure finances or a bond in place to fund decommissioning.

5.4 Summary

There is evidence that soil compaction from machinery can have a residual impact on soil and land. Soil mixing may occur during construction and in the voids left after piles are extracted. Soil compaction and mixing may result in issues for land management. Removal of physical infrastructure on site and re-instatement of soil/land is necessary if the land is to be capable of reversion to a BMV agricultural land quality as well as a non BMV agricultural land quality.

The finance available for the required decommissioning and the timings of these operations may be an influencing factor on the reversion to agriculture. There may be financial constraints, time penalties and contractual performance issues that affect the decommissioning programme and the quality of remediation works.

6 THE PARALLELS BETWEEN MINERAL SITE RESTORATION AND SOLAR PV SITE RESTORATION

There are a few parallels between mineral site restoration and solar PV site restoration. In both situations soil will have been subject to stripping, some form of storage and then spreading over a subsoil. Subsoil compaction is likely to be found in both situations.

There are significant differences in the approach to restoration undertaken.

- Mineral site restoration is detailed as part of the planning application stage, supported by a soil resource management plan and restoration is subject to a statutory aftercare period of 5 years. There is published guidance for solar PV sites (BRE, 2013) recommending that a soil resource management plan be prepared as part of the planning application. Where soil resource plans have been prepared they have usually been undertaken as a condition of planning approval.
- While mineral sites require planned soil storage in the form of bunds many solar PV site layouts do not typically accommodate soil storage in bunds within the site and soil may be spread thinly alongside access tracks on undisturbed land.
- Solar PV site restoration involves the pull out of piles with soil disturbance at the decommissioning phase.
- Only part of a solar PV site generally requires restoration with soil spreading. Most of the area is not disturbed by soil stripping but is subject to trafficking and therefore may be compacted. Mineral site restoration good working practices involve spreading the soil in such a way that trafficking is minimised but all the soil is disturbed leading to a greater disturbance of soil structure and soil biota.

In summary, there are significant differences between mineral site restoration and solar PV site restoration. The main parallel is the need for a soil management plan to protect the soil resource.

7 THE PARALLELS BETWEEN GOLF COURSES OR SIMILAR SOFT USES AND SOLAR PV SITE RESTORATION

There are very limited documented experiences of the reversibility of golf courses to agriculture.

Parallels between golf courses and solar PV sites can be found where there is site levelling and movement of soil. Golf course restoration to agriculture may involve the importation of fill and some land levelling. Fill may also have been imported at the golf course construction stage. Landscaping forms part of both golf course development and solar PV site.

The presence of physical infrastructure on a solar PV site where there may be a high density of piles (e.g. 492 piles per ha) and extensive lengths of trenching for cables are significant differences. The extent of constructed infrastructure on solar PV sites may be greater than on a golf course. The impact of compaction from trafficking would be expected to be greater on a solar PV site than a golf course development, although surface sealing on golf courses can be an issue due to footfall.

A study (MAFF,1995) reviewed the effect of golf course development on Grades 1, 2 and 3a land. The potential adverse effects that impact on high quality agricultural land are from earth moving during construction, soil mixing, sterilisation of land and construction of clubhouses and car parks. The impact of a golf course on land was defined as 'high' (more than 50% of the land irreversibly lost) to 'low' (10 to 25% of the land irreversibly lost). In the study 'irreversible' was defined as the *'ability to restore a site to a similar agricultural land quality which existed prior to development. It is not just the ability to restore land back to agricultural use'*.

The greatest irreversible loss of high quality agricultural land on golf courses resulted from earth shaping and sterilisation of land. Golf courses with the lowest impact used existing landform with little disturbance to the agricultural land. Soil mixing and compaction tended to be localised and the impact on the ALC grade of the land was variable. The study found that golf course constructions on over 30% of the courses took place in the winter period when conditions for soil handling were not suitable. The impact on high quality agricultural land and the reversibility to a similar grade was influenced mainly by the disturbance of the soil through earth moving.

Both golf courses and solar PV sites are presented as being reversible to an agricultural use.

The parallels for restoration between golf courses and solar PV sites include the disturbance of soil, soil mixing, trafficking of the land and unsuitable conditions for soil handling and trafficking during the construction, operation and decommissioning phases.

8 CAN SOIL HANDLING CONDITIONS, AS PART OF THE PLANNING PROCESS, MITIGATE OR REMOVE THREATS TO SOILS AND LAND

8.1 Soil Handling Conditions

Soil is moved through stripping, storage and replacement operations at the construction and de-commissioning phases of a solar PV site. Soil handling will be part of the construction of the site compound, access roads/track, bases for inverters and substations and cabling operations.

A soil resource assessment, undertaken as part of the pre-planning stage, gives a baseline of existing soil conditions on site. The assessment will identify different soil types and soil handling units, which will be required to be stripped, stored and replaced in discrete areas. Planning guidance on large scale ground mounted solar PV sites (BRE, 2013) recommends inclusion of a methodology for stripping, storage and replacement of soil within the developer’s planning application. The Institute of Quarrying guidance on soil handling (Institute of Quarrying, 2021), applicable to the civil engineering and the wider construction sectors, refers to the need for a soil resource and management plan (SRMP) at design stage through to site closure. Defra’s Code of Practice for the Sustainable Use of Soils on Construction Sites (2009) recommends the inclusion of a soil resource plan as part of pre-construction planning.

From the evidence ADAS has seen, it appears that the preparation of a soil resource and management plan (SRMP) for solar PV sites has usually been a condition of the planning permission granted by the planning authority – i.e. as a condition of permission rather than being prepared to support the planning application. The responsibility for the standard and quality of the SRMP lies with the planning authority.

The SRMP considers the management of soil at the construction phase and is a separate document to a decommissioning plan, which is generally conceived at a much later stage of the project life. From the perspective of protecting the soil resource the two documents should be closely intertwined.

While the preparation of a SRMP may meet a condition of the planning authority, on its own it cannot mitigate or remove the risks of harmful impacts on soil and land or be a guarantee for a successful outcome. The key to mitigation is how the SRMP is implemented, the time of year when construction work is undertaken and the day-to-day management on site during soil handling and trafficking. ADAS experience on infrastructure projects has shown that the on-site presence of a soil scientist can ensure that soils are stripped at the appropriate depth and in suitable conditions for soil handling. A recording of soil stripping movements and storage locations should be made.

The lifespan of a solar PV site is generally around 40 years. To safeguard the soil resources for this number of years any soil stripped is best placed in planned storage bunds within the site boundary and a record of soil type and volume in each bund made. The physical and chemical conditions of the soil are likely to have changed from the pre-construction (pre-storage) baseline. Storage can cause a reduction in soil porosity and structure. The preparation of a remediation plan with an aftercare programme as a condition of planning permission will give details on soil handling, but the implementation is key to the outcomes.

8.2 Restoration of BMV agricultural land

A research project undertaken in the 1990s considered the quality of agricultural land at the post restoration stage for a number of mineral sites (Defra, 2000). The study included 34 sites with best and most versatile agricultural land quality and of these about half had maintained their pre-working grade at the start of the 5-year aftercare period and the majority had maintained or improved the grade at the end of the 5-year aftercare period. On these sites the soil was worked in phases over a much shorter period than a solar PV site lifespan and therefore was not in long-term storage.

There are many factors that can influence the outcome of restoration of Best and Most Versatile (BMV) agricultural land and these may include:

- The inherent soil properties and variability across the site
- The amount and duration of climatic wetness
- The daily weather conditions and the soil moisture assessment prior to and during soil handling with appropriate soil handling decision making
- Soil resource and management planning at an early stage in the planning process
- Trafficking the land when soils are in suitable conditions
- Recording details (soil type, volume) of stored soils
- Using appropriate machinery in suitable conditions.

Commercial pressures can influence a restoration programme, resulting in work taking place in unsuitable conditions, resulting in damage to the soil and potentially loss of BMV agricultural land.

The condition of the soil after removal from stockpiles will be a key factor in the realistic restoration of sites with BMV agricultural land. A programme of aftercare with finances provided to cover associated costs is essential if a there is to be a realistic restoration to BMV agricultural land.

At present the decommissioning of a solar PV site covers the removal of all physical infrastructure. Some developers refer to returning the site to its pre-development condition but give limited details. A detailed decommissioning plan is not required by planning conditions until near the end of the life of the site. The detail of a soil resource and management plan should inform the decommissioning plan.

Many solar PV sites change management over the period of operation and the agreements and responsibility for decommissioning at the granting of planning permission should be taken forward to the site closure.

It is important to note that soil is naturally fragile and restored soils remain particularly vulnerable for a variable period until the new soil structure has stabilised. This means that, even if all the correct plans and procedures are put in place and followed with best practice by all contractors during all phases, restoration of disturbed soil may still fail. This may occur when high rainfall causes prolonged waterlogging before the new soil structure has stabilised and causes the soils to slump.

8.3 BMV v non-BMV agricultural land

It is important to note, despite the risks of the construction, operation and decommissioning phases to BMV agricultural land, that in many instances the soils on BMV agricultural land may potentially be easier to restore after decommissioning than non-BMV. However much depends on the site location and interactions between climate and soil.

Non-BMV agricultural land, i.e. Subgrade 3b, Grade 4 and Grade 5, is described as moderate, poor and very poor quality land respectively. It has physical or chemical limitations ranging from moderate to very severe. On any land with heavier soil types in wetter, cooler climates the soil is likely to be more susceptible to damage during the construction, operation and decommissioning phases. There will be a shorter safe window for construction, decommissioning, aftercare and even sheep grazing through the operational phase. Where droughtiness is the main limitation the characteristics of a sandy soil profile with a moderately stony subsoil may be altered during soil handling and affect the water holding capacity of the soil profile at decommissioning, leading to a change in the ALC grade.

The management history of non-BMV agricultural land will influence the baseline soil reference values and the potential carbon capture benefit of solar PV sites. Land in Subgrade 3b may be used for cereals or grass, while land in Grade 4 may be used for grass with occasional arable crops. Land in Grade 5 is typically limited to permanent pasture or rough grazing.

There may also be greater environmental risks during construction, operation and decommissioning on non-BMV agricultural land. Soils may be at field capacity or have a clayey or silty soil texture with a landform resulting in surface water runoff. In such instances there may be a greater risk of soil erosion and pollution of water courses.

Key to managing the risks at any site is an adequate soil resource and management plan tailored to the individual site which is adhered to by contractors and which flows into an appropriate, and appropriately funded, decommissioning plan, including aftercare as required.

9 TYPICAL PLANNING CONDITIONS FOR RESTORATION OF AGRICULTURAL LAND

Planning conditions may be put in place by the planning authority to address matters of soil handling, storage, replacement and aftercare. An outline soil resource and management plan should be prepared taking into account an overview of the typical planning conditions, with attention to the times of soil handling. A detailed plan should be prepared as required, taking into account typical planning conditions. The potential planning conditions should be considered at the planning stage of the solar PV site and the limitations imposed on soil handling by soil and climate interactions. Welsh Government (2014) give an example of conditions applicable to solar PV development. These conditions are reproduced below and can be linked to the three phases in the life of a solar PV site.

9.1 Whole Lifetime site Condition

General Handling of Soils

All soils shall only be stripped, handled, stored and replaced in accordance with document *(insert ref.)* dated *(insert date)* except as modified by this schedule of conditions or unless otherwise agreed in writing with the Local Planning Authority. *Reason: To prevent loss or damage of soil, or mixing of topsoil with subsoil, or subsoil with aggregate or mixing of dissimilar soil types.*
Topsoil shall be stripped to a depth of *(insert ref. / mm)*, subsoil shall be stripped to a depth of not less than *(insert ref. / mm)* and they should be stored separately in mounds within the site. *Reason: To prevent loss of soil, and ensure the direct replacement of soil*
All topsoil and subsoil shall be permanently retained on site and used in restoration. *Reason: To prevent loss of soil.*
In each calendar month, the Local Planning Authority shall be notified in writing at least 7 days before each of the following stages: (a) Before each phase of soil stripping is due to commence; (b) When soil subsoil has been prepared ready for topsoil replacement to allow inspection of the area before further restoration of this part is carried out; and (c) On completion of topsoil replacement *Reason: To ensure that the Local Planning Authority is given opportunity to check that soil operations do not occur under unsuitable conditions and to provide sufficient notice for site inspection.*

Soil Stripping

In each calendar year, soil stripping shall not commence on any phase until any standing crop or vegetation has been cut and removed. *Reason: To avoid incorporation of concentrations of decaying vegetation in soil.*
Topsoil and subsoil shall only be stripped when they are in a dry and friable condition. The developer shall give 48 hours notice to the Planning Authority of the intention to carry out any soil movement operation and no movement of soils shall occur: (a) During the months May to October (inclusive), unless otherwise agreed in writing with the Local Planning Authority; and, (b) Topsoil and subsoil handling for the restoration of land to agriculture, shall cease during rain, applying the following criteria: (i) If there is light rain or drizzle, handling can proceed for up to four hours unless the soils are already in too moist a state (see tables below); (ii) If there is light rain, handling will cease if the rain has not stopped in 15 minutes; (iii) If there is heavy rain (as from intense showers, slow-moving depressions) handling shall stop immediately; (iv) If sustained heavy rainfall (e.g. ≥10mm in 24 hours) occurs during soil stripping operations, work must be suspended and not re-started until the ground has had at least a full dry day or agreed moisture criteria (see below) can be met; (v) Soil shall not be handled or trafficked during or shortly after heavy precipitation (including rain, snow and hail) in a waterlogged condition, and when there are pools of water on the ground surface; and (vi) After rainfall has ceased, field tests shall be applied to determine when handling may re-start *Reason: To prevent damage to soils.*

9.2 Construction Phase

Soil Storage

All topsoil and subsoil shall be stored in accordance with document *(insert ref.)* dated *(insert date)* and in separate mounds which shall: (a) Not exceed 3 metres in height in the case of topsoil, or exceed 5 metres in height in the case of subsoil unless otherwise agreed in writing with the Local Planning Authority; (b) Be constructed with only the minimum amount of soil compaction to ensure stability and shaped so as to avoid collection of water in surface undulations; (c) Not be subsequently moved or added to until required for restoration unless otherwise agreed in writing by the Local Planning Authority; (d) Have a minimum 3.0 metre standoff, undisturbed around each storage mound;

(e) Comprise topsoils on like texture topsoils and subsoils on like texture subsoils;

(f) In the case of continuous mounds, ensure that dissimilar soils are separated by a third material, which shall have previously been agreed in writing by the Local Planning Authority.

Reason: To prevent the loss of soil and minimise damage to soil structure during storage.

Prior to soil stripping and formation of storage mounds, a scheme for grass seeding and management of all storage mounds that will remain in situ for more than three months shall be submitted for the written approval of the Local Planning Authority. Seeding and management of the storage mounds shall be carried out in accordance with the approved details.

Reason: To protect mounds from soil erosion, prevent build up of weeds in the soil and remove vegetation prior to soil replacement

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Within three months of completion of soil handling operations in any calendar year, the Local Planning Authority shall be supplied with a plan showing:

(a) The area stripped of topsoil, subsoil and soil making material;

(b) The location of each soil storage mound; and

(c) The quantity and nature of material therein.

Reason: To facilitate soil stock taking and monitoring of soil resources

9.3 Temporary Compound Decommissioning

Soil Replacement

Soil material shall be placed in accordance with the approved scheme. Any alteration to this working method shall only be carried out with prior approval from the Planning Authority.

The soil material (topsoil and subsoil) set aside for use in the agricultural restoration shall be spread uniformly and in correct sequence.

The soil profile in all areas restored to agricultural after use shall be in accordance with the approved scheme. Any intention to alter this soil depth will require prior approval from the Planning Authority.

All operations to move and place soil material shall be carried out only when such material is in dry and friable condition and ground conditions are dry and firm. The developer shall give 48 hours notice to the Planning Authority of the intention to carry out any soil movement operation, and no movement of soils shall occur:

(a) During the months May to October (inclusive), unless otherwise agreed in writing with the Local Planning Authority; and,

(b) Topsoil and subsoil handling for the restoration of land to agriculture, shall cease during rain, applying the following criteria:

(i) If there is light rain or drizzle, handling can proceed for up to four hours unless the soils are already in too moist a state (see tables below);

(ii) If there is light rain, handling will cease if the rain has not stopped in 15 minutes; (iii) If there is heavy rain (as from intense showers, slow-moving depressions) handling shall stop immediately; (iv) If sustained heavy rainfall (e.g. ≥10mm in 24 hours) occurs during soil stripping operations, work must be suspended and not re-started until the ground has had at least a full dry day or agreed moisture criteria (see below) can be met; (v) Soil shall not be handled or trafficked during or shortly after heavy precipitation (including rain, snow and hail) in a waterlogged condition, and when there are pools of water on the ground surface; and (vi) After rainfall has ceased, field tests shall be applied to determine when handling may re-start The site shall be restored only in accordance with the approved *(insert ref)* Plan and all items therein shall be maintained to the satisfaction of the Planning Authority for a period of 5 years. Maintenance shall include the re-seeding of any areas of grassland that are in unsatisfactory condition in the view of the Planning Authority. *Reason: To ensure that the site is reclaimed in an orderly manner to a condition capable of maintaining the BMVAL[11] status.*
All structures, buildings, debris and mounds shall be removed from the site on completion of permission. Compounds and access tracks shall be ripped and any resulting spoil removed from the site and the access removed unless otherwise agreed in writing with the Local Planning Authority.

9.4 Decommissioning Phase End of Life

Soil Replacement

Soil material shall be placed in accordance with the approved scheme. Any alteration to this working method shall only be carried out with prior approval from the Planning Authority. The soil material (topsoil and subsoil) set aside for use in the agricultural restoration shall be spread uniformly and in correct sequence. The soil profile in all areas restored to agricultural after use shall be in accordance with the approved scheme. Any intention to alter this soil depth will require prior approval from the Planning Authority. All operations to move and place soil material shall be carried out only when such material is in dry and friable condition and ground conditions are dry and firm. The developer shall give 48 hours notice to the Planning Authority of the

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	intention to carry out any soil movement operation, and no movement of soils shall occur: (a) During the months May to October (inclusive), unless otherwise agreed in writing with the Local Planning Authority; and, (b) Topsoil and subsoil handling for the restoration of land to agriculture, shall cease during rain, applying the following criteria: (i) If there is light rain or drizzle, handling can proceed for up to four hours unless the soils are already in too moist a state (see tables below); (ii) If there is light rain, handling will cease if the rain has not stopped in 15 minutes; (iii) If there is heavy rain (as from intense showers, slow-moving depressions) handling shall stop immediately; (iv) If sustained heavy rainfall (e.g. ≥10mm in 24 hours) occurs during soil stripping operations, work must be suspended and not re-started until the ground has had at least a full dry day or agreed moisture criteria (see below) can be met; (v) Soil shall not be handled or trafficked during or shortly after heavy precipitation (including rain, snow and hail) in a waterlogged condition, and when there are pools of water on the ground surface; and (vi) After rainfall has ceased, field tests shall be applied to determine when handling may re-start The site shall be restored only in accordance with the approved *(insert ref)* Plan and all items therein shall be maintained to the satisfaction of the Planning Authority for a period of 5 years. Maintenance shall include the re-seeding of any areas of grassland that are in unsatisfactory condition in the view of the Planning Authority.
Reason: To ensure that the site is reclaimed in an orderly manner to a condition capable of maintaining the BMVAL status.	
	All structures, buildings, debris and mounds shall be removed from the site on completion of permission. Compounds and access tracks shall be ripped and any resulting spoil removed from the site and the access removed unless otherwise agreed in writing with the Local Planning Authority.

Aftercare

	An agricultural aftercare scheme outline strategy shall be submitted for the written approval of the Local Planning Authority at least three months before spreading of subsoil commences. The strategy shall provide for: (a) The physical characteristics of the land to be restored, as far as it is practical to do so, to what they were when the land was last used for agriculture; (b) A five year period of aftercare, specifying the steps to be taken and the period during which they are to be taken, and who will be responsible for taking those steps. The scheme shall include provision of a field drainage system; (c) A detailed annual programme, to be submitted to the Local Planning Authority
Reasons: To ensure the land is capable of retaining its BMVAL status.	
	Before the start of the calendar *year* and every subsequent year during the aftercare period, the operator shall provide the Local Planning Authority and the landowner/occupier with a detailed annual programme for the approval of the Local Planning Authority including: (a) Proposals for managing the land in accordance with the rules of good husbandry including planting, cultivating, seeding, fertilising, draining, watering or otherwise treating the land for the forthcoming 12 months; (b) A record of aftercare operations carried out on the land during the previous 12 months.
Reasons: To ensure the productive afteruse of the land.	
	Before *(insert date)* of every year during the aftercare period, unless otherwise agreed with the Local Planning Authority in writing, a site meeting shall be arranged by the operator, to which the Local Planning Authority and the landowner/occupier *(including the Welsh Government)* shall be invited to monitor previous performance and to discuss and agree future aftercare proposals. The meeting shall also be attended by the person(s) responsible for undertaking the aftercare steps.
Reasons: To ensure the productive afteruse of the land.	
	Aftercare operations shall be carried out in accordance with the submitted aftercare scheme unless otherwise agreed in writing with the Local Planning Authority.
Reasons: To ensure the productive afteruse of the land.	

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APPENDIX 1 – Project Brief

Soil Policy Evidence Programme SPEP 2021-22/03

The impact of solar photovoltaic (PV) sites on soil and agricultural land quality.

VERSION 2 (Draft)

Introduction:

Solar photovoltaic (PV) sites started commercial distribution in the UK in 2007. The number of solar photovoltaic sites in the UK has increased from c. 1700 in 2010 to just over one million in 2019 https://www.statista.com/statistics/418830/number-of-solar-photovoltaic-installations-uk/.

It appears there has not been any systematic review of the impact of these sites on agricultural land, Best and Most Versatile (BMV) land and associated soils. The SPIES project is useful background though soil does not feature heavily https://www.lancaster.ac.uk/spies/. Similarly, the Armstrong *et al* (2016) paper: *Solar park microclimate and vegetation management effects on grassland carbon cycling* https://iopscience.iop.org/article/10.1088/1748-9326/11/7/074016 is useful background.

Solar PV sites can involve significant soil disturbance in installation, operational phase and decommissioning. A recent proposed 34ha site in Wales involved 70,000 solar panels with 140,000 piles driven into the soil to 1.8 metres, 1.75km of access track and 3.5km Security fencing (boundary measurement), plus associated cabling. Because solar PV energy is relatively new, there are no UK examples of decommissioned sites.

There are questions on the reversibility of these sites back to agriculture and the longer term impact on associated land and soil. There are claimed improvements to some soil properties (e.g. increased carbon storage and improved soil structure). However, are these simply just short term for the period of the scheme?

The impact of mineral sites (e.g. sand and gravel extraction / restoration) is reasonably well understood and with field experience. This is not the case for solar PV sites, partly because the decommissioning timescales are long (c40 years) and the evidence does not yet exist. Can parallels could be drawn with other developments such as golf courses, gas pipelines, and pylons. Similarly, are there parallels with horticultural activities such as grubbing out orchards and glasshouse removal? What impacts do these have on soil, how are effects mitigated and how successful are restorations?

This review is to provide an evidence based assessment of the impact of solar PV sites on agricultural land, Best and Most Versatile (BMV) land and associated soils. The scope of the study should be within the UK but look to international experience where possible. The study will inform Welsh Government and Natural England specialists when dealing with solar PV applications.

The review could be used as evidence at planning appeals. Consequently, clarity and accessible is really important, despite the likely complexity of some technical content.

