Meridian
Solar

Meridian Solar Farm

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Volume 6

Environmental Statement

6.3 ES Appendix 16-4: Unplanned Emissions Assessment from Battery Energy Storage System

APFP Regulation 5(2)(a)

Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

March 2026

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1. Introduction

1.1.1. This Unplanned Emissions Assessment has been undertaken for submission with Development Consent Order (DCO) Application for a proposed solar farm and overhead line connection to the National Grid planned substation in Weston Marsh, near Spalding in Lincolnshire (the 'Scheme').

1.1.2. The Scheme includes the construction, operation and decommissioning photovoltaic energy generation facilities and associated infrastructure including a Battery Energy Storage System (BESS). The Scheme would have an operational lifecycle of 40 years.

1.1.3. By its very nature a thermal event (the overheating of batteries or a fire) in part of the BESS is not an intended outcome from the use of the BESS. Considerable effort goes into designing and operating BESS units in a way that avoids any thermal event and thereby maintains the units in an operational condition, as described within the **Outline Battery Safety Management Plan (OBSMP)** (Doc Ref. 7.18) submitted with the DCO Application. As such, these events are considered unlikely.

1.1.4. A fire is a 'possible' event for any development and there are regulatory requirements in place to ensure that the safety and environmental consequences of a fire have been considered and planned for. That work is normally finalised at the detailed design stage for a BESS scheme, after planning or development consent has been granted. This report aims to bridge the information gap at this stage and provide information of the likely magnitude of impacts of accidental (unplanned) emissions to air as the result of a thermal event at a BESS.

1.1.5. The scope of this study includes:

- A review of potential emissions to air from a thermal event within a single cabinet and within multiple cabinets;
- Consideration of the potential magnitude of emissions;
- Consideration of likely rates of dilution between potential emission locations and sensitive receptors located outside the Site; and
- Consideration of the likely consequences of emissions to air from the proposed BESS.

2. Background

2.1.1. Battery technologies are used at renewable energy generation facilities to store electrical power so it can be supplied to the National Grid when it is most needed. Battery technologies can act as a standalone grid balancing service due to the intermittent nature of renewable energy generation supplying the grid which is the case here.

2.1.2. The BESS for the Scheme would consist of a compound and battery array at maximum import and export capacity of 350MW. Details of the design for the BESS elements, including the power and energy ratings, and the final enclosure dimensions and appearance, are currently in development and, therefore, the assessment has been based on maximum parameters which would not be exceeded (as set out in **ES Chapter 2: The Scheme** (Doc Ref. 6.1)). This assessment is based on the following assumptions:

- Each battery enclosure would be a single storey (with maximum dimensions of 8m in length, 2m in width and 4m in height).
- The land parcel (B-5) which would contain the BESS is approximately 350m away from the nearest residential properties.
- Included within the design, each enclosure would have:
  - Smoke, heat, and gas detection and control systems ;
  - Active ventilation to prevent build up of off-gases; and
  - Non-combustible walls, floor and ceiling, with a minimum internal fire resistance rating of up to 1 hour.

2.1.3. An **OBSMP** (Doc Ref. 7.18) has been submitted with the DCO Application, which would be developed into a fully detailed fire safety management plan with input from the Lincolnshire Fire and Rescue Service (LFR). This is secured as a requirement of the **draft DCO** (Doc Ref. 3.1). The purpose of the OBSMP is to identify how the Applicant will use good industry practice to reduce risk to life, property, and the environment from a BESS failure event. The document provides a summary of the safety related information requirements which will be provided in advance of construction of the BESS. These details are not repeated here, but have been built into the modelling assumptions used.

3. Guidance and Standards

3.1.1. The Planning Practice Guidance for Renewable and Low Carbon Energy[1] encourages Local Planning Authorities to consider guidance produced by the National Fire Chiefs Council (NFCC). This guidance was first issued in 2023 with an updated version published in 2026[2]. The new NFCC BESS Guidance applies to BESS in open air environments with an energy capacity of 1MWh or greater and is therefore relevant for the Scheme.

3.1.2. The NFCC guidance intends to help reduce the fire exposure risk to the public and emergency responders as far as reasonably practicable. The guidance encourages relationships between Fire and Rescue Services, developers, and planners, to help assess risk and form effective emergency response plans. The guidance outlines the need to consider safety in design, have effective battery management systems in place, including alerts for battery fault and combustible gas detectors. The guidance further outlines the need for means of containment, suitable thermal barriers, and emergency plans. The guidance also emphasises the need for each potential Site to be considered individually.

3.1.3. The selected BESS design will include integrated fire and explosion prevention and protection systems following key industry safety standards (e.g. NFPA 855, UL 9540, BS EN IEC 62933-5-2) and based on comprehensive UL 9540A (2025, 5th Edition) and / or 3rd party LSFT / full scale destruction testing. This testing involves burning the full BESS system to validate minimum safe equipment spacing distances and performance test active and passive mitigation systems integrated into the BESS design. A BESS system and site-specific Emergency Response Plan (ERP) will be developed at the detailed design stage, based on national and international best practice measures.

3.1.4. Section 1.5 of the **OBSMP** (Doc Ref. 7.18) references the guidance documents and standards considered by the Applicant that have been used to inform the design of the Scheme. There is currently limited UK specific guidance for BESS, however the Applicant has incorporated good practice from around the world.

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[1] Ministry of Housing, Communities and Local Government, Ministry of Housing, Communities & Local Government and Department for Levelling Up, Housing and Communities (2023) Planning for Renewable and Low Carbon Energy. Available at: https://www.gov.uk/guidance/renewable-and-low-carbon-energy [Accessed 10 October 2025]

[2] NFCC (2026) National Fire Chiefs Council (NFCC) Grid-Scale Battery Energy Storage System planning – Guidance for FRS (2026).

4. Emissions from Incident Fires

4.1. Potential Sources of Emissions to Air

4.1.1. For the purposes of this document, a concept design has been considered that uses a BESS system based upon lithium iron phosphate (LFP) lithium-ion battery technology that is currently used on the majority of UK solar projects in development. This is considered a reasonable worst case for the purposes of the assessment in terms of safety (toxic and explosive gas production risks).

4.1.2. The general arrangement for BESSs is to have 'cells' grouped into 'modules' (sometimes called 'packs') and a number of modules housed on shelves within a 'rack'. The racks are housed in a cabinet that takes the form of a metal, fireproof enclosure, with front opening doors. There is not a set number of cells which constitute a module, modules within a rack, or cabinets within a container – these will vary by manufacturer. The latest designs favour 3 or 4 cabinets within one container for the larger units.

4.1.3. LFP cells are associated with a risk of 'thermal runaway' if manufacturing defects are present, or in situations of overcharging, overheating, or mechanical damage.

4.1.4. Thermal runaway results in the release of gases, including flammable gases which may then go on to produce a fire, giving rise to a range of organic and inorganic air pollutants. This situation is true of any incident fire and sets of emission factors have been collated by the Environment Agency[3] for incident fires involving automobiles, buildings, and waste materials, for example. A standardised set of emission factors for BESS is not currently available from the Environment Agency.

4.1.5. A few recent studies have investigated the toxic gas constituents of fires in general[4] and lithium-ion battery fires specifically in controlled test environments[5,6]. It has been established that lithium-ion battery fires may

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[3] Environment Agency (2009). *Review of emission factors for incident fires, Innovation for efficiency science programme, Science Report SC060037/SR3*. Available at: https://assets.publishing.service.gov.uk/media/5a7c7177e5274a5255bceadc/scho0809bqut-e-e.pdf [Accessed 10 October 2025]

[4] JC Wakefield (2010). *A Toxicological Review of the Products of Combustion.* Available at: https://assets.publishing.service.gov.uk/media/5a74afd1ed915d0e8e39a374/HPA-CHaPD-004_for_website.pdf [Accessed 10 October 2025]

[5] O. Willstrand et al. (2020) Toxic Gases from Fire in Electric Vehicles. Available at: https://ri.diva-portal.org/smash/get/diva2:1522149/FULLTEXT01.pdf [Accessed 10 October 2025]

[6] Andersson et al. 2013, *Investigation of Fire emissions from Li-ion batteries, Report SP 2013:15, SP Technical Research Institute of Sweden.* Available at: https://www.diva-portal.org/smash/get/diva2:962743/FULLTEXT01.pdf [Accessed 10 October 2025]

produce carbon monoxide (CO), hydrogen cyanide (HCN), hydrogen chloride (HCl), hydrogen bromide (HBr), hydrogen fluoride (HF), sulphur dioxide (SO_2), NO_X (nitrogen oxides), hydrocarbons, and particulate matter. The prevalent gas production mainly comprises CO, CO_2, hydrogen and hydrocarbon gases, with most of the toxic gases referenced generally only detected as trace elements.

