Drakelands Restoration Limited

HEMERDON MINE

Noise Impact Assessment

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Noise Impact Assessment

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EXECUTIVE SUMMARY

This Noise Impact Assessment has been prepared in response to the Schedule 5 notice issued by the Environment Agency (EA) dated 1st March 2023. The Schedule 5 notice is specifically in relation to low frequency noise (LFN) from the Minerals Processing Facility (MPF). A satisfactory response to the Schedule 5 notice is required to enable the EA to issue an Environmental Permit for the operation of the mine.

The Noise Impact Assessment has considered:

- The history of LFN emissions from the site, which is summarised in Section 1 of this Report.
- The relevant legislation, policy, guidance and standards pertaining to LFN, and the available research on the generation, propagation and effects of LFN, which is summarised in Section 2 of this Report.
- The locations and receptors that could be affected by LFN emissions from the MPF, which is summarised in Section 3 of this Report.
- The results of measurement surveys (including measurements of LFN and meteorological conditions) to determine typical background levels of LFN in the absence of operations at Hemerdon.
- The measurement results from on site trials to quantify the reductions in LFN emissions that can be achieved from various mitigation interventions, including the implementation of acoustics enclosures and deck venting applied to the screens. This is summarised in Sections 4 and 5 of this Report.
- The results of a LFN noise modelling exercise to calculate the levels of LFN that would likely be experienced within the community surrounding the Hemerdon mine, should the MPF become operational upon implementation of appropriate LFN mitigation measures as identified in Section 5 of this Report. The results of this modelling exercise are presented in Section 6.
- An assessment of the predicted LFN levels in the context of their acceptability, using comparisons with the previous Wolf Minerals operations and the existing (i.e. excluding Hemerdon mine operations) LFN in the area. The results are presented in Section 7 of this Report.
- The possibility of implementing further mitigation measures upon operation, should it be deemed necessary. This is presented in Section 8 of this Report.
- A consideration of uncertainties in the assessment, including the noise measurements, data analysis, noise model predictions and assessment, how these have been minimised and the degree to which they have influenced the outcome of the assessment. This is summarised in Section 9.

The results of this assessment are that:

- The background noise climate as measured at various residential locations includes LFN from sources external to the Hemerdon site. The measured background data suggests that there are other sites in the area operating screens or other equipment with a similar operating speed / frequency to the screens proposed for Hemerdon MPF.

- The results from on site trials has demonstrated that the implementation of acoustic enclosures (including outlet chutes) provides a reduction of 11 dB compared to the situation without enclosures (which was the case when the mine was operating under the control of Wolf Minerals as the previous operator).
- On site trials have also demonstrated that a further reduction in LFN of 6 dB can be achieved through the use of deck venting to the screens.
- The implementation of both acoustic enclosures and deck venting is proposed for Hemerdon MPF. The combined effect of these measures will be a reduction of 17 dB compared to the previous situation when the site was operating under the control of Wolf Minerals.
- Furthermore, the proposed future operations at Hemerdon will utilise a set of screens with a lower overall screening area than was used previously under Wolf Minerals.
- The combined effect of these measures is that the expected levels of LFN at receptor locations in the community surrounding Hemerdon will be of the order of 23 dB lower than was the case when the site was operated by Wolf Minerals.
- There will be beating effects associated with the LFN as experienced at locations within the community surrounding Hemerdon mine. This was the case under previous operation by Wolf Minerals and is an inevitable consequence of having multiple screens in operation. However, the reduction in overall levels of LFN ought to make beating effects less noticeable.
- There are some known uncertainties associated with the LFN predictions. In particular, LFN if experienced within the neighbouring community will vary depending on meteorological conditions. This was the case under previous operation of the Hemerdon site by Wolf Minerals, and will remain the case under operation by DRL. The potential uncertainties have been quantified in Section 9 of this Report and, in summary, the assessment is considered to be conservative in its approach.

Recommendations and Next Steps

This noise impact assessment has demonstrated that upon implementation of the proposed mitigation measures (use of acoustic enclosures and deck venting applied to the screens), LFN will be reduced by 17 dB compared to the previous situation when the site was operated by Wolf Minerals. Additionally, changes to the proposed operation of the MPF including the use of new screens with a lower total screening area (compared to the Wolf Minerals operations) are projected to result in a total combined reduction of 23 dB.

This represents a substantial reduction in levels of LFN. As such, it is recommended that an Environmental Permit be issued for operation of the mine.

DRL has committed to the implementation of additional control measures (identified as secondary and tertiary control measures in Section 8 of this Report) if, following operation and implementation of the inherent mitigation, LFN is substantiated to be impacting noise sensitive receptors.

The Noise Management Plan, submitted alongside this Noise Impact Assessment, identifies the future LFN monitoring protocols that will be implemented should the MPF become operational following receipt of the necessary permits. The results from this monitoring will be used to identify the need for further control measures as required.

The results of future LFN measurements, alongside data obtained from the on site meteorological station, can be used to further investigate the LFN prediction uncertainties associated with meteorological conditions.

1 INTRODUCTION

1.1 SCOPE

1.1.1. This noise impact assessment has been prepared in response to the Schedule 5 notice issued by the Environment Agency (EA) dated 1st March 2023, as included in Appendix A and described in more detail in Section 1.4 below. This Schedule 5 notice is specifically in relation to low frequency noise from the mine processing operations.

1.1.2. A satisfactory response to the Schedule 5 notice is required to enable the EA to issue an Environmental Permit for the operation of the mine. In considering the response to the Schedule 5 notice, it is appropriate to consider the EA's online guidance *Noise and vibration management: environmental permits*[1] as summarised in Section 2.

1.1.3. This report addresses low frequency noise (LFN) only[2] from the Minerals Processing Facility (MPF) which itself is described in detail in Section 1.2.1 below. As agreed with the EA at a meeting on 4th May 2023, LFN covers the range 10 Hz to 160 Hz. The assessment of audible noise (defined as being the frequency range from 63 Hz to 16 kHz, in line with the ISO 9613-2 prediction methodology) from the site has been provided to the EA in the SLR report titled *"Hemerdon Mine Processing Plant Environmental Permit Application Noise Impact Assessment"* dated November 2022.

1.1.4. Table 1-1 below provides a high level summary of each of the Schedule 5 items which are discussed and addressed in this report with the comments providing reference to the appropriate report section and/or providing additional information.

Table 1-1 – Summary of LFN Schedule 5 Items

Item	Summary of Schedule 5 Item	Comments
A	Aspects to include in the noise impact assessment: • The potential sources of low frequency noise, and location; • New equipment at the site, the location and mitigation; • Disused equipment at the site, and location; and, • Main mitigation measures.	See Section 1
B	Amend the NVIA to include all potential sources of low frequency noise, or provide a justification for the exclusion of potential sources of noise from the assessment.	See Section 1 and, for the jaw crusher, Section 6.

[1] Noise and vibration management: environmental permits - GOV.UK (www.gov.uk), last updated 31st January 2022

[2] The Schedule 5 notice uses the terms "low frequency noise" and "infrasound". It has been confirmed by the EA that the terms are used interchangeably in the notice; this report uses only the term low frequency noise.

C	Amending the NIA to include impacts at 20 Hz	This refers to data which were missing from the previous NIA. As agreed with the EA during a meeting on 02/08/2023, this assessment focuses on noise levels at the fundamental frequency of the screens and their harmonics. In this context, specifically focusing on 20 Hz is no longer required and this Item is not referenced further.
D	Justification of acoustic efficiency	See Sections 6 and 9
E	Appraisal of mitigation options	See Section 8. Also see separate Options Appraisal Report submitted in support of the application.
F	Provide additional information on the proposed cladding and ensure that this is consistent with the BS 4142 assessment and any Noise Management Plan.	Cladding is addressed in Sections 5 and 8 and detailed in the Noise Management Plan submitted in support of the application.
G	Provide an assessment of amplification within the receptors or provide a justification for why this has not been provided.	See Section 9.
H	Uncertainty in the noise model (including beating)/noise impact assessment	See Section 9

1.1.5. This noise impact assessment is structured as follows:

- Section 1: The remainder of this section includes an introduction to the site and the minerals processing facility in particular. A brief history of LFN noise at the site is also provided for context and general information.
- Section 2: Assessment methodology. This section sets out the general approach to the assessment including relevant legislation, policy, guidance and standards. An overview of the noise survey and noise model prediction is provided followed by a summary of consultation undertaken with the EA.
- Section 3: Assessment Locations. This section includes detailed descriptions of the assessment locations, including photographs.
- Section 4: Equipment and Meteorology. This section includes details of the monitoring undertaken; both for noise and weather.
- Section 5: Measurement Objectives, Methodology and Results. The purpose and objectives of the noise measurements are provided in detail with a summary of the noise survey results.
- Section 6: Noise Prediction Model: This section provides a detailed approach to the noise modelling including any inherent mitigation, assumptions and corrections applied. The results of the noise modelling are also provided in this section.
- Section 7: Noise Impact Assessment. The predicted noise levels at the assessment locations are discussed in the context of their acceptability, using comparisons with the previous Wolf Minerals LFN levels and the existing (i.e. excluding Hemerdon mine operations) LFN in the area.
- Section 8: Mitigation/Noise Control. This section provides a summary of the inherent mitigation (for which the detail is included in Section 6) and references additional mitigation in the Noise Management Plan which could be implemented upon operation, should it be deemed necessary.

- Section 9: Uncertainties. This section summarises the uncertainties in the assessment, including the noise measurements, data analysis, noise model predictions and assessment, how these have been minimised and the degree to which they have influenced the outcome of the assessment.

1.1.6. The report has been prepared by individuals holding relevant qualifications and/or professional membership of the Institute of Acoustics. The credentials and relevant experience of the report contributors are provided in Appendix B.

1.1.7. This report is necessarily technical in nature, therefore, a glossary of acoustic terminology is provided in Appendix C.

1.2 SITE LOCATION

1.2.1. The site consists of the Hemerdon Deposit located to the north-west of Plymouth in Devon and north of the villages of Hemerdon and Sparkwell. The site location is shown on the plan in Appendix D.

1.2.2. The Site is located in a rural area and includes isolated residential and commercial uses within 500 metres of the site boundaries (see Section 3.1 for a list of sensitive receptors and assessment locations).

1.2.3. The topography in the area is undulating with the site generally being at the highest elevation in comparison to the immediately surrounding areas.

1.3 DESCRIPTION OF HEMERDON MINE OPERATIONS

1.3.1. The Hemerdon Deposit was operational between August 2015 and October 2018 under its previous ownership of Wolf Minerals. As such, much of the mine infrastructure and processing equipment and buildings are in-situ, whilst not currently operational. However, there will also be new buildings and plant in operation upon a permit being issued.

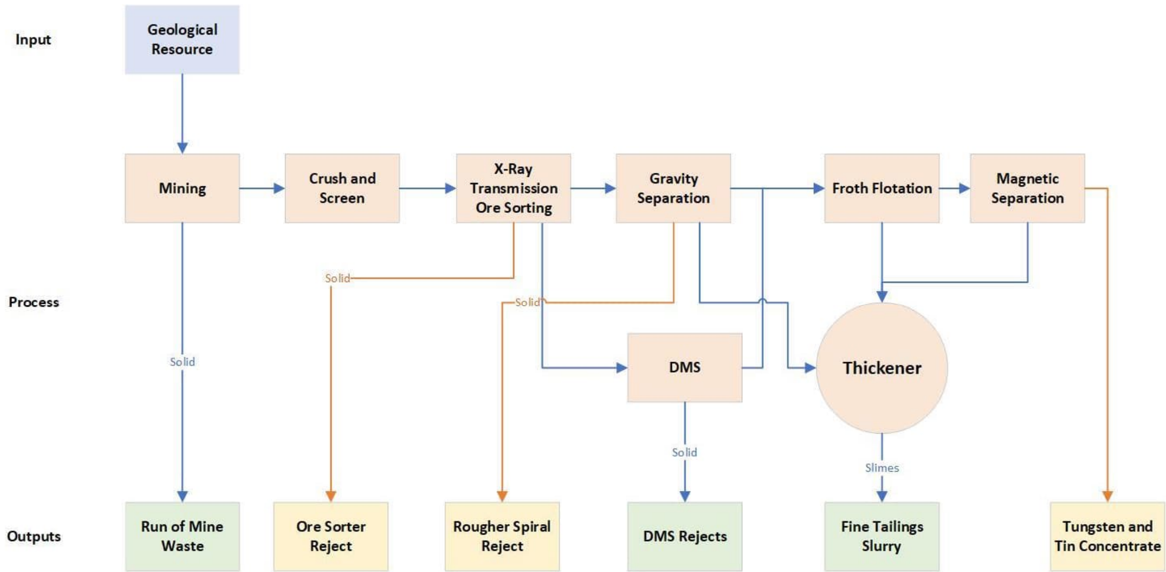
1.3.2. The activities to be undertaken at the site include the following:

- Primary, secondary and tertiary crushing and screening of mineral ore;
- X-ray transmission ore sorting;
- Dense Media Separation (DMS);
- Grinding, fines and floatation separation;
- Concentrate drying;
- Magnetic separation;
- Separation and tin concentrate drying; and
- Mining waste facility, as regulated separately under Environmental Permit reference EPR/JB3209MD.

1.3.3. The facility will produce non-ferrous mineral concentrates to be exported overseas for processing into non-ferrous metals.

1.3.4. The process flow is shown in a simplified image in Figure 1-1 below.

Figure 1-1 - Process Flow (Simplified)



MINERAL PROCESSING FACILITY (MPF)

1.3.5. The plan in Appendix E shows a simplified layout of the processing plant area including existing and new buildings/areas.

1.3.6. Under the previous operator, screening was concentrated within the Mineral Processing Facility primarily within Area 120 – Washing and Screening; and Area 140 – Dense Media Separation. As a result of the Project Trident work, and decommissioning of the old Area 110 – Primary and Secondary rolls, and replacement of this with a semi-mobile primary jaw and secondary cone crushing circuit, provisions and locations for mineral sizing screening have changed.

1.3.7. The primary change in screening infrastructure has occurred through the decommissioning of Area 120 within the Mineral Processing Facility and introduction of X-ray transmission (XRT) ore-sorting. Screening for the preparation of ore-sorting and tertiary crushing requires the addition of eight new screens, seven of which will be located in new buildings within Areas 125 – Ore Sorting and Area 130 – Tertiary Crushing. The introduction of these new screens will be at the expense of the two previously operated screens in Area 120 – The Scrubber and Product Screens.

1.3.8. As a result of the reduced throughputs from the introduction of XRT ore sorting, four screens in Area 140 will not be required for the startup of operations, and all other screens will see reduced throughput rates from previous operations. The outcome of the above has resulted in a total screening area of 120.2 m^2 compared to 172.08 m^2 under the previous operator.

1.3.9. The main activities to be undertaken at the MPF comprise:

- Primary, secondary and tertiary crushing and screening of mineral ore; and
- Processing of mineral ore to produce non-ferrous mineral concentrates.

1.3.10. The MPF will comprise a 20 unit operation. This includes seven unchanged unit operations from the previous development under Wolf Minerals, eight unchanged unit operations but with reduced duty and five new unit operations. A summary of the revised operations is provided below.

Primary and Secondary Crushing

1.3.11. The existing primary and secondary hybrid roll crushers will not be capable of crushing hard Hemerdon ore and will be replaced with a new mobile jaw crusher, complete with a pre-screen and a secondary cone crusher in closed circuit with a screen. Cone crushers are not a significant source of low frequency noise.

1.3.12. The primary jaw crusher will be mounted on a wheeled frame and include a screen to filter out ore that is the correct size for secondary crushing. This screen is a static (non vibratory) screen and is not a source of LFN. The oversized ore will be crushed through Metso Outotec's Nordberg C130 jaw crusher located in Area 115. The secondary cone crusher shall be a Metso Outotec's Nordberg GP300s, also in Area 115.

Ore Sorting

1.3.13. The ore sorting infrastructure will be installed to the northeast of the existing Area 130 building in the new Area 125.

1.3.14. The ore sorter sizing screen will be fed via conveyor and consist of a double deck screen inside a standalone cladded building. The screen will be conducted wet, with pebble and cobble being conveyed to two separate storage hoppers. Ore of less than 10 mm will be pumped to the tertiary crusher dewatering screen.

1.3.15. From each hopper two conveyors will draw material to a dewatering screen ahead of the four ore sorters. A sump pump will pump the underflow from the dewatering screens back to the tertiary dewatering screen.

Tertiary Crushing

1.3.16. The tertiary dewatering screen will be housed in a cladded building on the north-eastern side of the tertiary crusher building in Area 130A.

1.3.17. Material larger than 8 mm will be conveyed using the existing 130-CV-05 screen to the tertiary sizing screen. On this screen material less than 8 mm will be removed and a short shuttle conveyor will place it on to the existing extended 140-CV-06 screen. It will be conveyed via 140-CV-07 to the DMS feed bin (140-BN-01). The screen oversize will be conveyed by the existing 130-CV-04 to the pre-existing tertiary crushers (2 x Sandvik CH 440) in a close circuit configuration.

1.3.18. Table 1-2 below includes a list of the main LFN sources associated with the previous Wolf Mineral operation, noting which are remaining (included in red) and including new screens procured by DRL. Those noted as remaining operational under DRL and those noted as new screens/plant are all of the LFN sources considered in this assessment.

Table 1-2 – Plant Schedule

Screen Detail	Comments	Location
120-SN-01 scrubber screen	Formerly Wolf Minerals: not required for DRL operation	N/A
120-SN-02 product screen	Formerly Wolf Minerals: not required for DRL operation	N/A
140-SN-01 DMS feed prep screen	Formerly Wolf Minerals: will remain in operation under DRL	Area 140 (DMS) - Existing processing plant building
140-SN-02 primary sinks screen	Formerly Wolf Minerals: not required for DRL operation	N/A
140-SN-03 primary sinks screen	Formerly Wolf Minerals: not required for DRL operation	N/A
140-SN-04 primary floats screen	Formerly Wolf Minerals: not required for DRL operation	N/A
140-SN-05 primary floats screen	Formerly Wolf Minerals: not required for DRL operation	N/A
140-SN-06 secondary DMS screen	Formerly Wolf Minerals: will remain in operation under DRL	Within Area 150 (DMS) - Existing processing plant building
140-SN-07 scavenger DMS screen	Formerly Wolf Minerals: will remain in operation under DRL	Within Area 150 (DMS) - Existing processing plant building
150-SN-01 primary mill sizing screen	Formerly Wolf Minerals: will remain in operation under DRL	Area 150 (Primary Milling) - Existing processing plant building
115-SN-02 Secondary Crushing Scalping Screen	New screen	Area 115 – Primary / Secondary Crushing
125-SN-11 Ore Sorter Sizing Screen	New screen	Area 125A – Ore Sorter Sizing - New Building
125-SN-01 Pebble Ore Sorter 1 Dewatering Screen	New screen	Area 125B – New Building - Ore Sorting
125-SN-02 Pebble Ore Sorter 2 Dewatering Screen	New screen	Area 125B – New Building - Ore Sorting
125-SN-03 Cobble Ore Sorter 1 Dewatering Screen	New screen	Area 125B – New Building - Ore Sorting
125-SN-04 Cobble Ore Sorter 2 Dewatering Screen	New screen	Area 125B – New Building - Ore Sorting

130-SN-12 Tertiary Crusher Sizing Screen	New screen	Area 130B – New Building
130-SN-13 Tertiary Crusher Dewatering Screen	New screen	Area 130A – New Building
Jaw crusher	New plant	Area 115 – Primary / Secondary Crushing

1.4 SITE HISTORY

1.4.1. The site previously held an Environmental Permit for the MPF (EA reference: EPR/GP3531EX), granted in 2014 to Wolf Minerals.

1.4.2. There is an established history of LFN issues at the site from its operation under Wolf Minerals. Both the EA and Wolf Minerals have investigated these issues and complaints from the public, with further detail provided below.

PREVIOUS EA REPORT 2017

1.4.3. The EA produced a report in 2017 titled *"Low Frequency Noise Assessment: Drakelands Mine"* providing the detail of three LFN investigations it had undertaken.