It is anticipated the work will form 4 work packages (WPs):

Work Package 1: Literature review

This work package will:

1. Identify and review any relevant research or experience related to impacts of solar PV developments (published or anecdotal) on land and soil, within the UK or internationally.
2. Identify and review any relevant research or experience, related to (e.g.) golf courses, glasshouse removal, grubbing out of orchards or similar developments / activities (published or anecdotal) on land and soil, within the UK or internationally.
3. Identify and review the key research and experience relating to mineral developments on land and soil, within the UK and internationally.
4. Host a virtual workshop with key soil specialists in the area and record key findings. The key outputs from this need to be recorded as part of the contract.
5. Summarise key findings in a clear and accessible format.

Work Package 2: Description of Solar PV site history and development stages

This work package is intended as a short and simply a statement of facts, rather than in depth interpretation:

1. Provide a summary history of solar PV sites development in the UK. This should include date introduced, number of sites over time and basic explanation of how solar PV sites work. It would be useful to know approximately how many applications there have been (split by UK country), some information on range of site size, preferred types of location, and whether cumulatively large amounts of BMV are likely to be involved. Is the average size of sites increasing?
2. Identify and summarise the main interventions to land and soil with solar PV sites at installation (e.g. pile driving, panel installation, cable laying, track-laying & fencing). Averages (e.g.) of piles / ha or metres of buried cable / tracks / ha would be useful as context. Use of case studies could help. It will be important to summarise the potential levels of disturbance and any differences between different types of site.
3. Identify and summarise the potential benefits and threats to land and soil during the operational phase of the site. Claimed benefits are (for example) topsoil carbon content increases and soil structure improvements.
4. Identify and summarise the main interventions to land and soil when decommissioning sites (e.g. soil disturbance linked with equipment removal).

Work Package 3: Review of Solar PV site impacts on land and soil:

This Work Package is the main review of impacts. It will largely be based on WPs 1 & 2.

1. Review and summarise the main threats to soil and land associated with solar PV site developments. This will need to assess commissioning and decommissioning phases. Assessment of impacts on BMV land - and its reversibility - will be very important.
2. Review and summarise potential effects (positive and negative) on soils during the active phase of the site. Claimed benefits are (for example) topsoil carbon content increases and soil structure improvements. Are such claims realistic and are they only likely to be short term for the duration of the active site? What are the effects of shading and changes in soil microbial activity and microclimates under the panels? Armstrong et al (2016) is useful background: https://iopscience.iop.org/article/10.1088/1748-9326/11/7/074016. What effect does 'rilling' have on soil loss / erosion, accelerated run-off and in creating differential areas of soil

wetness? A discussion of short term changes in soil properties vs long term physical limitations (as in ALC) would be useful. A summary of claimed benefits to soil from previous cases would be very helpful.

3. Review and summarise to what extent evidence supports solar PV sites are physically reversible to agriculture in the BMV and non BMV context. What are the main issues and what evidence is there to support this? What factors influence reversibility (e.g. soil handling conditions, monitoring, soil types & climate).
4. Discuss the parallels between mineral site restoration and solar PV site restoration? Are the two comparable or do significant differences exist?
5. Discuss the parallels with golf course or similar type developments or activities and their reversibility. Are these comparable or do significant differences exist? IN Wales, Technical Advice Note 6 "TAN 6" (para 6.2.2) - Planning for Sustainable Rural Communities says, *"once agricultural land is developed, even for 'soft' uses such as golf courses, its return to agriculture as best and most versatile agricultural land is seldom practicable".*
6. Discuss to what extent soil handling conditions, as part of the planning process, can mitigate or remove any threats to soil and land. Can BMV sites realistically be restored to BMV and what factors influence this? Again, differences between sites will be useful to discuss.

Work Package 4: Summary of key issues and recommendations for future work

Based on the above work packages:

1 Summarise the key findings from this work. A non-technical executive summary is needed.

2 Identify evidence / knowledge / experience gaps.

3 Recommend what future work is needed to better understand the impacts of solar PV sites on soil and land.

APPENDIX 2 – Evidence Provided by Solar Energy UK

Project	Details	Wales	Information on Construction Methodology, Mitigation Techniques	Visual evidence of imagery of site impacts during construction	Construction method statements	Soil Management Plans	Evidence of soil quality improving on sites	Evidence of decommissioning requirements and provisions made for existing projects	Any further comments?
Cleve Hill Solar Park	Graveney, Kent	No	**> 'Cleve Hill Solar Park - Outline Construction Environmental Management Plan'** **Access to document** https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010085/EN010085-001554-CHSP%20-%20D6%20-%206.4.5.4.pdf **Please take specific note to 3.4(64),4.3(78). 5.5(105), 6.1 (107,108,109) and Appendices, particularly appendix E which outlines LBMP construction mitigation measures. (Appendix E - LBMP)** **>'Cleeve Hill - Environment Statement'** **Access to document -** https://drive.google.com/drive/folders/1bKEBKmZv9SqFz4K8DAlElc80Bz-1gDTF **Please take specific note to 5.5.4**		**Updates to existing documents outline construction environmental management plan revision E'** **Access to document -** https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010085/EN010085-001554-CHSP%20-%20D6%20-%206.4.5.4.pdf			> **'Cleve Hill Solar Park - Environmental Statement'** 9.5.2.6 Deposition of dust 171. Fugitive dust emissions and track-out dust during construction and decommissioning have the potential to affect ecological receptors. Chapter 16: Air Quality of the ES provides an assessment of the potential effects of the impacts of dust emissions and track-out dust. The assessment concluded that in the absence of mitigation, there was a low risk of dust soiling to ecological receptors as a result of the earthworks and trackout and a negligible risk from the construction works (building of substation, control building, battery storage units, transformers and solar panel installation). Decommissioning effects were assessed to be similar in nature and no greater than those predicted for the construction phase.	**Full Preliminary Environmental Information Report can be accessed here.** https://drive.google.com/drive/folders/1lE-fACqMlJCzrf9v0dn8DYUed6WY9xU9
Botwwnog Solar Farm	Gwynedd, 5MW	Yes	**'Soils and Agricultural Land Classification'** **Access to document - as**		**Construction Method Statement - (Proposed)**	**Soils and Agricultural Land Classification'** ***Document sent**			**Landscape and Visual Impact Assessment -** **Access to document - see zip file.**

			attached. **Please pay particular reference to 7.3.1, 7.3.2,7.3.3**		**Access to document as attached.**	**as attachment*** **Please pay particular notice to 2.2.1,**			**Please pay particular notice to chapter 7 (7.1.1-7.1.5) and chapter 10.**
Bypass Solar Farm	Lincolnshire49.9MW	No	**Ecological Impact Assessment Report Access to document** http://bypassfarmsolar.com/documents/update110920/12904_r01a_eia_as_mm_210820_compressed.pdf**Please pay particular attention to:**(4.12,4.36) No solar panels are proposed adjacent to watercourse WC1, or within the RPA of hedgerows and trees, minimising the potential for impacts to this habitat. However, the ditch and hedgerows within the site could be affected during construction by soil compaction from machinery, which could impact on the root systems, and/or by accidental damage. As such, they will be fenced and protected during construction in accordance with best practise guidance detailed in BS 5837:2012 'Trees in relation to design, demolition and construction'(British Standard, 2012) to reduce potential for impacts and accidental damage., , page 21)**Flood Risk AssessmentAccess to the document** http://bypassfarmsolar.com/documents/update110920/14516_hyd_xx_xx_rp_fr_0001_p02_bypass_farm.pdf **Please refer to page 9** of the assessment which outlines mitigation techniques			**Planning Statement, Proposed Solar farm, land at Bypass Farm, South of A1 Bypass** http://bypassfarmsolar.com/documents/update110920/bypass_farm_solar_planning_statement_v3.pdfPlease take note to point **2.1.6**			**Full planning documents can be found here** http://bypassfarmsolar.com/downloads/

			regarding to construction and soil compacting/surface run off.						
Low Farm Solar Farm	West Yorkshire, 49.9MW		**Construction Traffic Management Plan'Access to the document** https://www.boom-power.co.uk/wp-content/uploads/2021/10/General_896661-17298-HYD-XX-XX-RP-TP-P004-Construction-traffic-management-plan.pdf**'Flood Risk Assessment & Drainage Strategy'You can access the document here**https://www.boom-power.co.uk/wp-content/uploads/2021/10/FloodRiskAssessment_896753.pdf**Please refer to point 5.2.2 'Planning Statement'Access Document** https://www.boom-power.co.uk/wp-content/uploads/2021/10/General_896701-Planning-Statement.pdf**Please take note to pages - 33,34,38, 46**			**Agricultural Land ClassificationAccess the document**https://www.boom-power.co.uk/wp-content/uploads/2021/10/General_896760-AGRICULTURAL-LAND-ASSESSMENT.pdf**Please pay particular attention - Page 12**		**Design and Access Statement Access Document** https://www.boom-power.co.uk/wp-content/uploads/2021/10/DesignandAccessStatement_896749.pdf Page 32Design and Access Statement https://www.boom-power.co.uk/wp-content/uploads/2021/10/DesignandAccessStatement_896749.pdf **Pay Particular attention to page 32**	
Eveley Farm	Stockbridge, Hampshire		See attachment	See attachment					
Llanwern	Newport, South East Wales	Yes	**'Land on Caldicot levels to the south of Llanwern Steelworks site'** **Full document accessed here** https://dns.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/DNS/3213968/DNS-3213968-000525-Report%203213968%20(for		**'Local Impact Report'** **Full document can be accessed here** https://dns.planninginspectorate.gov.uk/wp-content/ipc/upl				**A full suite of planning documents can be found here** https://dns.planninginspectorate.gov.uk/projects/wales/llanwern-solar/?ipcsection=docs&stage=1

			merly%203150137).pdf **Please pay attention to points 127, 139, 240**		oads/projects/DNS/3213968/DNS-3213968-000525-Report%203213968%20(formerly%203150137).pdf **Please pay particular attention to the construction method statement on Page 27**				
Outside the UK									
Neoen Solar Farm	Australia	No				**Soil and Water Management Plan** https://parkessolarfarm.com.au/wp-content/uploads/2020/08/PL-EV-04-Soil-and-Water-Management-Plan-Rev2.pdf			

APPENDIX 3 – Satellite Imagery of Three Solar PV Sites

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APPENDIX 4 – Solar Farm Construction Images

Site A

Figure 1

Figure 2

Figure 3

Site B

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

APPENDIX 5 – Impact of Soil Wetness Limitation

Table A shows the example of a **medium-textured soil** in **Wetness Class I** before commissioning, classified as BMV land and then **disturbed** during construction, the interaction of climate (FCD) and the depth to an introduced slowly permeable layer.

Where there is evidence of an SPL starting within 60 depth cm reference is made to Figure 7 of the ALC Guidelines (MAFF, 1988) and where there is an SPL starting between 60 cm and 80 cm depth reference is made to Figure 8 of the ALC Guidelines (MAFF, 1988).

Table A Residual Impact of Introduced SPL on ALC Grade- Medium -texture soil

FCD	Pre-construction		Post-decommissioning		
	Wetness Class	ALC Grade	Depth to introduced SPL	Wetness Class	ALC Grade
230	I	3a	0 to 25 cm	V	4
		3a	25 to 60 cm	IV	3b
		3a	60 to 80 cm	III	3b
225	I	2	30 to 60 cm	IV	3b
		2	60 to 80 cm	III	3a
170	I	1	35 to 46 cm	IV	3b
		1	46 to 60 cm	III	3a
		1	60 to 80 cm	II	2
125	I	1	35 to 60 cm	III	3a
		1	60 to 80 cm	II	2

Table B shows the example of a **medium-textured soil** in **Wetness Class I** before commissioning, classified as BMV land and **undisturbed** during construction, the interaction of climate (FCD) and the depth to an introduced slowly permeable layer. Where there is evidence of gleying within 40 cm depth and an SPL within 80 cm depth reference is made to Figure 7 of the ALC Guidelines (MAFF, 1988). Where there is gleying within 70 cm depth and an SPL within 80 cm depth reference is made to Figure 8 of the ALC Guidelines (MAFF, 1988).

Table B Residual Impact of Introduced SPL on ALC Grade- Medium- textured soil

FCD	Pre-construction		Post-decommissioning			
	Wetness Class	ALC Grade	Depth to introduced SPL, with gleying <40 cm	Depth to introduced SPL, with gleying >40 cm	Wetness Class	ALC Grade
230	I	3a	0 to 25 cm		V	4
			25 to 62 cm		IV	3b
			62 to 80 cm		III	3b
				0 to 80 cm	III	3b
225	I	2	25 to 61 cm		IV	3b
			61 to 80 cm		III	3a
				28 to 80 cm	III	3a
170	I	1	35 to 46 cm		IV	3b
			46 to 74 cm		III	3a
			74 to 80 cm		II	2
				35 to 60 cm	III	3a
				60 to 80 cm	II	2
125	I	1	35 to 62 cm		III	3a
			62 to 80 cm		II	2
				35 to 42 cm	III	3a
				42 to 80 cm	II	2

Table C shows the example of **a light-textured soil** in **Wetness Class II** on **disturbed land** and the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land.

Where there is evidence of an SPL starting within 60 depth cm reference is made to Figure 7 of the ALC Guidelines (MAFF, 1988) and where there is an SPL starting between 60 cm and 80 cm depth reference is made to Figure 8 of the ALC Guidelines (MAFF, 1988).

Table C Residual Impact of Introduced SPL on ALC Grade- Light- texture soil

FCD	Pre-construction		Post-decommissioning		
	Wetness Class	ALC Grade	Depth to introduced SPL	Wetness Class	ALC Grade
230	II	3a	0 to 25 cm	V	4
		3a	25 to 60 cm	IV	3b
		3a	60 to 80 cm	III	3b
225	II	2	25 to 60 cm	IV	3b
		2	60 to 80 cm	III	3a
170	II	1	35 to 46 cm	IV	3a
		1	46 to 60 cm	III	2
		1	60 to 80 cm	II	1
125	II	1	35 to 60 cm	III	2
		1	60 to 80 cm	II	1

<u>Table D</u> shows the example of a **light-textured soil** in **Wetness Class II** on **<u>undisturbed land</u>** and the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land.

Where there is evidence of gleying within 40 cm depth and an SPL within 80 cm depth reference is made to Figure 7 of the ALC Guidelines (MAFF, 1988). Where there is gleying within 70 cm depth and an SPL within 80 cm depth reference is made to Figure 8 of the ALC Guidelines (MAFF, 1988).

Table D Residual Impact of Introduced SPL on ALC Grade- Light-texture soil

FCD	Pre-construction		Post-decommissioning			
	Wetness Class	ALC Grade	Depth to introduced SPL, with gleying <40 cm	Depth to introduced SPL, with gleying >40 cm	Wetness Class	ALC Grade
230	II	3a	0 to -25 cm		V	4
		3a	25 to 62 cm		IV	3b
		3a	62 to 80 cm		III	3b
		3a		0 to 80 cm	III	3b
225	II	2	35 to 61 cm		IV	3b
		2	61 to 80 cm		III	3a
		2		35 to 80 cm	III	3a
170	II	1	35 to 46 cm		IV	3a
		1	46 to 74 cm		III	2
		1	74 to 80 cm		II	1
		1		35 to 60 cm	III	2
		1		60 to 80 cm	II	1
125	II	1	35 to 61 cm		III	2
		1	61 to 80 cm		II	1
		1		35 to 42 cm	III	2
		1		42 to 80 cm	II	1

APPENDIX 4

Historic England: Piling and Archaeology – Guidance and Good Practice

Historic England

Piling and Archaeology

Guidance and Good Practice

Summary

This guidance note has been prepared to assist planning authorities and archaeological officers, developers and their consultants to make clear and informed decisions about piling schemes and their potential impact upon archaeological remains. It provides information on piling types, impacts, and solutions for sustainable foundation design and is illustrated by case studies.

Originally published in 2007, it has been revised by a team of archaeologists and engineers, to place a greater emphasis on the planning process and current planning guidance (NPPF). This new edition also includes a risk assessment methodology to provide a framework in which clients and their contractors can identify, avoid or otherwise manage the key construction risks to archaeological remains arising from their schemes.

This is one of a number of documents dealing with the preservation of archaeological remains, the other documents are:

Preserving Archaeological Remains

Land Contamination and Archaeology

Please refer to this document as:

Historic England 2019 *Piling and Archaeology: Guidance and Good Practice*. Historic England. Swindon: Historic England.

First published by English Heritage July 2007.

This edition published by Historic England March 2019.

HistoricEngland.org.uk/advice

Front cover: Excavating a Roman timber-lined tank in between the 1950s piles on the site of Bloomberg's European Headquarters © MOLA

Contents

1 Introduction

The National Planning Policy Framework (NPPF) recognises the desirability and importance of securing the conservation of heritage assets and taking account of impacts upon them as part of the decision-taking process (MHCLG 2018).

Whilst piling has the potential to cause a high level of harm to archaeological remains, nonetheless, it forms one of the most commonly used methods of delivering sustainable development in challenging development conditions.

Foundation solutions that seek to preserve archaeological remains by avoiding and minimising harm, are an essential tool in ensuring that development can take place where archaeological remains are present, particularly where technical or economic factors might otherwise prevent development.

Planning background

The policies of the NPPF identify heritage assets, including archaeological remains, as an irreplaceable resource. Any harm to or loss of the significance of heritage assets requires clear and convincing justification; local planning authorities are required to consider how conflict between heritage assets' conservation and development might be avoided or minimised as part of their decision-taking process.

In all cases where development will lead to harm to or loss of heritage assets, the NPPF places the onus on the determining body to make a balanced judgement, taking account of the significance of the heritage asset affected, the scale of any harm or loss caused and any public benefits it would deliver. Through this process, it can be possible for development to take place in areas of high archaeological sensitivity by providing protection to the majority of the remains on site.

This guidance is intended to support and enable sustainable development to proceed, by ensuring that harm is avoided or minimised wherever possible and that where harm or loss can be justified, that the impact on archaeological deposits and artefacts is appropriately managed. Specifically, this document illustrates how piled foundations can play an important part in delivering the objectives set out in the policies of the NPPF, subject to an informed and cooperative design process.

This document follows and expands upon the approach set out within the Managing Significance in Decision-Taking in the Historic Environment: Historic Environment Good Practice Advice in Planning Note GPA2 (Historic England 2015). It should also be read in conjunction with Preserving Archaeological Remains, Decision-taking for Sites under Development (Historic England, 2016) which provides the overarching framework for decision taking on these types of sites. Both documents emphasise the importance of adequate information and a robust understanding of significance (as required by the NPPF).

Information required

Where piling is being considered as part of a foundation design on a site containing archaeological remains, a range of site-specific information will be needed to meet the standards of understanding set out under the NPPF. This is necessary to enable sound decision taking with regard to the particular technical issues raised by the use of piled foundations.

The applicant will need to provide sufficient information demonstrating an adequate understanding of the significance of the archaeological site and assessment of potential harm to that significance arising from the development. As set out in Historic England guidance on Preserving Archaeological Remains (2016), the state of preservation of archaeological remains may be a key element of their significance.

The NPPF states that local planning authorities (LPAs) should require developers to submit an appropriate desk-based assessment and where necessary, appropriate field evaluation.

In addition to information required to take planning decisions, it is recommended that sufficient geotechnical site investigation (undertaken in accordance with Eurocode 7) has been conducted early in the design process. This ensures that appropriate engineering information is available to allow for a flexible foundation design to reduce the impact on archaeological remains.

Close working and good information exchange between all parties involved in developing a site containing archaeological remains where piling is proposed as a foundation solution is recommended. It is beneficial for the developer, client and architect to have considered foundation options and inform the piling contractors that archaeological remains are present on site before they tender. This ensures that these sub-contractors are adequately aware of these issues and are able to identify foundation solutions which minimise potential harm to the site and its significance.

It is good practice for technical aspects associated with piled foundations to be appropriately assessed. These include but are not necessarily limited to:

- the potential for the particular pile type utilised to damage archaeological deposits. This may include the possibility that drilling fluids and concrete (prior to setting) from bored or augered piles might leach out adjacent to the pile bore.

- the cumulative impact of successive piling on a site resulting in damage to so much of a site that future re-examination would not be worthwhile.

- the potential for piling to change the site hydrology, draining waterlogged deposits.

Risk assessment

Risk assessment forms a conventional tool in the identification, evaluation, avoidance and control of risk. This guidance lays out an approach to assessing risk to the significance of archaeological remains (with the input of appropriate archaeological advice) as a means to select the most appropriate foundation methods and control measures when working on archaeological sites and to justify this choice with appropriate design and avoidance measures.

The process of risk assessment is best commenced at pre-planning stage and continuously updated during design development as new information becomes available such as from desk based research and site investigations. In many cases the risk assessment process will assist in the identification of opportunities to avoid potentially adverse impacts on the significance of archaeological remains.

Archaeological field evaluation (trial trenching) of a sufficient sample of the site is an important part of the risk assessment process. Piling carried out without effective evaluation of the site could lead to piles being inappropriately located, leading to potential loss or damage to archaeological features. In addition to causing additional loss of information, this is also likely to increase the cost to the developer, such as from the need for foundation re-design.

Overall, it is important that sufficient information is provided to all parties at each of the relevant stages of the pre-application and statutory planning processes and throughout the delivery phases. The design of an appropriate foundation strategy will depend on cooperation, close working and open information exchange between the applicant, the local planning authority and their specialist advisers, and the contractor.

Structure of the document

- This introduction has outlined the planning background and the need for adequate information to be assembled to inform planning decisions, so that appropriate foundations can be designed.

- A summary overview follows which highlights the key points from the text.

- Piles, and the main piling types, are covered in Chapter 3. This outlines the piling techniques used to construct foundations. It also sets out the engineering choices and constraints. This should enable readers to consider the appropriateness of each technique within proposed sustainable foundation schemes.

- Chapter 4 summarises the potential impacts of each pile type on archaeological deposits.

- Chapter 5 discusses how the impact of piling on archaeological sites can be appropriately managed, giving a range of design options and solutions. An emphasis is placed on the types of decisions that planning and archaeological officers, developers, and their archaeological consultants need to consider throughout the design and construction process.

- The risk assessment process is described in Chapter 6, which also includes a blank risk assessment form.

- Case studies are provided in Chapter 7 to demonstrate how some of the design solutions have worked in previous situations.

- Supplementary information is given in Chapter 8 detailing past observations of piling impacts and laboratory studies. These provide the evidence-base for pile impacts described in Chapter 4.

2 Overview of key points

2.1 Early involvement and gathering information

- Pile design is best considered early in the development programme and planning process.
- Feasibility studies for foundation re-use are best carried out early on.
- The risk assessment tool is best used to identify the least damaging foundation solution.
- It is good practice for site evaluation and site investigation to be sufficiently detailed so that the impact of piling on all archaeology across the site can be fully understood.
- Site characterisation is likely to be insufficient without a detailed model showing the depth of archaeological deposits.
- Close working between the applicant, the local planning authority and the contractor is recommended from the outset.
- As set out in Historic England advice on Preserving Archaeological Remains, following the NPPF, the applicant will need to ensure that they adequately understand and can describe the significance and state of preservation of archaeological materials present and have assessed the harm to that significance arising from the development.

2.2 Pile impact

- New piling impact on the site's archaeological remains is best kept to a minimum.
- The cumulative impact of previous foundations may mean that the impact of new piling will compromise the legibility of the archaeological deposits. Under these circumstances, piling may not offer a viable design solution for preserving the archaeological remains within the development.

- It should be possible to avoid the most archaeologically sensitive areas of the site through careful pile placement and appropriate load-bearing spanning structures.