4.1.6. The UK has air quality objectives and targets to protect public health from exposure to air pollutants including NOx when present as nitrogen dioxide (NO_2), particulate matter (size fractions PM_{10} and $PM_{2.5}$), SO_2, CO and hydrocarbons. These objectives and targets are mostly based on long averaging periods, such as 24hr mean concentrations and annual mean concentrations. A single event, only lasting a few hours, is incapable of materially effecting such long-term average concentration values, used to measure ongoing exposure from the combined contributions of background and local emissions sources. Even short-term objectives, such as the hourly mean concentration of NO_2 is based on a percentile of hourly values that can be exceeded a small number of times per year.

4.1.7. The short duration of a fire event, the limited scale of emissions and the unlikely nature of the event, mean that a significant effect is highly unlikely for emissions of NOx, NO_2, SO_2, CO, particulate matter or hydrocarbons at any receptor location. HCN concentrations can become elevated in close proximity to any fire, especially within enclosed spaces, but is rapidly dispersed and oxidised as it travels downwind of the fire. BESS fires do not present HCN risks in ambient air to first responders that are any greater than for any other form of building or vehicle fire.

4.1.8. Emissions of HCl, HBr and HF are possible, with emissions of HCl and HBr being much smaller in magnitude than HF, and so HF is used in this assessment to represent these substances.

4.1.9. Further, in 2016, a U.S. based organisation, The Fire Protection Research Foundation (FPRF), conducted a full scale (100kWh) BESS test fire[7] that included gas sample measurements from batteries subjected to external and internal ignition tests. This provided further evidence that CO and HF are produced in such cases. Elevated concentrations of CO were detected in the first 30 minutes of the test and this decreased to near zero during the main period of self-sustaining combustion, which is not unexpected for a fire

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[7] Fire Protection Research Foundation, 2016, Hazard Assessment of Lithium-Ion Battery Energy Storage Systems, Final Report. Available at: https://www.nfpa.org/education-and-research/research/fire-protection-research-foundation/projects-and-reports/hazard-assessment-of-lithium-ion-battery-energy-storage-systems [Accessed 10 October 2025]

occurring outdoors, and HF was detected at concentrations > 100ppm (i.e., over range for the detector used) after 30 minutes and then for the duration of the fire.

4.1.10. HF is the primary emission of concern for this assessment. Based upon the studies described above, it is likely to be present within a BESS fire at concentrations of concern at distances of more than a few tens of metres from the fire. It is also highly toxic. It is considered that HF has the greatest potential for harm compared to other products of combustion and therefore modelling of HF represents worst case impacts and modelling of other pollutants is not required.

4.1.11. It is noted that HF is formed by the decomposition of the fluoride-containing electrolyte and/or its atmospheric reaction with the hydrogen released due to the thermal runaway. The production of HF therefore depends both on the quantity of electrolyte within the battery cells and the specific conditions of the thermal runaway/fire. Although the mechanism is not certain, it has also been found that the state of charge (SOC) influences HF production, with cells burnt at 100% SOC found to produce less HF than those burnt at lower SOC. The concentration of HF is also dependent on the total length of the incident with a shorter, fiercer fire likely to be associated with higher peak HF concentrations than a longer one.

4.1.12. In theory, it would be possible to base a dispersion model on the concentration of HF measured in the plume near to the BESS during a whole unit test firing. However, there are serious limitations with such an approach, primarily arising from the large variation in HF concentrations that have been reported in the literature[8]. There is also substantial variation in concentration over time during the same test. For example, one test firing[9] reported a very large amount of variation in measured concentrations for HF from sample to sample, ranging from 575mg/m^3 down to the low tens of mg/m^3. The peak concentrations are short lived and infrequent events, typically lasting seconds. Such peak values are not representative of conditions that occur over the timescales of relevance to this assessment, which uses criteria that are 10 minute mean and 1 hour mean concentration values. The use of mean values in air quality standards takes into account the presence of values being higher than the mean value for the time period. The use of the peak values measured over a few seconds as a basis for assessment would be overly conservative. Data with

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[8] J. Hynynen (2023). *Analysis of combustion gases from large-scale electric vehicle fire tests.* Available at: https://www.sciencedirect.com/science/article/pii/S0379711223000978 [Accessed 10 October 2025]

[9] Clearstone Energy (2024). *Axminster Energy Hub Plume Assessment Study*

sufficient granularity to enable the mean concentration over a relevant time period to be calculated from short term measurements are not captured during standard fire tests.

4.1.13. The Electrical Power Research Institute (EPRI)[10] is a research Institute in the U.S. that provides technical research for its corporate membership, which are mostly electricity generation companies. In 2024, they published a review of *Lessons Learned from Air Plume Modelling of Battery Energy Storage System Failure Incidents).* Of particular relevance to this report are the following findings:

- Staking multiple conservative assumptions in dispersion model studies, even if not 'worst case' (i.e. conservative and improbable) can result in unrealistically conservative results;
- Based on 67GW and 150GWh of Li-ion BESS deployed to end of 2023 and 85 cell failure incidents from those units, a cell failure rate of less than 0.1% was observed. This is 1 incident per 1.76GWh deployed. Only a small fraction of those cell failures would then develop into fires. The implication is that the likely number of fire incidents at a BESS of less than 1GWh is less than 1 incident during its operational lifetime; and
- Consideration of the proportion of the time when meteorological conditions would give rise to potential impacts at actual receptors is a useful approach to establish how often an exposure pathway is present under real world conditions.

4.1.14. EPRI has collated best practice in the dispersion modelling of emissions from BESS fires[11] and have noted that where UL 9540A emission data is not available an appropriate emission factor for HF emissions would be in the range of 0.4g to 1.5g of HF per kilogram of battery weight. An increasing number of modules and whole cabinets have demonstrated during testing that no fire propagation occurs beyond the tested module. Therefore, this assessment assumes that any incident could be limited to a single module (Section 5) or could include multiple modules (Section 6)

4.1.15. Example emissions are calculated here based upon a single module containing 104 cells[12]. Taking a conservative estimate of weight based upon the total container weight (which also includes non-battery material), it is estimated that

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[10] EPRI (2024a), *Lessons Learned from Air Plume Modelling of Battery Energy Storage System Failure Incidents*

[11] EPRI (2024b). *Comparing the fire dynamics and SCICHEM plume models for battery fires, report ref 03002030364*. Available at: https://www.epri.com/research/products/000000003002030364 [Accessed 10 October 2025]

[12] E-storage, 2024, SolBank 3.0 Datasheet v1.62 Available at: https://csestorage.com/wp-content/uploads/2025/08/CS-Datasheet_SolBank-3.0_v1.62_EU.pdf [Accessed 10 October 2025]

this module weighs 895 kg, which using the worst-case weight-based emissions factor equates to 1.3kg of HF. An alternative calculation (excluding non-battery weight) would give a cell weight of 5.7kg each, resulting in a total battery weight of 593kg, equating to 0.9kg of HF.

4.1.16. An alternative approximation is based around the emissions per Wh, with findings from one small scale test[13] of 20-200mg/Wh. This method is considered less reliable than the EPRI method as it is less well proven at scale, although experience indicates that the lower end of the range is more appropriate at the larger scale, therefore the same example single module of 104.5kWh capacity equates to 2.1kg of HF.

4.1.17. These example HF content values are similar to values used in some previous DCO environmental impact assessments[14] where values of 2kg of HF content have been cited based on the more limited data available at that time.

4.1.18. In summary, the use of emission factors based on the HF content of battery systems remains the most defensible approach for dispersion modelling. As the volume of available test reports grows, the design of BESS is changing to meet the requirements of fire safety tests, resulting in increased use of smaller fireproof cabinets to restrict fires to smaller number of battery modules than was the case ten years ago. The approach taken in this assessment is that a 2kg of HF content per incident (based upon only one module experiencing thermal runaway i.e. no module-to-module propagation) remains a reasonable central estimate, with a 50% higher and lower sensitivity test scenario to reflect uncertainties in module composition (in terms of number of cells, battery weight, and energy capacity), and state of charge. However, in recognition that these estimates are becoming increasingly conservative as technology develops, a low HF content scenario of 0.5kg of HF has also been included.

4.1.19. At the detailed design stage further modelling can be done to consider the thermal risk from the fire, based on an understanding of combustible materials released in a fire for the selected make and model of equipment and such modelling can also include a plume assessment to confirm that the density of smoke or pollutant concentrations remain in keeping with fire and rescue service expectations.

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[13] Larsson et al. (2017). *Toxic fluoride gas emissions from lithium-ion battery fires*. Available at: https://www.nature.com/articles/s41598-017-09784-z [Accessed 10 October 2025]

[14] LaChance SA, 2018, Cleve Hill Solar Park Air Quality Impact Assessment Li-ion Battery Fire, Appendix C.

4.2. Assessment Criteria

4.2.1. The UK Health Security Agency (UKHSA) (formerly Public Health England (PHE)) publish Incident Management guidance for specific air pollutants including HF[15]. These documents summarise the physical and chemical properties of the substance and the hazard they pose to human health. Internationally recognised best practice emergency response guidelines are reported by UKHSA.