1.4.4. The report shows that LFN from the mine is predominantly seen in the 16 Hz 1/3 octave band and is generated by the screens (referred to in the EA report as "shaker tables"). Noise at 50 Hz is also considered to be attributable to the mine. The 16 Hz levels were found to be below the LFN criteria in NANR45[3] whilst the criteria were exceeded in the 50 Hz 1/3 octave band. The EA investigated LFN at three locations and gained a detailed understanding of how the LFN was impacting on the occupants of these properties and their accounts were found to be consistent.

1.4.5. Whilst the EA report acknowledged that Wolf Minerals had "impressive plans for controlling noise from the shaker tables" they were not implemented when the pollution was observed and were, therefore, not considered further by the EA.

1.4.6. Using both the measured noise levels and information on how occupants of nearby properties were being impacted by the LFN, the EA concluded that noise from the site should be classified as a "significant pollution".

PREVIOUS WOLF REPORTS

Noise Management Plan

1.4.7. Wolf Minerals produced the report *Noise and Vibration Management Plan*, dated January 2018. The Noise Management Plan (NMP) was influenced by a number of acoustics industry experts to assist

[3] Moorhouse, A; Waddington, D and Adams, M: *Procedure for the Assessment of Low Frequency Noise Complaints*. Defra Report NANR45 (2005)

Wolf Minerals in completing LFN studies to progress their knowledge and understanding of LFN sources on the site and the effects of LFN transmission.

1.4.8. Noise Reduction Targets were derived based on available guidance and consideration of Best Available techniques (BAT). Mitigation options were explored, and contingency measures identified, should the expected noise reduction not be achieved in practice.

1.4.9. The NMP concluded with a commitment to implement a cladding system to existing buildings.

Options Evaluation Process

1.4.10. The report titled *Low Frequency Noise Options Evaluation Process*, dated January 2018 took 32 conceptual mitigation options through various screening and evaluation stages. This resulted in a shortlist of four options with the retrofitting cladding to the existing buildings being ranked highest.

1.4.11. A review of the 32 conceptual mitigation options is presented in the Options Appraisal report submitted with the current application.

COMPLAINT HISTORY LOG

1.4.12. Both Devon County Council and South Hams District Council have confirmed that they have received no LFN complaints over the past 12 months. At the time of writing, it is our understanding that no other complaints relating to noise with a significant low frequency component have been received.

2 ASSESSMENT METHODOLOGY

2.1 INTRODUCTION

2.1.1. The noise impact assessment approach has been one of using existing and new information and approaches. The existing information refers to studies undertaken when the site was operated by Wolf Minerals, including those detailed in reports listed in Section 1.4. New information relates to studies undertaken specifically for this noise impact assessment (and to inform the NMP submitted with the application) which generally furthers the knowledge gained from Wolf Minerals' operations and/or address any additional issues raised in the Schedule 5 notice.

2.1.2. The assessment methodology is informed by the Scope, as set out in Section 1.1.

2.1.3. This section provides the following:

- relevant policy, guidance, technical standards and research used to inform the assessment;
- the approach to the noise surveys and low frequency noise trials;
- the noise prediction methodology; and
- consultation and meetings with the EA.

2.2 POLICY, GUIDANCE, STANDARDS AND RESEARCH

2.2.1. The following policy, guidance, standards and research are considered potentially relevant to this noise impact assessment. Some are listed below although ultimately discounted and these considerations are included for completeness.

2.2.2. There are very few British Standards and guidance documents which are directly applicable to LFN and so many research papers have been referenced in this assessment.

LEGISLATION AND POLICY

2.2.3. Whist the assessment doesn't specifically mention the following legislation and policy, they underpin the approach to the noise assessment and are included for completeness.

- Environmental Protection Act (1990)[4];
- National Planning Policy Framework (NPPF) (2021)[5];
- Noise Policy Statement for England (NPSE) (2010)[6];

[4] UK Government (1990). Environmental Protection Act.
[5] UK Government (2012). Available at: National Planning Policy Framework - GOV.UK (www.gov.uk)
[6] Department for Environment, Food and Rural Affairs (DERA) (2010). Noise Policy Statement for England (NPSE), 2010

GUIDANCE

2.2.4. The EA's Noise and vibration management: Environmental permits (2022)[7] is relevant to this NIA. It is a web-based resource and the guidance provided includes:

- how the EA will assess noise from certain industrial processes;
- what the law says you must do to manage noise and vibration; and
- advice on how to manage noise – in particular, how to carry out a noise impact assessment and what operators should include in a noise management plan.

TECHNICAL STANDARDS

2.2.5. The following technical standards have been considered.

- BS 4142: 2014+A1:2019: Methods for rating and assessing industrial and commercial sound (2019)[8]
  Whilst BS 4142 doesn't state the frequency range over which it is considered valid, it does reference the ISO 9613-2[9] calculation methodology which is valid between 63 Hz and 16 kHz. BS 4142 states in Section 1 *Scope* that "The standard is not applicable to the assessment of low frequency noise". For this reason, it has not been further referenced in this assessment.
- BS 4142: 2014+A1:2019: Technical Note (2020)[10];
  The Association of Noise Consultants (ANC) Technical Note was prepared by a working group of seven industry experts with the Note being considered a "discussion document" and not a prescriptive guide. The Note states the following (inter alia) with reference to low frequency noise in Section 1 *Scope*:

  > *"BS 4142 states 'The Standard is not applicable to the assessment of low frequency noise' (Subclause 1.3) and NANR45 is referenced in this connection. Sound referred to as low frequency in NANR45 is energy within the 10 – 160 Hz frequency range. The WG [Working Group] considered that BS 4142 does not necessarily exclude such a wide range. It would be reasonable to use BS 4142 down to 50 Hz and possibly lower as part of a tonality assessment, for example.*
  > *In connection with this:*
  > - *It would generally be inappropriate to remove low frequency content from data sets;*
  > - *Where low frequency noise is the dominant component of the specific sound source, the applicability of BS 4142 should be carefully considered and justified if necessary;*
  > - *BS 4142 should not be used, even if an assessment is requested, for example by a regulator or client, in a situation that is considered to be inappropriate."*

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[7] Environment Agency (EA) (2022). Noise and vibration management: environmental permits Available at: https://www.gov.uk/government/publications/noise-and-vibration-management-environmental-permits/noise-and-vibration-management-environmental-permits
[8] British Standards Institute (2019). Methods for rating and assessing industrial and commercial sound (BS 4142:2014+A1:2019)
[9] International Organization for Standardization (1996). Acoustics – Attenuation of Sound During Propagation Outdoors (ISO 9613:1996)
[10] BS 4142: 2014+A1:2019 Technical Note Version 1.0 (March 2020)

Whilst the Technical Note to BS 4142 suggests that the Standard could be used for the assessment of LFN, it is considered inappropriate. This is because the frequencies which are of most interest are 12.5 Hz and 16 Hz as these are the operational frequencies / running speeds of the plant generating the LFN (see Section 5 for further details). The harmonics are also of interest. However, Section 6 shows how harmonics are not particularly evident at receptor locations. The application of BS 4142 would, therefore, need to apply to specific frequencies and it is deemed outside of its scope. Furthermore, the EA has not signposted it as a relevant Standard for the assessment of LFN and it is for these reasons that it is not considered further.

RESEARCH PAPERS

2.2.6. As noted above, research papers have been referenced extensively. They have been used in various aspects of the noise modelling and noise assessment. Generally, where they have been referenced, it has been part of a "mini-project" to develop a better understanding of a technical issues and, therefore, provide a more robust response to the Schedule 5.

2.2.7. The main areas of this assessment which have referenced research papers are:

- LFN propagation and meteorological effects;
- LFN propagation and topographical effects; and
- LFN and building amplification.

2.2.8. For example, the Schedule 5 notice requires an assessment of building amplification due to LFN, or a justification for excluding it. This can only be robustly addressed by undertaking a review of existing research. In these instances, the mini-project has been provided in an appendix to this report which details the various research papers it draws on.

2.2.9. For the reasons above, there are too many research papers to list here. However, all papers used in this assessment are referenced at the appropriate point, be that in the main body of the report or an appendix.

GUIDANCE DOCUMENTS NOT REFERENCED

2.2.10. Previous Noise Impact Assessments undertaken for the Hemerdon site, including those conducted by Wolf Minerals as the previous operator, made reference to LFN acceptability criteria set out in various documents, including NANR45 (*Moorhouse et al: Proposed Criteria for the Assessment of Low Frequency Noise Disturbance, Salford University, 1997*), ASHREA (*Noise and Vibration Control, in ASHREA Handbook, 2015*) and Broner (*A Simple Criterion for Low Frequency Noise Emissions Assessment, J. Low Frequency Noise, Vibration and Active Control, 2010*). Following consultation with the EA, DRL has decided not to align with the prescriptive criteria set out in these documents and they are not considered further.

2.3 NOISE SURVEY APPROACH

2.3.1. The noise survey was undertaken in the form of an LFN trial to test the effectiveness of an acoustic enclosure in mitigating the noise levels at the fundamental frequency and second harmonic. The purpose of the trials was to quantify the reduction in noise levels such that an acoustic enclosure can be considered a proven mitigation for LFN, rather than just a concept.

2.3.2. The trial was at Hemerdon mine and there were various monitoring locations in close proximity to the trial area (the "nearfield measurement"). Simultaneous measurements were undertaken at off-site locations (the noise-sensitive receptors – see Section 3) and these are the 'far field' monitoring locations.

2.3.3. The full details of the LFN trial, including the measurement methodology and the monitoring results, are included in Section 5.

2.4 NOISE PREDICTION METHODOLOGY

2.4.1. Conventional noise models (such as CadnaA and SoundPlan) implement the ISO 9613 prediction methodology which is valid for the frequency range 63 Hz to 16 kHz. Whilst this methodology overlaps in part with the EA's definition of LFN (that being from 10 Hz to 160 Hz), it has been established that the LFN generating plant operate at a natural frequency of 12.5 Hz and 16 Hz (with the second harmonics being 37.5 Hz and 48 Hz respectively). The ISO 9613 prediction methodology and, therefore, conventional software has been discounted as it is not valid at the frequencies of interest.

2.4.2. Instead, a wave equation model has been utilised. This model has been configured as follows:

- Source characterisation is based on the 'characteristic pressure', $p_{sc}(t)$, defined as the sound pressure that would be experienced at 1m from a point source. The derivation of the source strength takes into account the measurement data obtained from the on site mitigation trials.
- The effects of atmospheric absorption are negligible and are excluded for the sound prediction model.
- Ground attenuation effects will be negligible under any meteorological conditions where there is a wind or temperature gradient (changing with height in the atmosphere). As such, ground attenuation effects are excluded from the prediction model.
- Similarly, any barrier or screening effects due to the intervening terrain will be negated by wind and temperature gradients and, as a worst case, are excluded from the model.
- Other meteorological effects such as sound focussing will occur under certain weather conditions, but when such conditions prevail, the effects could be significant. This is considered within the uncertainties in the prediction model. Quantification of these uncertainties requires further research. Calculations are undertaken for the situation with neutral meteorological conditions.

2.4.3. Justification of the assumptions used for the sound propagation model, with reference to the relevant research, is presented in Appendix L.

2.4.4. The adopted sound prediction model is a time domain model capable of predicting the sound pressure level with the values being displayed as noise contours or at selected receptor locations. Further details of the noise model setting and assumptions are provided in Section 6 Noise Prediction Model.

2.5 CONSULTATION WITH THE ENVIRONMENT AGENCY

2.5.1. Various consultation meetings/calls have been held with the EA since the Schedule 5 notice was issued. These meetings have been essential in understanding concerns the EA has with respect to LFN and for DRL to keep the EA abreast of progress.

2.5.2. These are in addition to fortnightly calls between DRL and the EA which were arranged with the intention of providing an update on the progress of any permit applications, submissions, or for more general discussions surrounding ongoing compliance obligations at Hemerdon Mine.

2.5.3. The consultation meetings/calls are noted below.

- 4th May 2023: Meeting with DRL and EA representatives and DRL's external project team including WSP, Eatec Dynamics, Pinnacle Acoustics and Shann Pitts Consulting.
  The meeting was held as the initial technically-led consultation with respect to the Schedule 5 notice. Each of the technical issues was addressed in turn such that the detail which informed the Schedule 5 could be fully understood. The details LFN trial were discussed with the EA and an invitation extended to them to witness some of the tests, which was accepted. An overview was also provided by DRL on the differences between the future operation and that of Wolf Minerals.
- 5th July 2023: Meeting with DRL and EA representatives and DRL's external project team including WSP, Eatec Dynamics, Shann Pitts Consulting and Galliford Try
  The meeting was to present and discuss the initial findings of the LFN trial and for the EA to ask any questions, raise concerns and/or suggest any reasonable additional work.
- 2nd August 2023: Meeting with DRL and EA representatives and DRL's external project team including WSP, Eatec Dynamics, and Shann Pitts Consulting.
  The meeting was held to present the results of the LFN trial and the noise modelling results and to confirm the approach to each of the Schedule 5 items prior to submission of the reports to the EA.

3 ASSESSMENT LOCATIONS

3.1 NOISE SENSITIVE RECEPTORS/ASSESSMENT LOCATIONS

3.1.1. The following 18 noise-sensitive receptor locations have been referenced in this assessment. Not all have been used throughout the monitoring and assessment, and this is explained further in Section 5.

3.1.2. The receptor locations are described in Table 3-1 below and shown on the drawing in Appendix F.

Table 3-1 – Nearest Noise Sensitive Receptors

Receptor Reference	Land Use	Compass Direction from the Site	Approximate Distance to Closest Site Boundary (m)	Approximate Distance to the Existing Processing Plant (m)
A: Birchland Farm	Residential	South-east	300	1,100
B: Galva House	Residential	South-west	480	950
C: Newnham House	Residential	South-west	1,000	1,475
D: Boringdon Hall	Hotel and spa	South-west	760	3,000
E: Mumford Cottage	Residential	North-east	820	2,000
F: Portworthy Farmhouse	Residential	North-west	200	1,900
G: Windwhistle Farm	Residential property and hotel	South-west	950	1,400
H: Dartmoor Zoo	Zoo	South-east	320	1,250
I: Wotter	Residential	North-west	1,640	3,245
J: Broadoaks Cottages	Residential	North	990	2,390
K: East of Lee Moor*	Public land	North-east	1,520	2,900
L: Lutton	Residential	East	2,120	2,930
M: Cornwood Inn	Pub and restaurant	East	3,050	3,820
N: Gorah Cottages	Residential	East	1,150	1,950

O: Yondertown	Residential	East	1,680	2,490
P: Road Junction^	Public land	South-west	1,530	2,070
Q: Colebrook**	Public land	South-west	1,150	2,480
R: Elfordleigh Hotel	Hotel	West	1,070	2,340
*Representative of residential receptors in Lee Moor. ^Representative of residential receptors in the area of Highglen Drive ** Representative of residential receptors in the north of Plympton in the area of Elford Crescent				

3.2 DESCRIPTION OF NOISE SENSITIVE RECEPTORS

3.2.1. The noise-sensitive receptors listed above can, for the purpose of describing them, be grouped into the following:

- Receptors to the east and south-east of the processing area, including Cornwood Inn (Receptor M), Lutton (Receptor L), Yondertown (Receptor O), Gorah Cottages (Receptor N) and Dartmoor Zoo (Receptor H) and Birchand Farm (Receptor A).
- Receptors to the south-west and west of the processing area, including Galva House (Receptor B), Windwhistle Farm (Receptor G), road junction (Receptor P), Colebrook (Receptor Q) Boringdon Hall (Receptor D), Elfordleigh Hotel (Receptor R) and Newnham House (Receptor C)
- Receptors to the north-west, north and north-east of the processing area, including Mumford Cottage (receptor E), Portworthy Farmhouse (Receptor F), Wotter (Receptor I), Broadoak Cottages (Receptor J) and East of Lee Moor (Receptor K).

3.2.2. The receptors to the east and south-east are generally visually screened from the mine by intervening topography. With the exception of Dartmoor Zoo, they are rural residential areas.

3.2.3. The receptors to the south and south-west are, with the exception of the road junction, a mix of residential and commercial properties. The mine is at a higher elevation than these receptors. All, except Colebrook are in a rural location.

3.2.4. The receptors to the north-west, north and north-east are generally at a higher elevation than the mine, some with intervening topography which visually screens the mine. With the exception of East of Lee Moor, they are all residential and in a rural setting.

3.2.5. Whist the intervening topography between the site and some of the receptors visually screens the site, there are considered to be no structures or topography in the areas which is capable of screening LFN from the mine at the receptors. The lack of screening at low frequencies is addressed in Section 6.

4 EQUIPMENT AND METEOROLOGY

4.1 INTRODUCTION

4.1.1. This section details the equipment used to undertake noise and meteorological measurements.

4.1.2. In summary, noise measurements were undertaken for the purpose of a low frequency noise mitigation trial. The trial was at the Hemerdon mine site and there were various monitoring locations in close proximity to the trial area; these are the 'near field' monitoring locations. Simultaneous measurements were undertaken at off-site locations (the noise-sensitive receptors) and these are the 'far field' monitoring locations. Please refer to Section 5 for the measurement methodology, objectives and the monitoring results.

4.2 NEAR FIELD NOISE MONITORING

4.2.1. The equipment used for the nearfield measurements, as described in Section 5 of the report are detailed in Table 4-1 below.

4.2.2. The equipment was field calibrated at the start and end of each day and also prior to starting measurements for any new LFN trial test scenarios. No significant drift in calibration was noted. The field calibration was undertaken using a handheld calibrator that had been calibrated by a UKAS-accredited laboratory within the preceding 12 months.

Table 4-1 - Details of Noise Monitoring Equipment – Near Field Positions

Equipment Description	Manufacturer & Type No.	Serial No.
Near field microphone 1	ACO Pacific 7052E	61075
Near field microphone 2	Bruel & Kjaer 4189	2670727
Near field microphone 3	ACO Pacific 7052E	60604
Near field microphone 4	PCB 4260E01	163421
Near field microphone 5	PCB 4260E01	163452
Near field microphone 6	PCB 4260E01	310658
Near field microphone – above screen	PCB 4260E01	41432
Nearfield microphone calibrator	Bruel & Kjaer 4231	2136424
Screen accelerometer	Endevco 7254-100	AE46
Accelerometer calibrator	IMI 699A02	977
Data acquisition system	National Instruments using 9234 modules in a cDAQ 9189 chassis	

4.3 FAR FIELD NOISE MONITORING

4.3.1. The noise monitoring equipment used for the far field measurements is shown in Table 4-2 below. The meters were field calibrated at the start of the measurement and weekly thereafter with no significant drift in calibration noted. The three meters had been calibrated in a UKAS-accredited laboratory within the preceding two years and the associated calibrators within the preceding year. The monitoring locations are shown on a plan in Appendix G and the calibration certificates are included in Appendix H.

Table 4-2 - Details of Noise Monitoring Equipment – Far Field Positions

Monitoring Position	Equipment Description	Manufacturer & Type No.	Serial No.
LT1 Portworthy	Sound Level Meter	01dB-Stell Duo Datalogging Integrating Sound Level Meter	10616
	Pre-amplifier	01dB-Stell PRE 22 Preamplifier	10180
	Microphone	G.R.A.S Type 40CD Condenser Microphone	154423
	Calibrator	01dB Cal 21	34924053
LT2 Dartmoor Zoo	Sound Level Meter	01 dB CUBE Integrating-Averaging Sound Level Meter	10630
	Pre-amplifier	Acoem PRE 22 Preamplifier	10261
	Microphone	G.R.A.S Type 40CD Condenser Microphone	231588
	Calibrator	01dB-Metravib Cal 21	34344461
LT3 Windwhistle Farm	Sound Level Meter	01dB-Stell Duo Datalogging Integrating Sound Level Meter'	10617
	Pre-amplifier	01dB-Stell PRE 22 Preamplifier	10324
	Microphone	G.R.A.S Type 40CD Condenser Microphone	162071
	Calibrator	01dB Cal 21	34924010

4.4 METEOROLOGICAL DATA

4.4.1. The meteorological station was located at Windwhistle Farm alongside the noise monitoring equipment (Position LT3 – see Section 5 for further details). The following meteorological equipment was installed.

Table 4-3 - Details of Meteorological Equipment

Monitoring Position	Equipment Description	Manufacturer & Type No.	Serial No.
LT3 Windwhistle Farm	Meteorological station	Davis Vantage Vue Integrated Sensor Suite and console	MK141008083

4.4.2. The meter was configured to measure the wind speed, wind direction, temperature and rainfall in intervals of 15 minutes.