- Where piles are placed in clusters, the close spacing reduces the future legibility of the enclosed archaeological deposits. Groups of three or more piles and pile cap represent a single area of impact and need to be mitigated accordingly.

2.3 Choosing the right foundation solution

- Piled foundations are typically chosen over shallow foundations eg, footings or rafts because of high loading and settlement performance. But nevertheless, shallow foundations should first be considered, where appropriate, to mitigate impacts on archaeology.

- Using the risk assessment methodology (see Chapter 5), the appropriate pile choice should be made identifying the one that will provide the greatest level of preservation of the archaeological remains on site. The choice will also depend on the engineering requirements of the development and these two will need to be balanced.

- As part of that risk assessment process, the impact of each pile type is assessed by the design team. This impact will vary depending on ground conditions and the type of archaeological deposit. The risk assessment process considers physical impact as well as any impact on the site hydrogeology, chemistry and microbiology.

- The choice of pile solution must also consider the impact of any enabling and temporary works required for a pile solution. These will differ with pile type eg pile probing, piling platform, access to pile locations. For example, the piling platform could be greater than 1 metre thick depending on the ground conditions and size of the piling equipment.

- It is good practice for a thorough archaeological evaluation and characterisation of the site to be undertaken prior to piling to indicate the likelihood of encountering buried structures (either archaeological or modern) which can cause obstructions to piling.

- Where these obstructions cannot be avoided by careful placement of the piles, a methodology for removing or coring through them, forms a key element of the mitigation strategy. In the latter case, a tool capable of cutting through these obstructions should be specified in the risk assessment process and used.

Displacement piles

- Displacement piles may be driven (impact or vibrated) or pressed in. Where displacement piles are used, the area of potential damage is not just restricted to the pile itself, but can impact the adjacent area as well. The area of impact will vary depending on ground conditions and method of installation.

- A general estimation (based on laboratory studies and on-site observations) is that driven displacement piles can damage an area twice the width of the pile cross-section (and so four times the area).

- As the actual zone of effect of a displacement pile may differ, the onus rests with the applicant to demonstrate if they believe the area of impact will be lower than indicated here. Evaluation of previous foundations where they exist on a site will help to establish specific conditions.

- To achieve more certainty about the total area of damage from displacement piles, and to reduce the amount of damage, pile locations can be pre-augered before the pile is installed.

Non-displacement piles

- The area of physical loss is designed to relate purely to the area of the pile, but exceptions occur when the pile bore sides collapse (not likely for CFA piles), or when concrete from the pile migrates into voids or the unconsolidated deposits adjacent to the bored/augered hole. In both cases, these impacts can be mitigated by installing temporary or permanent casing (Figure 1). The impact on fragile deposits such as timber and other structures should be considered.

2.4 Managing construction risks

- Ground investigation, boreholes, test trenches and other invasive work to understand ground conditions for geotechnical purposes will have an archaeological impact. A methodology for such work should be drawn up and agreed by all parties.

- To avoid damage during piling, it is recommended that in addition to the risk assessment document, a detailed methodology for the piling works and enabling works is drawn up and agreed by all parties.

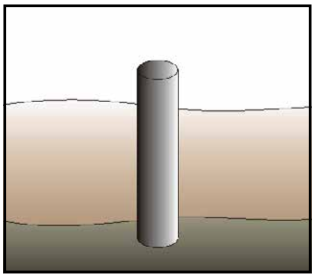
- To ensure that this plan is adhered to, it may be appropriate to maintain an archaeological presence on site during the piling works.

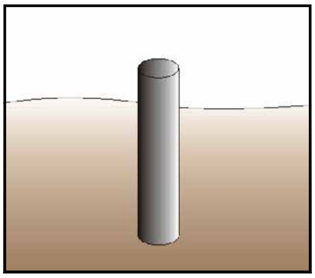
- In addition to damage during pile installation, damage to archaeological remains can also occur during site remediation and from ground clearance work, including pile probing. These activities should be avoided on sites containing archaeological remains; their impact should be assessed using the risk assessment methodology.

Figure 1: Concrete migration into a void, in this case from the pile cap. © University of Leicester Archaeological Services (ULAS)

3 Piling types

Piling is a method of transferring load from a structure into the ground. The engineering objective of a pile is to support a structure by using the strength of the ground some distance below the surface that can resist the imposed force. This can be by direct bearing onto a firm stratum present at depth below the site or by using the frictional resistance of the soil against the pile shaft to develop the load-bearing capacity. In some cases, a combination of these is used where the pile is founded on a firm horizon and the sides develop surface friction (Figures 2 and 3).

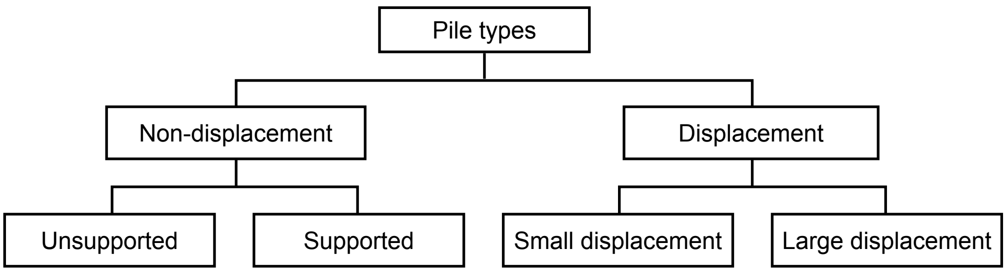




Engineering factors influencing the choice of pile type may include:

- The proposed building design, structure and location (for example, high-rise urban flats or low-rise greenfield warehousing).
- Ground conditions (ie cohesive or non-cohesive soil) and location of the water table.
- Durability (for example, concrete can suffer chemical attack and steel piles may corrode).
- Cost (including speed of installation and certainty of the chosen method being effective).

Pile types in this guidance note are grouped and described under the headings of displacement and non-displacement piles (see Figure 4).

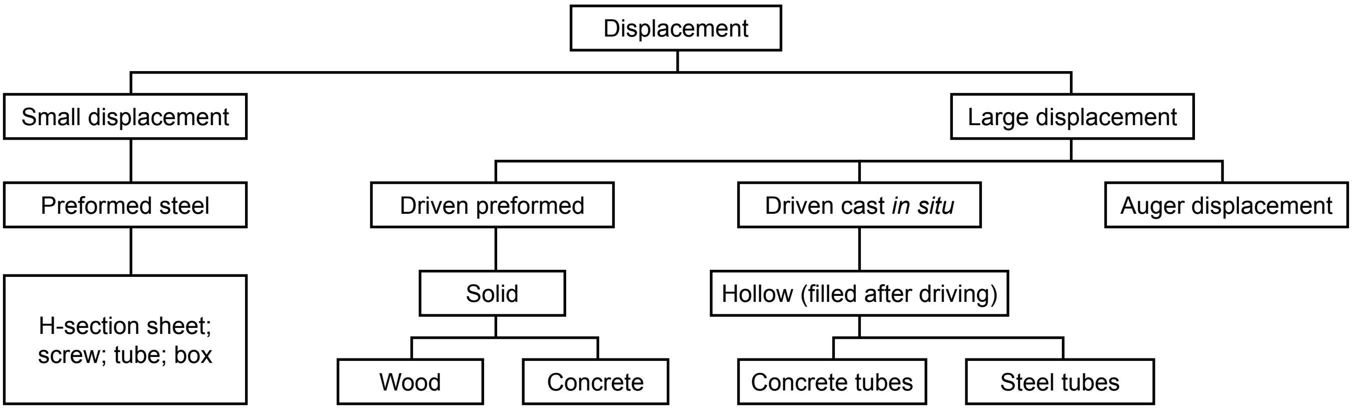


Figures 2, 3 and 4: End bearing pile, where the pile is founded in the hard incompressible layer rather than the soil above (top). Friction bearing pile, where the sediment becomes increasingly stiff with depth (bottom). Pile types (right).

3.1 Displacement piles

Displacement piles push the sediment aside as they are installed, compressing the ground and increasing the resistance of the foundation. Displacement piles are environmentally positive in the sense that there is no need to remove spoil, no landfill requirements, and reduced vehicle movements. This is particularly important on contaminated sites where the arisings (spoil) would require remediation. There are several forms of displacement pile (Figure 5).

Figure 5: Displacement pile types.



3.2 Large displacement piles

Large displacement piles (enclosed solid element) can be constructed from concrete, metal or, less commonly timber, and are installed by impact (hammering), pressing in (jacking) or vibrating the piles (or tubes) into the ground (Figure 6). Traditionally a drop-hammer would simply drop a large weight onto the top of the pile, however, they can produce significant

Figure 6: Displacement pile installation: Piles arrive at site, pile located, pile section driven, additional section attached, pile driven. © Roger Bullivant Limited

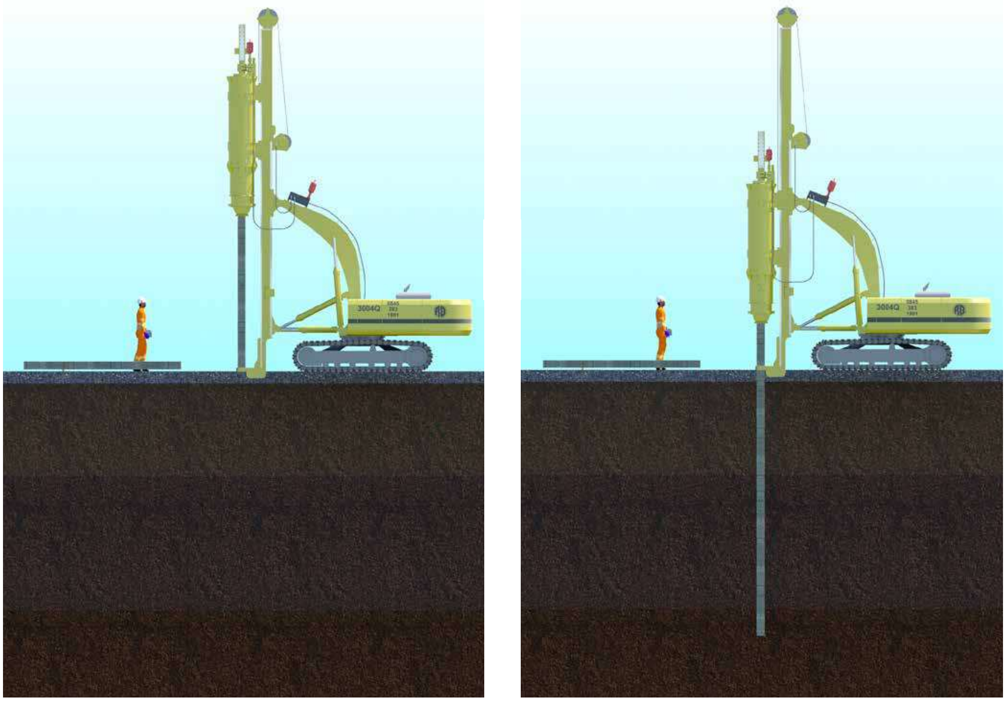


Figure 7: Preformed concrete displacement pile being installed. © Roger Bullivant Limited

noise and vibration (Figure 7 – in this image the hammer is encased which helps to minimise the noise generated). Modern hydraulic hammers use a controllable powered ram and are quieter and cause less vibration than the drop-hammer. To drive or extract a pile by means of inducing a vibration into the pile element, greatly reduces skin friction properties and allows the pile to move through the ground with considerably less resistance than it would do under a static load. Fast rotation, out of balance, cams apply vertical vibration to the pile, liquefying granular solid and facilitating very speedy pile installation. These machines have been refined so that they can jump between frequencies and amplitude to suit the ground whilst avoiding damaging harmonic vibrations which would stress nearby structures. A crane suspended unit allows reach, often beneficial in marine works or areas where piling rig access would be problematic. It can be a lower cost option than a piling rig configuration. If sediments are soft, preformed piles are pressed in (jacked) rather than hammered in, which has the advantage of being quiet and effectively vibration-free.

Driven preformed piles

Solid piles are usually constructed from precast concrete (and occasionally wood) and come as specific lengths or sections joined together on site to form a longer pile, up to *c* 40m; in Figure 8 pile sections can be seen stored in the background, waiting to be installed. Low headroom rigs can be used in areas of restricted access. The normal range of preformed concrete pile sizes in the UK is 150-300mm diameter. The advantage of using preformed concrete piles is that there is no need to wait for concrete to set, nor for liquid concrete to be transported to, or prepared on, site. The pile sections can be coated before insertion to prevent reaction with the surrounding soil, improve concrete durability and/or to reduce friction with the ground during installation.

Figure 8: Installing sections of a preformed concrete pile. © Roger Bullivant Limited

Hollow piles are tubes generally constructed of steel or occasionally precast concrete. The concrete may be pre-stressed to enhance durability. Hollow piles are often used when large diameters (>500mm) are needed and are hollow for ease of handling, or for economy. For hollow steel piles, concrete is poured into the hollow section to complete the pile (as for driven cast *in situ*), except that in this case the tubes are not withdrawn.

Driven cast *in situ*

This method is used less often than driven precast piles. A tube (steel or precast concrete) with a sacrificial shoe or detachable point is driven into the ground, displacing and compacting the soil around the tube. Reinforcement is lowered into the tube and concrete poured into it. As the concrete is added, the tube is withdrawn and the concrete may be compacted. This method is normally used to create piles from about 250-500mm diameter with depths of up to 25m.

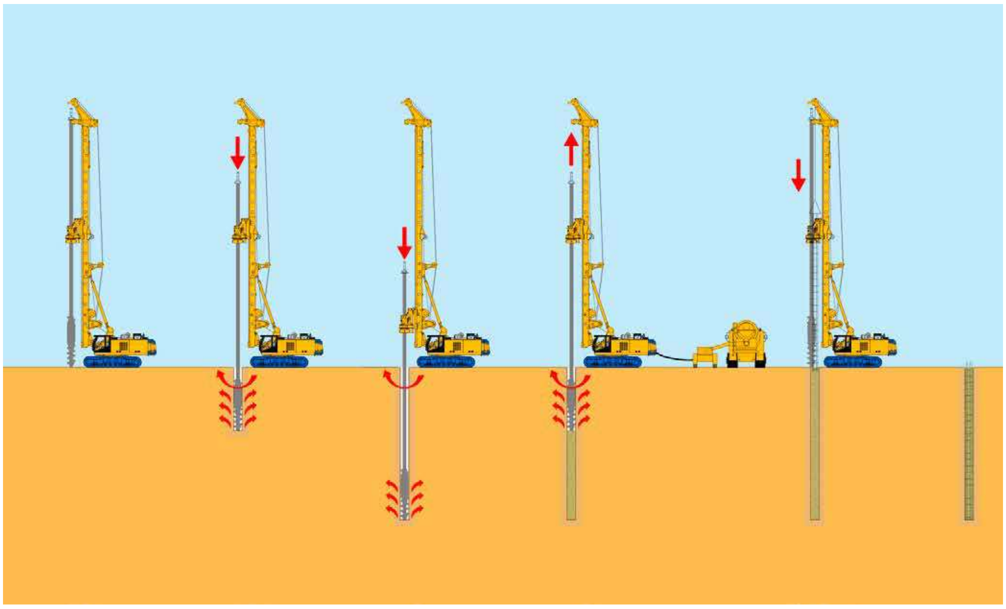
This method is particularly useful in contaminated soils, because no arisings are produced; however, removal of the tube can cause distortion of the surrounding sediment and may allow movement of liquid concrete into voids.

Auger displacement piles

This method uses a spiral auger that displaces the spoil laterally into the ground around the hole. Concrete is poured down the auger shaft as the auger is withdrawn, see Figures 9 and 10. The displacement consolidates the ground surrounding the pile, resulting in enhanced soil properties and therefore shorter pile lengths.

Pile sizes will depend on the individual pile company's specific auger design, but diameters of 300mm to 600mm are likely. This type of pile is relatively 'green', its installation producing very little spoil, vibration and noise.

Figures 9 and 10: Construction process for auger displacement piles (left). Auger displacement pile rig, note tapered auger head (right). Both images © Cementation Skanska



3.3 Small displacement piles

Driven preformed steel

Small driven displacement piles are typically steel sections (H-section, sheet, tube or box) are either hammered (impact) or vibrated into the ground. Sheet piles (Figure 11) are often constructed as interlocking piles, used to create cofferdams or retaining walls, and less often to support load from a structure above. Where they are used for retaining walls, sheet piles may also need tie-backs, which will have a further impact on adjacent deposits. Small displacement piles can also be extracted by means of vibration or jacking.

Figures 11 and 12: Sheet pile retaining wall along the edge of a site at Drapers' Gardens (left) © Pre-Construct Archaeology Ltd. Rolled steel tube being installed at Skirbeck Road, Boston (right).

Steel pile installation is covered in detail in guidance provided by the Steel Piling Group (2018).

Smaller metal piles include rolled steel sections (see Figure 12), screw piles and H-section piles. Rolled steel section piles are easily handled and can be driven hard, and in very long lengths; while the pile length can be readily varied, lengths of up to 36m can be achieved.

Press in preformed steel

Pressing in of preformed steel piles (typically sheet piles or tubes) by hydraulic pushing has brought noise and vibration to minimal levels. The installation plant can walk on the top of a line of piles and hence install in restricted access areas which were previously impossible (eg over water or soft ground) without the need of a piling platform. Where driving is very difficult a pre-bore auger or high-pressure water jet can be attached to locally disturb the ground ahead of the toe.

Steel screw piles

Screw piles (eg helical piles), for lightly loaded structures, are often of modular configuration, often consisting of a number of connected tubes 2-3m with a series of steel plates welded to the tubes (see case study 7.2 for an example of their use on an archaeologically sensitive site). Due to installation constraints, lengths are often limited to 12-15m but may be less depending on ground conditions. Steel piles are liable to corrosion, which can be treated using cathodic protection, or a pile coating.

Engineering advantages and disadvantages of displacement piles

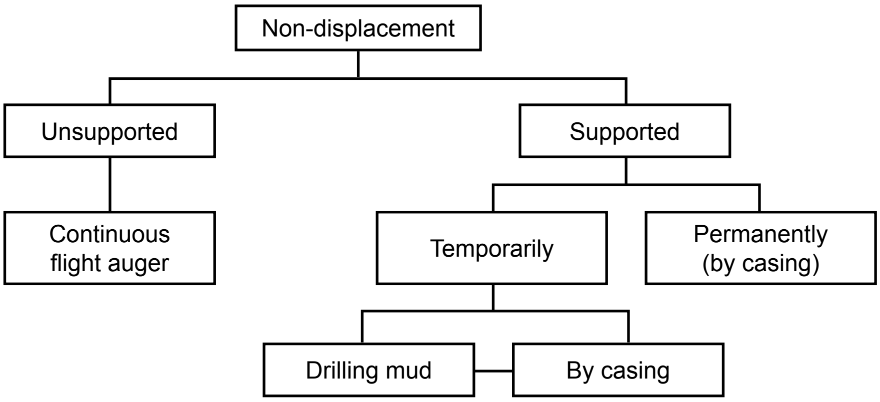
The advantages of displacement piles lie in the range of installation methods available, their preformed construction and the controlled and clean nature of the installation. They are also extractable. Very limited volumes of spoil are produced and piles are generally preformed with no need to transport or make fresh concrete on site, except when casting *in situ*. Piles can be quickly constructed in variable and long lengths, (also in low-headroom areas) and are unaffected by the presence of groundwater. Additionally, off-site production in controlled conditions means the preformed sections are constructed to a higher and more uniform specification than is possible with on-site piles cast *in situ*. In general, small driven piles and metal screw piles are particularly useful if ground displacements and disturbance must be curtailed.

Disadvantages with displacement piles include breakage below ground, and the difficulties of checking pile quality. Soil displacement can cause heave, and lift or damage adjacent piles or damage adjacent buildings. The noise and vibration associated with pile installation can be considerable, and can make this method unsuitable in built-up areas and adjacent to fragile historic structures.

3.4 Non-displacement (bored) piles

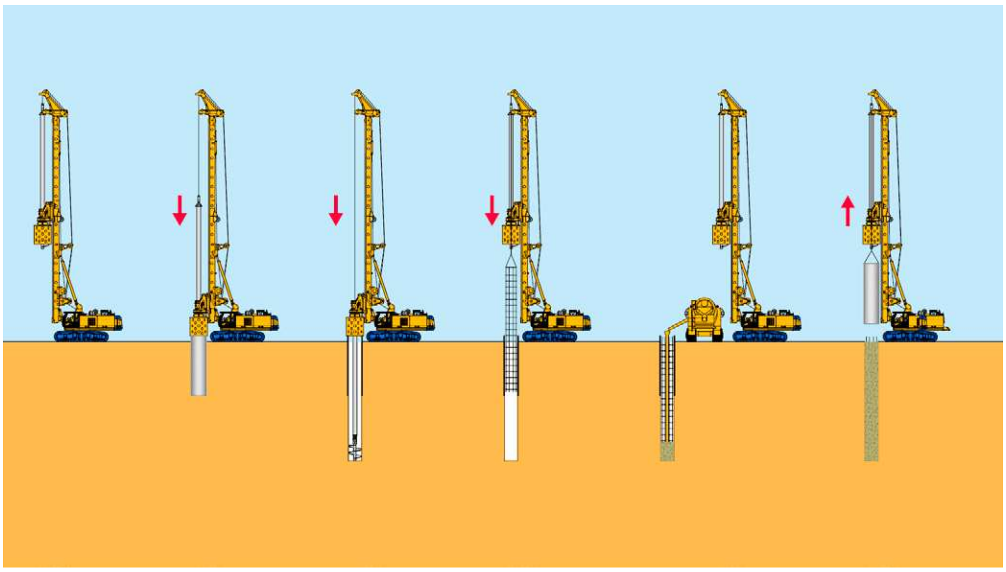
Non-displacement piles (Figure 13) are installed by boring a hole, removing the arisings and filling the hole with concrete (and often reinforcement). The bore tends to consist of a screw-type auger on a piling rig, which augers directly into the ground and removes arisings in a series of passes, using a ‘flighted’ or bucket auger (see Figure 14). Piles are usually cast *in situ* or occasionally constructed using pre-cast concrete ring sections, which are then filled with concrete. Piles can be constructed with diameters of up to 3m, and can be bored to depths of up to 70m, with under-reamed bases up to three times the shaft size. Small diameter bored piles are usually less than 600mm diameter and can reach 30m in most ground conditions. Bored micro-piles are of the order of 200-300mm in diameter and reach up to 30m deep and are particularly capable of penetrating obstructions due to the wide variety of drilling techniques available, such as high-speed rotation, drilling bits etc.

Figure 13: Non-displacement pile types.



In some instances a casing is inserted, usually temporarily, to prevent the collapse of the hole, and the auger drills inside this (shown in Figure 14). In the case of continuous flight-augered (CFA) piles, the arisings are removed at the end of the operation when the auger is removed, making support unnecessary. With any of these non-displacement piling methods, there is typically little or no sediment displacement adjacent to the shaft of the pile. Increased pile capacities can be achieved through the formation of enlarged pile bases (under-reams).

Figure 14: Illustration of rotary bored pile construction. A temporary casing is installed to prevent the upper deposits collapsing, The auger is advanced and soil removed, the reinforcement and concrete are added, the casing is removed and the pile is complete. © Cementation Foundations Skanska



3.5 Supported non-displacement (bored) piles

In unstable soils a casing or a support fluid, such as bentonite/polymer, may be used to temporarily support the pile bore. The choice between using steel casing or support fluid is an engineering decision; generally casings are used to line a relatively shallow depth of unstable ground to reach a self-supporting stratum below, while a support fluid is used to temporarily support the pile bore at deeper depths.