4.2.2. Emergency response planning guideline (ERPG) values that start at ERPG-1 and increase in concentration to ERPG-3, have been defined by the American Industrial Hygiene Association[16]. They are described below:

- ERPG-1: the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse health effects.
- EPRG-2: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual’s ability to take protective action.
- ERPG–3: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

4.2.3. Acute exposure guideline level (AEGL) values have been defined by the US Environmental Protection Agency[17] based on slightly different criteria are defined below:

- AEGL-1: Above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
- AEGL-2: Above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

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[15] Public Health England, 2021, Hydrogen Fluoride Incident Management

[16] American Industrial Hygiene Association (2020). *ERPGs (Emergency Response Planning Guidelines™)*. Available at: https://www.aiha.org/get-involved/aiha-guideline-foundation/erpgs [Accessed 10 October 2025]

[17] US Environmental Protection Agency (2025). *About Acute Exposure Guideline Levels (AEGLs)*. Available at: https://www.epa.gov/aegl/about-acute-exposure-guideline-levels-aegls [Accessed 10 October 2025]

- AEGL-3: Above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

4.2.4. The values adopted as being most protective of receptors (or the most conservative in terms of likely impacts on receptors) surrounding the Scheme are listed in Table 1. Concentrations of 1 ppm and 2 ppm of HF gas are equivalent to 0.82mg/m^3 and 1.64mg/m^3 respectively. The time periods used for ERPG and AEGL are based on different considerations, but for the purposes of this assessment they represent a maximum concentration value in a 10-minute period. These concentration values are also valid at an averaging time of 1 hour, which is the resolution of the meteorological data used in this assessment.

Table 4-1: Summary of Emergency Response Criteria

Substance	EPRG-1 Value (ppm)	Time period for EPRG	AEGL-1 (ppm)	Time Period AEGL
HF	2	10 minutes & up to 1 hour	1	10 minutes & up to 8 hours

4.2.5. The most conservative criteria, the AEGL-1 of 1ppm has been chosen as the relevant assessment level for this assessment.

5. One Module Event Scenario

5.1. Introduction to dispersion and dilution

5.1.1. Any gaseous pollutants emitted from a BESS would be transported from the BESS towards receptor locations by the air movements occurring at the time of the emission to air. These movements are determined by the direction of the wind and the amount of turbulent mixing of the air as it blows towards the receptor location. Differences in the temperature of the plume of air containing the emission and the surrounding air can also affect the vertical movement of the pollutants. To help understand the minimum rates of dilution likely to occur to pollutant concentrations as they disperse from the source of the emission to receptor locations, the dispersion has been modelled.

5.1.2. The calculations have made use of the dispersion model ADMS (version 6.0.0.1). As a definitive emission rate will not be known until later in the detailed design stage (once battery technology and the composition of modules in terms of number of cells, battery weight and energy capacity are known), the dispersion model has not been used to predict absolute impacts at specific receptor locations. Instead, a nominal unit emission rate has been used to calculate concentrations close to the source and at fixed nodes that are at 50m increments downwind, for all wind directions in 10-degree segments. The relative concentration at the nodes is expressed as the amount of dilution compared to the near source concentration. This is then displayed as a colour scale on a polar plot overlaid onto base mapping.

5.1.3. The dispersion modelling has been undertaken using 5 years of hourly sequential meteorological data to represent approx. 43,800 sets of meteorological conditions that have been observed at a representative meteorological station. The values reported represent the minimum amount of dilution (maximum concentration at the receptor) predicted in any 1-hour period (100th percentile). In addition, the 99th percentile (upper 1% of cases) and 90th percentile (upper 10% of cases) values have also been calculated to provide context to the likelihood of each outcome. If the magnitude of the maximum (100th percentile) concentration was very similar to the 99th or 90th percentile value, then the likelihood of those meteorological conditions being present at the time of the fire is high. If the 100th percentile concentration value is much larger in magnitude than the 99th or 90th percentile values, then the predicted concentration would only occur under meteorological conditions that are very unusual and that may only occur for a small number of hours per year.

5.2. Emission Parameters

5.2.1. As the exact emissions from the BESS cannot be meaningfully estimated at present, the modelling is based on emissions that have been modelled as a volume source, at a nominal emission rate of 1µg/m^3/s. This approach establishes the pattern of dispersion and dilution, that can be scaled up to consider any other emission rate value.

5.2.2. A number of assumptions have been made to the model to ensure the assessment approach is precautionary and provides an upper estimate of likely outcomes. Near source temperatures in excess of 300°C can be reasonably expected to be present, which would result in the plume rising rapidly, reducing near-ground concentrations. However, the emission is not from a stack or open fire, but from a vent and the source is a volume of air adjacent to the vent with an elevated concentration. This assessment has assumed a volume source with no initial vertical momentum and the temperature has been modelled as if it was emitted at ambient air temperature. These two assumptions represent a very conservative approach in terms of dispersion modelling as they remove the vertical momentum of the emission and consequently the predicted near ground level concentrations from the model are considerably higher than would be experienced under real world conditions, as the plume has been modelled without that initial vertical momentum caused by the fire.

5.2.3. The emission parameters modelled are summarised in Table 5-1, and they are discussed in the following sections.

Table 5-1: Emission Parameters and General Model Conditions included with the Model

Variable	Input
Surface Roughness at source	0.3m
Receptors	Polar grid centred at location of source. Nodes at 50m intervals, segments at 10 degrees intervals.
Emissions	Indicative scenario at unit emission rate
Sources	A single volume source 2m (length) by 2m (width)
Volume Source Vertical height	2m, located between 1m and 3m above ground
Emission Temperature	Ambient (15 °C)

Variable	Input
Exit Velocity	None
Emission Rate	1 µg/m^3/s
Source Location	Indicative location
Meteorological data	5 years of hourly sequential data from Coningsby meteorological station (2020 – 2024)

Modelling Domain

5.2.4. The model outputs are at nodes on a polar coordinate grid extending 1.5km from the source (i.e., 1.5km radius circle) with grid nodes at 50m intervals along each of the 36 segments (one every 10 degrees).

Meteorology

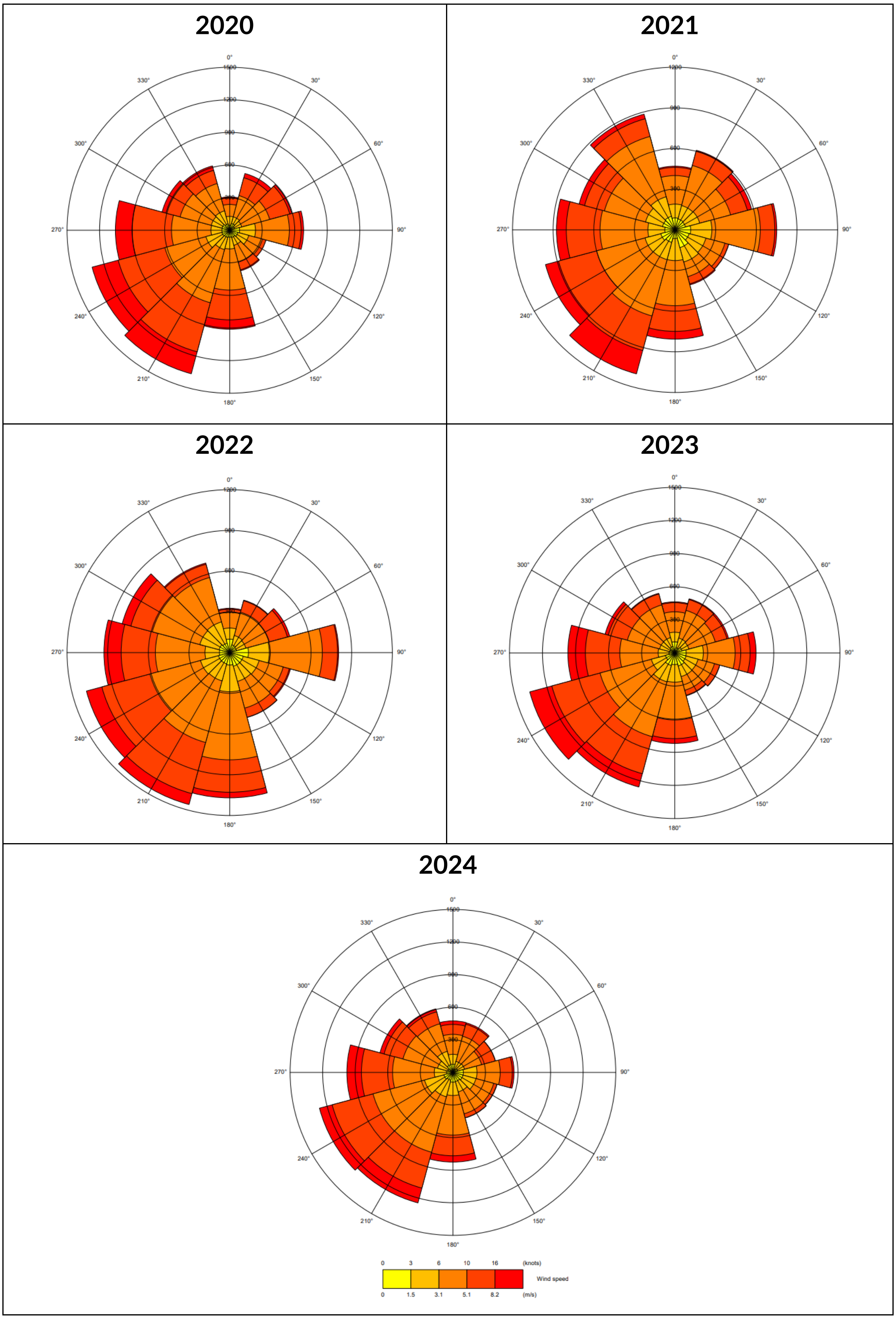
5.2.5. The dispersion of emissions from a point source is largely dependent on atmospheric stability and turbulent mixing in the atmosphere, which in turn are dependent on wind speed and direction, ambient temperature, cloud cover and the friction created by buildings and local terrain.