4.4.3. There is also a weather station at Hemerdon mine for which wind speed, wind direction, temperature and rainfall data were provided over a 13 month period from 1st July 2022 to 31st July 2023.

5 MEASURMENT OBJECTIVES, METHODOLOGY AND RESULTS

5.1 OVERVIEW

5.1.1. Noise measurements were undertaken for the purpose of a low frequency noise mitigation trial and to better understand the background LFN at nearby receptors. The trial was conducted at the Hemerdon mine site and there were various monitoring locations in close proximity to the trial area; these are the 'near field' monitoring locations. Simultaneous measurements were undertaken at off-site locations (the noise-sensitive receptors) and these are the 'far field' monitoring locations.

5.1.2. This section describes the objectives and methodology of the LFN trial and the results. It also presents data at the far field receptors which were gathered over a period of approximately one month which coincided with the LFN trial.

5.2 LFN TRIAL: OBJECTIVES AND METHODOLOGY

5.2.1. Nearfield noise monitoring was undertaken in support of a low frequency noise trial, the objectives and methodology of which are shown in the report in Appendix I titled '*LFN Trial Objectives and Methodology*[11]'. In summary, the trial was to test the effectiveness of enclosures in reducing noise at specific frequencies, these being the fundamental frequency and second harmonic. The trial included a Vibramech screen (130-SN-13 – see Table 1-2 for a description of the screens) operating under various conditions, including within a bespoke acoustic enclosure.

5.2.2. As part of the low frequency noise trial, measurements were undertaken on the site within the enclosure and at six locations immediately surrounding the enclosure, as shown on the plan in Appendix J. The acoustic enclosure was designed to have a number of removeable panels so that different configurations could be tested. The top of the enclosure had a removeable panel to represent the material infeed and the material discharge was configured to have two removeable panels to represent a single or twin deck screen. Photos of the trial scenarios are provided later in this section.

LFN TRIAL SCENARIOS

5.2.3. The LFN trial was conducted over several days (between 12th and 27th June and 13th and 14th July 2023) and the following scenarios were tested:

[11] Note that the trial methodology evolved after producing this report to include only one test enclosure. This is because the enclosure designed was deemed sufficient in reducing noise at both the fundamental frequency and the 2nd harmonic, therefore negating the need to design and manufacture a second enclosure.

- 12th and 13th June 2023: Test of the screen with no enclosure including the following configurations:
  - Screen panels only and no ply cover[12];
  - 1/3 ply cover at the discharge end of the screen;
  - 2/3 ply cover at the discharge end of the screen; and
  - Full ply cover.
- 19th and 20th June 2023: Tests of the screen and enclosure including the following, all undertaken with full ply covering and no material chutes:
  - 19th June 2023: Tests of the screen fully enclosed (See Appendix J for details of the acoustic enclosure)
  - 20th June 2023: Tests of the screen fully enclosed with slots.
- 27th June 2023:
  - Tests of the screen and enclosure with Kingspan cladding (Kingspan 8W KS1000 RW/40+I+L).
  - Test of screens 140-SN-06 and 140-SN-07 in the processing building.
- 13th July 2023: Tests of the screen and enclosure with discharge chute and open area for infeed.
- 14th July 2023: Tests of the following four existing screens in the Process Building with 100% ply cover:
  - Screen: 140-SN-06;
  - Screen: 140-SN-07;
  - Screen: 150-SN-01; and
  - Screen: 140-SN-01.

5.2.4. As mentioned above, the enclosure has three removeable panels, allowing for the LFN testing to be undertaken in the following configurations. Note that not all configurations were used during each of the tests (further explanations in the following sections).

- Fully enclosed – no openings;
- Lower end full width panel removed;
- Lower end and top full width panels removed;
- Lower and upper end and top full width panels removed;
- Fully enclosed with slots;
- One end opening and one top opening (single deck screen); and
- Two end openings and one top opening (twin deck screen).

5.2.5. Measurements were also undertaken at the three far field locations (see Appendix G) during the LFN trial.

[12] Ply wood is used cover the screen in full or part to represent different volumes of material on the deck which will influence the noise level generated by the screen.

5.3 NOISE MEASUREMENTS

NOISE SURVEY RESULTS FOR LFN TRIALS

5.3.1. This section details the noise survey results in the near field and far field from the LFN trials. The various scenarios tested (as listed above) are presented below with near field and far field survey results grouped together for each test scenario to aid comparison.

Unenclosed Screen

Near Field Monitoring Results

5.3.2. The nearfield monitoring results obtained during the LFN trial for the different ply coverings and when the screen was open (i.e. no acoustic enclosure) are shown in Figures 5-1 to 5-3 below for the fundamental frequency, first harmonic and second harmonic respectively. Test 1 and Test 2 were exactly the same and the sound pressure levels (shown in dBZ) are an average of those obtained at the six nearfield microphones.

Figure 5-1 - Open Screen Test Results at the Fundamental Frequency (12.5 Hz), dBZ

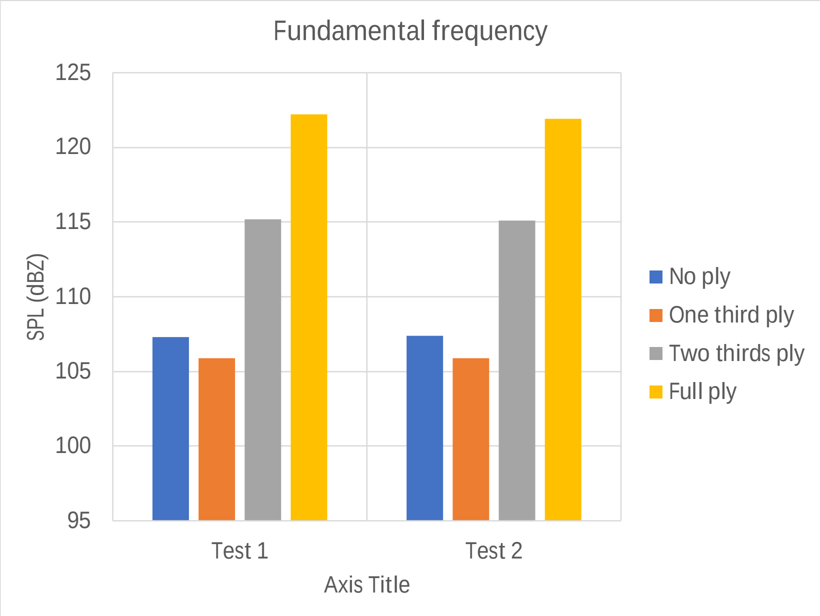


Figure 5-2 - Open Screen Test Results at the First Harmonic (25 Hz), dBZ

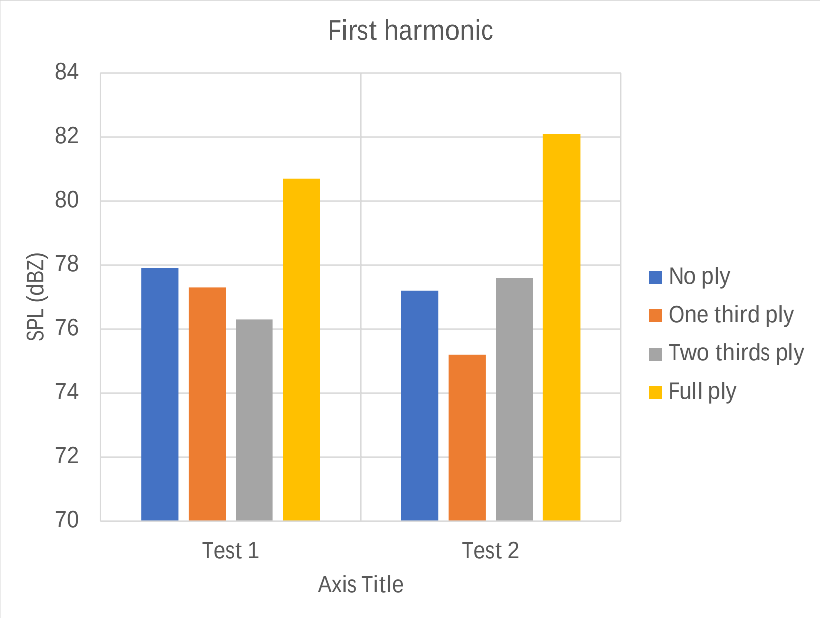
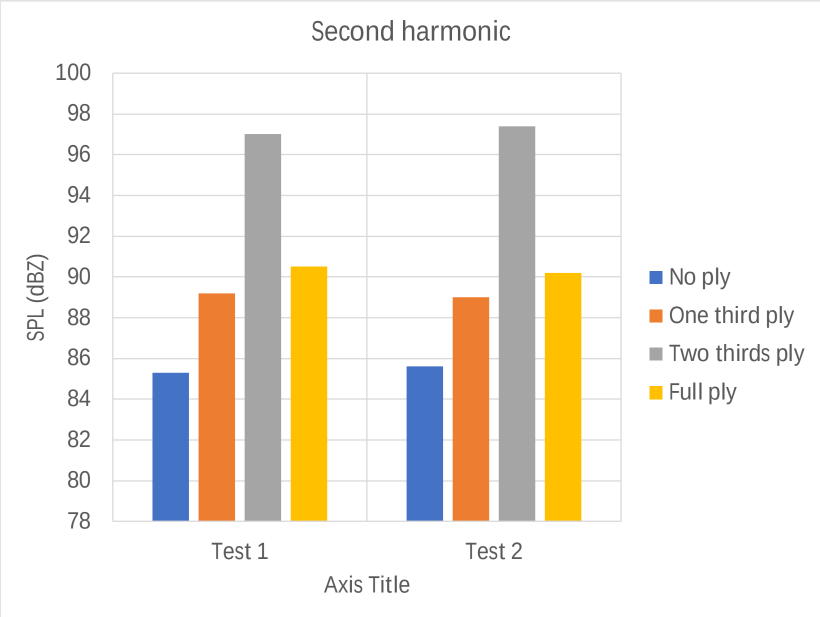


Figure 5-3 - Open Screen Test Results at the Second Harmonic (37.5 Hz), dBZ



5.3.3. The Figures above show a trend of the fundamental frequency producing the highest sound pressure levels, followed by the first and second harmonic, as expected.

5.3.4. The measurements for each of the two tests (Tests 1 and 2) are shown in Figures 5-4 and 5-5 below at the fundamental frequency of the screen (12.5 Hz) to demonstrate the directivity of the unenclosed screen. Good correlation can be seen between the two tests, particularly over the frequency range of interest (10 Hz to 160 Hz).

Figure 5-4 - Test 1 Open Screen Noise Levels at Six Near Field Positions, dBZ

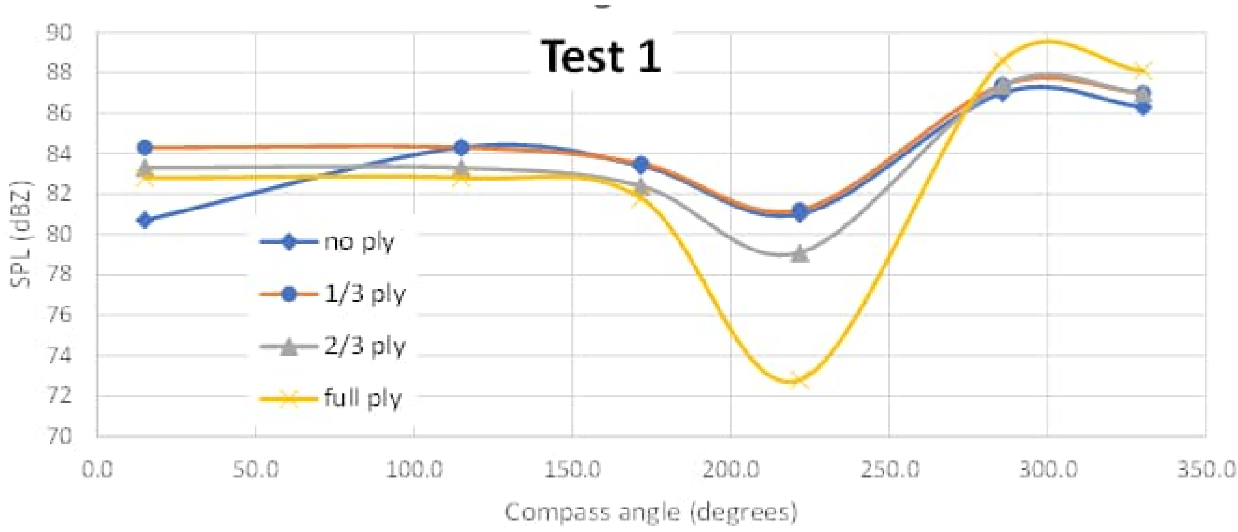
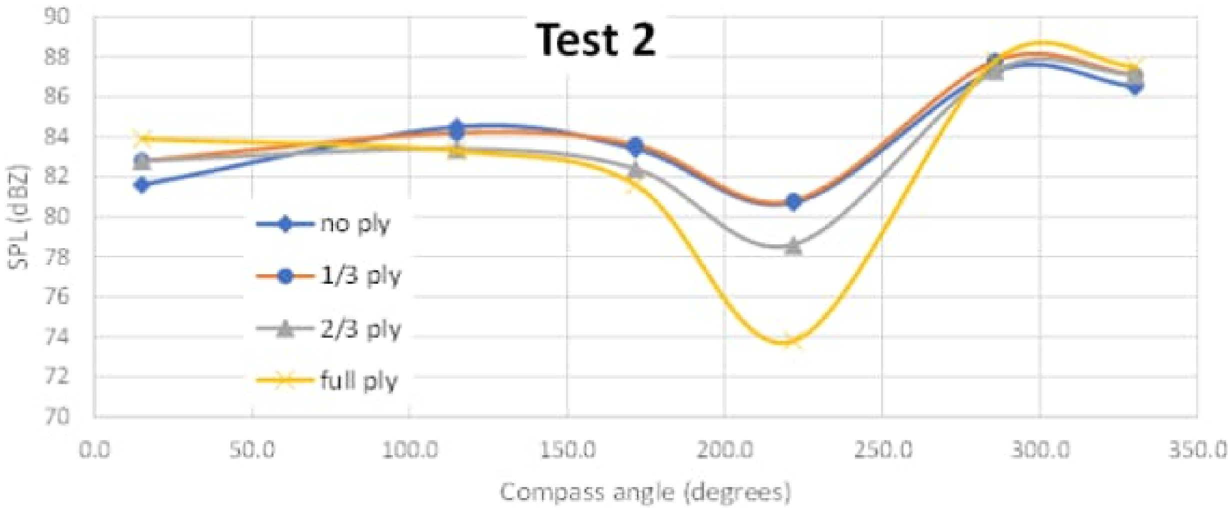


Figure 5-5 - Test 2 Open Screen Noise Levels at Six Near Field Positions, dBZ



5.3.5. The overall sound pressure levels from the unenclosed screen at the fundamental frequency for each of the test scenarios (i.e. the ply covering) is provided in Table 5-1 below.

Table 5-1 – Noise Levels from Unenclosed Screen at the Fundamental Frequency, dBZ

Ply Covering	Test 1 Sound Pressure Level, dBZ	Test 2 Sound Pressure Level, dBZ
No ply	84.4	84.6
1/3 ply	85.1	85.0
2/3 ply	84.6	84.5
Full ply	85.1	84.8

Far Field Monitoring Results

5.3.6. The corresponding test results at Portworthy Farmhouse, Dartmoor Zoo and Windwhistle Farm are shown in the table below (see Appendix G for a plan showing the monitoring locations). The grey cells are where the screen was not noticeable above the background LFN levels.

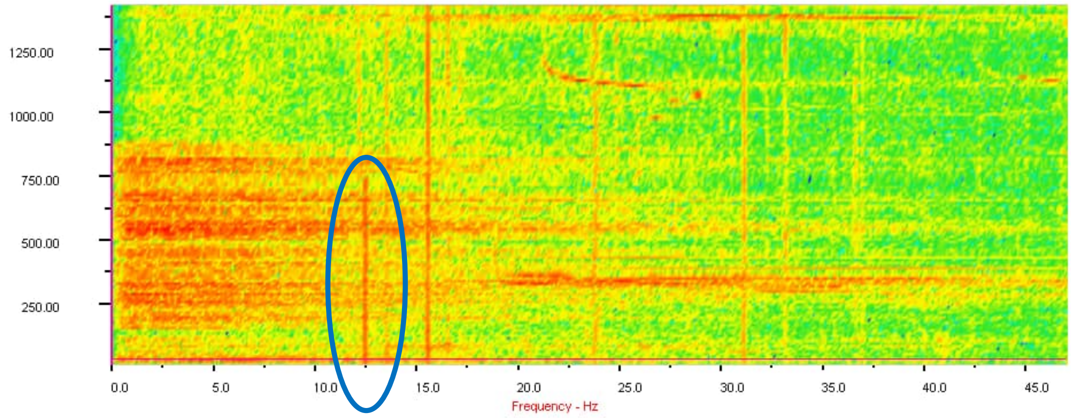
Table 5-2 – Far Field Results for Unenclosed Screen at the Fundamental Frequency, dBZ

		Portworthy Farmhouse		Dartmoor Zoo		Windwhistle Farm	
		Background	Screen	Background	Screen	Background	Screen
Test 1	No ply	41.3	40.7				
	1/3 ply	31.3	41.8				
	2/3 ply	44.2	44.4				
	Full ply	46.4	44.1	25.1	40.7	44.5	37.6
Test 2	No ply					30.3	41.0
	1/3 ply	26.2	44.3			27.9	40.4
	2/3 ply	23.9	44.1			30.7	42.1
	Full ply	33.3	43.1	27.3	40.1	33.2	44.1

Note to Table 5-2: background noise levels were lower during Test 2. This was considered to be due to meteorological effects (rustling leaves / wind)

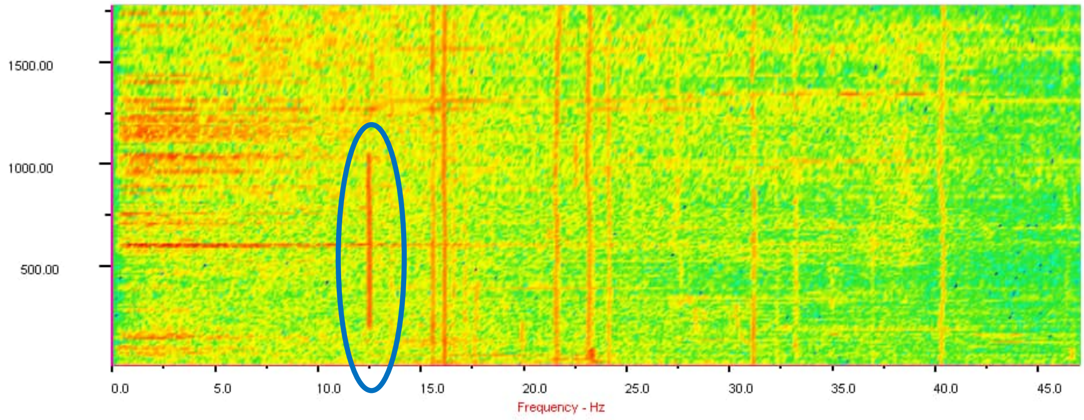
5.3.7. Spectrograms for the full ply test scenario are shown in the three figures below for Portworthy Farmhouse, Dartmoor Zoo and Windwhistle Farm respectively (note the fundamental frequency of the screen is 12.5 Hz).