Temporarily supported

A support fluid would be used when piling through a deep, unstable stratum and subsequently pumped out. The use of support fluid has specific implications, including adverse environmental effects and the large space required for support fluid plant and storage on site. Bentonite support fluids may be classified as controlled waste, in which case disposal requires special precautions and additional expense.

Pile casings are generally steel tubes inserted into the ground by driving, vibration, oscillation or rotation. Noise and ground vibration can be high where a casing is installed. These levels, however, will generally be much less than for driven pile installation, although tripod-bored piles can also produce significant noise and vibration. Casings are also installed by pre-boring an open hole or 'mudding in', the contact between the casing and soil being lubricated using support fluid. This can significantly reduce the noise and vibration effects.

Casing is typically not installed through obstructions. However, where advance obstruction removal is not feasible or there are extensive or deep obstructions temporary thick wall casing can core through most obstructions. Where archaeological deposits contain significant voids, casing can be used to mitigate concrete migration. However, on temporary casing extraction, some concrete migration may occur. Most casings are removed after the pile has been formed, although some are left in place permanently, even though this adds significantly to the cost.

3.6 Unsupported non-displacement continuous flight auger (CFA) piles

The CFA technique is one of the most common piling forms and can be used in most soils. The auger is screwed into the ground to the specified depth and high slump concrete is then pumped down the auger stem to the base (see Figures 15-17).

As the concrete is inserted, the auger is withdrawn, taking the arisings with it. A reinforcing cage can then be pushed into the liquid concrete. Limited vibration or noise is generated using this piling technique. Pile diameters are usually 0.3-1.2m and they can reach depths of 30m. Casing is rarely needed as the sides of the bore do not need supporting as the arisings are not removed until the concrete is pumped in. The cased CFA technique, where the auger is advanced together with temporary casing, may be employed when having to penetrate a known obstruction or hard ground, or when constructing secant piled walls.

Engineering advantages and disadvantages of non-displacement piling

The benefits of using non-displacement piles include the variability of length and diameter, the low risk of ground heave resulting from pile installation, and the low noise and vibration.

Disadvantages include the need to bring liquid concrete to site, or create concrete/support fluid plant on site. A further disadvantage is that CFA piles cannot be inspected once cast. For bored piles where a support fluid has not been used, the open pile bore can be inspected before placing of concrete, so the length, depth, shaft, and base quality and verticality can be easily verified. Support fluid or casings are usually required to construct bored piles

Figure 15: Photograph from above a CFA pile during the construction of a pile. Soil can be seen in the lower flights, and around the auger where it has been cleaned off. The reinforcement cage stands adjacent (left). © Cementation Foundations Skanska

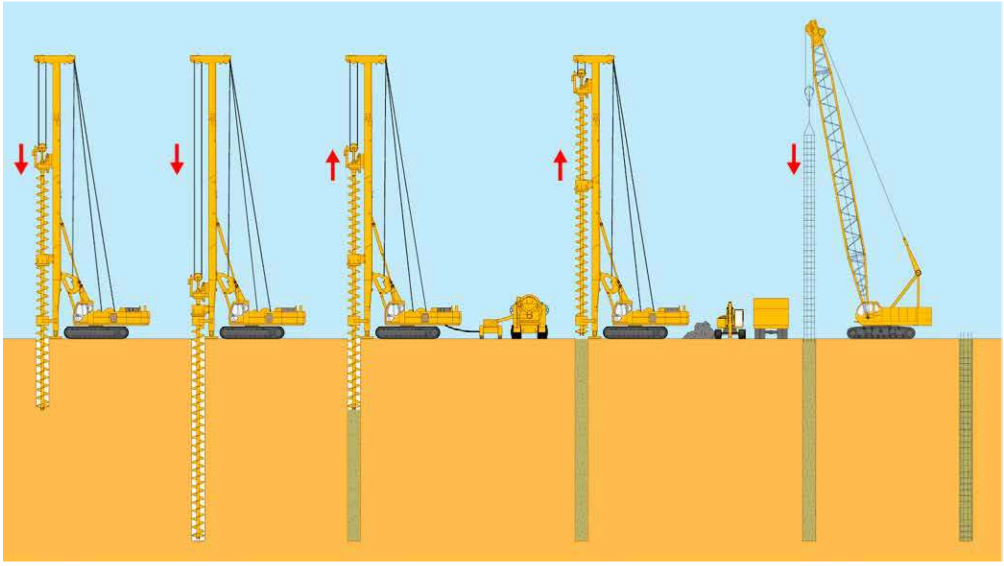


Figure 16: Illustration of CFA pile construction: The auger is located and rotated into the ground to the desired depth, as it is withdrawn the concrete is added, and finally reinforcement is added and the pile is complete. © Cementation Foundations Skanska

Figure 17: Continuous Flight Auger (CFA) piling. © Cementation Foundations Skanska

in unstable sediments and the transport, use, storage and disposal of these materials and fluids all need to be taken into account. Site establishment of plant, materials, access and working platforms can be more extensive than displacement piles.

3.7 Pile retaining walls

Bored concrete pile retaining walls are created by drilling a line of holes and forming piles either as contiguous (adjacent) or interlocking (secant) sections (Figure 18). Secant walls are drilled in two phases – primary piles, then secondary piles that partly cut the primary piles. They are often used to retain the surrounding ground as well as for their high stiffness and water-retaining properties. Contiguous pile walls will not retain water but are cheaper than secant walls. These types of pile are generally between 0.45m and 3.0m in diameter and can reach lengths of 60m. In virtually all cases guide trenches are constructed before secant (but not necessarily contiguous) walls are created in order to remove obstructions and create the line. This will therefore remove soil, which might then need to be taken from site. Pile retaining walls are not always used to support a building, but to contain lateral stress, for example within basements.

Retaining walls can also be formed by interlocking preformed steel sections eg steel sheet pile (see Section 3.3). Further information on pile retaining walls is given in the Institution of Civil Engineers Manual of Geotechnical Engineering Volume II (Burland *et al* 2012).

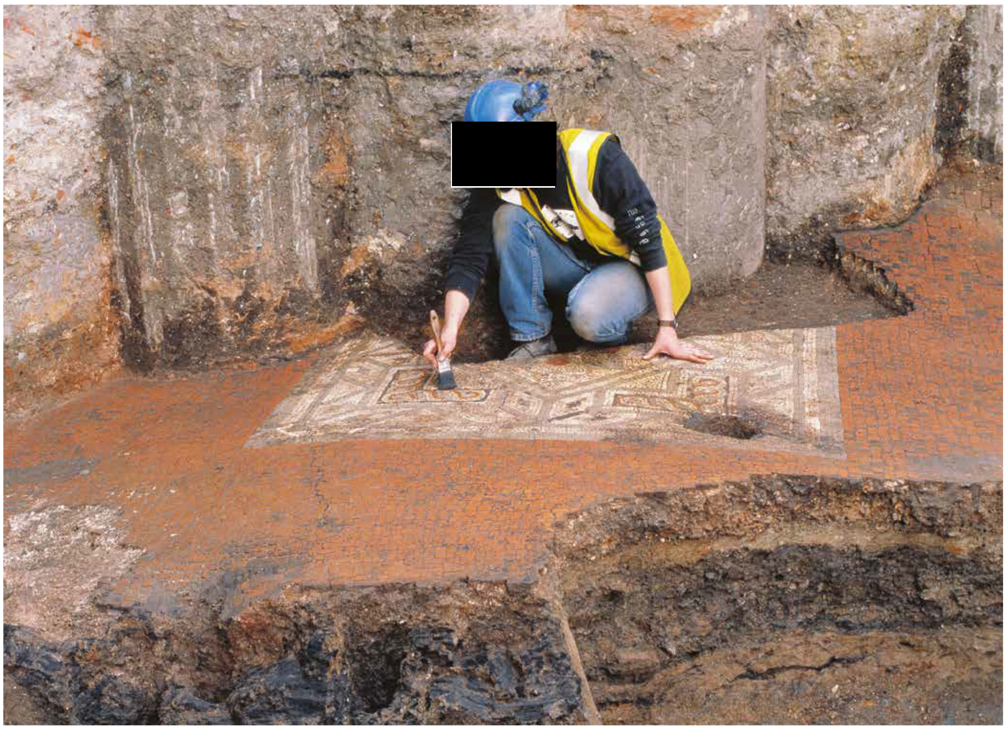


Figure 18: Secant pile wall in background, from Gresham Street, London. © MOLA

3.8 Vibro ground improvement techniques

In soft or loose ground conditions, ground improvement techniques (commonly using vibration) are sometimes used instead of piling to form foundations. However, from the archaeologist's point of view, vibro methods present similar problems and so are briefly considered here. They use densification and/or the insertion of stone or concrete columns to provide greater below-ground stability prior to construction. Key techniques are vibro compaction and the creation of columns using displacement and non-displacement methods, such as vibro replacement (Mitchell and Jardine 2002). Dynamic compaction involves dropping a large weight onto the ground and should not be confused with vibro compaction.

Vibro compaction and vibro replacement – stone columns

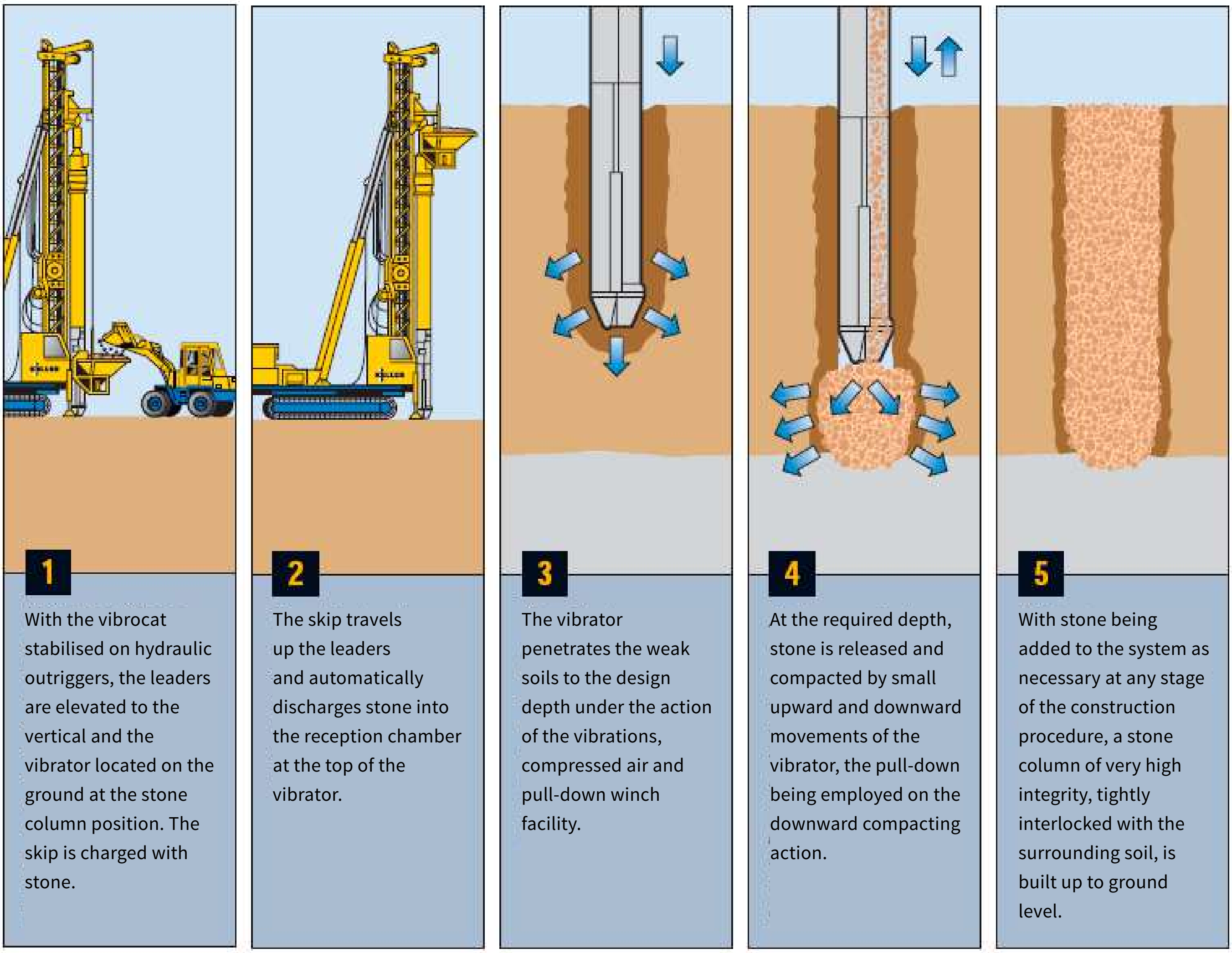
Vibro replacement methods are used in mixed cohesive, granular or purely cohesive soils, particularly weak soils and fill. A vibrating poker is used to create a hole into which stone aggregate is inserted and vibrated to bond with the surrounding soil. Vibro compaction is rarely used in the UK; it requires purely granular soils with low silt content. Vibro compaction uses a vibrating poker (often 300-400mm diameter), inserted into granular soils to agitate and compact them; water is often used with this system to remove very fine particles and assist in penetration (Figure 19).

Vibro concrete columns [VCC]

Concrete columns [VCC] can also be constructed using vibro techniques. A vibrating poker creates a void, usually through weak soils and is founded on a solid layer. Once the void is created by horizontally and vertically displacing the soil, a very low slump concrete is pumped into the hole through the poker (Figures 20 and 21).

Engineering advantages and disadvantages of ground improvement techniques

As columns of stone or concrete are inserted to create a support grid within the soil, this increases ground-bearing capacity without generating spoil and so is considered environmentally sustainable. Additionally, although 'stone' columns are often aggregate, recycled ballast is now regularly used, furthering sustainable development. A high-density grid of vibro columns is particularly useful where increased load-bearing is required. When stone columns are used as foundations (rather than for ground stabilisation), more columns are usually required than piles.



Figures 19, 20, 21:
Bottom feed vibro replacement. © Keller Ground Engineering

4 Piling impacts upon archaeological remains

In this section, the impact of each of the pile types is explored, detailing physical and hydrogeological impacts upon archaeological remains. All piling techniques result in damage to or loss of artefacts and sediment deformation equal to at least the total volume of the pile or vibro-replaced column. This is the minimum impact that will result from any piling operation. In many cases, further disturbance may occur, and the extent of that disturbance must be understood in order that the impact and implications of foundations and piling schemes can be assessed. Additionally, hydrogeological impacts on the deposits may affect the deposit/groundwater chemistry. This is not only relevant on waterlogged sites, as changes in deposit hydrogeology and chemistry can affect inorganic as well as organic remains.

Unintended damage to archaeological remains can also occur during other elements of the construction programme, such as during demolition / site clearance / site investigation, or as part of enabling works; in the removal of obstacles to piling (often called pile probing); and from vehicle movements and loading from those vehicles (including piling rigs).

4.1 Large displacement pile impacts

Driven preformed piles: physical impacts

During pile installation, sediment is physically displaced vertically and horizontally, which can cause distortion and damage to archaeological deposits, structures and artefacts. The effects of this have been recorded in excavations adjacent to previous piles (see for example Figure 22) and from model scale laboratory studies. Details of these are given in Chapter 8. The level of impact depends on the pile type and deposits, but as a general rule of thumb, physical impacts from driven preformed piles occur within 1.5 pile widths of the pile centreline. However, in several cases the area of damage is less.

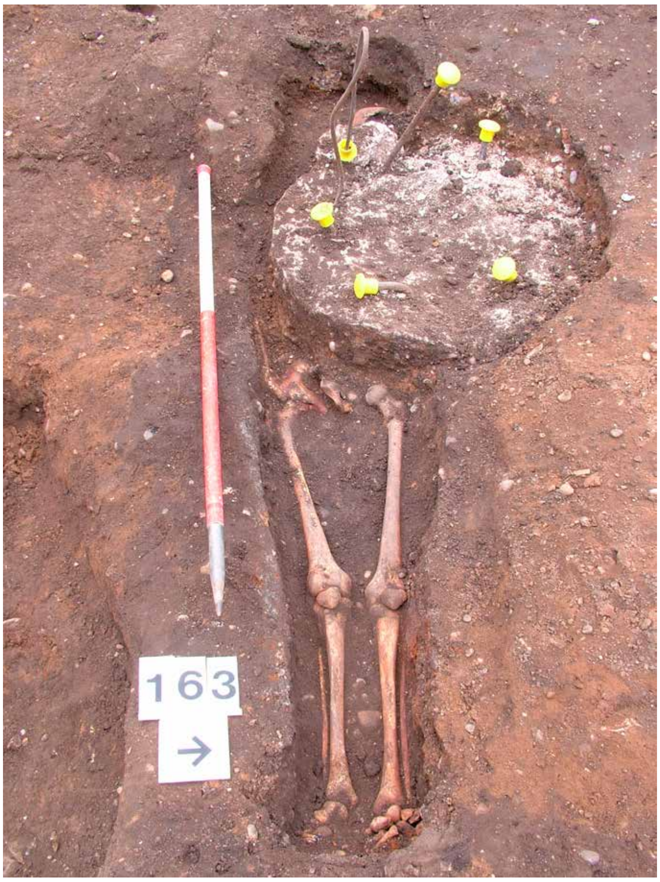


Figure 22: Damage to human remains caused by piling. © University of Leicester Archaeological Services (ULAS)

As driven preformed piles are constructed off-site, the potential impact on deposit hydrogeology and geochemistry is likely to be less than where the pile is cast *in situ*. The compression of deposits adjacent to the pile should lead to a reduction in permeability in this area, thereby reducing hydraulic conductivity of sediments at the soil/pile interface. However, where piling occurs through perched water-tables, there is a potential for dragged down and deformed deposits to create a pathway for downward migration of water, resulting in the dewatering of previously waterlogged deposits. From model scale research, this seems to be a greater risk with H-section piles.

Driven cast *in situ* piles: impacts

The physical impact of driven cast *in situ* piles is similar to driven piles, that is, vertical and horizontal displacement of deposits up to 1.5 pile widths from the pile centreline. It is possible that further modification of deposits occurs when the casing is removed. Currently, there has been no evaluation of this, so caution should be applied in assessing the likely damage using this technique. Aside from the physical impact associated with the removal of the tubing, if the pile grout is still liquid it could escape into any voids. These voids might be present in poorly consolidated deposits, or perhaps in fissures within the sediment. In waterlogged deposits there is a risk that chemical interaction will occur between the pile grout and archaeological remains. This is discussed in more detail within the section on non-displacement (bored) piles below.

Screw displacement piles: impacts

Limited evidence exists about the physical impacts on archaeological remains from screw displacement augers. This technique may be more damaging than non-displacement piling, because the displacement auger forces the sediment aside, leading to sediment deformation in the vicinity of the pile. The sediment adjacent to the pile will have been compacted, decreasing permeability at the soil/pile interface, relative to a non-displacement pile. Therefore, potential impacts, discussed in more detail for non-displacement piles, such as grout migration are less likely to occur. However, this is an area where further research is needed to characterise the nature of below-ground soil movement. It would not be good practice for screw displacement piles to be used as a foundation solution on an archaeological site without a full impact and risk assessment to gain a firm understanding of the likely zone of deformation.

4.2 Small displacement pile impacts

Preformed steel

H-section piles have a smaller cross-sectional area, and therefore, in theory, should lead to less sediment displacement than square preformed driven piles. Although no field investigations have confirmed this, model-scale analysis has shown that there is a reduction in the amount of vertical deformation of deposits. However, the geometry of H-section piles might increase the potential for liquid movement along the pile, which is discussed further in Chapter 8.

Sheet piles also have a limited cross-sectional area and the amount of material displaced during installation will be significantly lower than other pile types. Sediment deformation is therefore most likely to occur where obstructions are encountered, and archaeological material is dragged down, or the original orientation of materials is altered. In many cases though, sheet piling will cut through archaeological materials. The installation techniques used for sheet piling, including impact and vibro driving can induce ground vibrations that might damage fragile archaeological materials or adjacent buildings.

Where sheet piles are used to create an impermeable barrier (such as a cofferdam), then de-watering may occur. One study carried out in Bergen, Norway, has shown that substantial water flow occurred through a small hole in the sheet pile (Matthiesen 2005). An investigation of the state of preservation of material on either side of the sheet piling indicated that there was no significant difference. The potential risks from dewatering will depend on the true level of permeability of any given barrier and the specific hydrogeological circumstances of any given site.

Figure 23: Small screw piles in advance of installation in Salisbury (see case study 7.2). © Tim Sheward

Steel screw piles (see Figure 23) are likely to have minimal physical impact on archaeological deposits (where obstructions are avoided) and have the added benefit that they can be unscrewed when they are no longer required, a process that should also involve little damage to deposits. The main impact will be the displacement of material during insertion. Additionally, if obstructions become caught between the pile blades, then this could lead to further disturbance. Since some compaction of the ground adjacent to the pile will occur, the pile is unlikely to act as a major conduit for migration of water or contamination within archaeological deposits. There is potential for corrosion of the pile above the groundwater table. This may have an impact at the time of pile removal if corrosion products have become integrated with the surrounding soil or archaeological material, which may lead to greater disturbance as the pile is removed.

4.3 Supported non-displacement (bored) pile impacts

Temporarily supported bore: physical impacts

An accepted impact associated with conventional bored piles is the loss of material from within the cross-section of the bore. In principle, the boring should not disturb material adjacent to the hole, but this is negated if the auger encounters obstructions (eg timber, concrete, masonry, cobbles, boulders) that are forced outward or dragged down through significant deposits outside the intended bore.

Few published examples exist where archaeological evaluations recorded details of previously installed non-displacement piles and this is an area where further field observations are needed.

During the installation of temporary or permanent casing vibration may occur, and the impact of this, in addition to that of the installation and removal of the casing, has not been fully evaluated. There is a potential risk, highlighted by Nixon (1998), that the installation and removal of the casing may damage an area greater than the diameter of the casing itself. As temporary casings are usually installed to support poorly consolidated deposits, this should reduce any collapse of the bore walls or migration of pile grout into sediment voids. These concerns should be identified in the risk assessment process and discussed by archaeologists and piling engineers on a site-by-site basis.

Other physical impacts may occur where stone, timber and other materials are not cleanly severed by the bore or casing and are pushed aside or dragged down (Nixon 1998, 41). It is possible to get borers capable of cutting through brick and soft stone and it is essential that the likelihood of encountering such sub-surface ground obstacles is clearly addressed in the risk assessment and piling method statement; unforeseen obstructions may hold up the construction programme, and necessitate excavation to remove them. This excavation can be exceptionally damaging to archaeological deposits, and can mean that much a greater area of the site is affected than just the pile locations.

Where bentonite (or synthetic polymer) is used to support unstable sediments, consideration should be given to the impact of this on archaeological deposits. The complexity of the operation means that a compound often needs to be constructed on site for the slurry processing plant. Bentonite is inert so it should pose no chemical risks to archaeological deposits. There may still be physical impact from the use of bentonite which need to be considered within the risk assessment process. For example, where the site is likely to contain voids or the archaeological deposits are poorly consolidated, there is an enhanced risk of the slurry entering these areas. In these cases, a temporary casing could be used for the depth of the archaeologically sensitive deposits.