5.2.6. Actual observed hourly sequential meteorological data is available for input into dispersion models, and it is important to select data as representative as possible for the Site that is modelled. This is usually achieved by selecting a meteorological station as close to the Site as possible, although other stations may be used if the local terrain and conditions vary considerably, or if the station does not provide sufficient data. For point sources, such as stacks, the Environment Agency recommends the use of five years of the recent available meteorological data be used in modelling assessments to ensure that all typical weather conditions are considered within the modelling.

5.2.7. The meteorological site used in the modelling was Coningsby for the years 2020 to 2024 inclusive. The meteorological site is located approximately 38km north of the Scheme. The meteorological conditions at the Coningsby are considered representative of those experienced at the Scheme.

5.2.8. The wind-roses for Coningsby meteorological data are shown in Plate 5-1.

Plate 5-1: Wind-roses for Coningsby



Building and Terrain Effects

5.2.9. The presence of buildings or structures near to the emissions points may cause the airflow to be directed to ground level more rapidly than in the absence of a building. In this assessment, the use of a ground level volume source with air at ambient temperature and no initial vertical momentum means the airflow is already being modelled at ground level and there is no additional effect to be included through modelling building downwash functions within the dispersion model.

5.2.10. The Scheme is situated in flat open ground surrounded by open agricultural land and surrounded by small villages. A surface roughness of 0.3 m, corresponding to agricultural areas has been selected to represent the local terrain.

5.2.11. The model has used simple (flat) terrain. Site-specific terrain data has not been used in the model, a gradient of more than 1 in 10 are not present in the vicinity of the source.

Results of Dilution Modelling

5.2.12. The conventional output from a consequence model would be a plot illustrating a series of rings denoting a maximum concentration at a stated distance from the source. The output from the dilution modelling is similar, with the plots showing rings of nodes at 50m increments from the source, with the dilution factor illustrated using a colour scale. The reported dilution factors are relative to the concentration at a location 10m out from the centre of the source. Table 5-2 illustrates the smallest rate of dilution likely to be experienced under any meteorological conditions (the 100th percentile). Table 3 also illustrates a dilution rate that would be achieved under 99% (8,672 out of 8,760 hrs per year) of meteorological conditions and a dilution rate that would be achieved under 90% (7,884 out of 8,760 hours per year) of meteorological conditions. In real world terms, these represent the lowest level of dilution and the longest distances to achieve that level for the stated percentage of the year.

5.2.13. Results (Table 5-2 and Figures included in Annex A) demonstrate that source concentrations would be diluted to 1/1,000th of the source concentration (a dilution factor of 0.001) within 1,050m of the source in any direction under any meteorological conditions (the 100th percentile) likely to occur at the Site. Under 99% of meteorological conditions, the same level of dilution would occur within 650m of the source in any direction, and under 90% of meteorological conditions, the same level of dilution would occur within 150m of the source in any direction (see Table 5-2 and Figures 1, 2, and 3 in Annex A).

5.2.14. For any emission rate at the source, the use of the minimum (100th percentile) dilution rate gives an estimate of dilution rates that is approximately seven times more precautionary that the use of the 90% value. As such, it represents an extreme combination of meteorological conditions that are unlikely to occur should there be a fire incident.

Table 5-2: Dilution with distance from source

Direction from Source	Dilution factor of 0.001 for 100% of meteorological conditions	Dilution factor of 0.001 for 99% of meteorological conditions	Dilution factor of 0.001 for 90% of meteorological conditions
0° N	1,050m	400m	150m
50° NE	1,000m	600m	150m
90° E	1,050m	450m	150m
130° SE	1,050m	550m	150m
180° S	1,050m	450m	150m
230° SW	1,050m	450m	150m
270° W	1,050m	650m	150m
310° NW	1,050m	550m	100m
*Based on 2021 meteorological data as highest impact in the period 2020 – 2024.			

Likely Consequences of Battery Emissions

5.2.15. At present the detail of the BESS for the Scheme are subject to detailed design and procurement. Based on information from Section 5.2 of this Appendix, indicative scenarios to represent the potential emissions of HF are summarised in Table 5-3.

5.2.16. The central estimate of HF content that could be emitted has been taken as 2kg. A lower estimate based on 50% of the central estimate and an upper estimate of 150% of the central estimate are included in Table 4 to reflect uncertainty about the available HF mass in the module at the time of any future fire incident.

5.2.17. The HF has been assumed to be released at a steady rate during a fire and a time period based on the FPRF BESS fire test of 3 hours has been adopted as the shorter time period. A longer 6-hour fire period has been adopted as a lower emission rate condition. The mass of HF released is the same both fire duration scenarios, but the concentration of the emissions is higher for the shorter fire duration scenario.

Table 5-3: Indicative Emission Rates

Scenario	HF content in one module	Duration of Fire	Concentration in 2m x 2m x 2m volume at source	Dilution factor to achieve AEGL-1 value of 0.82 mg/m^3	Indicative distance to achieve AEGL-1 value for 100% of met conditions (m)
Lower HF shorter fire	0.5kg	3hrs	6mg/m^3	0.136	50
Lower HF longer fire	0.5kg	6hrs	3mg/m^3	0.273	50
Central HF shorter fire	1kg	3hrs	12mg/m^3	0.068	50 - 100
Central HF longer fire	1kg	6hrs	6mg/m^3	0.136	50
Upper HF shorter fire	2kg	3hrs	24mg/m^3	0.034	100 - 150
Upper HF longer fire	2kg	6hrs	12mg/m^3	0.068	50 – 100
Upper HF shorter fire	3kg	3hrs	36mg/m^3	0.023	150 - 200
Upper HF longer fire	3kg	6hrs	18mg/m^3	0.046	50 - 100

5.2.18. Emissions of HF from a single cabinet fire could cause concentrations over time periods of 10 minutes, 1 hour or up to 6 hours that are above the AEGL-1 value at locations close to the fire. However, HF concentrations will fall to below the AEGL-1 value in 100% of meteorological conditions beyond 200m from the source. Under several modelled scenarios this distance would be even smaller. Given that containers will be sited a minimum of 350m from residential receptors, concentrations will be below AEGL-1 at all existing residential receptor locations. Any workers on agricultural land closer than this would be able to move back to a safer distance.

5.2.19. Given the specification reached in detailed design will be required to be consistent with the parameters assumed in this study (i.e., 0.5kg to 3kg of HF from a single module fire) then the potential consequence exposure to HF at actual receptor locations surrounding the BESS would be below the AEGL-1 value. It is noted that the use of a less conservative modelling approach that included consideration of plume rise at the source would report considerably lower ground level concentrations at receptors and shorter distances (<20m) for achievement of the AEGL-1 criteria, due to the plume passing overhead at receptor locations.

5.2.20. The expected HF emissions will be checked against the assumptions in this report at detailed design stage once the make, model and layout of the BESS is known, and, if necessary, consequence modelling will be undertaken to demonstrate that the impacts associated with an unplanned fire would not exceed the effects outlined in this report or cause any significance adverse health effects to the local community.

6. Multi-Cabinet Fire Scenario

Modelling Approach

6.1.1. The assessment approach considers the same indicative BESS plant as considered in Section 5, with a container that comprises 6 separate cabinets and each cabinet containing 8 modules. In this scenario, it is assumed that a fire develops within a cabinet and progresses to adjoining cabinets. It takes time for the fire to progress, meaning that as the fire develops in one cabinet, combustion has already occurred for part of the preceding cabinet. The peak hourly emission rate is considered to be equivalent to the potential emissions of 60% of the total HF from 2 cabinets. This is a conservative approach as it assumes all potential emissions from all modules are released.

6.1.2. This scenario requires the structure of the cabinets to fail allowing the fire to extend beyond the cabinet emitting directly to atmosphere, rather than through the vent as would occur for the one module event scenario. This is important as a fire with temperatures in the range of 1200 °C to 1500 °C will cause the air above the fire to rise. This phenomena is taken into account by calculating the 'effective height of release', which is the height the plume rises before the dispersion model calculates the downwind dispersion. Under calm conditions the effective height of release is calculated to be 10m and this is reduced to 5m during windy conditions.