Figure 5-6 - Unenclosed Screen at Portworthy Farmhouse



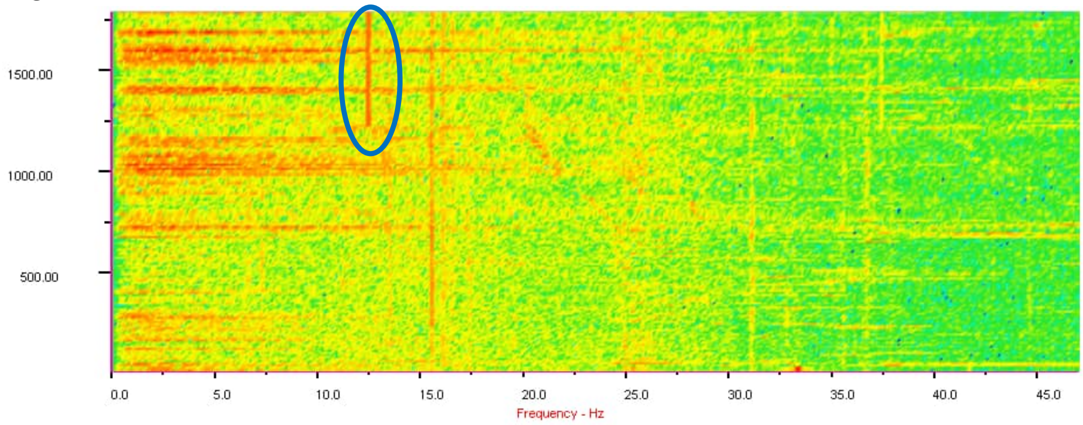
Note: The signal shown within the blue ellipse is the screen at Hemerdon. Other signals relate to unknown sources of background LFN.

Figure 5-7 - Unenclosed Screen at Dartmoor Zoo



Note: The signal shown within the blue ellipse is the screen at Hemerdon. Other signals relate to unknown sources of background LFN.

Figure 5-8 - Unenclosed Screen at Windwhistle Farm



Note: The signal shown within the blue ellipse is the screen at Hemerdon. Other signals relate to unknown sources of background LFN.

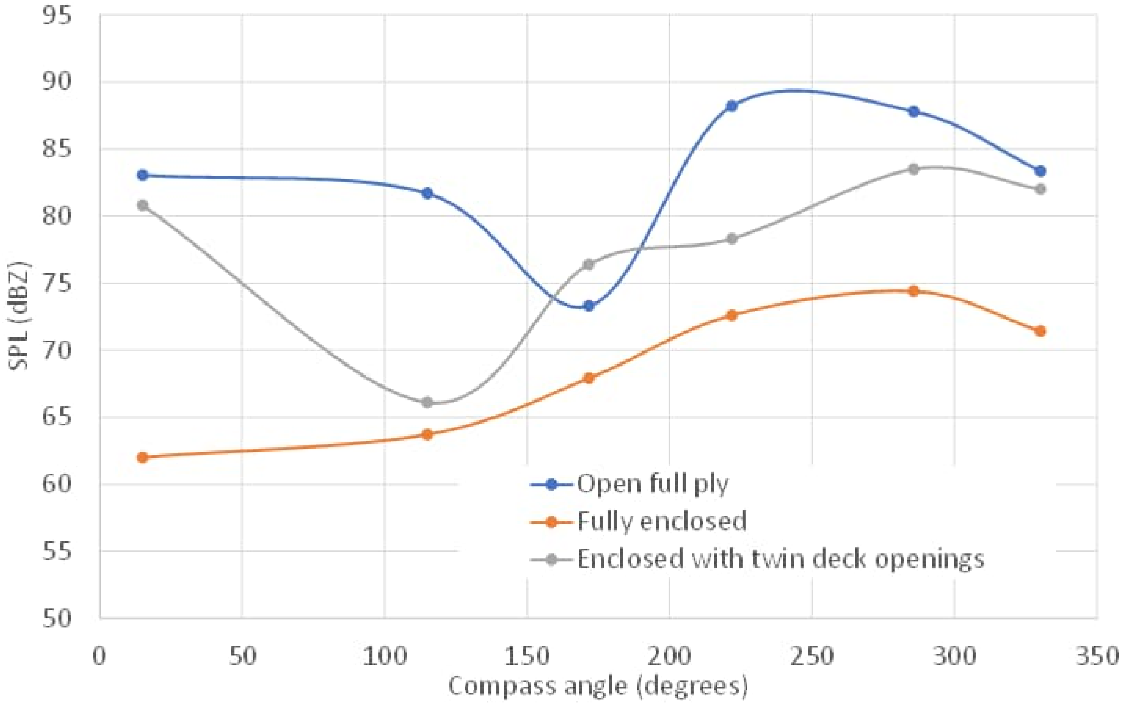
Enclosed Screen

Near Field Monitoring Results

5.3.8. The results for the various test configurations, as detailed in paragraph 5.2.3 are provided below. The test configuration of most interest is when the screen is enclosed with an opening for the infeed and twin deck opening for the discharge; this reflects the scenario most likely to occur in operation.

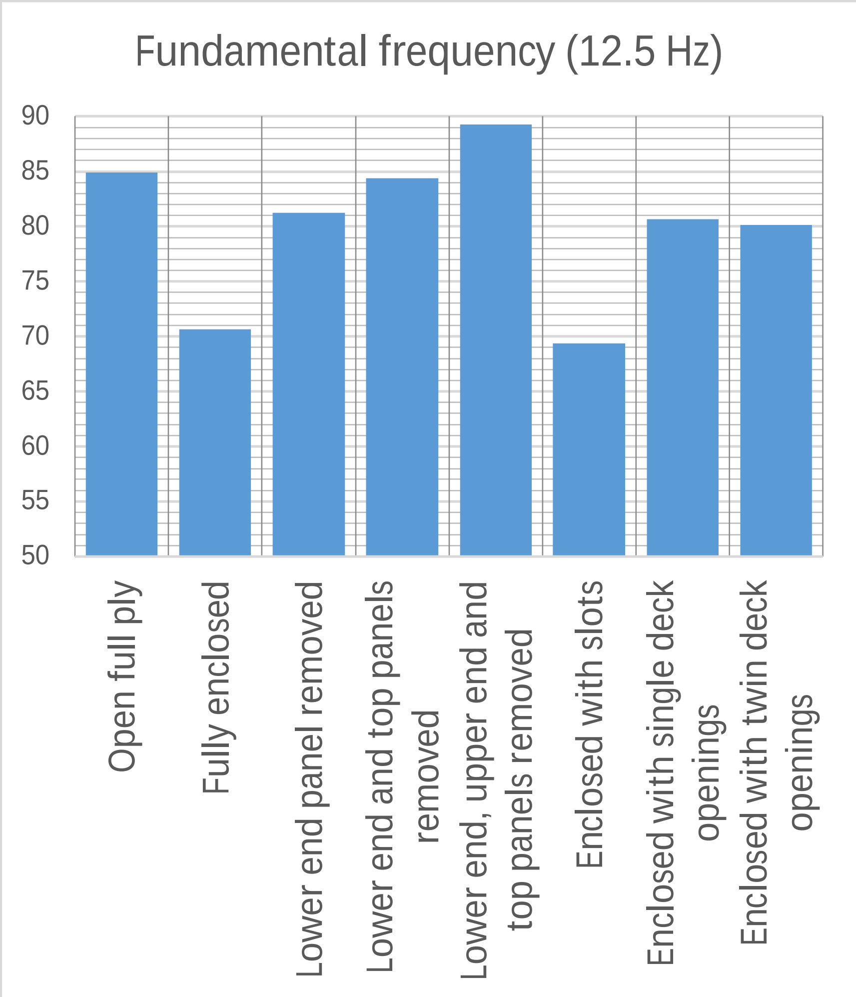
5.3.9. The graph below shows the results at the fundamental frequency for the fully enclosed screen test (with no openings in the enclosure) and for the enclosed screen with an opening for the infeed and twin deck opening for the discharge. For comparison, the results for the unenclosed screen are also shown.

Figure 5-9 - Noise Levels at the Fundamental Frequency for an Open Screen, Fully Enclosed Screen and Enclosed Screen with Infeed and Discharge Openings Scenarios, dBZ



5.3.10. For completeness, the nearfield results for all of the enclosed tests (excluding Kingspan cladding and the discharge chute which are detailed later in this section) are summarised in the graph below. The levels are an average of those obtained at the six near field microphone positions.

Figure 5-10 - Comparison of Test Results at the Fundamental Frequency, dBZ

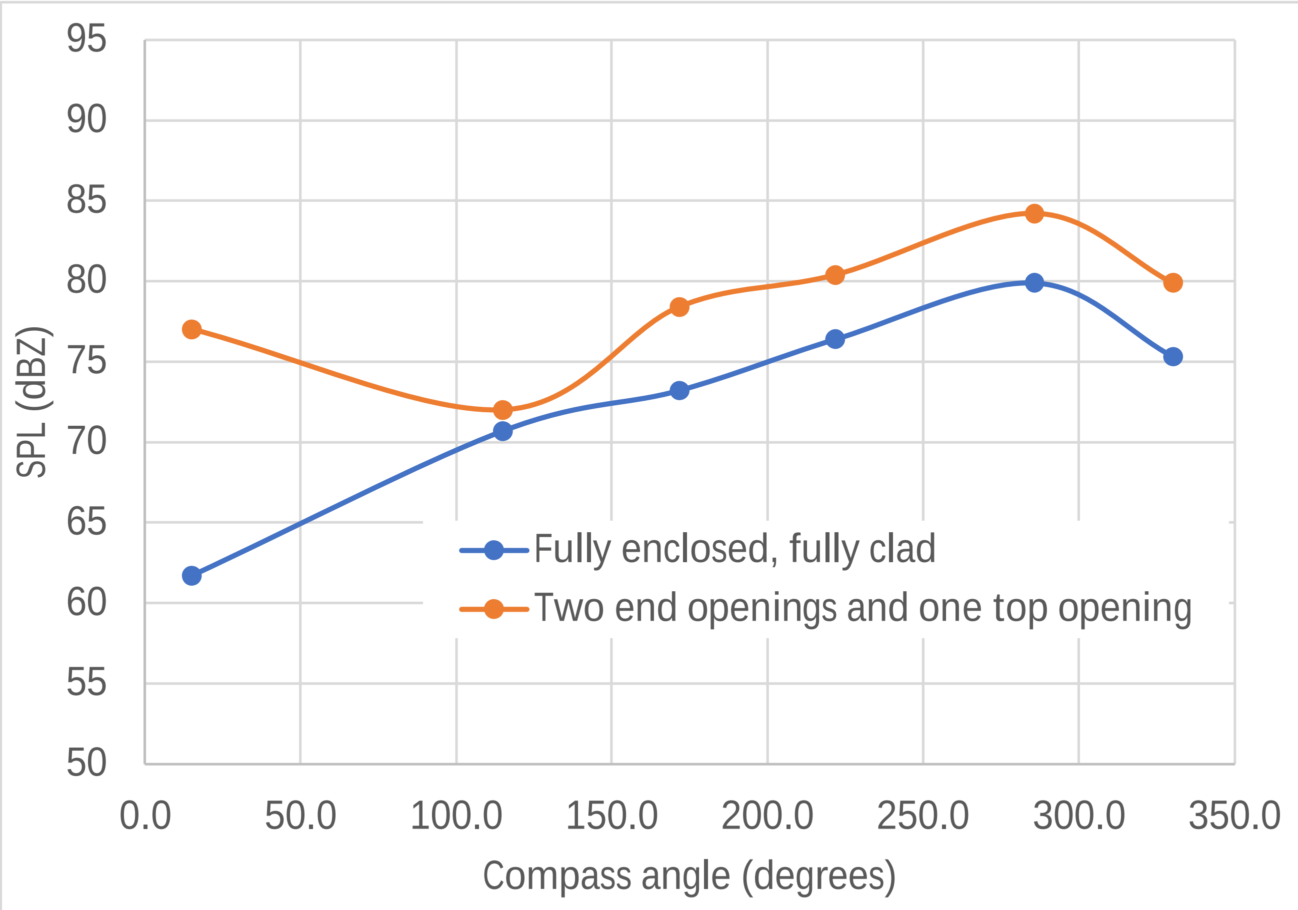


5.3.11. The next tests were with the acoustic enclosure and Kingspan cladding fitted to the external side, as shown in Figure 5-11 below. These tests were arranged with the understanding that there is unlikely to be a reduction in noise levels at the fundamental frequency. However, the Kingspan cladding is a mitigation measure recommended in the audible noise assessment and referenced in Item F of the Schedule 5 and understanding any reduction in LFN is necessary in providing a robust response to the Schedule 5.

Figure 5-11 - Acoustic Enclosure with Kingspan Cladding

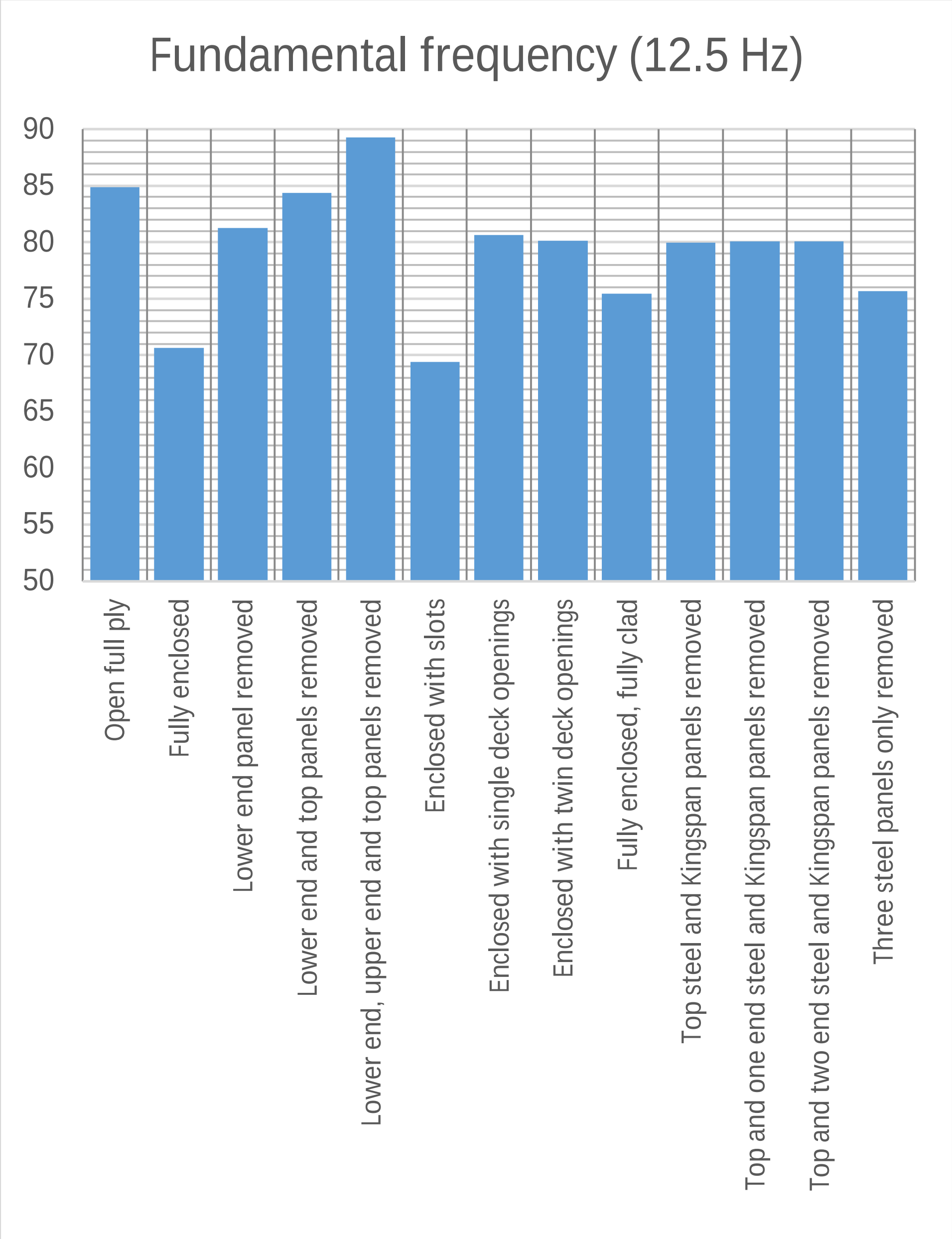
5.3.12. The results of the test with the enclosed screen and the Kingspan cladding are shown in the graph below for the fully enclosed plus cladding scenario and the same scenario plus an open area for the material infeed and discharge. These are shown for the 12.5 Hz fundamental frequency.

Figure 5-12 - Comparison of Noise Levels with Acoustic Enclosure + Kingspan Cladding at 12.5 HZ, dBZ



These results have been added to the graph comparing noise levels at the fundamental frequency for the various test scenarios, as below.

Figure 5-13 - Comparison of Test Results at the Fundamental Frequency, dBZ



5.3.13. During the tests noted above, it was clear that the enclosure scenarios were reducing noise levels at the fundamental frequency by up to approximately 5 dB which is less than the project team had envisaged. This was very likely to be a result of the open areas for the material infeed and discharge which would, in practice, be fitted with a chute.

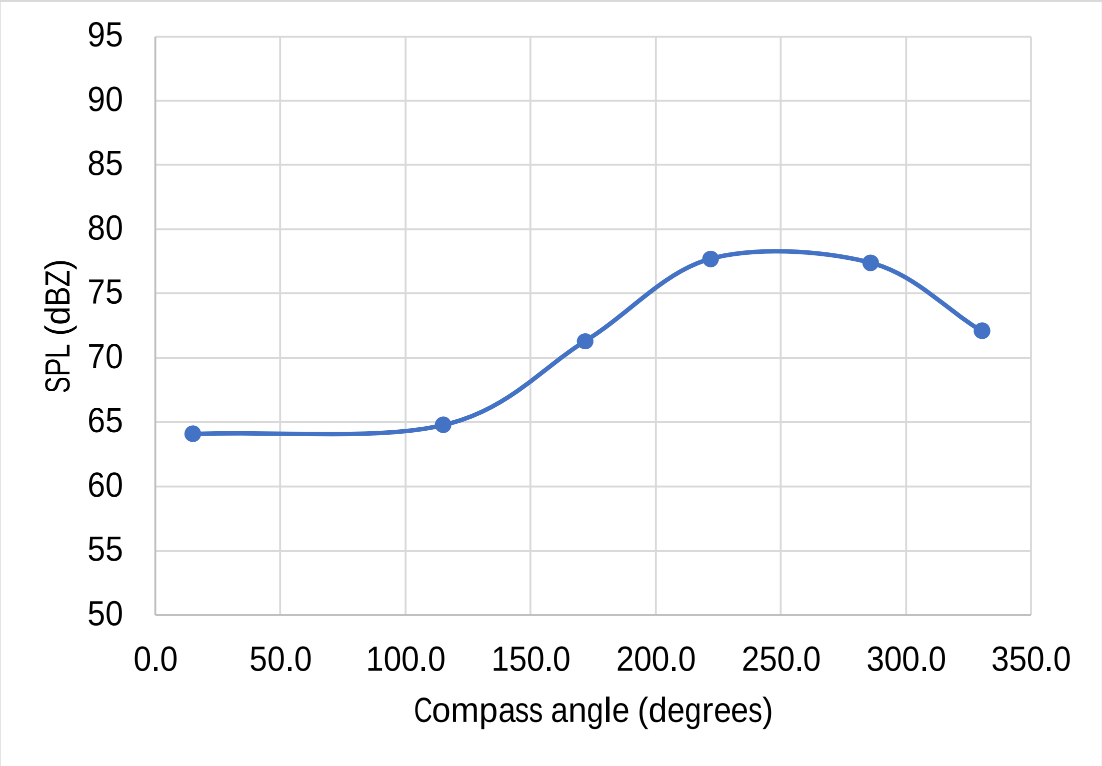
5.3.14. Additional tests were undertaken which included a chute at the material discharge end of the enclosure, as shown in the photo below.

Figure 5-14 - Acoustic Enclosure with Material Discharge Chute

5.3.15. Noise levels were measured using the same microphone configuration in the nearfield (see Appendix J) and at an increased number of far field receptors so that the propagation of the LFN could be investigated further.