Temporarily supported bore: hydrogeological impacts

There is a potential risk that the introduction of an alkaline mixture (concrete) will damage archaeological deposits, particularly waterlogged ones. Concrete curing is exothermic (Davis *et al* 2004), the heat potentially acting as a catalyst for further reactions (see Edwards 1998). The potential for mixing of grout and groundwater and for transport of alkaline solution across a greater proportion of the site has yet to be fully evaluated. Where concrete cures quickly and bonds with the sediment of the bore wall, permeability and the potential for transport of alkali materials from the concrete in the groundwater should be reduced. This is a topic where more research is

Figure 24: Borehole rig with CFA piling rig in the background, during sample retrieval to investigate pile cement migration. © Mark Allen

needed (for example as shown in Figure 24), particularly in places where the hydraulic conductivity of the deposits is high, and the movement of groundwater is therefore fast. Further consideration of these theoretical risks is given in Section 5.8.

4.4 Unsupported non-displacement CFA pile impacts

Continuous flight auger (CFA): physical impacts

With CFA piling the auger is screwed into the ground so that the auger provides temporary support for the pile bore. Upon reaching pile depth concrete is injected through the base of the auger whilst the auger is withdrawn. All of this significantly reduces the potential of pile wall collapse. If the auger is rotated too rapidly then adjacent material may be drawn into the bore (called flighting). Flighting is undesirable and will tend to occur when the auger penetrates a harder stratum beneath a soft or loose stratum or due to poor construction control. Flighting can be avoided by good construction control, using a cased-CFA or other piling method.

Provided the auger is advanced at the right speed, and obstructions are not encountered, CFA piling should not physically damage deposits outside the area of the auger.

Where archaeological deposits contain structural material (bricks, stone, wood) then these obstructions may be dragged within the auger flights and damage adjacent deposits. Structural remains can be displaced if the surrounding ground is too weak to restrict their movement or where a suitable cutting head has not been used. Observations of non-displacement pile impacts in The Netherlands verify these conclusions with the greatest levels of damage occurring to walls and floors. Pile probing to identify and clear possible below ground obstructions in advance of CFA piles can also cause significant damage (see pile probing).

A further risk with CFA piles is that concrete may migrate into any voids adjacent to the bore. Any hydrogeological and geochemical impacts will be similar to those discussed for supported non-displacement piles (above).

4.5 Vibro ground improvement techniques

Vibro replacement: physical impacts

One of the principal disadvantages of vibro replacement is that material is forced into the ground, displacing sediment (and archaeological deposits). As the process involves vibration, the soil adjacent to the column is considerably disturbed during the displacement process and this is likely to have a very significant impact on adjacent archaeological deposits. Furthermore, columns are usually installed at around 1.5m to 3.0m c/c (column centres) so there tend to be more replacement columns on a site than if it were piled, increasing the frequency of any impacts. However, there have been few opportunities for archaeologists to evaluate the effects of ground improvement techniques so at present the impacts are not fully understood. The onus should rest with those proposing to use this technique on an archaeological site to clearly demonstrate the harm to significance that it will cause. If the harm is perceived to be too high, then these techniques are unlikely to be a useful way to preserve the archaeological remains on the site.

Vibro compaction and vibro replacement: hydrogeological impacts

Where vibro replacement stone columns are constructed, although these are extremely dense, there is a potential that they could act as conduits for the movement of contaminants, moisture and fluids. In such conditions a concrete plug is generally installed to avoid the dispersion of contaminants. Where the hole created by the vibrating poker is filled with concrete rather than stone, the potential for grout migration will be very limited, as any voids are likely to have been consolidated by the initial vibration. Given the extent to which the physical impacts from vibration may have disturbed any adjacent archaeological deposits, consideration of hydrological impacts may be of limited consequence.

4.6 Summary of pile impacts on archaeological deposits and artefacts

Table 1 contains a summary of the information outlined above. Methods to reduce and manage these impacts are given in Section 5, below.

Pile Type	Lateral Sediment displacement	Concrete migration	Creation of preferential pathway	Vibration (noise and sediment movement)	Metal Corrosion (of piles)
Displacement piles (large and small)	Yes	No (although possibly for Driven in cast *in situ* piles)	Not usually, except thinly layered ground and with H-section piles	Yes, can be reduced	Yes with steel sheet and H-section
Auger displacement piles	Yes	Low potential	Low potential	Limited	No
Non-displacement piles	Low potential	Moderate potential, reduced by casing (except for CFA)	Low potential	Limited, but more likely where casing is used	No
Vibro compaction and vibro replacement – stone	Yes	No	Low potential	Yes	No
Vibro replacement – concrete	Yes	Low potential	Low potential	Yes	No

Table 1: Summary of pile impacts

Unfortunately, in England, there has been no clear requirement for archaeologists to collect piling data from redevelopment sites in any rigorous way. In many instances, evaluations have consciously avoided areas adjacent to piles because they are likely to be disturbed (Davies 2004). This results in vital opportunities to understand the past impacts of construction being missed. It is good practice for this to be a basic requirement on any excavation where previous foundations are encountered because it provides a better understanding of site conditions and the likely future potential impacts of proposed new piles.

4.7 Additional key considerations

Vibration

Vibration from piling can affect above-ground structures as well as below-ground archaeological deposits (Figure 25). The issue of vibration from piling in relation to above ground structures is covered in the British Standard (BS) 5228-2 (2009), BS 7385-1 (1990) and BS 7385-2 (1993). The potential impact will be affected by the type of foundation, underlying ground conditions, the building construction and the state of repair of the building (BS 2009: 37).

Figure 25: During pile installation adjacent to the Scheduled Monument of Hussey Tower, Boston, vibration monitors were used to ensure that vibration did not exceed the agreed limits. The pile locations were pre-augered in part to reduce ground vibration.

Although it is noted in BS 7385-2 that “ruins and near ruins” and a number of other constructions of “historical importance” have a lower resistance to vibration and lower tolerance of vibration effects, BS 5228-2 also notes that “a building of historical value should not (unless it is structurally unsound) be assumed to be more sensitive” (1990: 39). Information is also given in BS 5228-2 on how to reduce the impact of vibration from piling; an appendix gives summary case history data on vibration levels measured on site for a range of piling and ground improvement techniques, for a range of deposit types and buildings, including listed buildings.

Further detailed information on vibration from piling on above-ground historic structures is provided in a CIRIA technical note TN142 (Head and Jardine 1992). It summarises a number of other country codes, including the German DIN 4150, as well as Swiss and Swedish standards and codes. The simplest guidance is given below (Table 2), after DIN 4150 (1970) and provides levels of vibration for specific types of buildings.

Category	Type of structure	Permissible pvv (mm/s)
I	Ruins and damaged buildings, protected as monuments	2
II	Buildings with visible defects, cracks in masonry	4
III	Undamaged buildings in technically good condition	8
IV	Well-stiffened buildings (ie industrial)	10-40

Table 2: Permissible peak particle velocity (ppv) for different structures.

For structural monuments, particularly those in less than prime condition, category I (and possibly II) are relevant. Historic buildings, which are built to different specifications than modern well-stiffened buildings should be covered by categories II and III. If vibration from piling is likely to be an issue on site, a more detailed assessment should be made, considering frequency of vibration, ground conditions and the type of building and its foundations (see Head and Jardine 1992, 41-6).

Vibration can also affect archaeological materials below ground, and intense vibration through soil can damage stratigraphy and embedded artefacts (Sidell *et al* 2004). This can be caused by pile installation, dynamic pile testing, and ground improvement techniques such as vibro compaction. Additionally, vibro piling hammers generate high amplitude vibrations during start-up and close-down. The vibrations from the pile travel both laterally and vertically (Figure 26).

Figure 26: Vibration recording during driven piling using geophones, as part of the NERC Urgent project (see Sidell et al 2004).

Piling equipment

Piling equipment includes piling rigs, cranes, auxiliary tracked plant (eg pumps and power packs) and concrete trucks. Large piling rigs can weigh up to 200 tonnes and significantly increase the stresses in the underlying ground and on any buried archaeological remains. Although small piling rigs can exert high bearing pressures, these tend to be concentrated and dissipate quickly with depth. All piling rigs and cranes require a stable piling platform to operate upon and the thickness of this will also surcharge the ground.

Pile size and geometry

Piling requirements on individual sites will relate directly to the structural needs of the building, and the strength and compressibility of the below ground deposits. Since soils behave differently it is difficult to generalise about ground conditions, or specific pile design. For that reason it is not possible to produce simple tables that compare pile type, pile size and zone of impact on archaeological deposits as such tables be misleading. For example, some non-displacement piles may have a lower loading capacity than driven preformed piles of a similar diameter or width, and thereby require more piles to carry a similar load.

Conversely, the installation of preformed driven piles may have a greater impact on these archaeological deposits, with a zone of disturbance at least one pile-width either side of the pile centreline. In cases where it is possible to use a large single bored pile, multiple driven piles (connected by a pile cap) would usually be needed to provide the same load-bearing capacity. Such close grouping of piles makes it more difficult to interpret the intervening deposits, making the effective impact equal to or larger than that of the single bored pile (*see below*, Pile Groups). This underlines the importance of assessing all of these options within the risk assessment framework.

Pile groups

The pile impacts identified above are principally concerned with damage caused by individual piles. However, driven or mini / micro-bored piles are less usually installed as single piles when supporting large structures. Instead, they are grouped and joined by pile caps, which tie into other building elements (Figure 27).

In most cases isolated piles are likely to be less damaging to the site than grouped piles. This is because the area of sediment enclosed within a pile group, for example three or four piles with a triangular or square arrangement, will be more disturbed. It will be more difficult to interpret the site should it be re-excavated, because it can be hard to access small areas of archaeological deposits within a cluster.

These problems are likely to be exacerbated by the use of driven piles where deposits are modified through down-dragging of sediments. Additionally, any potential hydrogeological and geochemical impacts may be greater in areas where piles are more closely spaced. Where used, pile groups could be located in parts of the site that are not archaeologically sensitive, thereby reducing the harm to significance caused by piling.

Figure 27: Pile group (see concrete piles in bottom left of image) installed by chance adjacent to archaeological deposits. If the pile group had been placed slightly closer to these hypocaust *pilae*, they would have been more highly damaged, and would have been difficult to fully interpret. © University of Leicester Archaeological Services (ULAS)

Pile caps and ground beams

Piled foundations do not generally exist in isolation and the presence of pile caps, ground beams and other structural elements needs to be taken into account. Pile caps are generally concrete slabs at the top of the pile, larger than the pile itself and often spanning several piles grouped together. Ground beams are used to connect two or more piles. Their area and depth depends on the distance between piles and where large distances are spanned, the ground beam can be deep and have a significant impact on archaeological deposits. The depth of the existing building slab, and the depth and level of the new basement slab needs to be considered in assessing the impact of ground beams and foundation design. In combination with other foundations, ground beams can be used to span or cantilever over archaeological features allowing piles to be located away from archaeologically sensitive areas. Depending on the use of the building space (including basement requirements), it may be possible to form ground beams within the ground floor slab, so reducing the below ground impact.

Pile testing

To verify the performance of a pile, pile testing is sometimes undertaken prior to and/or during the main pile installation phase. This may require additional piles to be installed. The most common form of test is the 'static' pile test. Methods include applying a known load to the head of the pile and monitoring its settlement, or advancing the pile into the ground at a known rate and measuring the resisting load. In either case a hydraulic jack is required to apply load to the top of the pile. In turn this needs to jack against some form of rigid structure to provide reaction for the test (Figure 28). Two types of reaction are used, the simpler involving large heavy masses such as concrete or steel weights, which are placed above the test pile. The mass used is often referred to as kentledge. The other method of providing reaction is by means of installing two to more additional piles (reaction piles) around the test pile. Steel beams are then attached to the reaction piles such that they run over the test pile and provide reaction for jacking. Possible impacts on archaeological remains from using kentledge as reaction result from the high near-surface ground loads, which may pose a threat to shallow buried remains. Reaction piles will usually result in additional disturbance unless they form part of the foundation design (*see* below).

Figure 28: Static load test. © Cementation Foundations Skanska

Alternative methods of pile testing do not require additional reaction piles to be installed. The most common forms are dynamic (Figure 29) and 'Statnamic' pile tests (Figure 30). Dynamic pile tests are best suited to driven piles and may be undertaken during the installation phase with no additional plant requirements. Statnamic pile testing does require the mobilisation

Figures 29 and 30: Monitoring equipment being fitted to a driven pile in advance of dynamic pile testing (left). Statnamic pile testing equipment (right). Both images © Mike Brown

of specialist plant, but has the benefit of having a mass of only 5% of the equivalent kentledge and a limited surface footprint. Both dynamic and Statnamic pile testing should be assessed for vibration impact on adjacent structures similar to that required for driven piling. When positioning a test pile, its location in relation to the final construction piles should be considered. Where possible, test piles and reaction piles should be designed to form part of the final construction (working piles) reducing the need for additional piles. On very sensitive sites, this may affect the type of pile test chosen.

An alternative method of load testing piles is to use the bi-directional load cell method (eg Osterberg Cell). This system does not require additional reaction piles and so the impact on the archaeology will be reduced from only using the test pile itself. The bi-directional cell comprises a set of hydraulic jacks cast into the pile which then derives the reaction to the applied loading directly from the pile and ground both above and below the jacks, see www.loadtest.com for more information.

Pile testing is covered in detail by the *Handbook on Pile Load Testing,* produced by the Federation of Piling Specialists (2006).

Pile probing

It is not just pile installation that has the potential to cause damage to archaeological deposits. To investigate the presence of unknown below ground obstructions, pile probing is sometimes carried out on sites. This work does not necessarily take place during the piling contract, and can occur as part of the demolition or enabling works. Where this process does not fall into the construction phases, it can be difficult to manage, and it is best practice for it to be considered during the risk assessment process to ensure that its use is avoided on sites containing archaeological remains.

Probing for obstructions can be undertaken by several methods depending on the ground conditions, expected obstructions and their depth, as well as the proposed piling methodology. Common methods include: pushing a probe or rotating an auger into the ground at each pile location; or machine excavating a pit at pile locations. Probing is usually only undertaken to reach a depth of undisturbed natural ground, below which obstructions are not expected. Such methods and subsequent obstruction clearance though coring or excavations can significantly impact on archaeology.

The amount of probing can be mitigated in advance by undertaking a thorough desk study to overlay historical plans and the proposed pile layout and intrusive/non-intrusive investigations eg archaeological trenches and geophysical surveys.

Contaminated sites and piling

Many of the piling issues that concern archaeologists are similar to those that concern the Environment Agency regarding the effects of piling on groundwater. Pile installation on contaminated sites that overlie aquifers can give rise to increased leaching of pollutants to groundwater through vertical pathways created by the piling (Environment Agency 2001; Westcott *et al* 2003). On sites overlying fractured or fissured rock, or where there has previously been mineral working (ie deep mining), injection of grout (which might impact on shallow archaeological deposits) can also impact further down. At these sites, injection of grout could result in the migration of grout away from the bore over a very large area. Where possible, it is good practice for the archaeological and geotechnical investigations to be carried out alongside each other, to minimise the cost on developers with respect to site characterisation, risk assessment and risk management design. Further information on contamination assessment and management in relation to archaeological sites is given in Historic England guidance on Land Contamination and Archaeology.

5

Designing a sustainable foundation scheme

The NPPF requires developers to describe the significance of heritage assets, including that derived from their setting, affected by development. It is good practice to assess the archaeological and historical significance of a site at the earliest stage. This would include consulting the HER and assessing heritage assets using appropriate expertise. The archaeological potential of a proposed development site is set out in a desk-based assessment and explored further by field evaluation. This work can be in response to a development proposal where the impact of the scheme is already known, or to inform revisions or amendments to a design. In either case where the likely impacts of piling and foundation design are considered at the earliest stage, this allows relevant data to be collected, including foundation design of the existing and previous buildings on the site. This information will enable local planning authorities to consider the impact of the proposed scheme on the significance of heritage assets and to minimise harm. This helps to reduce risk and uncertainty in a development programme.

During the design process, the sharing of archaeological and engineering information will enable the development team to design a scheme to minimise harm to the character and significance of the archaeological remains. This will ensure that the most appropriate engineering and mitigation solutions are identified. It is therefore paramount that the character and significance of the archaeological deposits are drawn to the attention of the development team at an early stage so that the associated constraints can be considered as part of the design. Piling and building foundations can have a significant impact on archaeological remains. Piling may affect archaeological deposits over a wide area, for example by changing the site hydrogeology and it may be appropriate to consider the effects of the proposed works on deposits adjacent to the site.

The following sections of this chapter cover a series of different elements of the design process which will allow a sustainable foundation scheme to be developed. They focus on the avoidance or reduction of disturbance to archaeological remains and how that can be achieved, drawing on the technical explanations and principles outlined in the preceding chapters. Additional information is given in relation to human remains and waterlogged deposits which are particularly sensitive to the impacts of piling. By ensuring that all available alternative means of reducing archaeological impacts have been addressed in the formation of a foundation strategy, this document will assist in underpinning robust decision taking in this regard under the statutory planning system.

5.1 Pre-application discussion

Wherever possible it is recommended that developers seek early pre-application consultation with local planning authorities. Pre-application discussion is a key tool in managing risk for developers and can provide an early steer on the implications of development on a given site. It can give clarity on the likely scope and requirements of pre-determination archaeological work and associated evidence base requirements. It can also provide an understanding of any particular known risks or opportunities relating to archaeological remains within the site.

5.2 Collation of a robust evidence base

As part of the pre-application and pre-determination discussions, the earlier that supporting information is provided in the design process, the easier it will be to minimise harm and lower risk. Information to submit with a planning application (or pre-application discussion) might include:

- Desk based assessment (including assessment of significance)
    - Information about existing building foundations and basement levels
    - Deposit modelling
    - Tier 1 Hydrological Assessment (as appropriate, in accordance with guidance on Preserving Archaeological Remains)
- Field evaluation (if necessary, may include trial trenches, geophysical survey, geotechnical investigation, boreholes – some evaluation may include all of these techniques)
- An archaeological field evaluation report which sets out the findings of the evaluation, updates understanding of significance and the state of preservation of the archaeological remains, and assesses existing building impacts

All the information described above will provide valuable information to inform an approach for the foundation design to avoid or reduce archaeological impacts. It will also ensure that there is a clear understanding on which to devise an appropriate and proportionate scheme of archaeological mitigation where loss of such remains is considered to be justified.

5.3 Impact avoidance strategies

- The most effective method for mitigating the impacts of piling on significant archaeological remains is to adopt an avoidance strategy, whereby piles are located away from archaeologically sensitive areas (Figure 31). In these cases foundations can be designed so that they impact only on the less sensitive areas or on areas of existing disturbance.

- It is good practice for new foundations to be avoided in areas where there is potential for significant archaeological remains. Where this is not possible or feasible then a redesign of the foundations to include raft, ground beam, frame supports, or cantilevered structures above the significant archaeological horizon may be options.

- Another option is to reduce the number of piles within groups by increasing the dimensions of the piles. Where the engineers have been closely involved with the mitigation process throughout, they will be able to design a piling layout that causes the least damage to archaeological remains and, where feasible, avoids the use of pile clusters.

Figure 31: Piles can be located to avoid structures identified in evaluation or a site strip. © MOLA

5.4 Pile re-use

Where a site has an existing piled foundation, it is good practice to consider their re-use and to carry out a feasibility study. An example of how a feasibility study could be agreed between a local authority and developer is outlined in case study 7.10. It is recommended that the feasibility study is carried out before demolition or enabling works, because these may damage the foundation.

The benefits of pile re-use are obvious since they reduce the need for new foundations, thus limiting impact on archaeological deposits. Frequently this is a technique that is being used in urban areas where, as the number of times a site is redeveloped increases, so does the number of service trenches, old foundations and other below-ground obstacles (Figure 32).

Over time, the area available for new foundations is dramatically reduced, and in some areas, for example London (where there are many other below ground obstructions), pile re-use may soon be the only feasible option. This problem is exacerbated by the fact that new buildings have a relatively short design-life (Butcher *et al* 2006a).

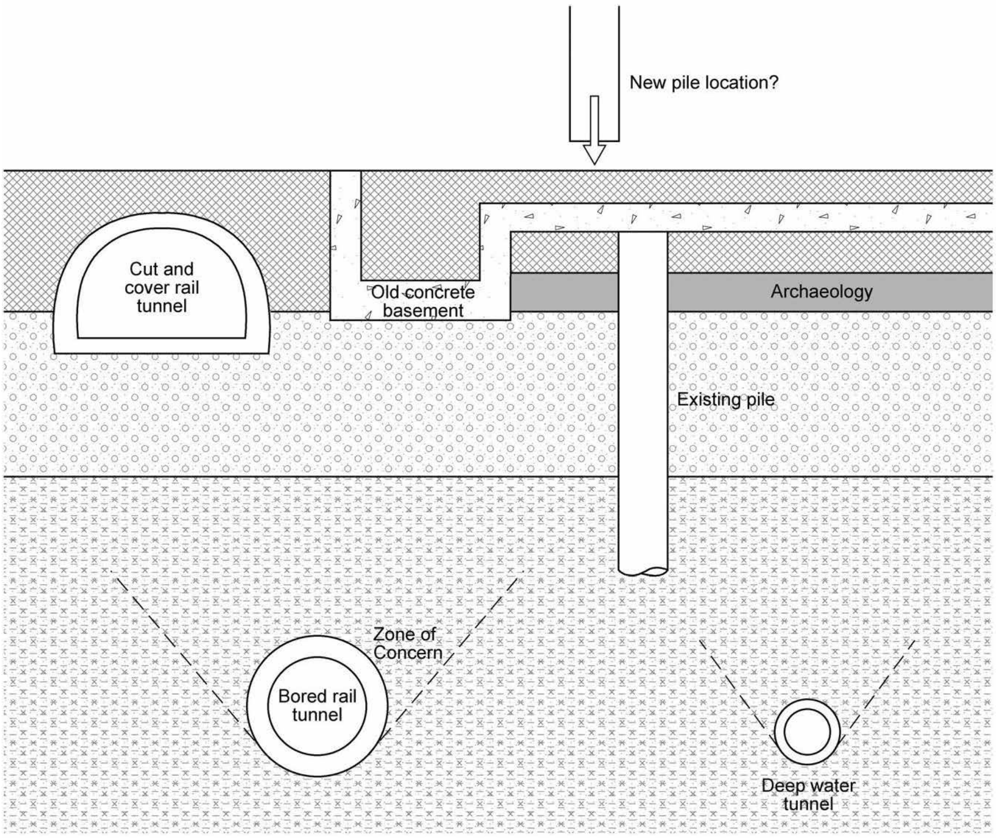


Figure 32: Ground congestion issues in urban centres severely restrict possible locations for new piles, making foundation re-use a very necessary technique. Image courtesy of the RuFUS Consortium 2006, and reproduced from Butcher *et al* 2006b

In some cases additional piles or foundations will be needed, or the existing piles may need to be strengthened, but even partial pile re-use will result in a reduction in the below-ground impact (Williams 2006). It is also possible to remove piles and re-use the locations for new piles if increased bearing capacity is needed (Hughes *et al* 2004, 101). This concentrates damage in areas that have already been affected by piling, although the process of removal is likely to be damaging and methodologies must be considered carefully.

Future pile re-use can be greatly assisted where Building Information Modelling (BIM) includes detailed information on the design and installation of piled foundations on the site.

Issues to consider

There are a large number of factors that need to be considered in any re-use strategy, including soil conditions, the structural capacity of the existing and new buildings, the character of the archaeological deposits across the site, and whether pile or pile location re-use is proposed.

A key factor in a successful pile-reuse strategy is a high-quality site investigation of the ground and existing foundation system, as set out in the CIRIA guide on foundation reuse (Chapman *et al* 2007).