6.1.3. For this scenario, the dispersion modelling was conducted using the U.S. Environmental Protection Agency's ALOHA software (version 5.4.7) to simulate the atmospheric dispersion of thermal plume. The model was configured as a continuous elevated release with a duration of one hour, consistent with the peak hourly emissions from a fire. while meteorological and surface parameters were defined according to the site conditions. The model assessed downwind HF concentrations, with particular focus on the maximum distance to the AEGL-1 threshold (1ppm) to evaluate potential off-site exposure risks. The overall approach followed established practices for emergency response and hazard assessment[18,19]. The model output report, detailing input parameters and corresponding results are provided in Annex B for a fire event under low wind speeds and the same fire event during high wind speeds.

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[18] U.S. Environmental Protection Agency (EPA) & NOAA. (2022). ALOHA User's Manual: Areal Locations of Hazardous Atmospheres. U.S. EPA Office of Emergency Management.

[19] Hanna, S. R., Briggs, G. A., & Hosker, R. P. (1982). Handbook on Atmospheric Diffusion. U.S. Department of Energy, DOE/TIC-11223.

Emission Parameters

6.1.4. The effective release height applied in ALOHA was estimated through a simplified plume-rise analysis based on the empirical relations developed by Briggs[20]. The calculation used the convective heat-release rate derived from experimentally measured combustion energy for LFP cells[21], which was estimated to be approximately 3.3 MW for a two-cabinet fire. The total energy of the involved portion of the system was determined from its rated capacity, assuming that only a portion of the stored energy contributes to the flaming phase of combustion[22]. A convective fraction of 70% of the total heat-release rate was adopted in accordance with standard fire plume modelling practice[23]. The resulting effective release heights were then used as source parameters in the ALOHA dispersion simulations.

Meteorology

6.1.5. Five years of hourly sequential data from Coningsby meteorological observation station were analysed to determine representative conditions for the low wind speed and high wind speed dispersion simulations. The 5th percentile of wind speed and air temperature was used to represent calm, low-dispersion conditions, while the 95th percentile values were used to represent windy, high-dispersion conditions. These percentiles capture the lower and upper extremes of local meteorology, providing conservative and contrasting boundary cases for assessing potential plume behaviour and HF dispersion.

Likely Consequences of Battery Emissions from two cabinets

6.1.6. Results (Table 6-1) confirm that HF concentrations would achieve the AEGL-1 value of 1ppm within 240m from the source under calm weather conditions and within 132m from the source under windy weather conditions. This is due to more vigorous mixing resulting in more rapid dilution of the plume under windy conditions. The AEGL-2 and AEGL-3 values for HF are predicted to be achieved at all locations under calm or windy conditions.

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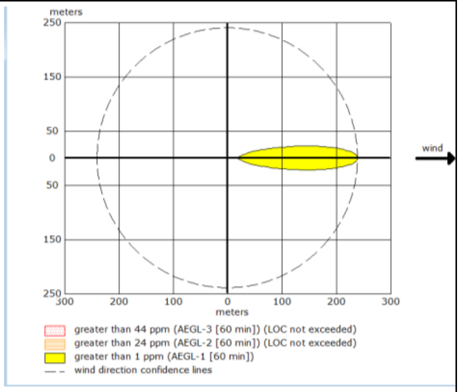
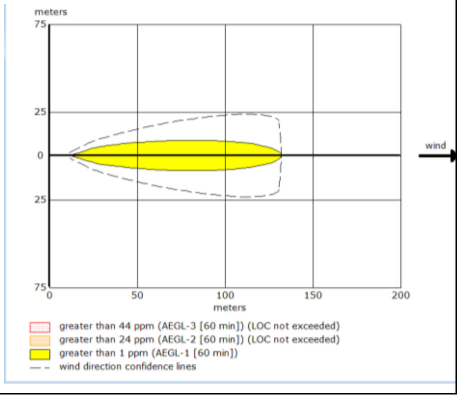
[20] Briggs, G. A. (1969). Plume Rise. U.S. Atomic Energy Commission Critical Review Series.

[21] Sturk, A., Rosengren, M., & Mellander, B. E. (2015). Fire Tests on E-Vehicle Battery Cells and Packs. SP Technical Research Institute of Sweden.

[22] Sun, J., Huang, Y., Wang, Y., et al. (2020). “A review on fire and thermal runaway characteristics of lithium-ion batteries.” Journal of Power Sources, 478, 228649.

[23] Heskestad, G. (2016). “Fire Plumes, Flame Height, and Air Entrainment.” In SFPE Handbook of Fire Protection Engineering (5th ed.). Springer.

Table 6-1: AEGL-1 Achievement Distances

Scenario	Meteorological conditions	Effective Release Height (m)	Distance to AEGL-1 (m)	Figure
Multi-cabinet fire calm, low-dispersion conditions	5th percentile (calm): Ambient Temperature: 1°C Wind speed: 1m/s	10	240	
Multi-cabinet fire windy, high-dispersion conditions	95th percentile (windy) Ambient Temperature: 21.3°C Wind speed: 9.3m/s	5	132	

7. Conclusion

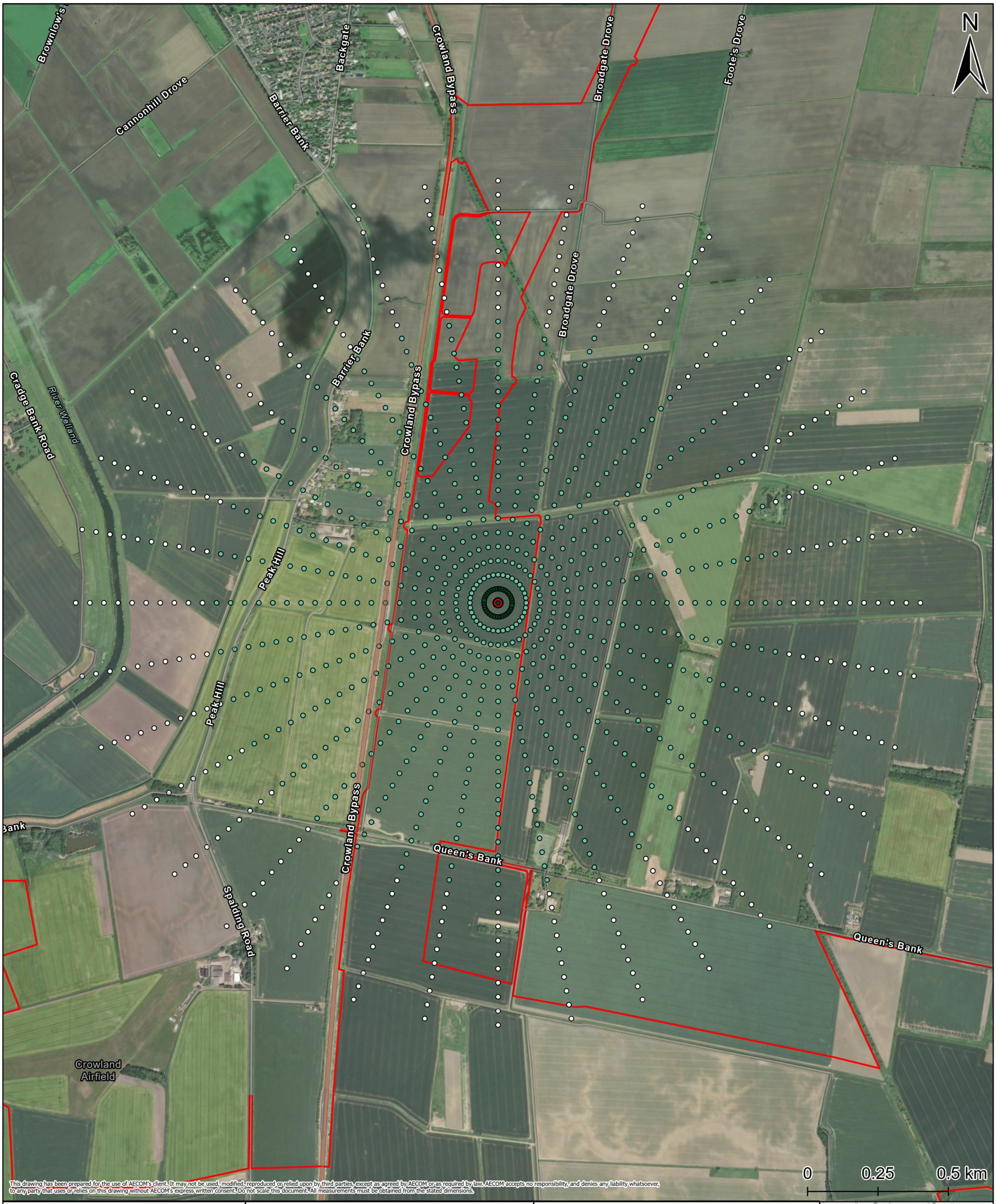
7.1.1. The predicted impacts for the two highly conservative scenarios demonstrate that the likely consequences of emissions of HF, for a thermal event is that the AEGL-1 value would be achieved within 50m to 240m from the fire. The containers will be sited a minimum of 350m from residential receptors, and as such, there are no residential receptors where the AEGL-1 value would likely be exceeded.