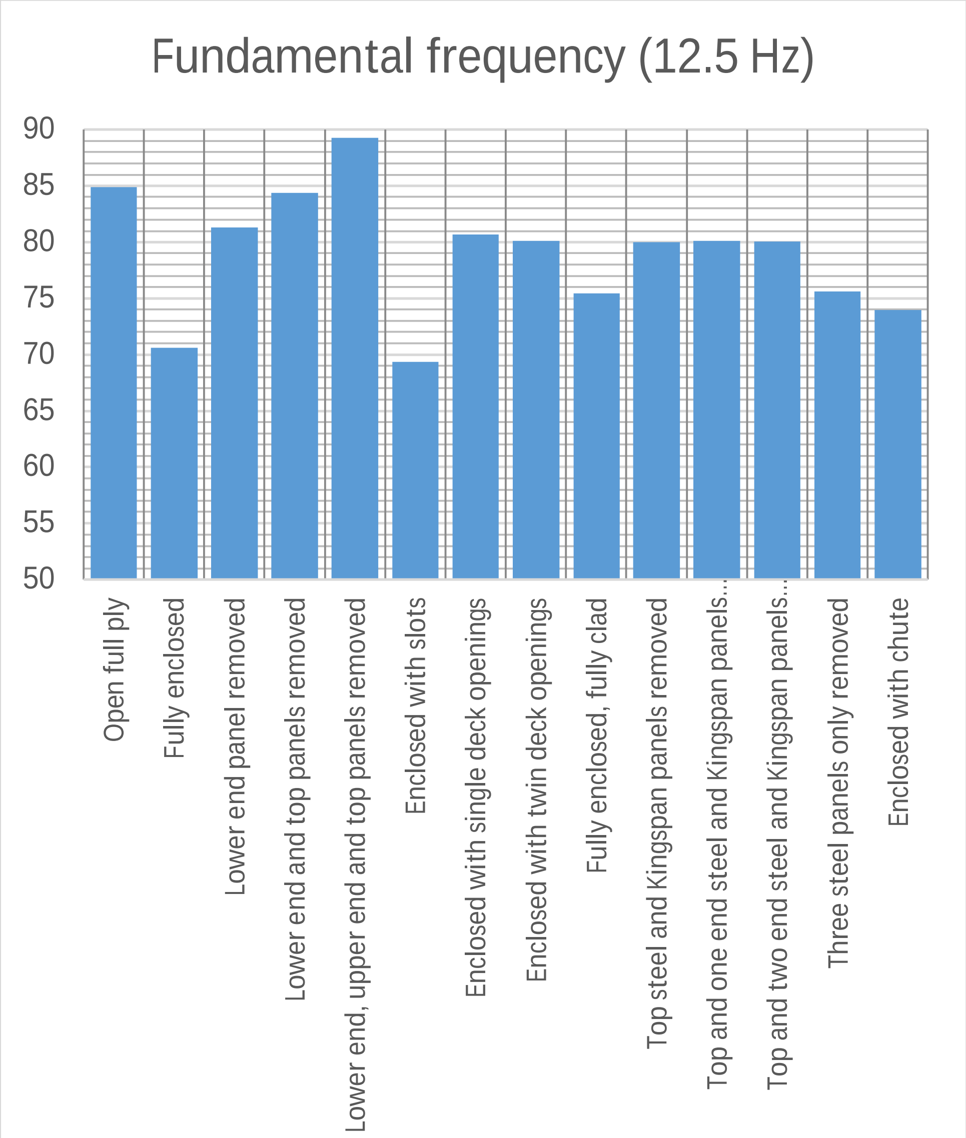
5.3.16. The nearfield noise levels for the acoustic enclosure with a discharge chute (and open area for the material infeed) at the fundamental frequency are shown in the graph below.

Figure 5-15 - Near Field Noise Levels at the Fundamental Frequency with Acosutics Enclsoure and Discharge Chute, dBZ



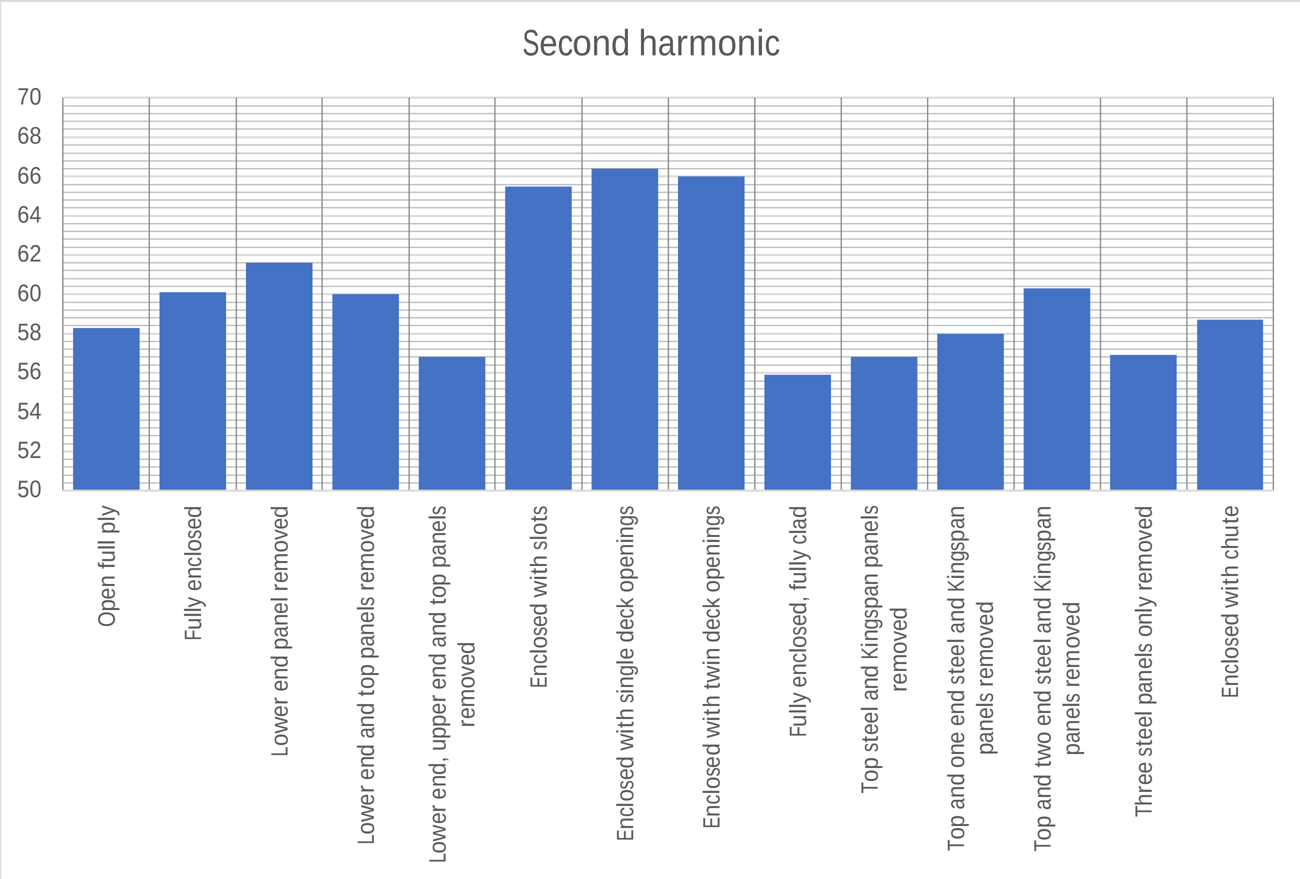
5.3.17. The graph comparing the noise levels at the fundamental frequency for the test scenarios has been updated below to include the enclosure with chute test.

Figure 5-16 - Comparison of Test Results at the Fundamental Frequency, dBZ



5.3.18. Finally for the near field monitoring results, a summary of the noise levels at the second harmonic are shown below for the various test scenarios. In comparison to the graph above, the levels at the second harmonic are far lower than those measured at the fundamental frequency.

Figure 5-17 - Comparison of Test Results at the Second Harmonic, dBZ



<u>Far Field Monitoring Results</u>

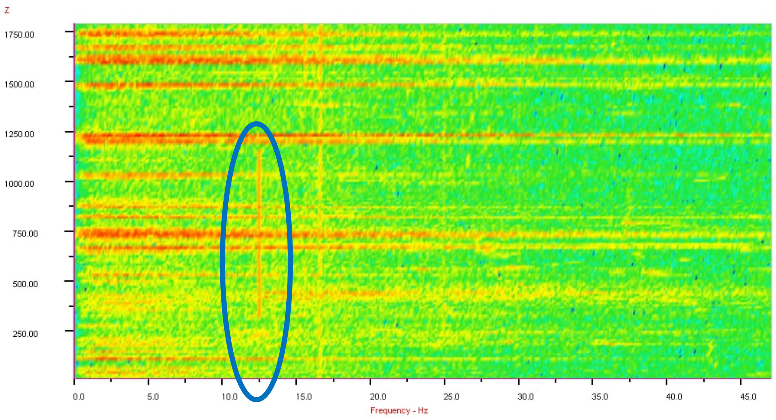
5.3.19. The table below shows the far field narrowband results for the fundamental frequency of 12.5 Hz for the various test scenarios with the influence from the background LFN (i.e. without the screen operating) removed.

Table 5-3 – Sound Pressure Levels at Fundamental Frequency at Far Field Location during Enclosed Test Scenarios (no Cladding), dBZ

Scenario	Date/Time	Portworthy Farmhouse	Dartmoor Zoo	Windwhistle Farm
Open full ply test 1	12/6 13:25	22.4	37.9	40.6
Open full ply test 2	13/6 11:21	43.1	44.0	40.1
Fully enclosed	19/6 11:53	22.0	46.6	34.2
Lower end panel removed	19/6 12:36	37.7	38.2	39.5
Lower end and top panels removed	19/6 13:10	47.0	39.6	41.4
Lower and upper end and top panels removed	19/6 14:11	50.1	50.5	42.6
Enclosed with slots	20/6 13:37	28.7	39.7	32.9
Enclosed with single deck openings	20/6 14:26	40.1	41.1	26.5
Enclosed with twin deck openings	20/6 15:05	39.2	39.5	31.8

5.3.20. The following spectrograms are for the enclosed screen with twin deck openings. The screen is visible at its fundamental frequency at Portworthy Farmhouse and just visible at Windwhistle Farm.

Figure 5-18 - Portworthy Farmhouse Enclosed Screen with Twin Deck Openings



Note: The signal shown within the blue ellipse is the screen at Hemerdon. Other signals relate to unknown sources of background LFN.

Figure 5-19 - Dartmoor Zoo Enclosed Screen with Twin Deck Openings

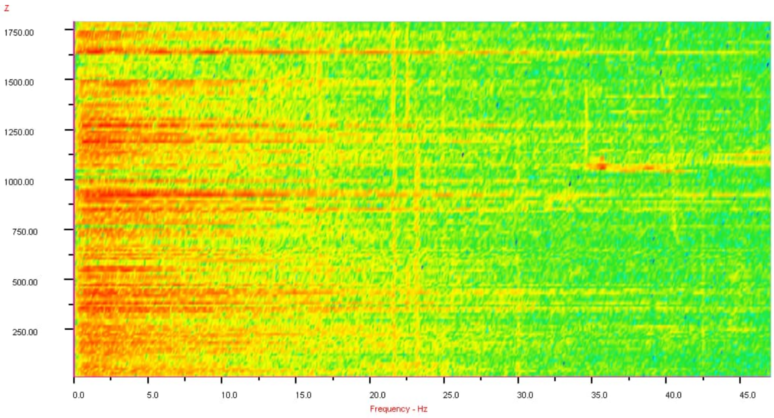
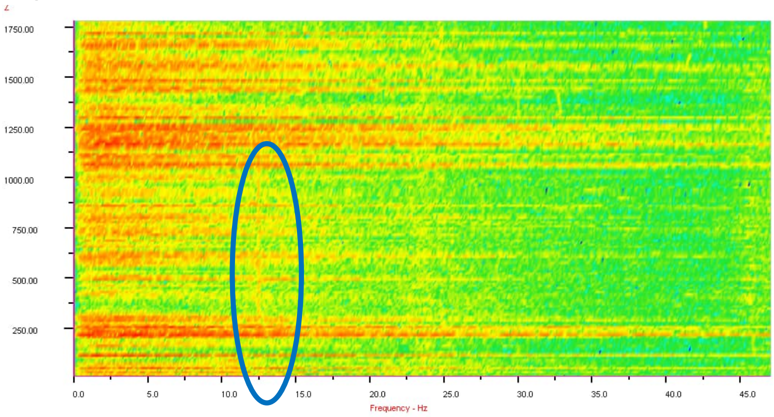


Figure 5-20 - Windwhistle Farm Enclosed Screen with Twin Deck Openings



Note: The signal shown within the blue ellipse is the screen at Hemerdon. Other signals relate to unknown sources of background LFN.

5.3.21. The following results are for the enclosed screen with Kingspan cladding.

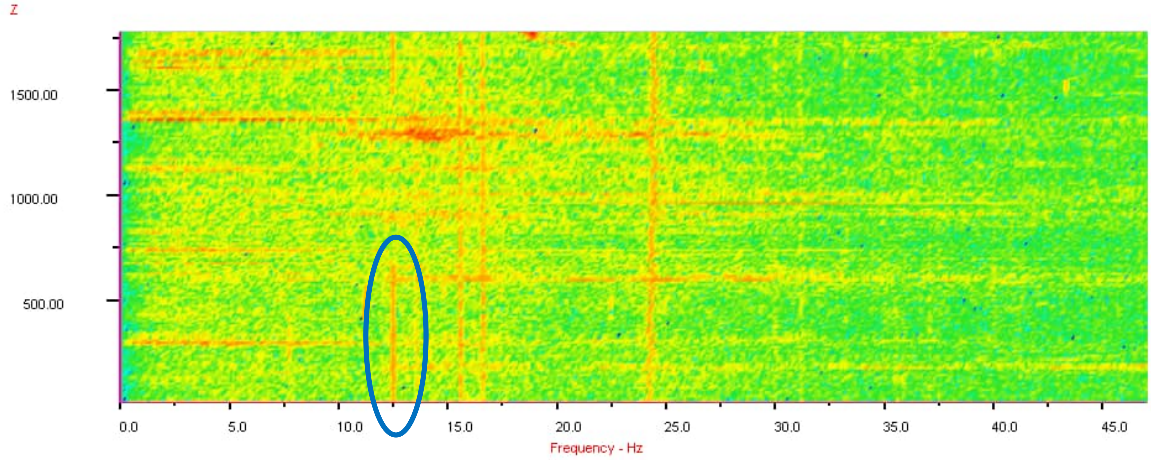
Table 5-4 - Sound Pressure Levels at Fundamental Frequency at Far Field Location during Enclosed Test Scenarios with Cladding, dBZ

Scenario	Date/Time	Portworthy Farmhouse	Windwhistle Farm
Fully enclosed, fully clad	27/6 09:13	33.3	38.9
Top steel and Kingspan panels removed	27/6 09:42	37.3	31.9
Top and one end steel and Kingspan panels removed	27/6 10:05	39.2	44.7
Top and two end steel and Kingspan panels removed	27/6 10:22	36.8	36.4

Three steel panels only removed	27/6 10:49	33.6	-

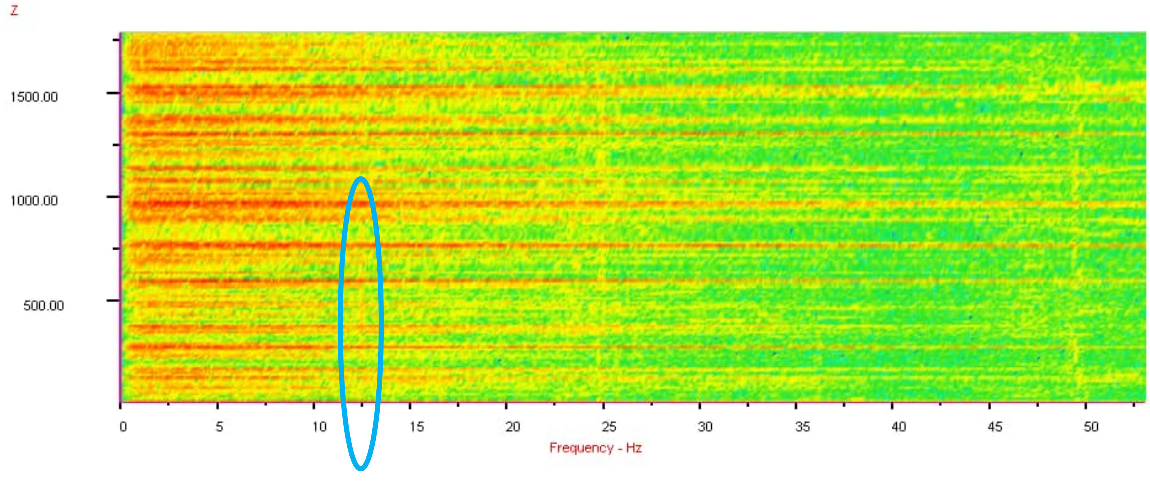
5.3.22. The scenario of the infeed and discharge open areas from the table above are shown in the spectrograms below. The screen remains visible at Portworthy Farmhouse and just visible at Windwhistle Farm.

Figure 5-21 - Portworthy Farmhouse Enclosed Screen with Cladding and Infeed and Twin Deck Openings



Note: The signal shown within the blue ellipse is the screen at Hemerdon. Other signals relate to unknown sources of background LFN.

Figure 5-22 - Windwhistle Farm Enclosed Screen with Cladding and Infeed and Twin Deck Openings



Note: The signal shown within the blue ellipse is the screen at Hemerdon. Other signals relate to unknown sources of background LFN.

5.3.23. The results from the test scenario which included the discharge chute (still with open area for the infeed) are shown in the table below. Note the Kingspan cladding was removed from the discharge end for this test. The grey cells are where the screen was not discernible amongst the background

LFN. There are an increased number of receptor locations for this test as it was also used to assist in better understanding LFN propagation.

Table 5-5 - Fundamental Frequency Noise Levels with Discharge Chute and Infeed Open, dBZ

Receptor Location	Sound Pressure Level, dBZ
Portworthy	39.0
Windwhistle	38.7
Dartmoor Zoo	38.2
Gorah Cottages	32.2
Yondertown	
Lutton	23.1
Cornwood Inn	
East of Lee Moor	48.8
Broadoaks Cottages	39.0
Wotter	
Elfordleigh Hotel	
Colebrook	30.7
Road Junction	41.1

5.3.24. The following spectrograms are for the second harmonic (at 37.5 Hz) and they show open and full ply followed by the enclosed screen with full ply. The red arrows on the x-axis point to 37.5 Hz.

Figure 5-23 - Open Screen with Full Ply Covering (Arrow shows Second Harmonic)

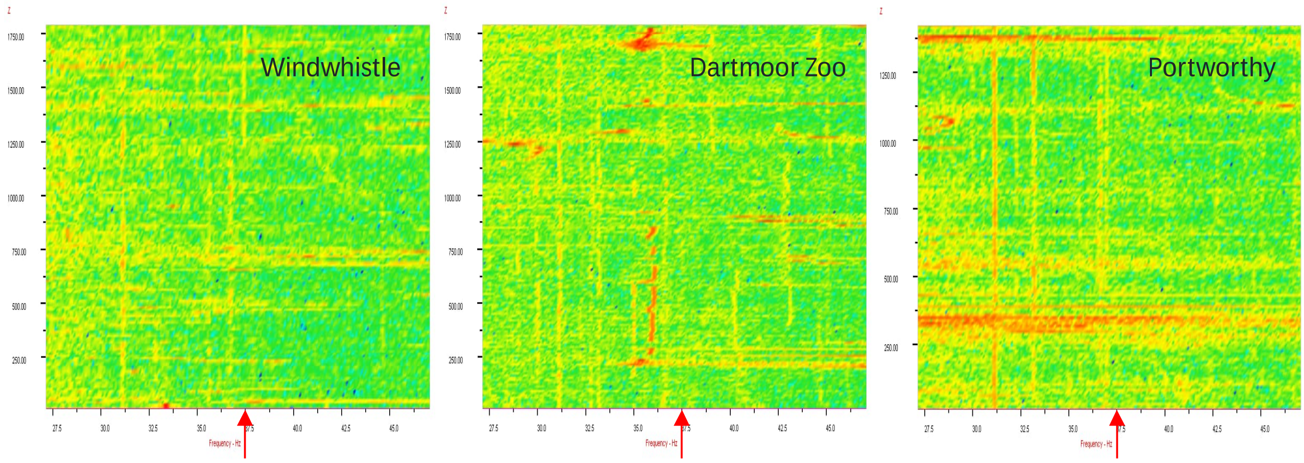
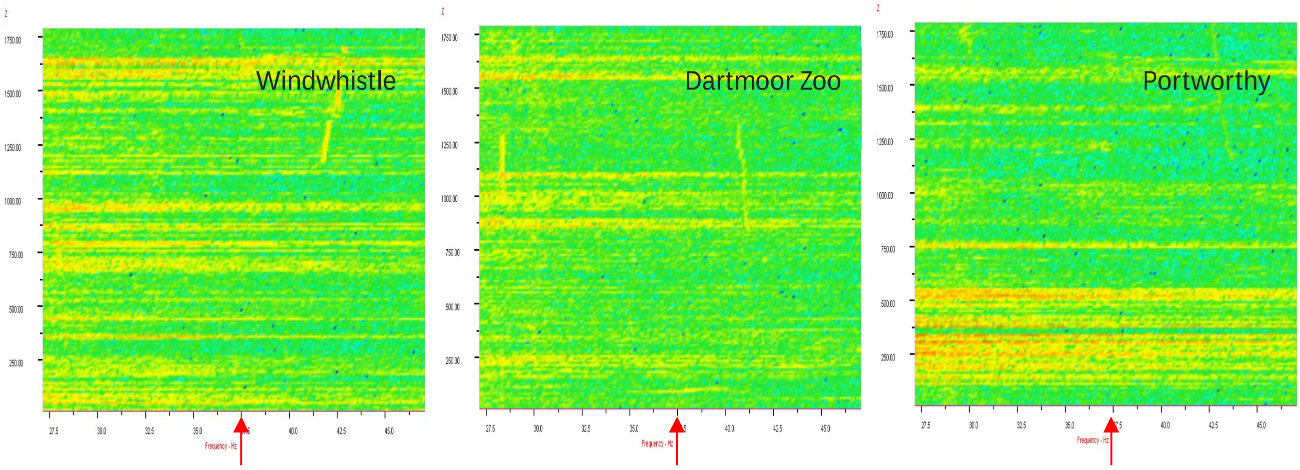


Figure 5-24 - Fully Eclosed Screen with Full Ply Covering (Arrow shows Second Harmonic)



Process Building Screens

Near Field Monitoring Results

5.3.25. The tests with the screen on the ground generally resulted in lower noise levels than expected. This led to additional tests being undertaken but this time on the four existing screens which are located in the main processing building and will be in used for future operations. These tests were undertaken to better understand whether the height of the noise source effected the propagation.