Further issues include insurance and liability for old foundations, locating technical information about existing piles, testing the capacity of the old piles and the fact that the existing piles may be in the 'wrong' place for the new building. Many of these issues were evaluated by the EC funded project project Reuse of Foundations for Urban Sites (RuFUS), which published a handbook for foundation re-use (Butcher *et al* 2006a), and the proceedings of an international conference on the subject (Butcher *et al* 2006b).

One of the perceived drawbacks of foundation re-use is that each time a site is re-developed, economic pressures dictate that the new building will be larger than that being replaced, which usually means larger foundations. The possibility of over-engineering new piles for future re-use may develop, but this has cost implications which in the short term may be difficult to justify. However, by investing in piles with greater capacity in the present, substantial cost savings can then be passed on when the site is re-developed in the future. Additionally, it is possible that increased structural loads from larger buildings can be offset by using lighter building materials than were used in the original building.

Programme stage	Design stage	Construction stage	Building operation
Geological information	Design philosophy	As-built documents	As-built drawings
Geotechnical information	Design codes	Non-conformance reports	Maintenance records
Groundwater level	Design calculations	Construction documents	Environmental changes
Groundwater quality	Necessary bearing capacity	Programme of piling works	Inspections
Contaminated soil	Force combinations applied on each pile	Plant and equipment	Pile behaviour
Site conditions	Pile data	Test piling	Service life measurements
	Settlement limitations	Working documents	Structural alterations
	Protocol for foundation record	Site records	
		Pile installation records	
		Effects on nearby foundations and structures	
		Results from monitoring	

Table 3: Information relating to new piles that should be stored to enable future pile re-use (Butcher *et al* 2006a).

Collating data for future re-use

It is worth emphasising that new piles are significantly more likely to be re-used in the future if engineers have full information on the design and construction of these piles. Where archaeological deposits are particularly significant, consideration should also be given to instrumenting piles to be able to verify performance for future reuse. Recommendations for the type of information needed for future re-use are provided in the RuFUS handbook, summarised in Table 3.

5.5 Understanding piling impacts

Avoidance strategies are considered on a site-by-site basis, taking into account the scale and nature of the development and the archaeological potential. All piling operations will result in the physical destruction of archaeological deposits directly in the path of the pile and, while it is accepted that destruction will occur, there has been much discussion of what constitutes an acceptable level.

As is highlighted in Chapter 4, depending on the type of pile used, it is possible that disturbance to a zone larger than the size of the pile might occur. For example, recorded impacts from displacement piles are extremely variable, ranging from no perceptible change through to distinct zones of impact where the integrity of the stratigraphy equal to at least twice the width of the pile has been compromised.

When considering the likely level of impact from displacement piles, it is suggested that an area of impact equal to twice the width of the pile (ie one pile width either side of the pile centreline) is assumed, which equates to a fourfold increase in the area of pile impact; it is this value that must be factored in when assessing the harm to the significance of archaeological remains on site. Furthermore, where three or more piles are placed within a cluster, the area within this cluster will be very hard to interpret in the future. For the purposes of assessing harm to the significance of archaeological remains on site, the impact to this area is usually be considered to be high.

Local authority planning and archaeological officers need to be aware of the cumulative impact of re-development on a site, which makes later interpretation more difficult. In these cases, foundation re-use, both of the existing foundations or their locations, may be a beneficial mitigation method. In other cases, archaeological excavation may represent a more appropriate option than any further attempts to preserve the site within the development.

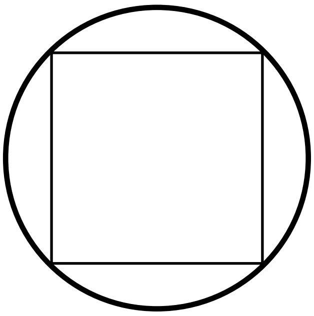


Figure 33: Recommended diameter for pre-augering (circle) shown along with the square pile, with the same distance across the diagonal as the diameter of the auger hole.

5.6 Pre-augering displacement pile locations

One method to reduce potential physical damage to sediments adjacent to preformed displacement piles is to pre-auger the pile locations. This technique was trialled on two sites which were subsequently excavated archaeologically (Davies 2003; Rayner 2005). In both cases the excavation demonstrated that the impact of the subsequent displacement piling was limited to the area already disturbed by the pre-augering.

In order that this technique is successful, it is recommended that the auger diameter is equal to the diagonal of the pile and augered to below the depth of known archaeological deposits (Figure 33). The material disturbed in pre-augering should remain in place by rotating the auger in the opposite direction to penetration during withdrawal.

5.7 Obstructions to piling

When piles are to be installed on sites where previous foundations or substantial structural archaeological remains are suspected (stone walls/ foundations, etc), then the piling contractor should be made aware of this issue; the applicant should have already identified the potential for obstructions within the risk assessment process.

Where non-displacement piles are used, it is possible that tools capable of cutting directly through these obstructions could be used. In these instances it is essential that the piling contractor is aware of these issues at the time that the work is specified, so that the right equipment and a methodology capable of overcoming such obstructions can be identified.

Where it is not possible to cut directly through obstructions, or preformed driven piling is undertaken, two options are available: either remove the obstructions through excavation from the surface or relocate the pile(s). Where archaeological remains are present, localised archaeological excavation of the remains forming the obstruction is likely to be needed, which could delay the piling programme. This is why it is important that a full understanding of the location, significance and state of preservation of archaeological remains present on site is compiled before this work takes place.

Locating obstructions is potentially a very damaging stage of construction as, quite reasonably, developers seek to avoid unexpected ground conditions. This work may not be part of the main piling programme, but included within a separate demolition or enabling contract. A methodology detailing steps to be taken when encountering obstructions should be prepared for each site and in some cases it may be appropriate for an archaeologist to be present during demolition or enabling works to ensure the methodology agreed by all parties to address this issue, is adhered to on site. In cases where a total site strip to the top of archaeological remains is undertaken as part of the evaluation and mitigation process, obstructions can be more readily identified, enabling a suitable methodology for removal (if necessary) to be agreed.

Removing obstructions that cannot be directly bored through may involve probing or pre-augering with diamond or chisel cutting tips. However, contractors must not engage in uncontrolled machine clearance of obstructions as this can result in a collateral loss of archaeological integrity as the area around an obstruction is checked thoroughly for obstructions.

5.8 Piling and waterlogged deposits

Understanding the full impacts of piling on waterlogged deposits is complex, and requires a thorough knowledge of the site hydrogeology. Appendix 3 of the guidance on Preserving Archaeological Remains provides detailed information on undertaking a water environment assessment.

Cofferdams constructed from augered secant or driven sheet piles, whether used to control water ingress during construction or in flood defence barriers, may impact on waterlogged archaeological remains by altering water levels. A water environment study, conducted to inform the decision-taking process, would provide an assessment of groundwater flow and availability and can be used to consider the effects of any barriers on water (or soil moisture) levels on site. Where the barriers are long-term there is every possibility that waterlogged deposits may be cut off from hydraulic recharge and decay as a result, rendering long-term preservation unviable.

The chemical impact of pile concrete from non-displacement piles on waterlogged deposits is not yet fully understood, and although two field tests (Williams *et al* 2008) did not identify any significant impacts, there still remains the potential that some chemical damage may occur. During the time that the pile cures, there is a potential risk that the migration of chemicals from the pile grout/concrete may locally affect the groundwater. The impact of this will, to a large degree, depend upon the nature of the waterlogged deposits, and the rate of groundwater flow. Deposits with a high hydraulic conductivity, such as gravel, may have fairly rapid groundwater movement, but organic-rich, peat-like deposits typically have a low hydraulic conductivity, meaning groundwater movement will be limited and therefore the potential risk is significantly reduced. This could be further reduced by the adoption of preformed piling solutions or, when casting of concrete in the ground cannot be avoided, the installation of a permanent casing. Evidence from the excavation of previous non-displacement piles in similar soil and groundwater conditions would help to refine the risks outlined above.

Concerns exist regarding the possibility of piles puncturing impermeable layers that contribute to the preservation of waterlogged deposits, particularly in urban environments where there are known to be perched water tables. Mitigation for development, where waterlogging is known to occur above the natural groundwater level, should include an appraisal of the proposed foundation design and consideration of a solution which avoids impacts. Model-scale research (Hird *et al* 2006) indicates that the most important factor is the thickness of the aquitard (the impermeable layer restricting groundwater flow). Where piling is the only option on waterlogged sites with perched water tables, then the use of permanent rather than temporary casings on non-displacement piles should be considered, as the removal of temporary casings may also disrupt the aquitard. Further information can be found in publications such as the Environment Agency's Decommissioning Redundant Boreholes and Wells and the Scottish Environment Protection Agency's Good Practice for Decommissioning Redundant Boreholes and Wells.

5.9 Piling and burial grounds

Burial grounds contain human skeletal remains and associated items such as monuments, coffins and grave goods. They constitute some of our most significant archaeological sites, containing important sources of information about our past. In addition, they may also contain structural remains such as paths, vaults and earlier phases of church buildings which enable us to understand the development and use of the site in tandem with what we can learn from the skeletal population.

When dealing with burial grounds of any denomination, their excavation, study and archiving require consideration of sensitive ethical and legal considerations (see APABE, 2017). For this reason the avoidance of disturbance is the preferred option, but any disturbance must be clearly and convincingly justified. The significance of all the archaeology, which includes the skeletal remains, should be understood prior to designing foundations for new schemes. The Ministry of Justice, who would need to provide a licence to undertake disturbance to a burial ground, (other than those of the Church of England in active use, which are subject to Faculty Jurisdiction) would not normally permit piling in such locations and this principle is upheld here.

An alternative to piling is the use of ground beams and raft foundations. This approach to foundation design presents a viable alternative to piling where human remains will be impacted and has been successful in many development situations (see for example case study provided by Shilston and Fletcher 1998). However, its use does not necessarily avoid all impacts and will require archaeological excavation within the area where human remains will be disturbed, ie the area of ground beams. Where such a foundation design can be employed, certainty is required that the human remains can be safely preserved below the raft construction. Although more burials may be impacted upon than through piling, this approach does not lead to destruction without record of both burials and other unknown archaeology (for example, see Figure 22).

Piling should only be considered if wholly exceptional circumstances prevail, and the public benefit outweighs the harm caused to the significance of the archaeological remains. In such circumstances a detailed project plan should be put into place, covering evaluation, excavation, foundation design, movement of piling rigs and exclusion zones (for instance over vaults). Archaeological excavation should take place within the area of the pile caps as a minimum, to ensure that no human remains are piled through. Ideally, the excavation should lead to the recovery of complete rather than partial skeletons, so that an archaeologically coherent and meaningful analysis can take place.

5.10 Reporting

It is imperative to the success of future foundation re-use schemes that all available design and construction data for current foundations are stored in a suitable location such as the site archive or local Historic Environment Record. Data should include the final pile locations, loading capacity, test results, and as-built drawings. Other information such as the engineers' design report, contractors’ method statements and more detailed designs should form part of the site archive.

Where excavation has provided information on the impact of previous foundations on archaeological remains, these impacts should be recorded as part of the reporting process, as they provide an indication of the impacts of similar foundations solutions planned for the site (or surrounding areas).

5.11 Summary

This edition of guidance does not prescribe the percentage of piling that might be appropriate on any given development, as on different sites, the archaeological deposits and the significance of the site will have a bearing on what is appropriate. The understanding of these issues will depend on the quality and quantity of information available from the site evaluation and understanding of previous truncation.

The guidance also does not contain specific advice on the amount of and methods of evaluation. In some places, a total site strip to the top of archaeological deposits with selective further sampling of deeper deposits has been identified as the most effective method of site characterisation; this method also provides information to aid in the micro-siting of foundations to avoid harm to areas of significance. In other locations, different methods may suit site constraints and the nature of the archaeological remains. Local planning authority archaeologists are in the best position to make these judgements on a case by case basis.

On many archaeological sites developed in the last 30 years, developers and their project teams have routinely designed foundation schemes where new piling impacts have been kept to a very low percentage of the overall site area. Reducing foundation impacts on archaeological remains is thus technically feasible. Equally, unless there are specific reasons for over-engineering a foundation scheme (for example to allow for future foundation re-use), it is an unnecessary expense to use more piles than is necessary to meet the design requirements and technical standards.

The key issues that need to be considered to avoid or reduce harm from piling on any site containing archaeological remains are:

- Evaluation and site investigation results
- Location, depth, character, significance and state of preservation of archaeological remains
- The impact of previous development on this site on the significance and state of preservation of archaeological remains
- The combined impact of the existing, proposed and previous development on the significance and state of preservation of archaeological remains

Early and constant discussion of these issues with the local authority archaeological advisers, and the use of the risk assessment methodology outlined in section 5 will help all sides come to an understanding about what represents a sustainable foundation solution for a given site.

Issues to consider when designing a sustainable foundation solution are presented in Table 4.

Pile Type	Mitigation
All pile types	Adopt 'avoidance strategy' and avoid use of piles in areas of archaeological sensitivity where possible. Where piling is unavoidable, limit extent of physical destruction as far as possible to avoid harm to significance. The impact of all ground intrusions, including ground beams and pile caps needs to be considered. Burial grounds should not be piled. Need to take into account potential pre-construction impacts, such as pile probing, on-site effects from piling equipment (plant), and associated infrastructure, such as piling mats, concrete plants etc
Large displacement piles	Zone of impact is potentially greater than diameter of pile, therefore calculate percentage loss of area in building footprint using four times the pile area, unless there is evidence of the impact of past piling activity recovered through excavation.
Small displacement piles	Sheet – If waterlogged remains are present, assess potential impacts on groundwater flow and recharge of deposits through undertaking water environment study to understand long-term effects on water-table and water chemistry. H-section – Not recommended for waterlogged deposits due to possible migration and oxygen ingress.
Non-displacement piles	Consider use of suitable cutting tools where obstructions are likely to be encountered. For secant walls see above for sheet piles. CFA – Avoid on sites where modern and archaeological structural remains likely unless suitable cutting heads can be used to cut through obstructions, or where site strip has allowed these to be identified in full.
Vibro ground improvement techniques	Require further investigation, but are likely to be extremely damaging to archaeology and should be avoided where possible.

Table 4: Key foundation issues to consider.

6 Risk assessment

As information about the significance of a site is obtained, through assessment and evaluation, it is good practice to consider and assess the risks of potential impacts.

Risk assessment forms a conventional tool used by project teams to identify, evaluate, avoid or control risk. This section lays out an approach to assessing risk to the significance of archaeological deposits within development. We recommend this is begun at pre-planning stages and continuously updated during design development, forming part of the documentation submitted in support of applications for planning permission.

6.1 Objective

To propose a robust, effective and transparent decision making process that allows project team to select appropriate foundation methods and control measures when working on archaeological sites.

Design and avoidance measures

In many cases it will be possible to remove a potentially adverse impact on the significance of the archaeological deposits by the design and specification of avoidance measures. These could be based, for example, on changes to the building location/structural arrangement, foundation option or changes to the piling installation method.

6.2 Risk assessment method

The recommended risk assessment process to be carried out by the project team is given in Table 5. It provides a framework for the project team to carry out (with the input of appropriate archaeological advice) a risk assessment to select the most appropriate foundation option and to justify this choice with appropriate design and avoidance measures. It is good practice for this process to start at the pre-planning stage concurrent with design development. It works best as a continuous iterative process with design and avoidance measures updated as new information becomes available from desk based research and site investigations.

Below is guide to the column heading and the type of information to be entered:

Foundation options

There could be various different alternatives to provide a sound foundation to a building. For example this could be a raft, slab and ground beams, groups of small diameter piles, or a reduced number of large diameter piles. All feasible foundation designs should be considered, using Table 5. For the various piling methods see Section 3.

Impacts

Six key impacts have been identified and these remain constant for each foundation option. The six impacts are:

- Enabling and temporary works (operations to prepare the site for construction)
- Installation damage (including vibration)
- Hydrogeology / compression / chemical / contamination
- Ground substructure (clusters, pile caps etc.)
- Cumulative attrition
- Post-construction remedial and maintenance activities

Hazards

The hazards represent the threat to the archaeological deposits from each impact dependent on the foundation option. These can include physical damage, changes to ground conditions (hydrology, contamination, chemistry), and simply through the cumulative impact of further new development. These threats should be clearly assessed in this column.

Design / avoidance measures

This column should be informed by the available information and continuously updated throughout design development as new information becomes available from desk based research and site investigations.

This column should suggest solutions to protect the significance of the archaeological deposits.

Uncertainties

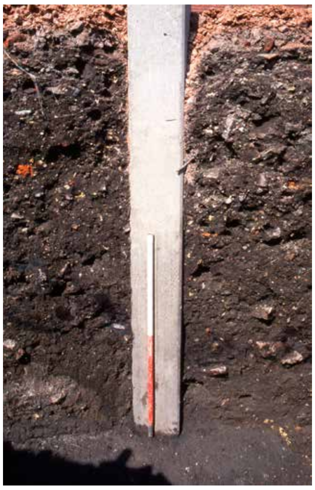
Use this column for any additional risk. It should identify areas that are not yet defined.

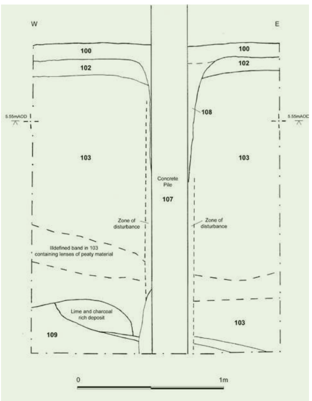
Foundation options	Impact	Hazards	Design / avoidance measures	Uncertainties
	Enabling and temporary works (operations to prepare the site for construction), including obstructions			
	Installation damage (including vibration)			
	Hydrogeology / compression / chemical / contamination			
	Ground substructure (clusters, pile caps etc.)			
	Cumulative attrition			
	Post-construction remedial and maintenance activities			

Table 5. Blank risk assessment form.

7 Case studies

7.1 Pile pre-augering: JunXion, Lincoln





Figures 34 and 35: Piling mat carried down adjacent to the pile, the JunXion, Lincoln (top) © ARCUS. Section drawing of sediment deformation from the JunXion, Lincoln (bottom). Image from Davies 2003.

An opportunity arose to test the potential for pre-augering concrete driven pile locations to reduce the drag down adjacent deposits, at a site in Lincoln. The piling contractor wanted to demonstrate that the area of impact from driven piles could be better controlled if the locations were pre-augered to below the depth of the archaeological deposits. They particularly wanted to use this technique along one side of the site to reduce piling vibration on the printing presses of the local newspaper, housed next door.

The methodology entailed pre-augering the pile location with a 350mm diameter auger to a depth of 3-4m which was then withdrawn whilst rotating in the opposite direction. This left the soil in the ground, but disrupted it sufficiently to make the insertion of 250mm square piles easier. The auger size was chosen to match closely the distance across the pile diagonal (353mm). As the technique had not apparently been used before on an archaeological site, it was agreed that an evaluation of its impact on archaeological remains would be carried out.

Following excavation, no evidence of disturbance outside the area of the auger (ie 350mm) could be identified (see Figures 34 & 35). Since the potential damage estimated for the driven piles on this site was twice the width of the pile (*c* 500mm), this therefore represented a reduction in the potential area of damage that might have occurred from driven piling alone. In this case, evidence from an example pile, driven without first pre-augering, indicated that down-dragging of material and its impact on these particular deposits was also limited to a zone no greater than that of the auger (ie 350mm). On this basis, for this particular site, it was decided that there was no need to pre-auger the majority of pile locations on the site (except those adjacent to the printing press).

7.2 Steel screw piles: Salisbury

This technique was used on a sensitive archaeological site in Salisbury (Figure 36). The piles were made up of a number of curved spirals of steel of varying diameters connected to a central shaft (as shown in Figure 23). Piles, which had a 250kN capacity (T Sheward pers comm), were screwed into the ground to depths of 5m (Sheward 2003). Benefits were that it was unnecessary to remove spoil associated with any piling operation, or to bring piling materials to the site through the city's narrow streets. Additionally, the piles can be removed by unscrewing at a later date theoretically causing very limited damage to below-ground deposits.

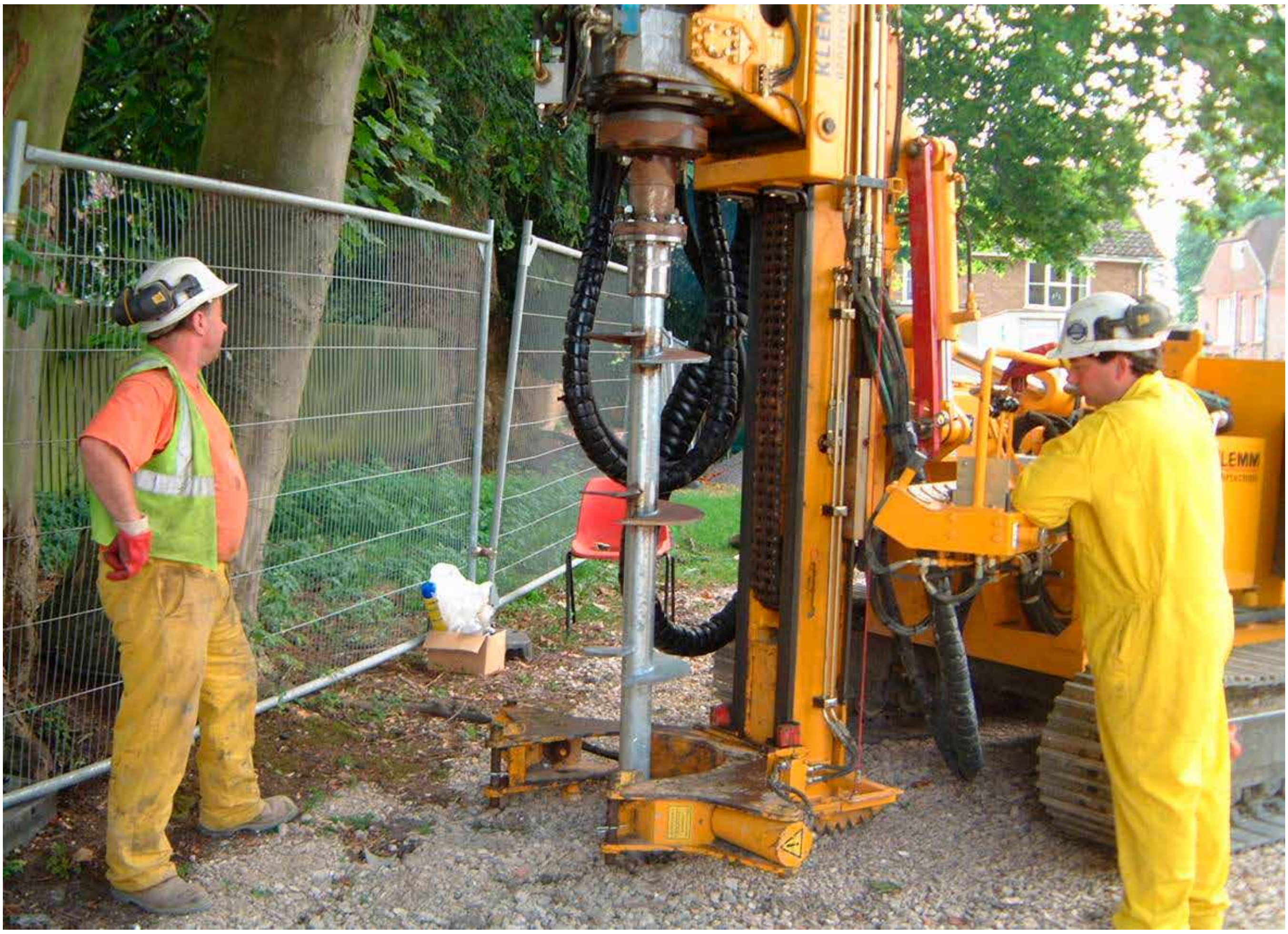


Figure 36: Screw piles being installed. © Tim Sheward

7.3 Pile re-use: Ramada Encore Hotel, Mickelgate, York

Figure 37: Exterior of the hotel which is built largely on re-used piles.