7.1.2. Any workers on agricultural land or users of public rights of way that were closer to the fire when it started, would be able to move back to a safer distance and thereby avoid exposure to elevated concentrations of all air pollutants.

7.1.3. The expected HF emissions will be checked against the assumptions in this report at detailed design stage once the make, model and layout of the BESS is known. Consequence modelling will be undertaken at that time to demonstrate that the risks associated with an unplanned fire would not exceed the effects outlined in this report or cause any significance adverse health effects to the local community.

Annex A: Dilution Rate Plots

Figure 1: Relative dilution from source based on the 100th percentile value at Meridian BESS



Project Title

Meridian Solar Farm

Map Title

Environmental Statement
Appendix 16-4
Figure 1: Relative Dilution from
Source Based on the 100th Percentile
Value at Meridian BESS

Scale	Version	Drawn	Reviewed
1:12,000	0	LL	AK

Legend

- ▭ Order Limits
- ● BESS Location

Relative Dilution Polar Plot

100th Percentile

- ○ 0.0005 - 0.001
- ● 0.001 - 0.05
- ● > 0.05

Date: 20/03/2026

Copyright

Meridian
Solar

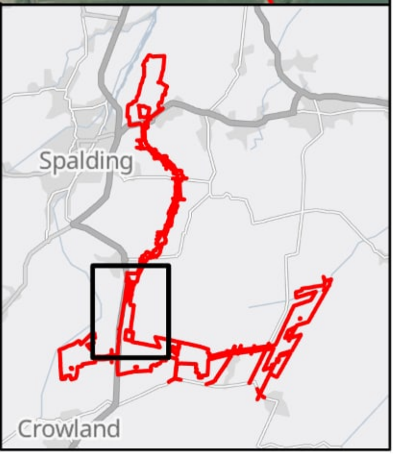
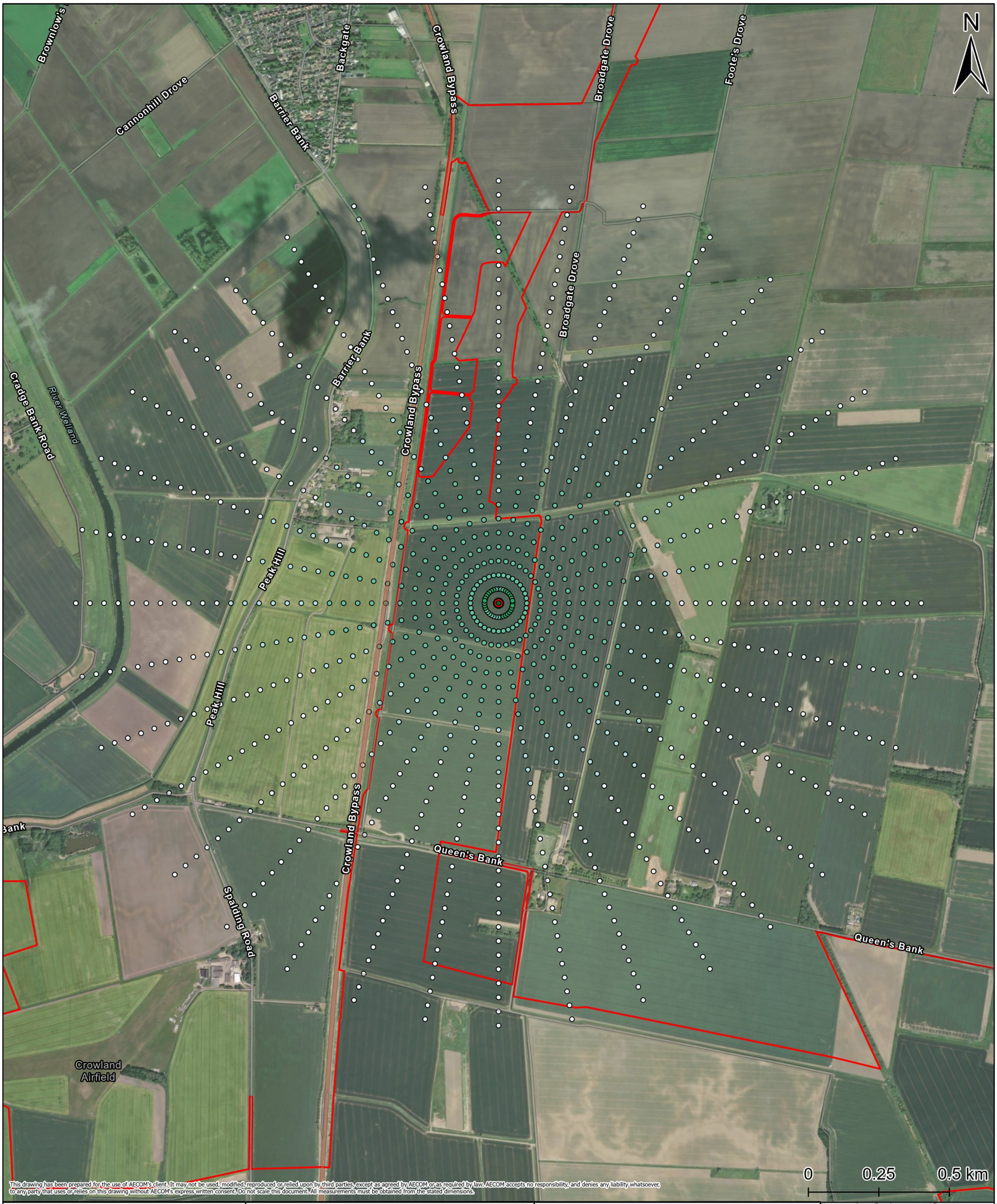


Figure 2: Relative dilution from source based on the 99th percentile value at Meridian BESS



Project Title

Meridian Solar Farm

Map Title

Environmental Statement
Appendix 16-4
Figure 2: Relative Dilution from
Source Based on the 99th Percentile
Value at Meridian BESS

Scale	Version	Drawn	Reviewed
1:12,000	0	LL	AK

Legend

- 🟥 Order Limits
- ● BESS Location

Relative Dilution Polar Plot

99th Percentile

- ○ < 0.0005
- ● 0.0005 - 0.001
- ● 0.001 - 0.05
- ● 0.05 - 0.1
- ● > 0.1

Date: 20/03/2026

Copyright

Meridian Solar

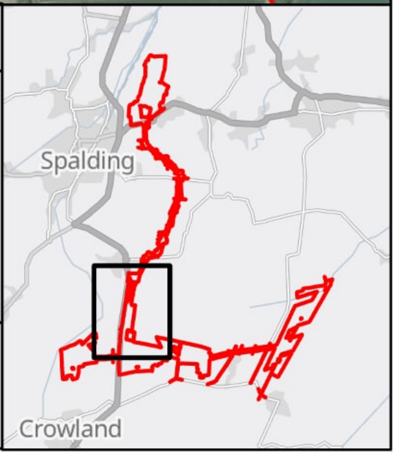
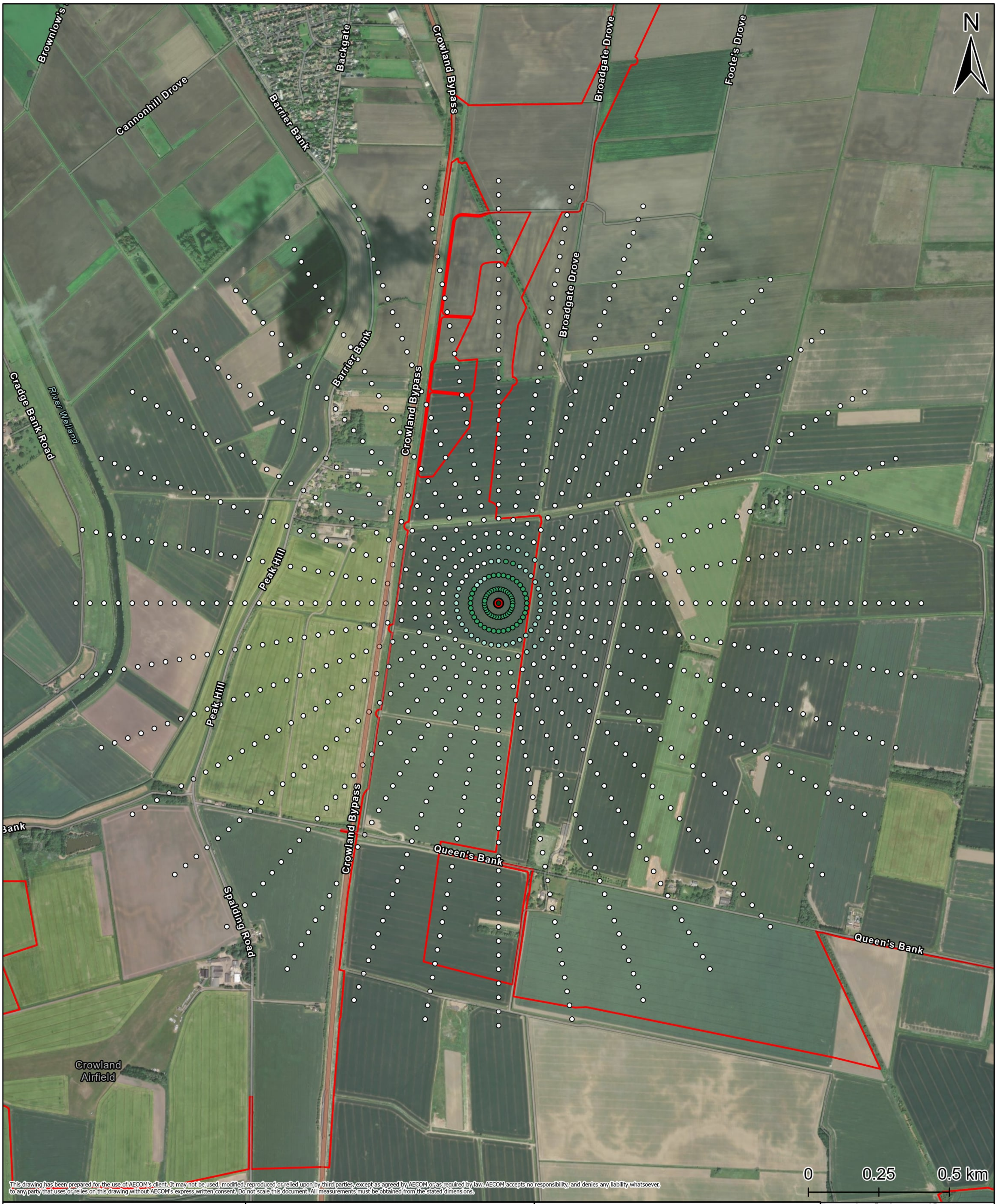