5.3.26. Nearfield noise measurements were undertaken at 1 metre from the screen decks with the sound pressure levels at 16 Hz (the fundamental frequency) detailed in the table below.

Table 5-6 – Sound Pressure Levels at 1 metre from the Screen Deck at 16 Hz – Existing Building, dBZ

Screen	Sound Pressure Level at 1m, dBZ
140-SN-01 DMS Feed Preparation Screen	127.2
140-SN-06 Secondary DMS Screen	124.5
140-SN-07 Scavenger DMS Screen	123.2
150-SN-01 Primary Mill Sizing Screen	125.6

Far Field Monitoring Results

5.3.27. The following six figures show the four screens operating at far field locations. Note the four screens were set to operate at slightly different fundamental frequencies so that they could be clearly identified at the far field locations.

Figure 5-25 - Windwhistle Farm, Process Building Screens

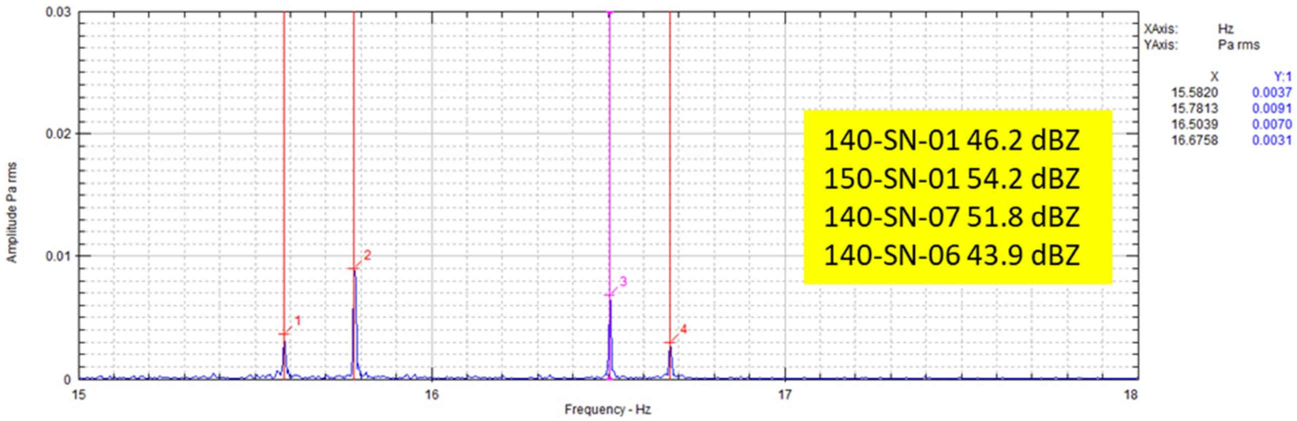


Figure 5-26 - Dartmoor Zoo, Process Building Screens

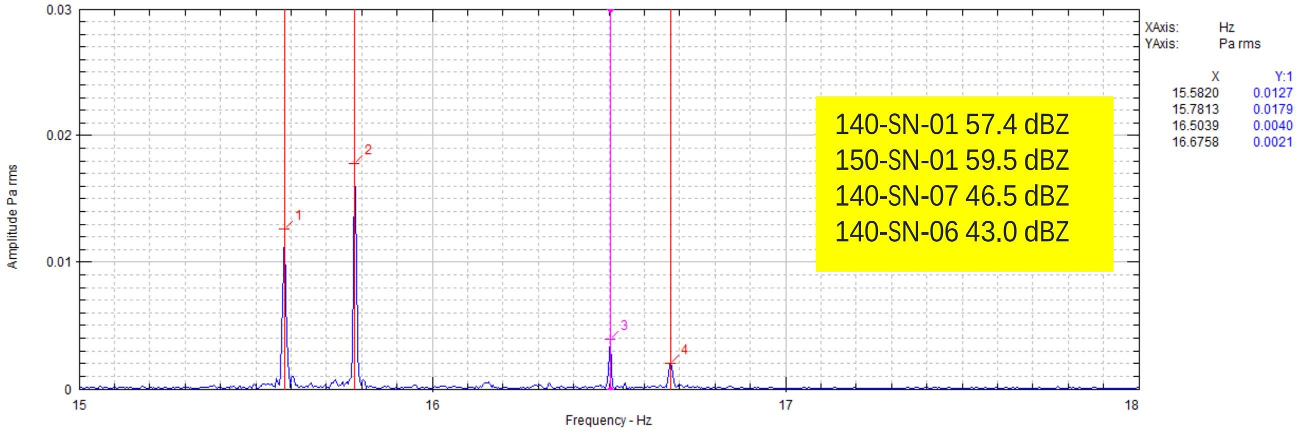


Figure 5-27 - Portworthy Farmhouse, Process Building Screens

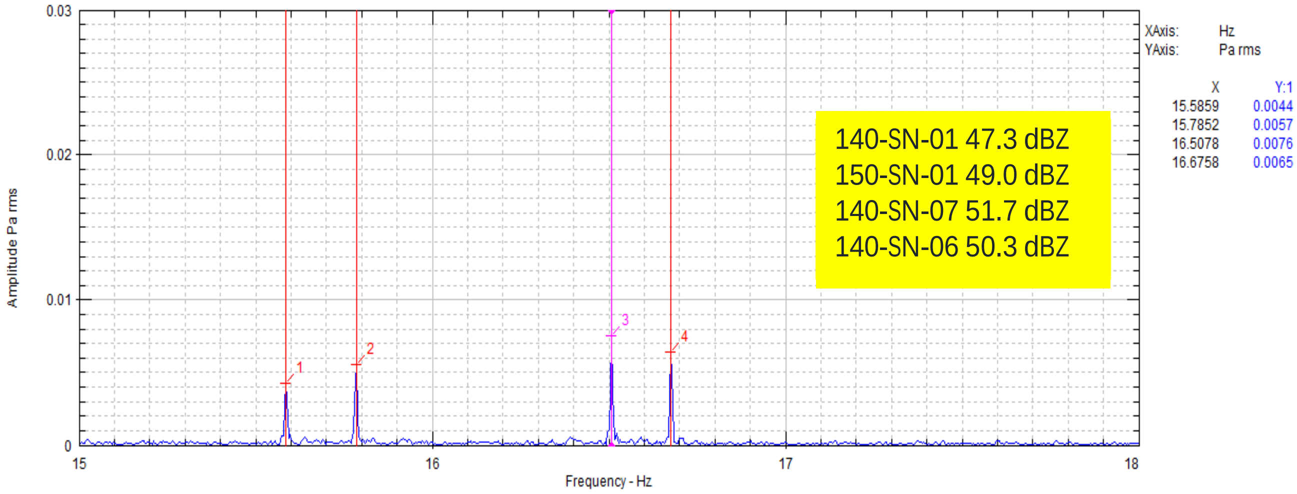


Figure 5-28 - Yondertown, Process Building Screens

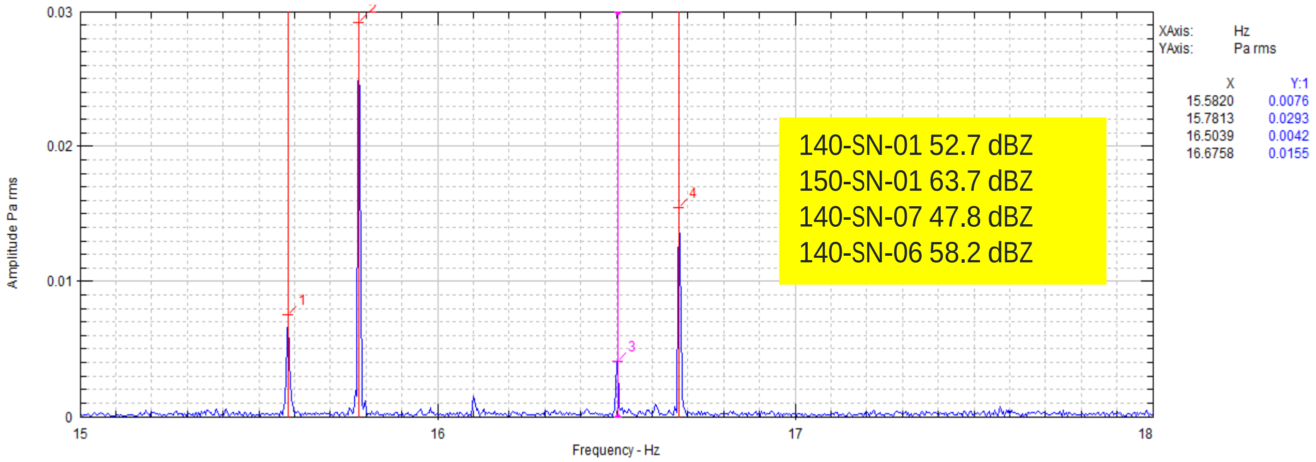


Figure 5-29 - East of Lee Moor, Process Building Screens

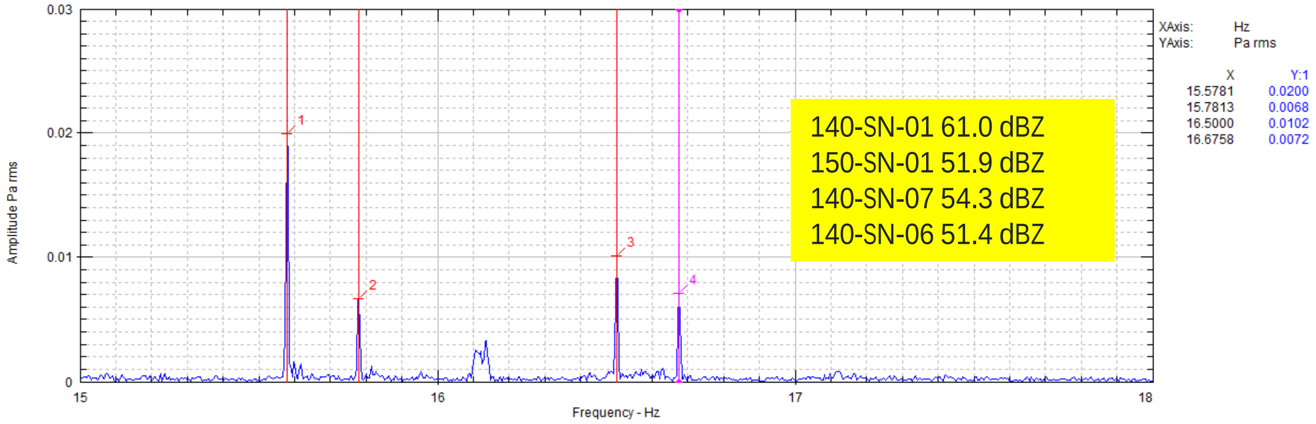
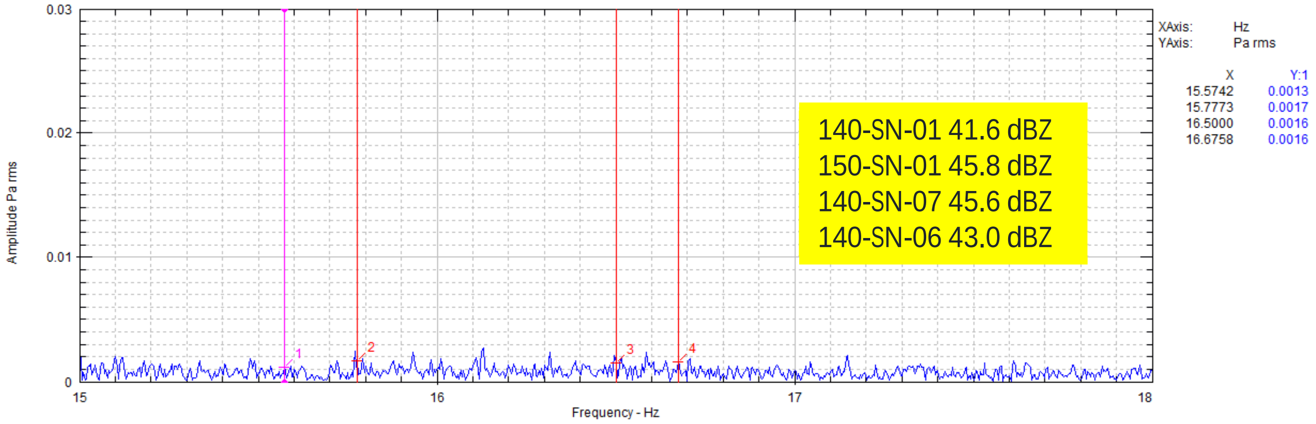
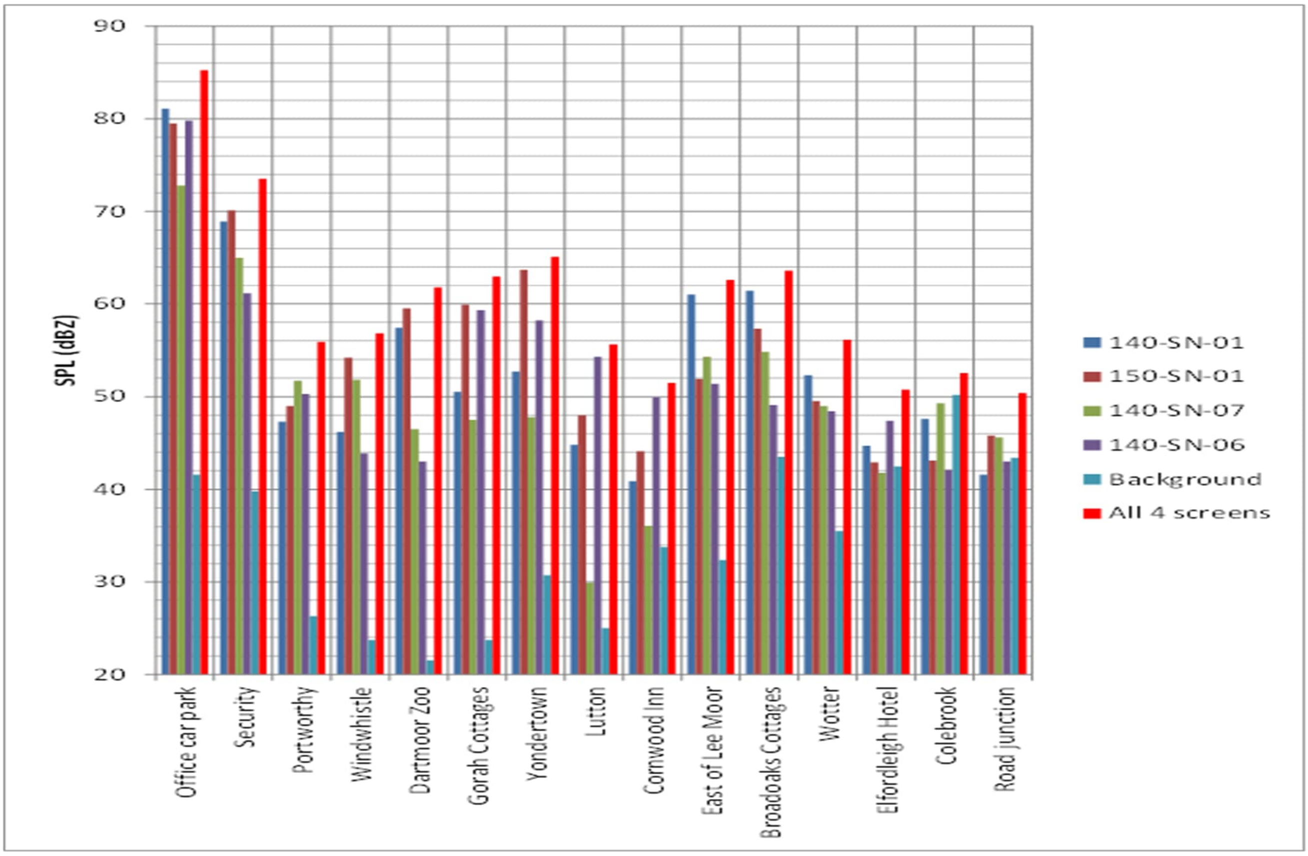


Figure 5-30 - Road Junction, Process Building Screens



5.3.28. Below is a graph showing the four screens in the existing processing building operating at all far field assessment locations considered.

Figure 5-31 - Four Process Screens at Far Field Locations, dBZ



CONCLUSIONS OF THE LFN TRIALS

5.3.29. The following conclusions can be drawn from the LFN trials:

- Full ply covering gave the highest near field sound pressure levels and they were marginally lower in the far field;
- The sound pressure level at 1 metre above the deck with full ply cover is 122 dBZ;
- The sound pressure levels vary between 72.8 dBZ and 88.6 dBZ at 30 m from the screen;
- The highest second harmonic sound pressure level at 30 m was 66.7 dBZ; this is insignificant at the far field receptor locations;
- The far field levels were low with highest value with full ply of 44.1 dBZ was measured at Windwhistle Farm;
- The spectrograms clearly show other machines running nearby. Some will be screens from other operations not associated with Hemerdon mine. This clearly demonstrates that there is an underlying LFN in the absence of Hemerdon mine operations.
- The full acoustic enclosure gives 14 dB reduction in the near field at the fundamental frequency;
- The acoustic enclosure with three open panels for inlet and discharge gives 5 dB reduction in the near field and the fundamental frequency;
- The far field levels at all three locations (Portworthy Farmhouse, Dartmoor Zoo and Windwhistle Farm) are extremely low with enclosure;

- The addition of Kingspan cladding resulted in no reduction in noise levels at the fundamental frequency;
- The addition of the discharge chute to the acoustic enclosure improved the reduction to 11 dB in the near field at the fundamental frequency;
- A further reduction in noise levels at the fundamental frequency is expected if an inlet chute was added to the acoustic enclosure;
- With the exception of the measurements from the plant in the processing building, all far field measurements were significantly lower than expected;
- The second harmonic noise levels can be excluded from further consideration as they are so low at the far field locations;
- The results from the plant in the processing building show that sources at elevation within the building increases transmitted sound levels at the far field receptors;
- There are wind effects which modify the far field levels; and
- Topography does not have a noticeable effect on propagated LFN levels.

NOISE SURVEY AT SENSITIVE RECEPTORS

5.3.30. The far-field noise survey was carried out between 8th June 2023 and 4th July 2023 to establish the noise climate at nearby noise sensitive receptors.

5.3.31. Unattended noise measurements were taken at three measurement positions as shown in Appendix G and described in more detail below.