The previous building on the site was the offices of the Yorkshire Co-operative Society, constructed in the 1960s. The site was acquired by a developer to build a hotel. During discussions with the City Archaeologist, the developer was informed of the likely archaeological potential of the site, which was situated within the medieval town walls, not far from the riverside, and therefore likely to contain well preserved organic material. On the basis of that discussion, the developer produced a plan to re-use the foundations of the existing building, thereby reducing the potential need for, and cost of archaeological evaluation (Figures 37 and 38). The scheme, which included the re-use of all 110 previous piles, needed a further 17 installed in three discrete locations. This meant that over most of the rest of the site, no ground disturbance occurred. Any below ground impact was further mitigated because the building was constructed on the existing ground slab with archaeological recording during the installation of services and pile caps, none of which were deep enough to encounter significant archaeological deposits.

This scheme was very successful, mainly because the potential for re-use had been highlighted early enough in the design phase of the scheme, and was led by the developer, who was keen to reduce the risk to the scheme of having to deal with archaeological material (Williams and Butcher 2006).

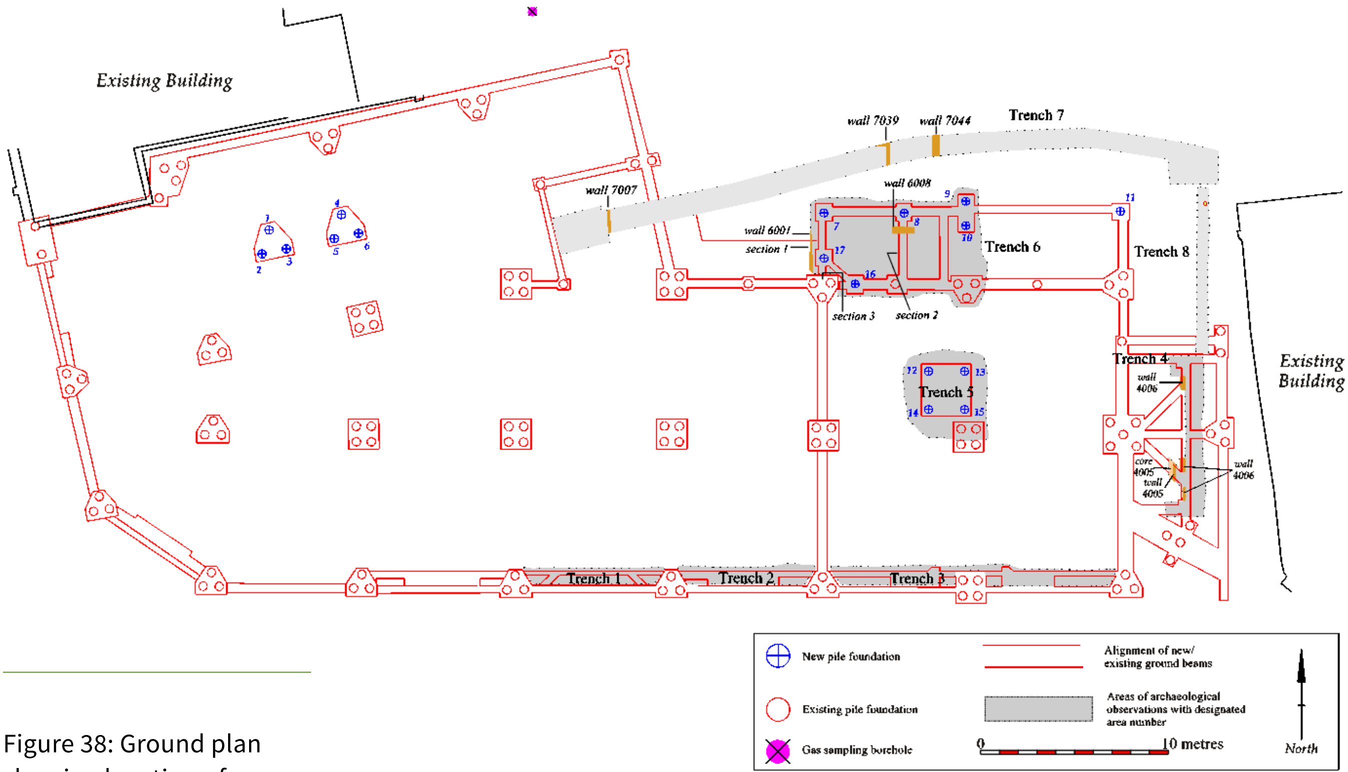


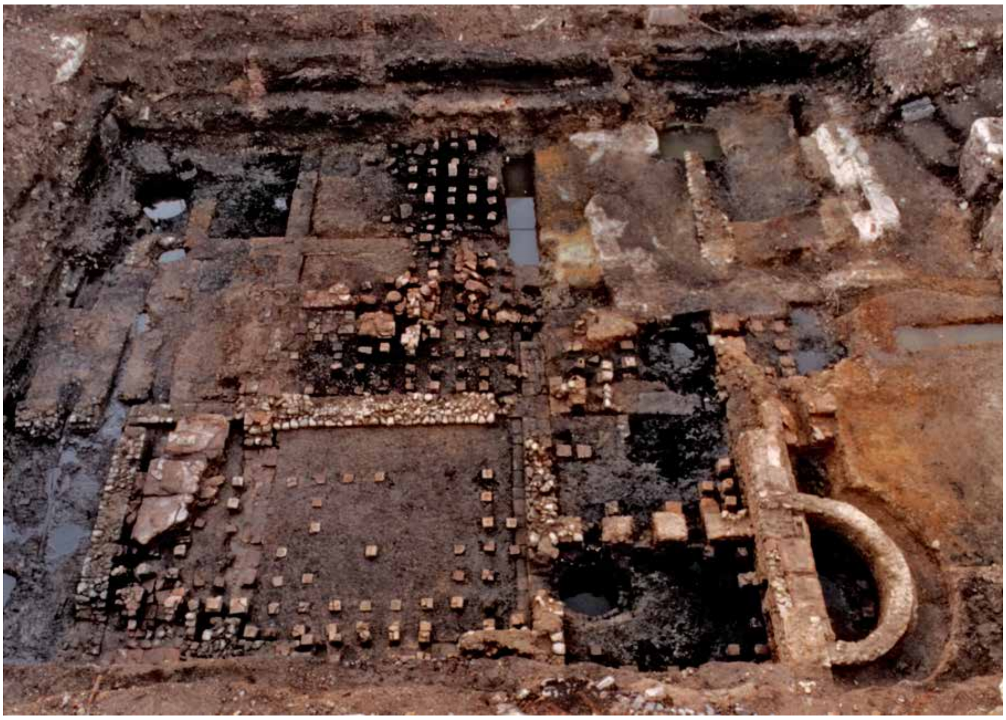
Figure 38: Ground plan showing location of previous and new piles. © York Archaeological Trust

7.4 Pile avoidance and redesign: 43 The Highway, Shadwell, London

An exceptionally well-preserved Roman building was discovered during excavation in advance of development (Figure 39). Roman remains had been anticipated following evaluation, but not the quality of the building and extent of its survival. It was considered by the archaeological curator to be a find of national significance and therefore preservation of the building was recommended and agreed by all parties. However, planning permission subject to a condition to archaeologically record and excavate the site had been granted for a multi-storey residential block of apartments.

The site is located in the Thames floodplain, on inherently unstable alluvial sediments, requiring substantial piled foundations through river silts and gravels. Discussions took place on exactly which aspects of the Roman archaeology needed to be preserved and what, if anything, could be preserved by record. It was decided that all intact structural elements needed to be preserved while some spaces between walls could be fully excavated, recorded, backfilled and then piled through. The use of detailed digital plans of the archaeology was extremely important to compare with the proposed foundation plan including pile locations. The foundations were redesigned to allow development while retaining the building intact. The proposed CFA technique was retained and no pile dimensions had to be changed. Piles were relocated to areas between the Roman walls and hypocaust *pilae*, with as much clearance as possible between pile locations and the Roman building. The building was backfilled to an agreed specification involving geotextile, inert sand, and then graded spoil from the site. CFA piles were then carefully located and installed, securing the safety of the building.

Figure 39: The Shadwell bathhouse. © Pre-Construct Archaeology Ltd



7.5 Communication and design changes: The Curtain Theatre, Shoreditch

When proposals were initially scoped to develop the area thought to incorporate the location of the Curtain Theatre, one of the earliest Shakespearean playhouses in London, the developer was enthusiastic about incorporating the remains into the new mixed use scheme as a public display. Archaeological evaluation was undertaken in difficult circumstances as the site was heavily built up, but traces were found of a Tudor polygonal building, tentatively identified as the playhouse. The design for the new scheme progressed, designing foundations carefully around a roughly circular space, to enable the playhouse to be preserved when finally revealed.

After demolition began on the site, further excavation led to an exciting, but unexpected discovery. The playhouse was well preserved but rectangular, rather than polygonal. By this time plans were advanced and required a significant redesign to incorporate a square playhouse into a round hole. The new buildings, including a substantial tower, would be hard up against and slightly over-sailing the playhouse, and require basements as well as a substantial piling scheme.

The developer was extremely supportive of protecting the archaeology (the site is nationally important) and the design and engineering teams worked with archaeologists to examine every pile location where there was a possible conflict and make adjustments to avoid the most significant elements of the site. Substantial concrete slabs were present in the ground, which form one element of the foundation design but no piles were suitable for re-use, owing to the much larger scale of the new build.

Several plunge piles were carefully inserted in the archaeological area between the masonry, in areas crucial for the new tower. These plunge piles allowed the construction of the superstructure to begin before the basement had been formed, helping with the programme.

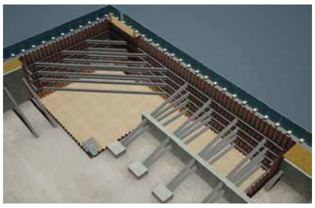
In addition to the permanent piling scheme, a temporary secant pile wall was built around the playhouse, to effectively box it in to protect the remains during construction of the new scheme. The partial reduction of this secant wall allows the public presentation of the remains. The success of this scheme, and the way in which new information was incorporated into redesigns has been possible because there was early evaluation which highlighted the significance of the site and constant communication between archaeologists, engineers and designers to accommodate the complex archaeological remains present on site.

7.6 Prior information used to reduce harm: Bloomberg European Headquarters, City of London

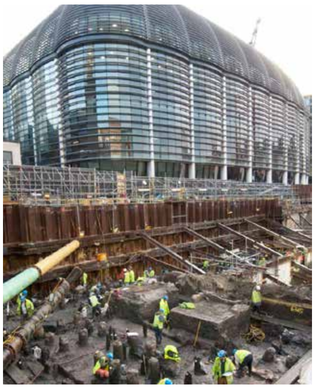
Archaeological evaluation in advance of the construction of Bloomberg's European Headquarters revealed that fragmentary remains of the eastern third of the Roman Temple of Mithras survived on the site, together with an antechamber or narthex just beyond the proposed new building boundary. The temple was discovered first in the 1950s and mostly relocated to a new site 100m away from its original location. As part of the Bloomberg development, a new reconstruction was to be built as close as possible to the original site. It was not possible to put the newly discovered remains on display due to their vulnerable condition and the waterlogged ground conditions. The decision was therefore taken to preserve them beneath the existing basement slab and to build the new reconstruction at the original Roman ground level but a small distance to the west of the surviving remains (see Figure 40).

To accomplish this, a large transfer beam was needed to carry the loads of a structural perimeter column that would have otherwise required a foundation pile to be located through the narthex. Another pile position was moved 500mm to avoid masonry remains of the narthex and was constructed within a permanent steel casing. This was to prevent disturbance of the ground close to the pile by the complete removal of the pile casings. The transfer beam was also designed to be at least 500mm above the highest surviving archaeological remains. These adjustments were possible because of the detail provided by the archaeological investigations on site, and constant dialogue between all parties.

Figure 40: Finalising the reconstruction of the Temple of Mithras. © MOLA



7.7 Ground-truthing a lower impact solution: Bloomberg European Headquarters, City of London



The north-east corner of the site was allocated for a new London Underground station entrance for Bank Station – requiring deep excavation to meet the level of the Waterloo and City Line. This was also the area of the site with the deepest archaeological deposits extending to up to 12m below modern ground level. The design for the new station entrance was not finalised by the time the site became available for archaeological excavation. In particular the line of the perimeter of the station box was not fixed and this meant that secant pile wall could not be installed. As the archaeology was such a big component of the project and on the critical path, the project team wanted to get started as soon as possible. An alternative perimeter retention solution was needed to support the surrounding streets and to facilitate safe working conditions for the archaeologists.

The solution was to use 15m driven steel sheet piles instead of the secant wall, which could be removed if required (see Figures 41 and 42). In order to avoid destructive pile probing for the sheets, geoarchaeologists augered the line of the piles at 1m intervals, gaining valuable samples and information (Figure 43). Because of the great depth of the archaeology in this area, the use of sheet piles instead of a pile wall meant that a large volume of approximately 350m^3 of archaeology of very high significance (including Roman timber property boundaries and wooden writing tablets) was not impacted by the construction of a pile wall (see Figure 44).

Figures 41, 42, 43 and 44: Engineers sketch of the shoring solution (above top) © McGees. Excavation underway using sheet piles for retention. The engineers were able to use these sheets for the final structure (above middle). Geoarchaeologists augering to check for obstructions and also evaluate deep deposits (above). The type of Roman deposits that would have otherwise been destroyed by secant pile wall (which would have extended out by approx. 1m from line of sheets) (right). All other images © MOLA

7.8 Prior information and close cooperation: Cannon Place, City of London

Cannon Place was a very complex commercial office development involving the construction of new piled foundations adjacent to and beneath a live railway station. The position of columns and supporting piles was limited by platforms and existing 19th century brick viaducts. The project also involved the re-use of 1970s foundations. Cannon Place is located over the Governor's Palace Scheduled Monument.

Figure 45: Roman masonry of the Governor's Palace, showing the complex working environment. © MOLA

The archaeological project involved several phases of evaluation to understand the potential impacts on nationally important Roman remains and extensive discussions between the project team, particularly the engineers, archaeologists and planners to achieve a piling design that minimised the damage to archaeological deposits.

It is easiest to focus on one pile location to illustrate the approach taken. Pile Group 9 was located partly within the area occupied by the 19th century brick viaduct and also in an area where the evaluation had revealed a substantial Roman masonry wall associated with the Governor's Palace complex (Figure 45). The project engineers designed a mini-pile solution. This allowed mini-pile groups and pile caps to be formed to fit closely around the masonry, with Terram, Flexcell Board and Visqueen providing protection between the pile structures and archaeology. The mini-pile clusters behave like a much larger pile, structurally.

The sequence of archaeological work for Pile Group 9 was as follows: the maximum area of impact 2.5m x 2m was marked out accurately on the slab and the concrete broken out by contractors. Modern material was removed to the top of archaeological deposits under archaeological supervision. Shoring was installed by contractors. Archaeological hand excavation and recording of all 'soft' deposits within the area of the trench was carried out down to base of archaeological deposits. Provision had been made for the trimming of any Roman masonry to ensure piling would not be obstructed. In the event this was not needed for this pile group. Protective materials were put in place and metal sleeves were installed in the mini pile locations and secured in position. The excavation area was backfilled with bentonite cement to ensure that the sleeves were held in place during piling. The brick viaduct arch was trimmed to allow the mini-piling rig to access the area required and piling operations took place. The pile cap area was subsequently excavated and new pile cap constructed.

7.9 Evaluation informed pile locations: Former All Saints Brewery, Leicester

This site, located within the walls of Roman and medieval Leicester, was proposed for redevelopment involving the construction of a ten-storey apartment block with wings ranged around a central courtyard. It was formerly occupied by a 1960s office block and a late 19th century brewery. Following demolition of existing buildings, a programme of archaeological trial trenching was undertaken in 2012 and 2014, revealing evidence for a Roman street, structures of the 2nd-4th C, part of the medieval street frontage and fragments of a medieval hospital (see Figure 46). The results suggested that, of the footprint of the proposed building, about 15% occupied areas of low archaeological significance with extensive truncation from cellars; 24% contained material of moderate significance with the survival of some stratification and 61% of the area was of high significance, with extensive archaeological remains and little previous disturbance.

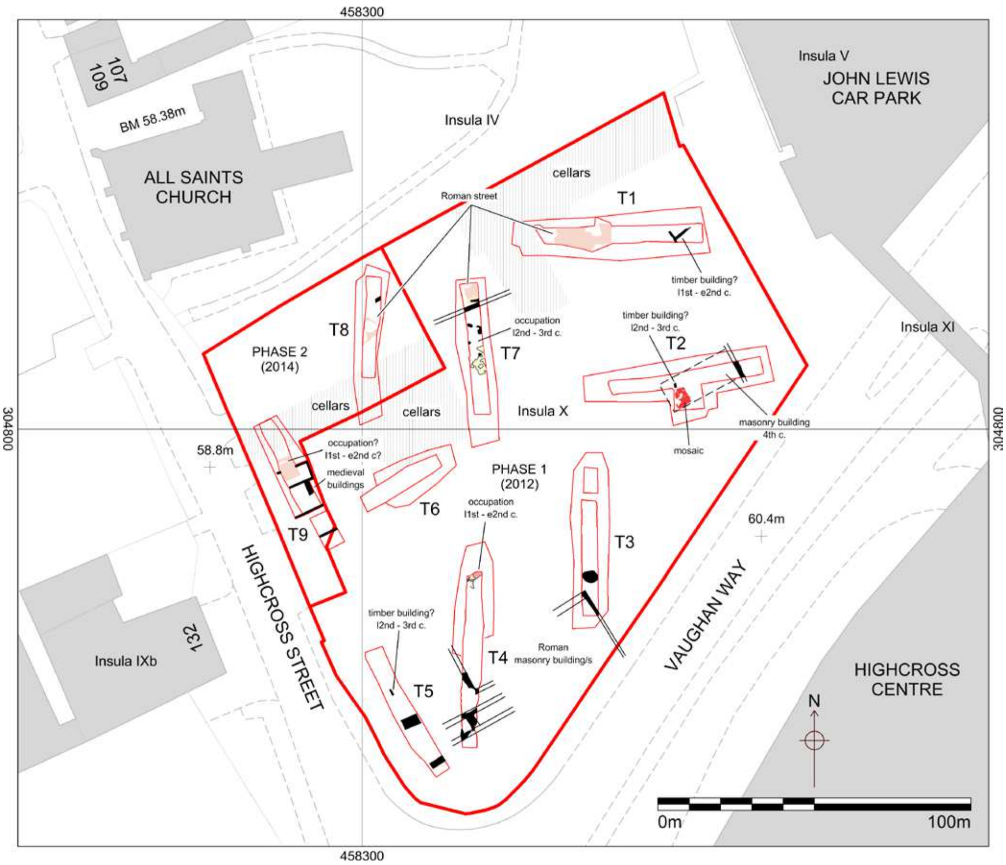


Figure 46: Evaluation trenches showing the survival of a range of Roman archaeological remains. © University of Leicester Archaeological Services (ULAS)

CFA piling was proposed for the new building. To come up with a sustainable foundation solution, archaeologists worked closely with the engineers to achieve a design solution which would minimise the archaeological impact. One result of these discussions was that pile caps would be accommodated within the 2m depth of late medieval garden soils and modern overburden which existed across the site. This meant that harm to archaeological remains would mostly be from the piles themselves.

The pile grid would disturb about 3% of the proposed footprint. To ensure that piling did not harm the significance of the site, (derived from complex structural remains, including fragments of a mosaic – see Figure 47), the footprint of the proposed building was stripped under archaeological supervision to the top of the archaeology. The deposits, thus exposed, were then cleaned, recorded and sampled to assess date and significance. This allowed the specific impact of individual piles to be assessed. Where harm to significance was deemed unacceptable, adjustments were made to pile positions and in some areas, the potential loss of significance was managed by excavating the area in advance of piling.

Figure 47: A section of Roman mosaic under excavation. © University of Leicester Archaeological Services (ULAS)

The results of this assessment indicated that for the most part, the piles would pass through deposits whose significance would not be harmed by the piling (as they would remain intelligible in the future). No further archaeological investigation was required in those areas. Elsewhere, some of the pile positions were re-adjusted (by moving them or spreading out pile clusters) to avoid specific structural remains and/or areas of existing 1960s piling where further development would render the archaeology uninterpretable.

This left three areas where the piles would go through complex archaeology, including walls, a hypocaust, a mosaic and associated deposits. Given that the CFA piles would cause unacceptable harm to significance in these areas (and in some cases, would not be capable of passing through archaeological obstructions without them being cleared first), the decision was taken to undertake a programme of limited excavation to address these impacts. Rather than targeting individual piles for excavation which would potentially provide meaningless results, larger areas were selected based on groups of piles.

The overall result of this foundation strategy has been an archaeological plan of the whole footprint of the proposed building at the level of the uppermost archaeological deposits; a sample of such deposits to clarify their, nature, extent, date and significance (as with an evaluation) and the full archaeological excavation of a small number of areas where the harm to significance would have been greatest. This included the lifting of the mosaic pavement which would be affected by a pile. This foundation strategy was made possible by good prior information, from adjacent sites and previous phases of evaluation, as well as regular communication and a developer willing to work collaboratively to find the most appropriate solution that ensured that harm to significance from piling was kept to a minimum. Figure 48 shows a summary of the information gathered from prior work (for example the Roman road grids shown in yellow), the evaluation and excavation, indicating the areas in blue where targeted full excavation took place.

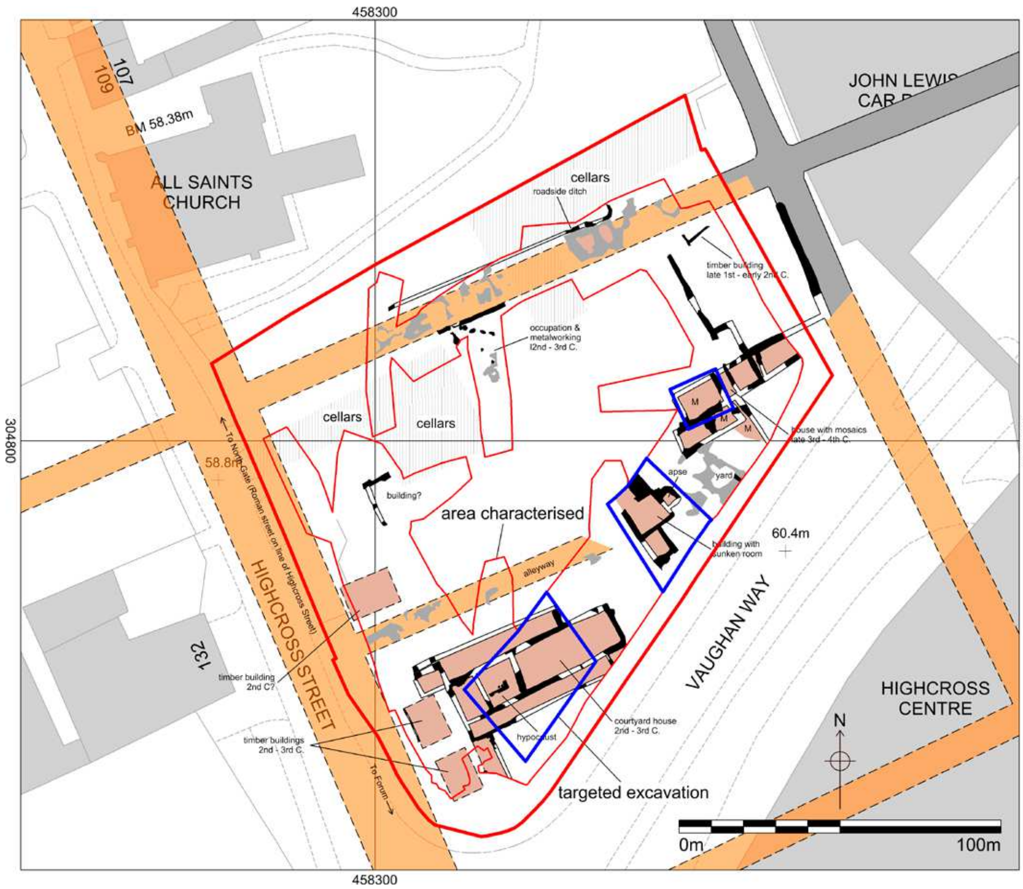


Figure 48: Summary plan of the site. The thick red line is the extent of the site, the thinner line the area of site strip and excavation. © University of Leicester Archaeological Services (ULAS)

7.10 Pile reuse planning conditions agreed in advance with developer, former Gloucester Prison site

On sites with significant archaeological remains or potential, it is good practice for the developer to seek an agreed approach with the local authority prior to the submission of the application. Early discussion on mitigation requirements and approaches can usefully be followed by consultation on the wording and structure of draft conditions. A developer who feels that they have had an input into the process and whose concerns are understood is more likely to take a positive and co-operative approach going forward.