Figure 3: Relative dilution from source based on the 90th percentile value at Meridian BESS



Project Title

Meridian Solar Farm

Map Title

Environmental Statement
Appendix 16-4
Figure 3: Relative Dilution from Source Based on the 90th Percentile Value at Meridian BESS

Scale	Version	Drawn	Reviewed
1:12,000	0	LL	AK

Legend

- 🟥 Order Limits
- ● BESS Location

Relative Dilution Polar Plot

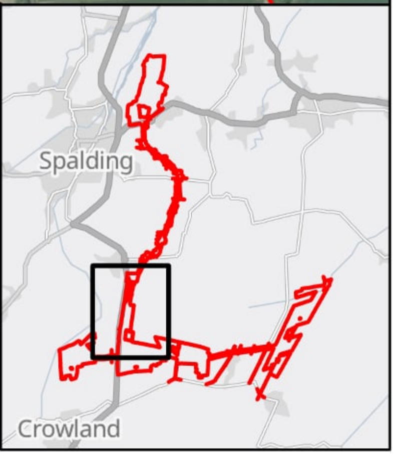
90th Percentile

- ○ < 0.0005
- ● 0.0005 - 0.001
- ● 0.001 - 0.05
- ● > 0.05

Date: 20/03/2026

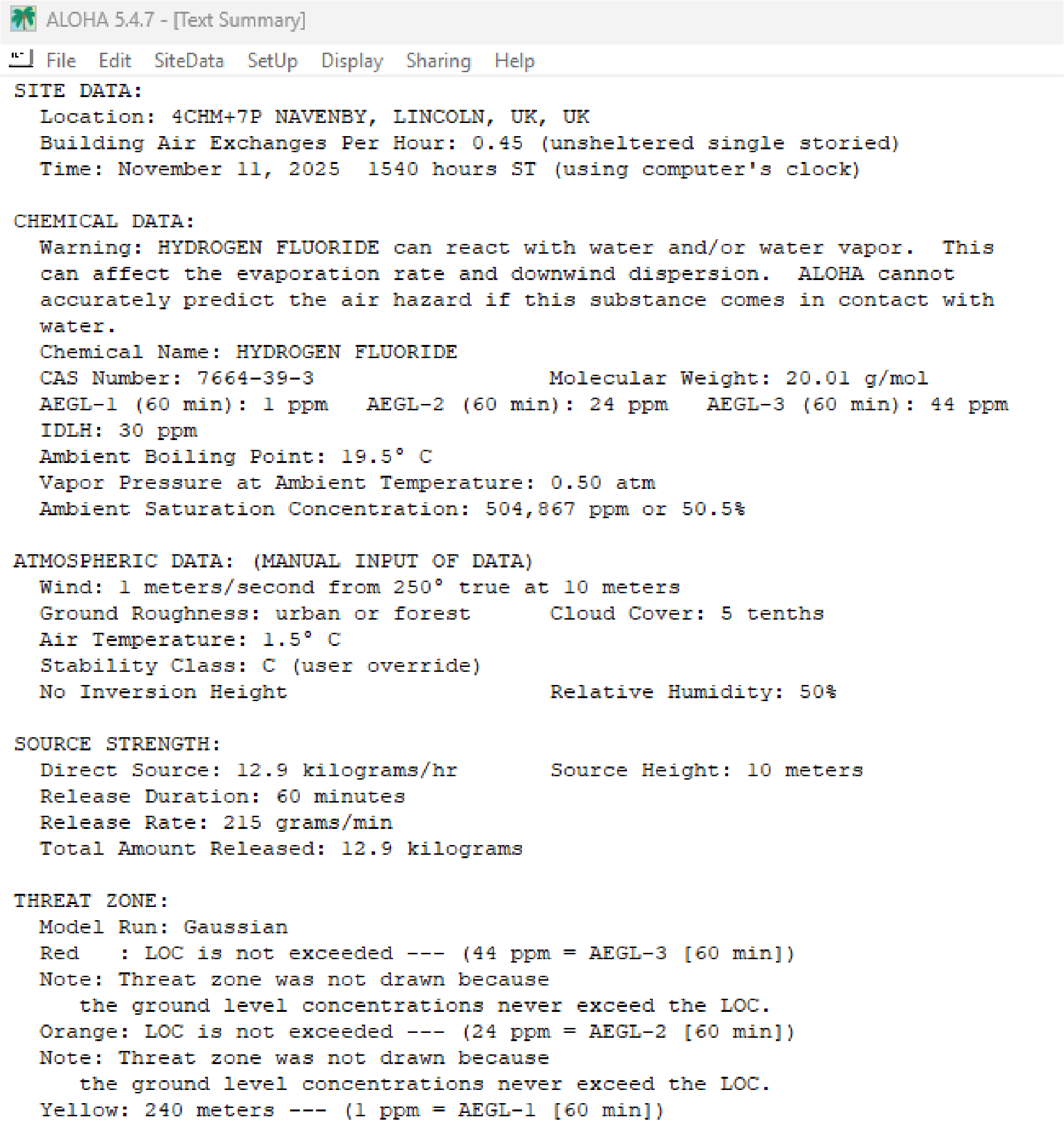
Copyright

Meridian Solar



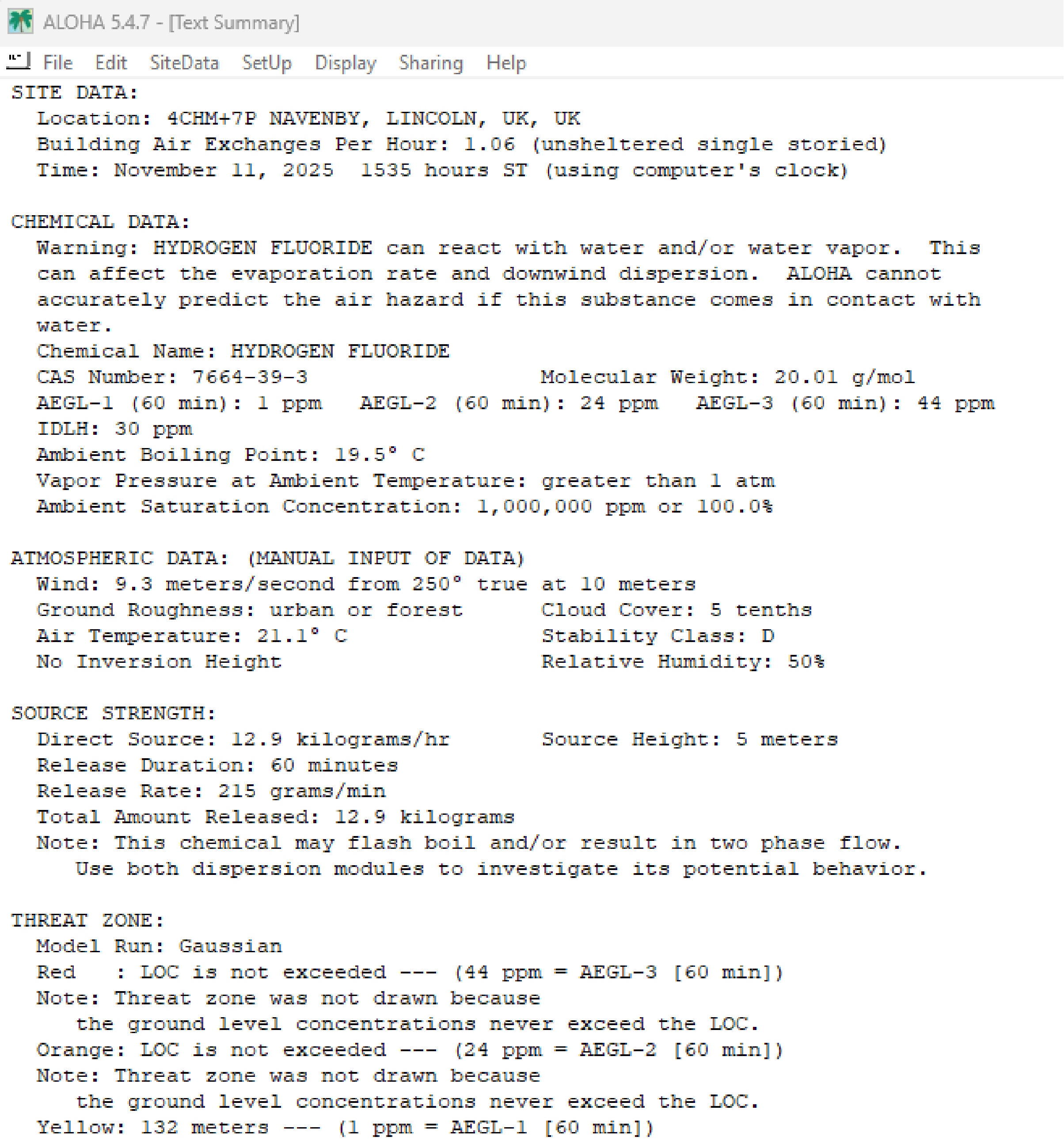
Annex B: ALOHA Run Reports

B1 1 Multi cabinet fire under calm wind conditions



```
SITE DATA:
  Location: 4CHM+7P NAVENBY, LINCOLN, UK, UK
  Building Air Exchanges Per Hour: 0.45 (unsheltered single storied)
  Time: November 11, 2025  1540 hours ST (using computer's clock)

CHEMICAL DATA:
  Warning: HYDROGEN FLUORIDE can react with water and/or water vapor.  This
  can affect the evaporation rate and downwind dispersion.  ALOHA cannot
  accurately predict the air hazard if this substance comes in contact with
  water.
  Chemical Name: HYDROGEN FLUORIDE
  CAS Number: 7664-39-3                  Molecular Weight: 20.01 g/mol
  AEGL-1 (60 min): 1 ppm   AEGL-2 (60 min): 24 ppm   AEGL-3 (60 min): 44 ppm
  IDLH: 30 ppm
  Ambient Boiling Point: 19.5° C
  Vapor Pressure at Ambient Temperature: 0.50 atm
  Ambient Saturation Concentration: 504,867 ppm or 50.5%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 1 meters/second from 250° true at 10 meters
  Ground Roughness: urban or forest      Cloud Cover: 5 tenths
  Air Temperature: 1.5° C
  Stability Class: C (user override)
  No Inversion Height                    Relative Humidity: 50%

SOURCE STRENGTH:
  Direct Source: 12.9 kilograms/hr       Source Height: 10 meters
  Release Duration: 60 minutes
  Release Rate: 215 grams/min
  Total Amount Released: 12.9 kilograms

THREAT ZONE:
  Model Run: Gaussian
  Red   : LOC is not exceeded --- (44 ppm = AEGL-3 [60 min])
  Note: Threat zone was not drawn because
     the ground level concentrations never exceed the LOC.
  Orange: LOC is not exceeded --- (24 ppm = AEGL-2 [60 min])
  Note: Threat zone was not drawn because
     the ground level concentrations never exceed the LOC.
  Yellow: 240 meters --- (1 ppm = AEGL-1 [60 min])
```

B1 2 Multi cabinet fire under windy conditions



```
SITE DATA:
  Location: 4CHM+7P NAVENBY, LINCOLN, UK, UK
  Building Air Exchanges Per Hour: 1.06 (unsheltered single storied)
  Time: November 11, 2025  1535 hours ST (using computer's clock)

CHEMICAL DATA:
  Warning: HYDROGEN FLUORIDE can react with water and/or water vapor.  This
  can affect the evaporation rate and downwind dispersion.  ALOHA cannot
  accurately predict the air hazard if this substance comes in contact with
  water.
  Chemical Name: HYDROGEN FLUORIDE
  CAS Number: 7664-39-3                  Molecular Weight: 20.01 g/mol
  AEGL-1 (60 min): 1 ppm   AEGL-2 (60 min): 24 ppm   AEGL-3 (60 min): 44 ppm
  IDLH: 30 ppm
  Ambient Boiling Point: 19.5° C
  Vapor Pressure at Ambient Temperature: greater than 1 atm
  Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 9.3 meters/second from 250° true at 10 meters
  Ground Roughness: urban or forest      Cloud Cover: 5 tenths
  Air Temperature: 21.1° C               Stability Class: D
  No Inversion Height                    Relative Humidity: 50%

SOURCE STRENGTH:
  Direct Source: 12.9 kilograms/hr       Source Height: 5 meters
  Release Duration: 60 minutes
  Release Rate: 215 grams/min
  Total Amount Released: 12.9 kilograms
  Note: This chemical may flash boil and/or result in two phase flow.
     Use both dispersion modules to investigate its potential behavior.