LT1 – Portworthy Farmhouse

5.3.32. The microphone was mounted on a gate post at the front of the property at a height of approximately 2 m above the ground and was considered to be in a free-field position (over 3.5 m from any acoustically reflecting surface other than the ground).

5.3.33. The weather conditions during installation were dry with temperatures around 21°C, with gusty wind conditions at 1-4 m/s. These conditions are not anticipated to have affected the noise measurements.

5.3.34. The noise climate at this monitoring position was dominated by wind and natural sounds including horses in nearby fields.

5.3.35. A photograph of the noise monitoring location is shown in in the Figure below.

Figure 5-32 - Portworthy Farmhouse Noise Monitoring Location LT1

LT2 – Dartmoor Zoo

5.3.36. Dartmoor Zoo is approximately 350 metres from the south-eastern boundary of the Site. The equipment was located at the rear of the reptile building and on the boundary of the wolf enclosure.

5.3.37. Noise levels measured at this location are considered broadly representative of those in the village of Sparkwell, although Sparkwell is located at greater than 500 metres from the closest site boundary and the zoo is approximately 350 metres from the site. Galva House is to the south-west of Dartmoor Zoo and slightly further from the site boundary, although Dartmoor Zoo is also considered representative of this location.

5.3.38. In all cases, the zoo is also at a higher elevation (and so more exposed to noise from the site) and closer to the site than the receptors of which it is considered representative. These all result in noise levels at Dartmoor Zoo being considered worst-case when applied to the receptors above.

Figure 5-33 - Dartmoor Zoo Noise Monitoring Location LT2

LT3 – Windwhistle Farm

5.3.40. Windwhistle Farm is approximately 1 kilometre from the south-western boundary of the Site. The equipment was located at the rear of the property on a raised area.

5.3.41. Noise levels at this location are considered broadly representative of those at Hemerdon village which is to the south-east of Windwhistle Farm and at Newnham House which is to the north-west of Windwhistle Farm; both locations are at a similar distance from the site as Windwhistle Farm. Whilst Boringdon Hall is located much further from the site and at a lower elevation than Windwhistle Farm, for the purpose of this assessment Windwhistle Farm is considered the most representative location at which baseline survey data have been gathered.

Figure 5-34 - Windwhistle Farm Noise Monitoring Location LT3

5.4 METEOROLOGICAL DATA

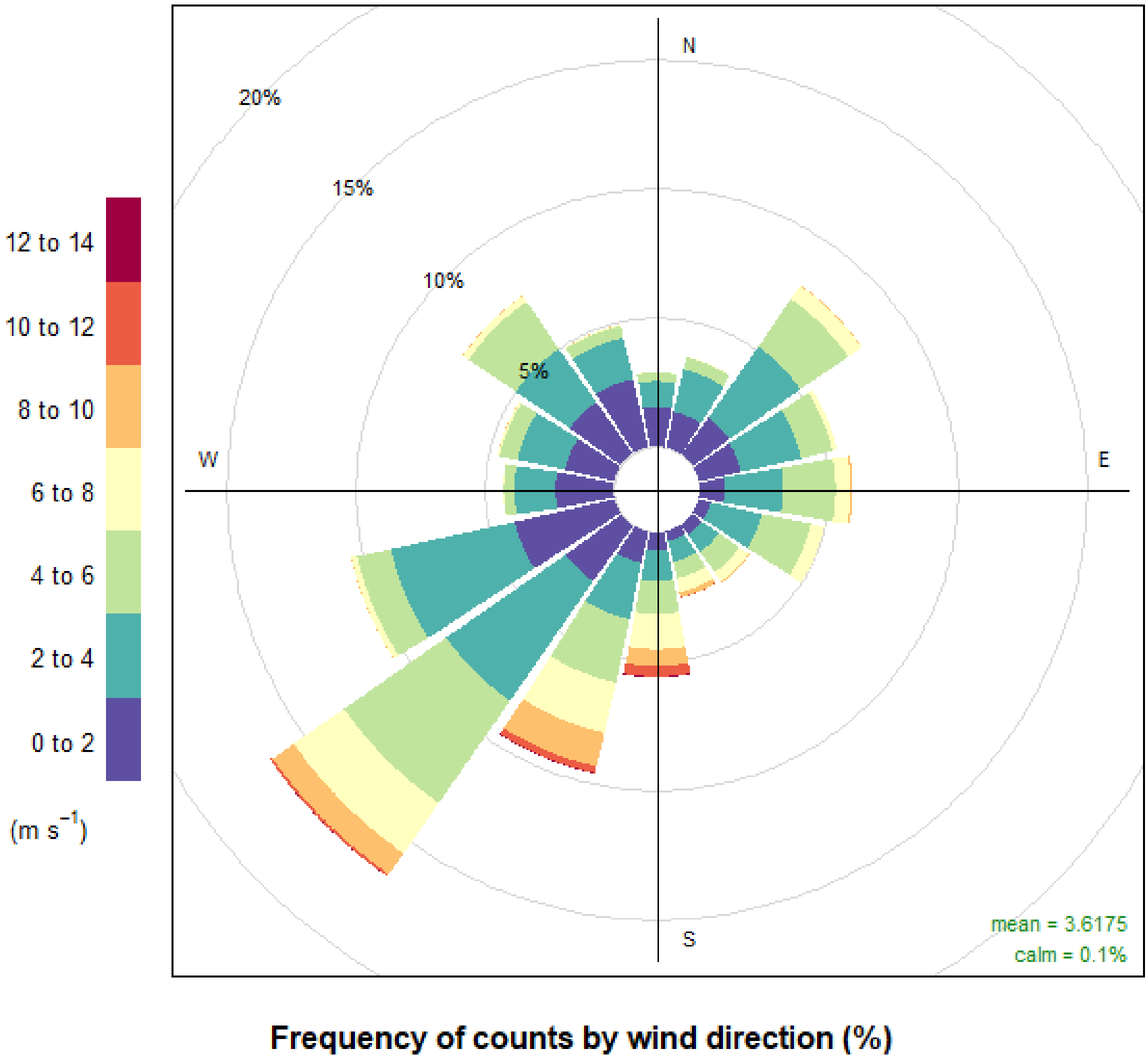
5.4.1. A meteorological station was installed at Windwhistle Farm alongside the noise monitoring location, as shown below. The metrological station was set to measure wind speed, wind direction, temperature and rainfall in ten minute intervals.

Figure 5-35 - Windwhistle Farm Meteorological Station LT3

5.4.2. A summary of the measured weather data from LT3 are shown in the graphs in Appendix K.

5.4.3. There is also a weather station at Hemerdon mine and wind speed, wind direction, temperature and rainfall are measured at this station. Data gathered over the last 13 months have been analysed and are summarised in the wind rose below. It can be seen that the prevailing wind direction is from the south west.

Figure 5-36 - Wind Rose from On-site Weather Station



6 NOISE PREDICTION MODEL

6.1 INTRODUCTION

6.1.1. This section includes information pertaining to the noise model settings, noise model verification process and the results at each receptor.

6.2 NOISE MODELLING SOFTWARE

6.2.1. As stated in Section 2, proprietary noise modelling software is not suitable for LFN and, instead, a bespoke wave based model has been created for the Hemerdon site.

6.2.2. Full details of the calculation algorithms used in the model are given in Appendix L.

6.3 NOISE MODEL SETTINGS AND VALIDATION

ACOUSTICS EFFICIENCY VALUE

6.3.1. The acoustic efficiency value used in the noise model has been referenced in Item d of the Schedule 5, hence it being described in more detail than some other aspects of the noise model. The detail of the Schedule 5 Item d is copied below:

"Provide further information to justify the chosen acoustic radiation efficiency of 0.1 for all screens, or justify and use a more conservative assumption for the assessment.

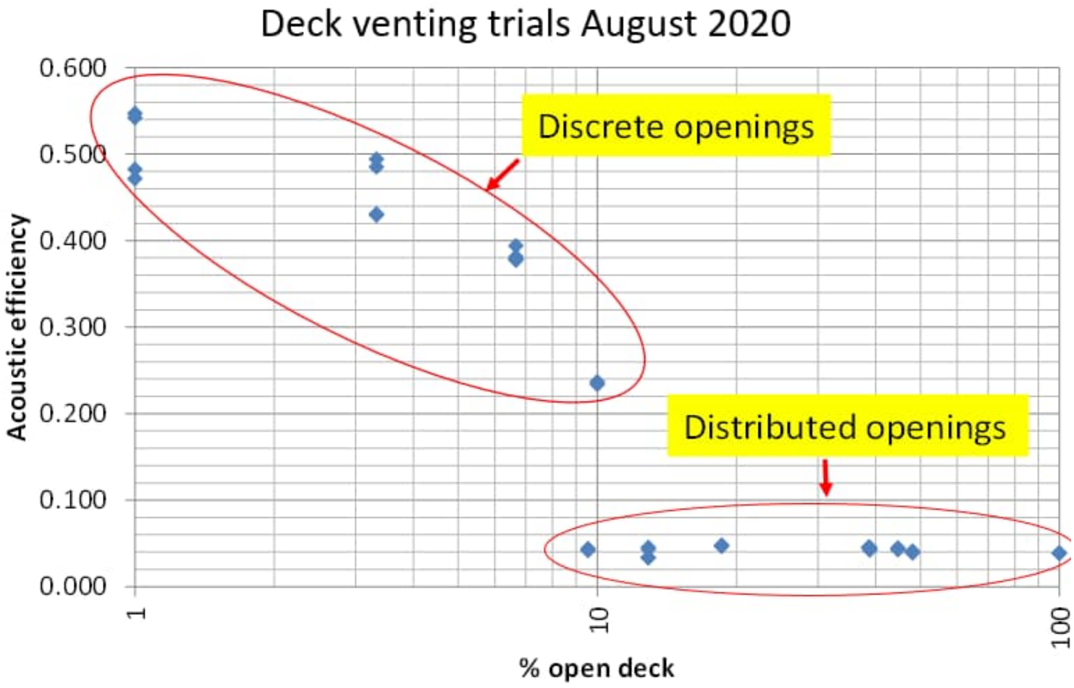
Table 17 of in [sic] *the previous NVIA report (Ref TWL-CP-PA-EN-006.2.23 dated 18/08/2021) identified an Acoustic Efficiency (AE) range of 0.005 to 0.819. Whilst it is understood that J5510B and J5645B screens are excluded, it is not clear why the higher AE figures from Table 17 have not been considered."*

6.3.2. It is a critical value to define as it can heavily influence the results of the noise modelling. A number of acoustic efficiency test were undertaken for the Wolf Minerals NIA which included both far field and near field measurements. These data have been revisited and interrogated in more detail, as well as additional measurements and analysis being undertaken.

6.3.3. The measurements in the far field locations which were gathered for the Wolf Minerals NIA have been discounted due to influence of meteorological effects which are now better understood (see Sections 7 and 9 for further information). These effects would have resulted in far greater levels of uncertainty in the acoustic efficiency value selected. The analysis of acoustic efficiency values has, therefore, been limited to data gathered at near field measurement positions.

6.3.4. The figure below shows the acoustic efficiency values calculated from deck venting trials undertaken in August 2020. The discrete openings are where openings have been cut in the ply covering to represent very small open areas. The distributed openings use different sized screen panels and, for these tests, the values drop considerably and are consistent. The situation with distributed openings is more representative of the situation in operation when the screens are loaded with materials.

Figure 6-1 - Acoustic Efficiency Values

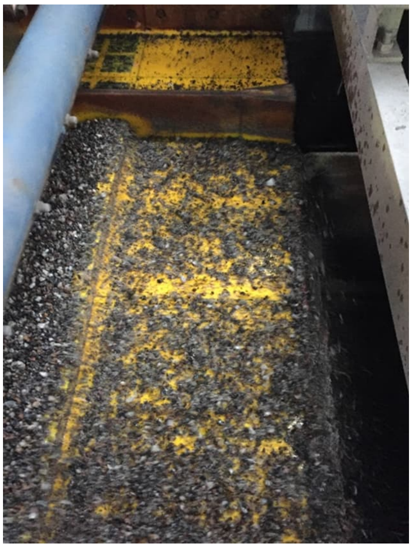


6.3.5. The above concludes that, as long as the screen has at least a 10% open area, a low acoustic efficiency value can be assumed.

6.3.6. Figure 6-2 below shows a typical screen in operation and this has a greater than 10% open area justifying the use of a low acoustic efficiency value. However, the acoustic modelling has assumed a 0.3 acoustic efficiency value which is deemed a conservative and, therefore, robust approach to the modelling. For comparison, the Wolf Minerals model included an acoustic efficiency value of 0.1.

6.3.7. A full description of the screen operations is presented at Appendix M, which provides justification for selecting an acoustic efficiency value of 0.3 as a conservative assumption.

Figure 6-2 - Typical Screening Operation



6.4 NOISE SOURCES WITHIN THE MODEL

6.4.1. The noise sources which have been included in the noise model are shown in Table 6-1 below, along with their location, assumed acoustic efficiency, sound pressure level (at 1m) and other relevant information.

6.4.2. Note that the quoted sound pressure levels in column 9 of the table are those for the scenario including screen enclosures (with a discharge chute and open area for the infeed) and deck venting.

Table 6-1 - LFN Sources Included in the Noise Model

Screen Detail	Location	Easting	Northing	Screen RPM	Stroke Normal to Deck (mm)	Vibrating Area (m^2)	Acoustic Efficiency	Sound Pressure Level, dBZ	Mitigation Included
140-SN-01 DMS feed prep screen	Area 140 (DMS)	56899.9	58963.9	936.12	6.98	11.52	0.30	122.8	Enclosure (with discharge chute and open infeed) and deck venting included as inherent mitigation*.
140-SN-06 secondary DMS screen	Within Area 150 (DMS)	56912.2	58956.7	1000.8	3.96	8.64	0.30	116.0	
140-SN-07 scavenger DMS screen	Within Area 150 (DMS)	56914.9	58958.6	990.96	3.76	8.64	0.30	115.4	
150-SN-01 primary mill sizing screen	Area 150 (Primary Milling)	56920.3	58955.8	948.54	6.57	9	0.30	120.2	
115-SN-02 Secondary Crushing Scalping Screen	Area 115	57124.2	59103.8	738	8.5	18	0.30	131.3	
125-SN-11 Ore Sorter Sizing Screen	Area 125A	57058.3	58979.4	738	8.5	14	0.30	129.1	
125-SN-01 Pebble Ore Sorter 1 Dewatering Screen	Area 125B	57040.6	59019.9	960	5.7	3.6	0.30	116.0	
125-SN-02 Pebble Ore Sorter 2 Dewatering Screen	Area 125B	57036.6	59017.9	960	5.7	3.6	0.30	116.0	
125-SN-03 Cobble Ore Sorter 1 Dewatering Screen	Area 125B	57033.5	59016.6	960	5.7	3.6	0.30	116.0	
125-SN-04 Cobble Ore Sorter 2 Dewatering Screen	Area 125B	57029.1	59014.7	960	5.7	3.6	0.30	116.0	
130-SN-12 Tertiary Crusher Sizing Screen	Area 130B	56958	58926.4	740	8.5	18	0.30	131.3	
130-SN-13 Tertiary Crusher Dewatering Screen	Area 130A	57013.5	58965.7	740	8.5	18	0.30	126.3	

*17 dB reduction assumed for the screen enclosure (with a discharge chute and open area for the infeed) and deck venting.

6.4.3. Whilst this section details the LFN sources which are included in the noise model, the EA has specifically requested that the assessment is clear about sources which are being dismissed. Particular reference has been made in the Schedule 5 to jaw crushers and this is addressed below.

6.4.4. Item b of the Schedule 5 notice states:

"Amend the NVIA to include all potential sources of low frequency noise, or provide a justification for the exclusion of potential sources of noise from the assessment.

You have stated that Tungsten West has updated the BS4142 background noise assessment to consider the impact of noise from a proposed Primary Jaw and Secondary Cone crushing arrangement. This does not justify its exclusion from the NVIA.

All potential sources need to be included in the NVIA, or provide a written justification as to why it is not. The new proposed jaw crushers are expected to be significant sources of LFN/infrasound. It is not known at what mechanical frequency those items of plant operate, nor the sound power at those frequencies. Any effects from these additional sources are therefore not currently quantified or understood."

6.4.5. The reference to the jaw crushers being a significant source of LFN above has been explored with the EA during consultation. It appears that there is little robust evidence to substantiate this in the form of previous noise measurements. However, to address Item b, the characteristic sound pressure level expected from the jaw crusher has been calculated using the same approach as for the screens (see Section 6.3 above). The candidate jaw crusher (Metso C130) was modelled with a worst-case acoustic efficiency of 1 (the maximum theoretical acoustic efficiency that is possible) and, based on this worst case assumption, the resulting sound pressure level at 1m from the jaw crusher is 114 dBZ. This is approximately 10 dB lower than a typical screen and has a lower fundamental frequency of 3.7 Hz.

6.4.6. At such a low frequency, human perception is limited and so G-weighting[13] was applied which reduces the sound pressure level to 97 dBG.

6.4.7. The resulting noise contour is shown in Figure 6-3 at the end of Section 6.

6.4.8. The sound pressure levels are very low and do not compare to those from the screens. For this reason, the jaw crusher is not considered a source of LFN which impacts on this assessment and has been excluded from further consideration.

6.5 NOISE MODEL VERIFICATION

6.5.1. The noise model has been verified via comparison of predicted and measured LFN levels during tests with 4 screens running at Hemerdon. These were screens 140-SN-01, 140-SN-06, 140-SN07 and 150-SN-01. The predicted and measured LFN levels at 13 receptor locations are presented in the following table.

[13] G weighting is typically applied to sources which fall within the infrasound range where human perception is limited.

Table 6-2 – Measured vs Predicted LFN Levels during Four Screen Operation

Receptor	Distance (m)	Angle (degs)	Elevation (m)	Measurement (dBZ)	Background (dBZ)	Prediction (dBZ)	Wind	Error (dB)
Portworthy	1907	304	98	55.9	26.3	60.5	Neutral	4.6
Windwhistle	1392	214	70	56.8	23.7	68.4	Upwind	11.6
Dartmoor Zoo	1146	102	189	61.8	21.5	70.6	Downwind	8.8
Gorah Cottages	1990	86	162	63.0	23.7	60.7	Downwind	-2.3
Yondertown	2456	85	120	65.1	30.7	58.7	Downwind	-6.4
Lutton	2906	78	95	55.6	25	56.7	Downwind	1.1
Cornwood Inn	3724	79	124	51.5	33.8	53.3	Downwind	1.9
East of Lee Moor	2919	23	233	62.6	32.4	59.0	Downwind	-3.6
Broadoaks Cottages	2376	358	162	63.6	43.5	61.0	Downwind	-2.6
Wotter	3158	334	205	56.1	35.5	55.1	Neutral	-1.1
Elfordleigh Hotel	2357	260	77	50.8	42.5	61.8	Upwind	11.1
Colebrook	2632	229	18	52.5	50.2	58.3	Upwind	5.8
Road junction	2007	214	53	50.4	43.4	63.6	Upwind	13.2

6.5.2. It can be seen from the results presented in Table 6-2 that for those measurement locations that were upwind of the LFN source, the model overpredicted by 5.8 to 13.2 dB. For those measurements undertaken under neutral wind conditions, the prediction error was between -1.1 dB (an underprediction) and 4.6 dB (an overprediction). For those measurement locations that were downwind of the source, the underprediction was between 6.4 and 8.8 dB.

6.5.3. It is clear from these results that wind direction has a significant effect on the resulting LFN as experienced at any receptor location. Under neutral wind conditions, the accuracy of the prediction model was found to be reasonably good, and comparable to the accuracy of models such as ISO 9613-2 which is used for audible noise. The model, though, underpredicts under downwind (source to receiver) conditions and overpredicts under upwind conditions. The effect of wind on prediction uncertainty is discussed further in Section 9.3.

6.6 NOISE MODEL RESULTS

6.6.1. The model, including all LFN sources, has been used to predict the unmitigated noise levels and the noise levels including inherent mitigation (with the acoustic enclosures (with a discharge chute and open infeed area) and deck venting). The noise sources in the model are those shown in Table 6-1 above.

6.6.2. The unmitigated noise levels are shown in Figure 6-4at the end of this section. The noise levels with the mitigation described in the paragraph above are shown in Figure 6-5. The noise levels are shown for the fundamental frequency.