In the case of pile-reuse, the pre-application process is a good time to highlight the benefits that pile reuse can bring in terms of cost and risk management. Conditions can be agreed that allow for the undertaking of feasibility studies for pile reuse if such work cannot be undertaken prior to determination. Whilst it may not be reasonable to require pile reuse, it is possible to require that a feasibility study is undertaken and separately, to require approval of the proposed foundation design.

This was the approach taken at the Former Prison site in Gloucester where archaeological evaluation had shown that fragments of a 12th and 13th century castle survived beneath the site (shown in Figure 49). It should be emphasised that these conditions were agreed in advance with the developer and only relate to part of the site. They were designed to work as two conditions undertaken consecutively. The first condition required a feasibility study be undertaken (in this case for just part of the site – but it could apply to the whole site). The second required approval by the local planning authority of the final foundation design. This final foundation design would be informed by the results of the feasibility study. If foundation reuse was possible this would have clear benefits to the developer as it would reduce the requirement for other forms of archaeological mitigation.

Figure 49: The castle keep found during evaluation. © Cotswold Archaeology

Condition: Feasibility Study for Pile Reuse

The planning conditions used in this case study were written in 2017 before the revision of the NPPF in 2018; the updated paragraph numbers should be used in any new conditions produced from this point forward.

'No development or demolition shall commence until a methodology for the undertaking of a feasibility study for the reuse of existing piled foundations in the area of block H (as referenced on plan 1803/004 amendment P1) has been submitted to and approved by the local planning authority in writing. This shall include provision for pre- and post-demolition analysis. Subsequently no construction of Block H shall commence until the feasibility study has been submitted to and approved in writing by the Local Planning Authority.'

Reason: To minimise impact to heritage assets of high significance by establishing the prospect for re-use of existing piled foundation or alternatively locating piles in areas of existing disturbance, in accordance with paragraphs 131, 132 and 139 of the NPPF and Policy SD8 of the Gloucester, Cheltenham and Tewkesbury Joint Core Strategy Adopted 2017.

This condition is intended to enable the undertaking of a feasibility study into the reuse of existing piled foundations in the area of block H. This is intended to be a physical assessment of the piles undertaken by an appropriately qualified structural engineer (prior to and following demolition to slab). At the end of the process a report will need to be produced outlining if reuse is viable and what potential options are available. This report will inform the City Council's consideration of the proposed foundation design when submitted.

Condition: details of foundations, groundworks and services

'No works below existing ground level shall commence until a detailed scheme showing the complete scope and arrangement of the foundation design and ground works of the proposed development (including pile type and methodology, drains and services, and for Block H shall take into consideration the results of the Feasibility Study approved under Condition X – above) has been submitted to and approved in writing by the Local Planning Authority. Development shall only take place in accordance with the approved scheme.'

Reason: The site may contain significant heritage assets. The Council requires that disturbance or damage by foundations and related works is minimised, and that archaeological remains are, where appropriate, preserved *in situ*. This accords with paragraphs 131, 132 and 139 of the NPPF and Policy SD8 of the Gloucester, Cheltenham and Tewkesbury Joint Core Strategy Adopted 2017.

It is important to note that the scope and arrangement of the foundation design can only be finalised once the feasibility study on pile reuse in block H has been undertaken. The Archaeological Impact and Mitigation statement will need to be updated accordingly.

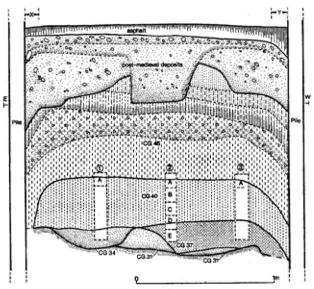
8 Supporting information – pile impacts

This chapter provides further detail to statements made in Chapter 4. It contains information from field-scale observations of piling impacts recorded adjacent to previous foundations as well as data from model-scale research.

8.1 Driven preformed piles: physical impacts

Physical impacts of driven preformed piles on archaeological remains have been recognised in a number of studies (Biddle 1994; Dalwood *et al* 1994). Such displacement is demonstrated in the image from Farrier Street, Worcester (Dalwood *et al* 1994), which shows down-dragging of deposits resulting from pile installation (Figure 50). Dalwood *et al* suggest (on the basis of calculations made from excavations adjacent to piles in Worcester), that the area of the site affected by piling operations was up to six times larger than originally predicted. Although numerous anecdotes of pile damage exist, few comprehensive studies have been published. A survey of 46 Historic Environment Records for reports of piling impacts produced only three examples (from 17 replies) where piling impacts had been recorded (Davies 2004). At the Marefair, Northampton, significant distortion was recorded adjacent to one of the piles (480mm in diameter), with disturbance up to 250mm either side. The total area of damage had a radius of approximately 1.0m and vertical displacement of over 1.0m, (Northamptonshire Archaeology undated).

Figure 50: Section drawing showing sediment deformation adjacent to piles. © Worcestershire Archaeological Society and Worcestershire Historic Environment and Archaeology Service



Unfortunately, while the characteristic inverted-cone resulting from down-dragging had been recorded, little is known about which pile installation technique was used on these sites in the past. It is therefore impossible to be sure, without going back to the original piling records (where they survive), whether such examples result from driving preformed piles. The pile excavated in Northampton was circular, and may not have been a preformed displacement pile. The same questions apply to Roman deposits at Vine Street in Leicester, which demonstrated similar sediment distortion associated with a circular concrete pile (Figure 51). The rough external surface of the pile suggests that it was a bored pile rather than a solid preformed pile, although it may have been installed

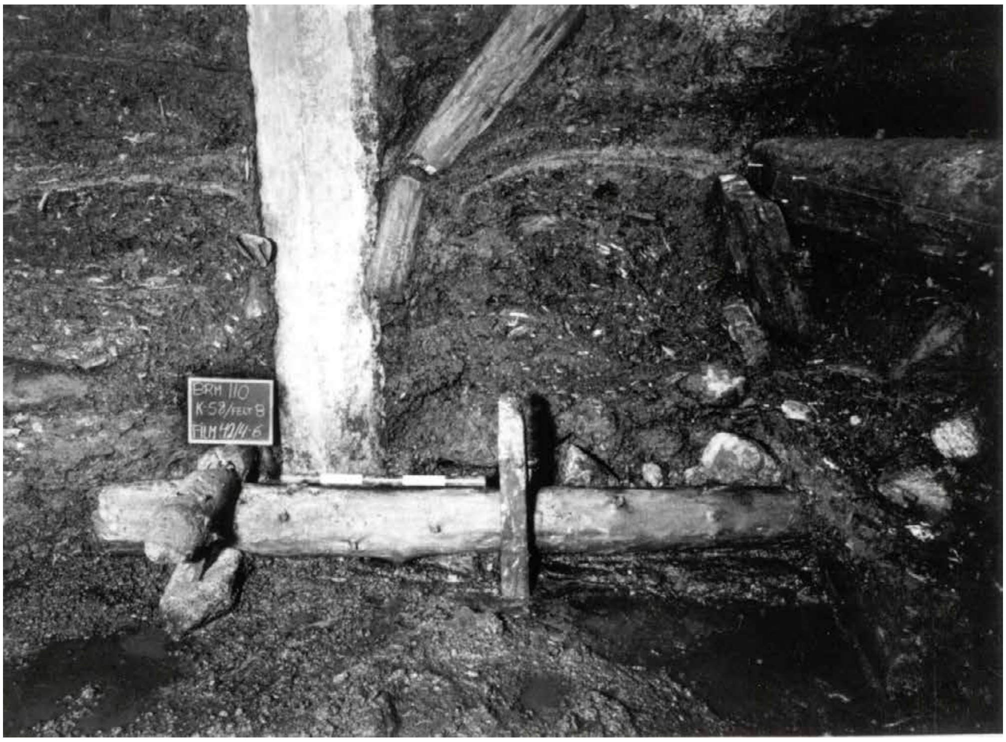
Figure 51: Layered deposits deformed by piling at Vine Street, Leicester. © University of Leicester Archaeological Services (ULAS)

with a temporary driven steel casing. It is therefore impossible to be sure, without going back to the original piling records (where they survive), whether such examples result from driven preformed piles.

Another example comes from Number 1 Poultry, London, where circular concrete piles installed in the 1970s were recorded during later excavation. Figure 52 shows a pile penetrating a Roman mosaic, which is undamaged outside the pile footprint (Rowsome 2000). The exact type of installation method is unknown, but again the surface finish of the piles is rough.

Figure 52: Pile and mosaic from No 1 Poultry. © MOLA

Figure 53: Impact of a driven pile on deposits at Finnegården 3A in Bergen, Norway, where dragged-down sediment layers and displaced wood are visible next to the pile. © Norwegian Directorate of Cultural Heritage

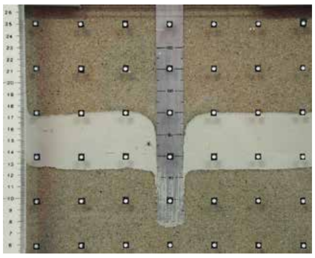


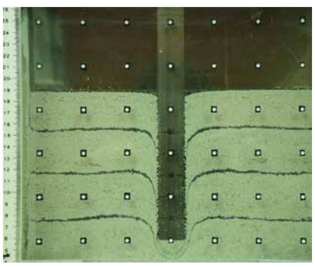
Waterlogged archaeological deposits are at great risk from driven piling, although much would seem to depend upon the orientation and state of preservation of surviving timberwork, in particular. Significant damage is reported from Finnegården 3A in Bergen, Norway (Biddle 1994) (Figure 53), and the Thames Exchange site, where waterfront timber revetments show damage up to three times the diameter of the pile (Nixon 1998, 42 and Figure 2). More limited deformation of deposits was reported by Stockwell (1984) from soft organic-rich deposits from Coppergate, where piles cleanly cut through waterlogged timber without significant levels of down dragging.

An ongoing project in The Netherlands to collect and assess images of past piling impacts has amassed an image library of around 10000 photographs showing piles on archaeological sites. Analysis of these images has yielded a similarly wide range of impact zones as described above, from little or no movement (seen in soft clay and peat soils) to large scale transformation witnessed in stiffer deposits, or where piles have encountered structural remains (Groenendijk *et al* 2016).

Engineering and field scale research

Figures 54 and 55: Typical result from model testing in layered ground, showing vertical displacement of the clay layer by the installation of a pile (Hird *et al* 2006 Figure 4.9) (top). Image of homogeneous sediment deformation, the composition of the sediment is 75% sand, with 25% kaolin clay. Marker layers are included to allow displacement to be recorded (bottom). © Keith Emmett





Down-dragging of sediment is also relevant to engineers, and several model-scale experiments have been carried out to characterise the extent of deformation. Most of these studies show a drop-off in visible sediment movement within about 1.5 pile diameters of the centre line of the pile (Hird *et al* 2006). This research was carried out predominantly on homogeneous clay soils, which may not effectively replicate all archaeological deposits. Model-scale (1:10) research on driven and CFA piles in layered soil has provided information on the mechanisms of sediment displacement and the extent of the impacts.

Figure 54 shows the typical extent of sediment distortion recorded in a model-scale experiment. Samples were tested in both consolidated and unconsolidated models, mostly with a clay layer sandwiched between two sand layers, with variable layer thickness and density. Some homogeneous samples with varying mixes of clay and sand, containing marker layers for identification of sediment displacement were also used (Figure 55).

Although a number of the tests in this work were on unconsolidated sediments (including both shown here), the results and data are physically and numerically similar to the tests on consolidated deposits that were also produced, and to the results from previous work (Hird and Moseley 2000). In almost all instances the maximum extent of deformation lies within 1.5 pile widths of the centre line of the pile, although 'most of the vertical displacement (or down-dragging of soil) is concentrated within a distance of 1 pile width from the pile centreline' (Hird *et al* 2006).

Field-scale evaluations have been carried out to test the extent of pile damage to archaeological deposits. At the JunXion, Lincoln, two 0.25m wide square preformed concrete displacement piles were installed (one driven and one pre-augered then driven) and evaluation trenches excavated alongside to investigate the degree of sediment deformation. The excavation demonstrated that sediment deformation had occurred adjacent to the driven pile, but this was only visible within 0.1m of the pile edge (less than one pile width from the centreline). The down-dragging effect had nevertheless extended 1m down, clearly seen with different coloured material (see Figures 34 and 35). Other visible effects included cracking, remoulding of deposits and the creation of voids (Davies 2003). As the deposit was homogeneous fill deformation features were not particularly clear.

Excavations were also carried out beside four piles at Skirbeck Road, Boston, Lincolnshire. These included three preformed concrete piles (one of which was pre-augered, and another was fitted with a pointed shoe), and a hollow steel pile (see Figure 12). In all cases, sediment deformation was difficult to make out owing to the complicated nature of the stratigraphy. All of the visible impacts were within 1.5 pile widths of the pile centreline, and in several cases, significantly less (Rayner 2005).

Driven preformed piles: hydrogeological impacts

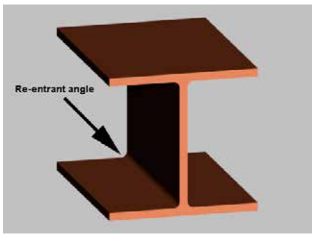
Model-scale tests suggest that there is no significant increase in permeability for driven piling in layered sand and clay samples, providing the impermeable (clay) layers are relatively soft and sufficiently thick, that is, more than two pile diameters thick. Changes do occur, however, where there is a thin clay layer relative to the pile diameter/width, which is exacerbated in the case of H-section piles (Hird *et al* 2006). These model-scale studies also demonstrate that small amounts of contaminants could be carried down at the pile toe but, in the absence of the creation of any long-term preferential pathways for further contamination, the impact that limited amounts of contaminant will have on archaeological deposits and artefacts is not likely to be excessive.

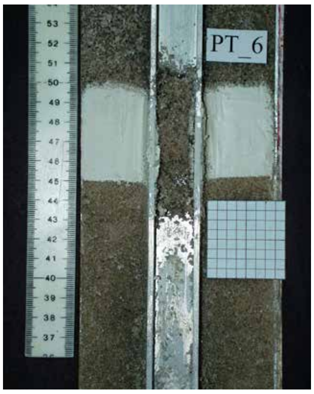
Excavations in Spurriergate, York have revealed extensive waterlogged deposits dating from the Roman and Anglo-Scandinavian periods. Much of the site had previously been piled using square-section preformed concrete piles. In one area of Roman dumping there was a clear zone of impact around each pile, and the sediments appeared much drier than the surrounding deposits. In another area, however, identical piles had been driven through a possible Anglo-Scandinavian timber building and organic-rich deposits showing no zone of impact around each pile. Equally, where concrete displacement piles were driven through Bronze Age timbers at Bramcote Green in London, the timbers were almost entirely destroyed; where there were no piles, the timbers were intact (T Nixon pers comm).

8.2 Small displacement pile impacts

Preformed steel

Figures 56 and 57: H-section pile showing re-entrant angle (top). © Trace Parts S.A. www.traceparts.com. H-section pile test with sand plugged within the flanges of the pile (Hird *et al* 2006 Figure 4.2a, bottom).





Although no field based evaluations of H-section piles have been carried out to assess potential impact on archaeological remains, some laboratory studies have been conducted. In model-scale tests with a clay layer between two sand layers, sand can be seen to plug within the re-entrant angles of the H-section pile and is carried down into, and possibly through, the clay layer (see Figures 56 and 57). This allows movement of liquid along the pile (Hird *et al* 2006). This partly confirms previous research on H-section piles (Hayman *et al* 1993; Boutwell *et al* 2000).

Another potential concern with steel piles is corrosion. A number of studies have been carried out on steel piles, which show very limited levels of corrosion occurring within the ground, within anoxic saturated soils (see for example reviews in Morley 1978 and in Tomlinson and Woodward 2008, Chapter 10, particularly 10.4). Fewer studies have looked in detail at the potential corrosion associated with soils above the groundwater table. Where data exist, corrosion appears to be enhanced in disturbed soils with fluctuating soil moisture / oxygen content and also on contaminated sites. It is possible that corrosion of metal piles may damage archaeological materials when corrosion products are transported into other parts of the deposit in solution through surface water/groundwater percolation, although the risk is fairly low. The use of plastic sheeting or pre-treatment of metal piles would avoid issues associated with pile corrosion.

8.3 Supported non-displacement (bored) pile impacts

Temporarily supported bore: physical impacts

Figure 58: Loss of material during bored piling operations at the level of the watertable, at Number 1 Poultry, London. © MOLA

In excavations next to new piles installed at Number 1 Poultry, about 7% of the bored piles had caused significant damage at the point at which they encountered the water table, with an area twice the diameter of the pile being affected (Nixon 1998, 41). This may have occurred during the installation of the pile casing as the damage was only seen next to (some of) the supported non-displacement piles, but not next to unsupported CFA piles (T Nixon pers comm). The impact is shown in Figure 58, with loss of an area of beaten earth floor (the yellow-coloured deposit) adjacent to the pile (Rowsome 2000).

8.4 Unsupported non-displacement CFA pile impacts

Continuous flight auger (CFA): physical impacts

The impacts of CFA piles have been investigated by model-scale research (Hird *et al* 2006; 2011; Ni *et al* 2010). These demonstrated that impacts outside the diameter of the pile were relatively small, compared with those recorded in model-scale driven circular, square- and H-section piles.

Figure 59: Model piles in transparent soil. © Ni Qing

This is shown in Figure 59, in which piles are inserted into a transparent medium which replicates the properties of a soft clay soil. Particles of mica are illuminated by a laser, and when they move due to soil displacement, this movement is captured by digital camera, the distance they have moved is calculated and indicated with a yellow arrow. The image of the driven pile on the left (a) clearly shows evidence of sediment movement. Very limited movement is detected in middle image (b) which represents a well-constructed CFA pile. The image on the right (c) shows what happens if the auger is flighted. In this case when the rotation speed was doubled halfway through insertion, the ground was drawn towards the auger.

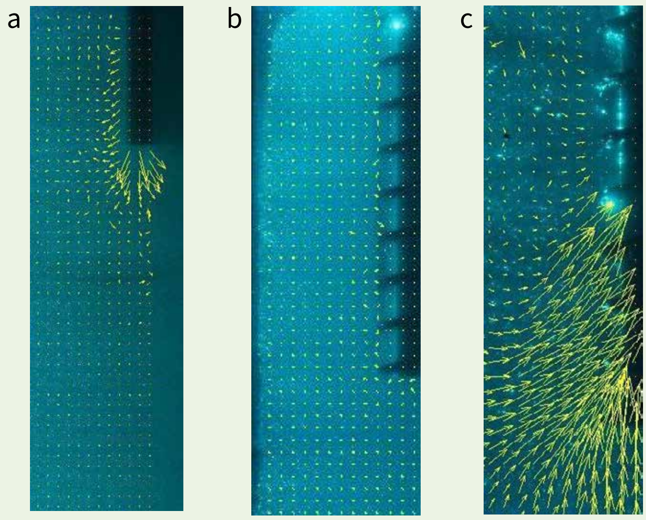


Figure 60: Pile installed into pre-augered hole at Skirbeck Road, Boston. The installation has not deformed the layers, and the edge of the borehole can be seen to the left of the pile. © APS

Aside from model-scale observations, some field-scale analysis of auger impacts has been undertaken, in both cases to assess whether pre-augering driven pile locations was an effective way to measure vertical sediment displacement (Davies 2003; Rayner 2005). As can be seen in Figure 60 there was no impact outside the diameter of the auger.

9 Glossary

anoxic used to refer to a deposit in which oxygen is virtually absent

aquitard an impermeable layer restricting groundwater flow between aquifers

arisings spoil generated and brought up through groundworks/drilling

bentonite an absorbent clay mineral used in slurry form as a drilling mud. It has a specific gravity of about 1.2 thus is sufficient to stop water and soil ingress

casing generally a tube used to line the pile hole; usually of metal and removed following piling

cathodic protection an electrochemical process used to protect metals from corrosion in water/aquatic environments

cohesive/cohesionless soils terms used to refer to firm or loose soils, ie clay rich (cohesive) or gravel (cohesionless)

deformation generally used to refer to a change in shape, in this case, usually to a soil or sediment, resulting from applied force

displacement generally lateral movement of soil during insertion of a pile

drilling fluids used to aid the drilling process, often a form of slurry, bentonite or even water

end bearing a piling system where most of the load is carried by the base (end) of the pile

exothermic a chemical reaction which produces heat

helical a helical pile is corkscrew shaped; a central bar with a series of pitched plates attached

high slump concrete has a high water to cement ratio, making it a highly workable material

hydraulic conductivity is a measure of the way and speed water passes through soils/other mediums

Hz Hertz

kentledge a form of incremental pile loading used for testing piling

kN = a kilonewton. A Newton is the force required to accelerate 1kg mass at $1m/s^2$. An apple exerts a force of approximately one Newton, and a mass of one tonne equates to 10kN in the Earth's gravity field.

particle velocity the velocity at which the ground vibrates. It is measured in millimetres per second. Peak particle velocity has been accepted as an important indicator of structural damage

perched (water table) water held above the real water table, usually through the presence of an impermeable layer

Plunge piles are a type of bored pile used where basement excavation takes place at the same time as the construction of the superstructure. The concrete pile is cast to the level of the basement, and a steel column / liner provides the link between the cast pile and the ground floor slab

secant technically a line passing through two points of a curve – in this case, a secant wall is a line of intercutting piles

shear strength this is the maximum stress which can be sustained before a material will rupture, or fail in shear

sleeving a casing for the pile, generally permanently left in the ground; can be paper, metal, plastic etc; sometimes used for guidance during drilling

statnamic a rapid load testing method for piles which may be used as an alternative to static or dynamic tests

tie-back an anchorage or the tie rod connected to it which may be used to support walls and other structures

underream an enlarged pedestal cut out of the soil at the base of a pile. This is usually done with a cutting tool, which can be expanded and rotated at the base of the pile shaft

unstable soils sands and gravels which are not self-supporting and therefore liable to collapse into a bored hole

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