THREAT ZONE:
  Model Run: Gaussian
  Red   : LOC is not exceeded --- (44 ppm = AEGL-3 [60 min])
  Note: Threat zone was not drawn because
     the ground level concentrations never exceed the LOC.
  Orange: LOC is not exceeded --- (24 ppm = AEGL-2 [60 min])
  Note: Threat zone was not drawn because
     the ground level concentrations never exceed the LOC.
  Yellow: 132 meters --- (1 ppm = AEGL-1 [60 min])
```

Abbreviations

Abbreviation/Term	Definition
AEGL	Acute Exposure Guideline Level
BESS	Battery Energy Storage System
CH_4	Methane
CO	Carbon monoxide
DCO	Development Consent Order
ERPG	Emergency Response Planning Guideline
FPRF	Fire Protection Research Foundation
HF	Hydrogen fluoride
KWh	Kilowatt hour
MW	Megawatt
PHE	Public Health England
PHEV	Plug in hybrid electric vehicle
ppm	parts per million
SOC	State of charge
UKHSA	United Kingdom Health Security Agency

Glossary of Frequently Used Terms

Term	Definition
ADMS	A regulatory atmospheric dispersion model software package widely used in the UK to model long and short term impacts of emissions to air.
ALOHA	A hazard modelling program which is part of the U.S. Environmental Protection Agency's software suite, that is widely used to plan for and to respond to chemical emergencies
Battery	A generic term for a single cell or a group of cells connected together electrically in series, in parallel or a combination of both.
Battery Energy Storage System	Electrochemical cells (lead acid, Li-ion, solid state batteries, flow batteries, etc.) linked together with control systems and associated housings, to form a facility that can store chemical energy and deliver the stored energy in the form of electricity.
Cabinet	A form of enclosure or part of a container, where doors or hatches enable direct access to equipment but a person cannot enter the enclosure.
Cell	The basic electrochemical unit, characterised by an anode and a cathode, used to receive, store, and deliver electrical energy
Concentration	The total mass or volume of a substance per unit volume of air. Typically expressed as milligrams per cubic metre or as parts per million (ppm).
Container	A form of enclosure where a door and internal walkway enables a person to enter the enclosure to access equipment.
Enclosure	The structure used to house racks of batteries, typically in the form of a container or a cabinet.
Energy Capacity	The amount of energy stored within the BESS, typically expressed in terms of electrical energy using units of kilowatt hour (KWh).
Emission	A substance released into the atmosphere.
Li-ion cell	A rechargeable cell that uses lithium ions as the

Term	Definition
	primary component of its electrolyte
Module	A self-contained unit made up of multiple cells, insultation, connections and a housing.
Node	A point within a dispersion model output grid, that a predicted value is reported for.
Off-gassing	Venting of electrolyte vapours from a cell.
Power Output	The aggregate net electrical energy that a Battery Energy Storage System can provide, typically expressed in units of megawatts (MW) or gigawatts (GW)
Rack	A structure used to hold a group of modules.
Receptor	A component of the natural or man-made environment that is affected by an impact, including people.
State of charge	The ratio of present dischargeable energy storage capacity to the maximum dischargeable energy storage capacity, typically expressed as a percentage value.
Thermal barrier	A physical measure to slow the rate at which heat transfers between two parts of a BESS, i.e., a thermal insulating material or the use of an air-filled gap
Thermal runaway	The condition when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion and progresses when the cell's heat generation is at a higher rate than it can dissipate, potentially leading to off-gassing or fire.