6.6.3. Figure 6-6 shows noise contours for the previous Wolf Minerals noise levels alongside the predicted DRL noise levels. The reduction in noise levels is a result of the acoustic enclosures and deck venting.

6.6.4. The table below provides the noise levels at each of the receptors identified in Section 3.

Table 6-3 - Noise Levels at Fundamental Frequency with Mitigation at Assessment Locations, dBZ

Receptor	Predicted Sound Pressure Level with Mitigation (A)	Wolf Minerals Sound Pressure Level (B)	Difference (A-B)
A: Birchland Farm	55.5	74.7	-19.2
B: Galva House	56.6	77.2	-20.6
C: Newnham House	43.1	71.3	-28.2
D: Boringdon Hall	34.1	57.8	-23.7
E: Mumford Cottage	47.0	66.0	-19.0
F: Portworthy Farmhouse	43.0	67.3	-24.3
G: Windwhistle Farm	48.1	70.8	-22.7
H: Dartmoor Zoo	49.7	75.9	-26.2
I: Wotter	33.6	57.5	-23.9
J: Broadoaks Cottages	35.6	62.6	-27.0
K: East of Lee Moor	40.4	59.6	-19.2
L: Lutton	39.7	59.5	-19.8
M: Cornwood Inn	35.5	55.2	-19.7
N: Gorah Cottages	45.6	66.3	-20.7
O: Yondertown	41.4	62.6	-21.2
P: Road Junction	43.4	65.1	-21.7
Q: Colebrook	34.5	60.9	-26.4
R: Elfordleigh Hotel	37.3	61.8	-24.5

Figure 6-3 - Noise Model Output of Predicted Sound Pressure Level from Jaw Crusher at the Fundamental Frequency, dBG

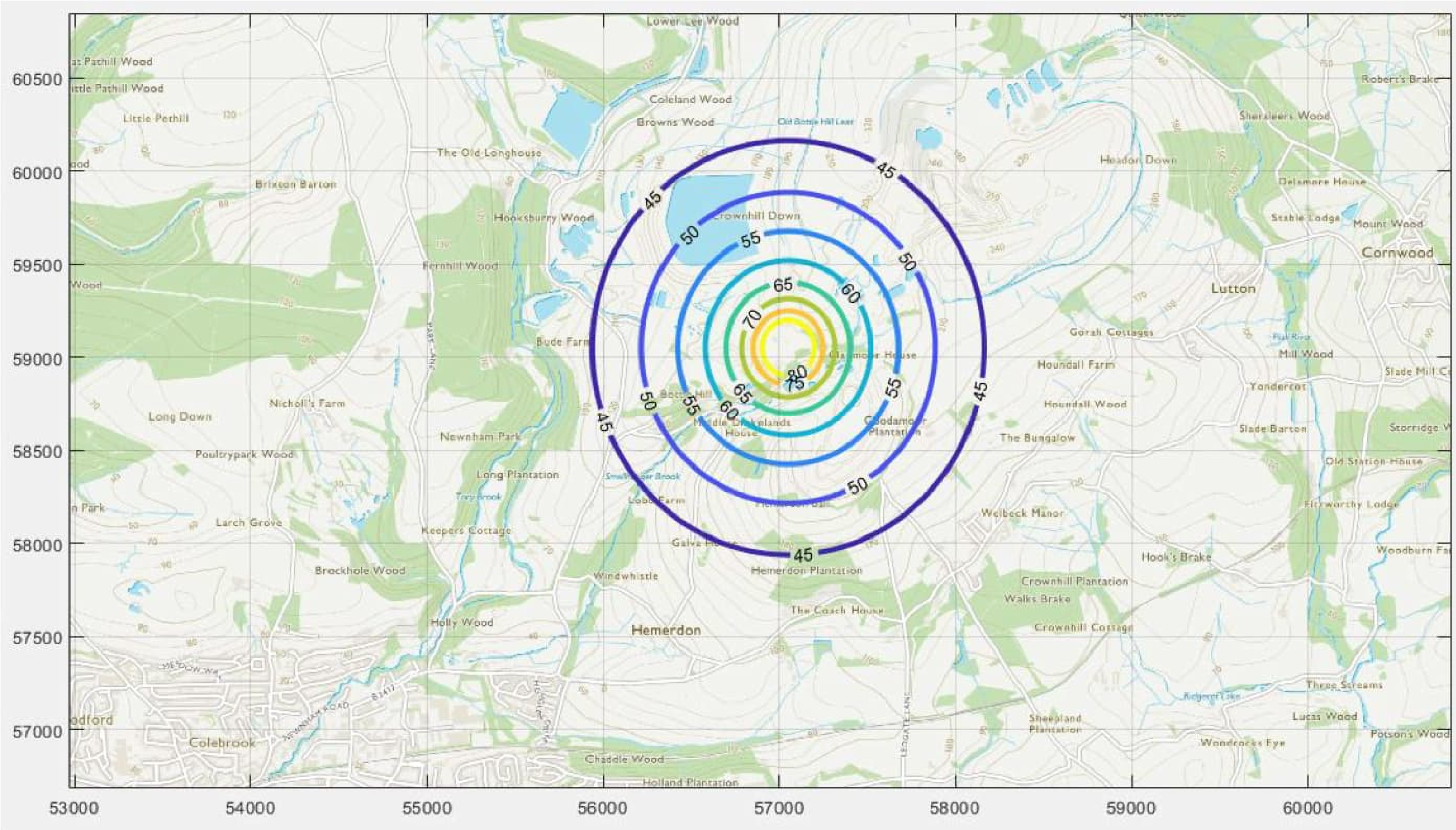


Figure 6-4 - Noise Model Output of Predicted Sound Pressure Level for Unmitigated Screens at the Fundamental Frequency, dBZ

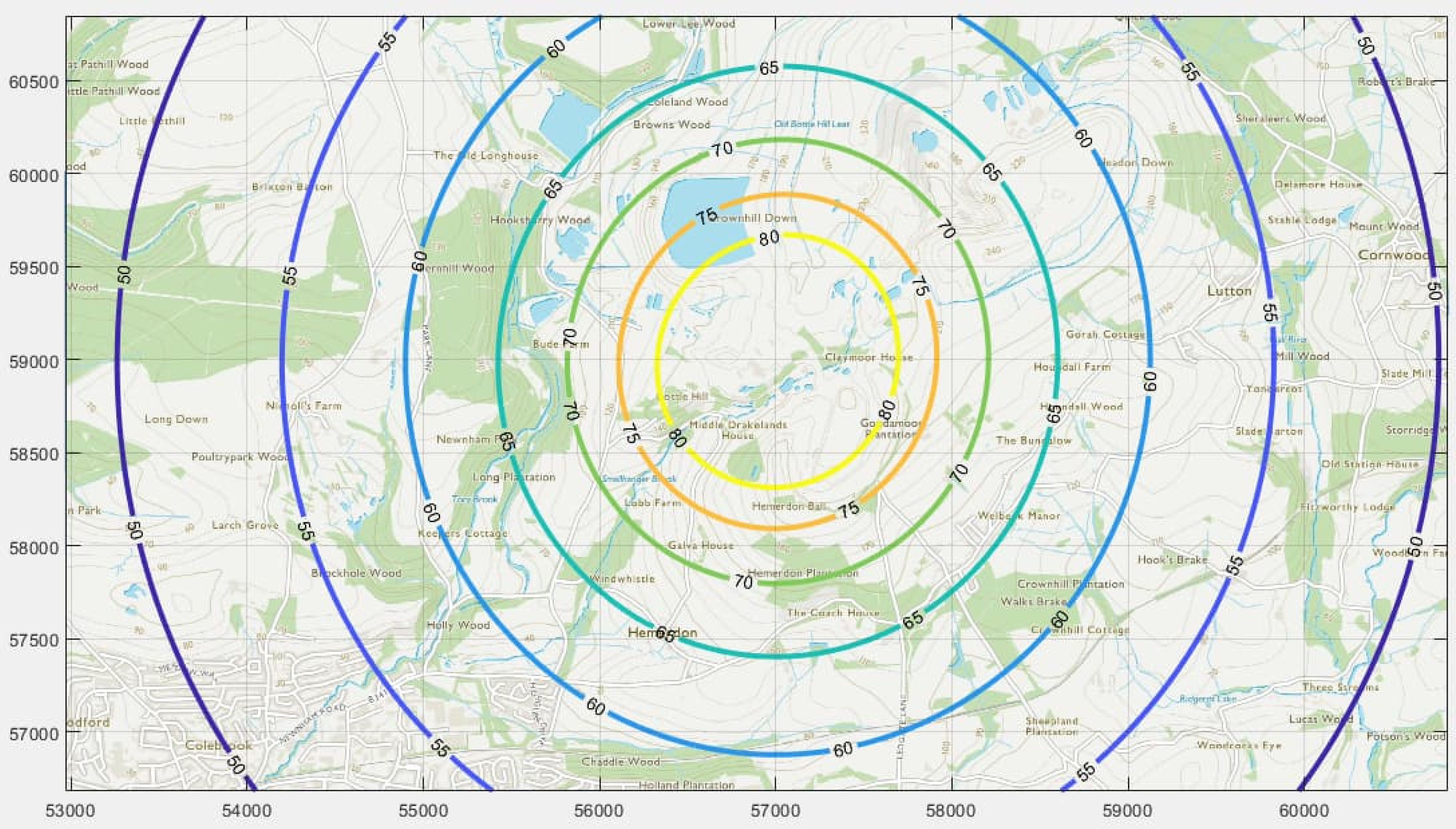
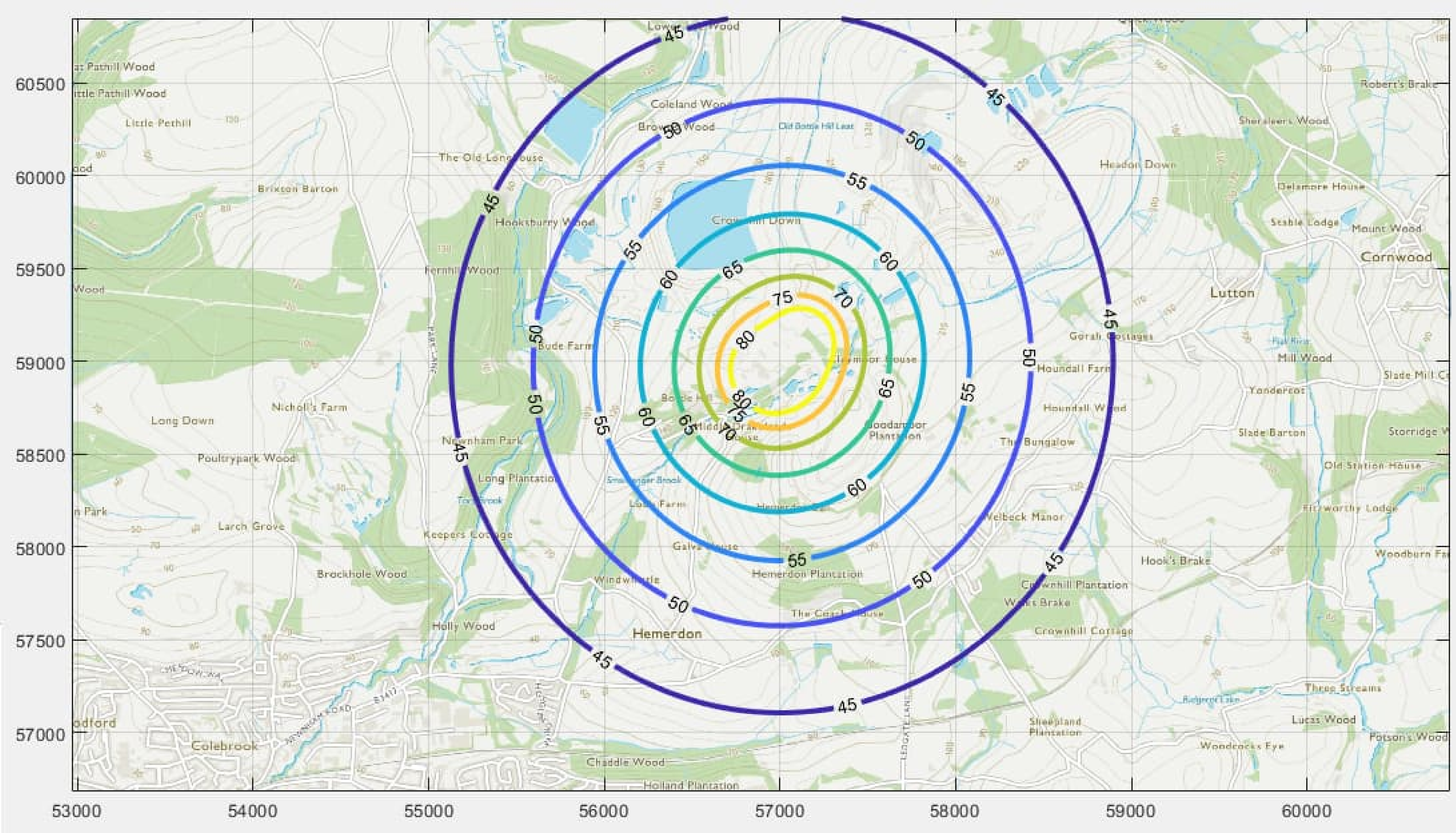
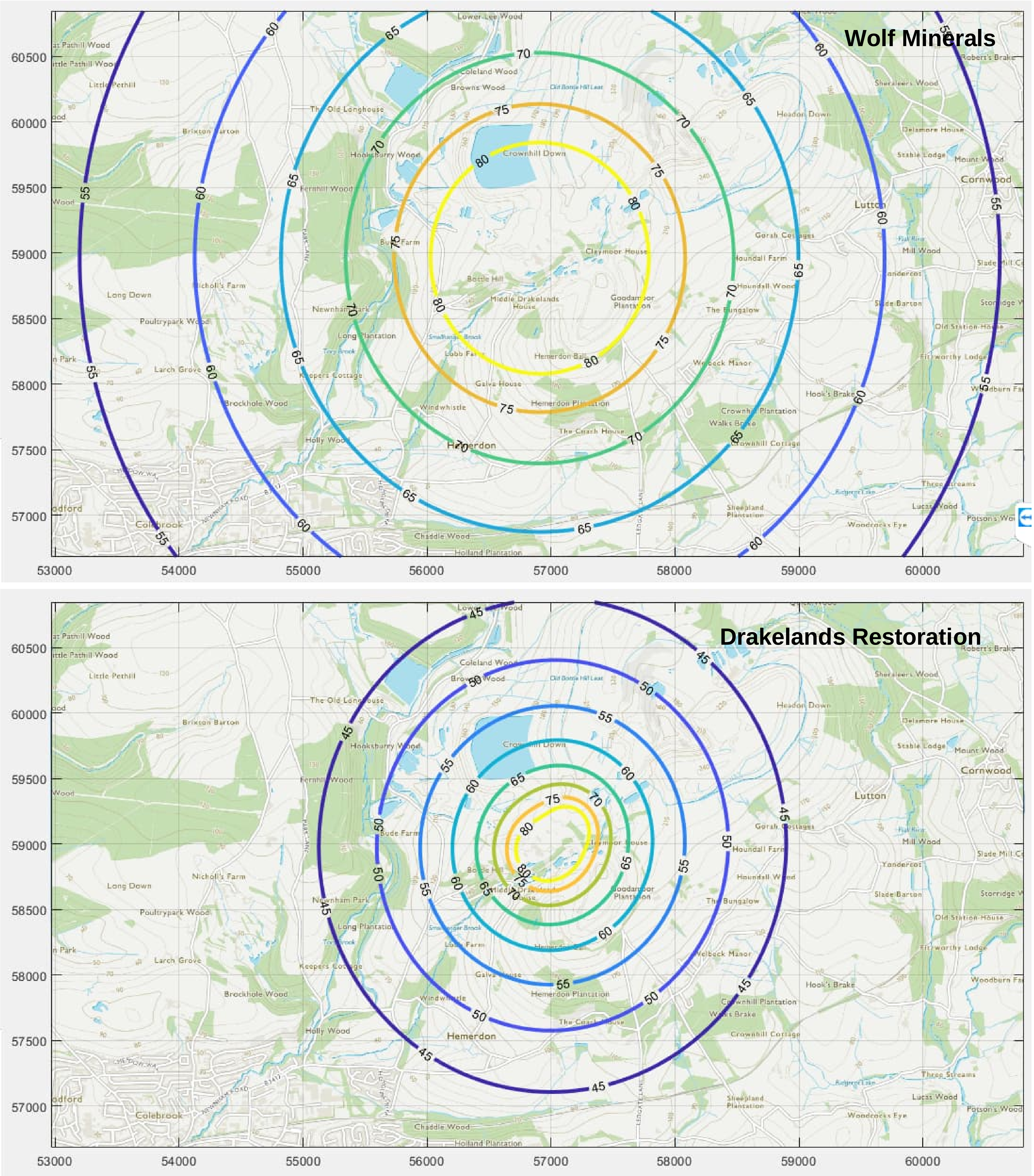


Figure 6-5 - Noise Model Output of Predicted Sound Pressure Level for Mitigated Screens (Acoustic Enclosure with Discharge Chute and Open Infeed, and deck venting) at the Fundamental Frequency, dBZ



Note to Figure 6-5: Contours at very close distances to the source are not circular – this is due to the spatial distribution of the screens which has a greater effect at short distances.

Figure 6-6 - Comparison of Wolf Minerals Unmitigated Noise Levels with DRL Noise Levels with Acoustic Enclosure (with Discharge Chute and Open Infeed) and Deck Venting, dBZ



7 NOISE IMPACT ASSESSMENT

7.1 INTRODUCTION

7.1.1. This section assesses the impact of the predicted LFN and determines whether any penalties should apply. It determines the impact in the context of previously measured noise levels, when the site was operated by Wolf Minerals, the existing background LFN noise levels in the area and links back to the requirements of the Schedule 5 notice, in particular the following from the “Notes” section:

“A reduction from the current proposed levels would need to be demonstrated within the NVIA for us to consider issuing an environmental permit authorising operation of the proposed Mineral Processing Facility.”

7.1.2. As shown in the spectrograms in Section 5, the second harmonic is not present at the locations of Portworthy Farmhouse, Dartmoor Zoo or Windwhistle Farm. On this basis, the impact assessment excludes these from further consideration. However, see Section 8 Mitigation which summarises the mitigation options appraisal and includes an easy to implement option to reduce noise levels at the second harmonic, if required once operational.

7.1.3. Item g of the Schedule 5 requested amplification of low frequency noise within receptors is included or dismissed with justification. Item g is also addressed in this section.

7.2 NOISE LEVEL REDUCTION

7.2.1. The EA has not identified a target reduction in LFN levels in its Schedule 5 and they have not provided LFN assessment criteria for the mine; it was suggested during a consultation meeting that we don’t use criteria. This is understandable, given the lack of research and understanding about the effects of LFN. However, given the wording of the Schedule 5 notice (i.e. the importance placed on a reduction in LFN), this assessment is based on the reduction achieved in comparison to the Wolf Minerals operations and the extent of mitigation that could be employed, should low frequency noise impacts be found to be of concern once the mine is operational.

7.2.2. The noise level reduction when comparing the Wolf Minerals operation with the DRL predicted levels is shown in - Noise Levels at Fundamental Frequency with Mitigation at Assessment Locations, dBZ above with contours of the two scenarios being provided in Figure 6-6 above.

7.2.3. The reductions achieved by the applied mitigation (acoustic enclosures and deck venting) are considerable. It is expected that they provide a reduction which would result in a subjective difference at those receptors where LFN was previously of concern.

7.2.4. The reduction provided by the acoustic enclosures with a discharge chute is 11 dB. The reduction provided by the deck venting is 6 dB. The combined reduction from both measures is 17 dB. As the enclosures and deck venting are considered inherent mitigation (see Section 8), they will be in use from the start of the new operations. The total cost for implementing this mitigation is estimated at £7-10million and this, along with the timescales for manufacturing the enclosures is not prohibitive to the operation of the mine.

7.2.5. The mitigation is considered (as well as the selection of new and quieter screens) to be in accordance with Best Available Techniques (BAT) as the mitigation considerably reduces noise close to its source.

7.2.6. Further measures to control noise from the screens, should it be needed, are provided in Section 8.

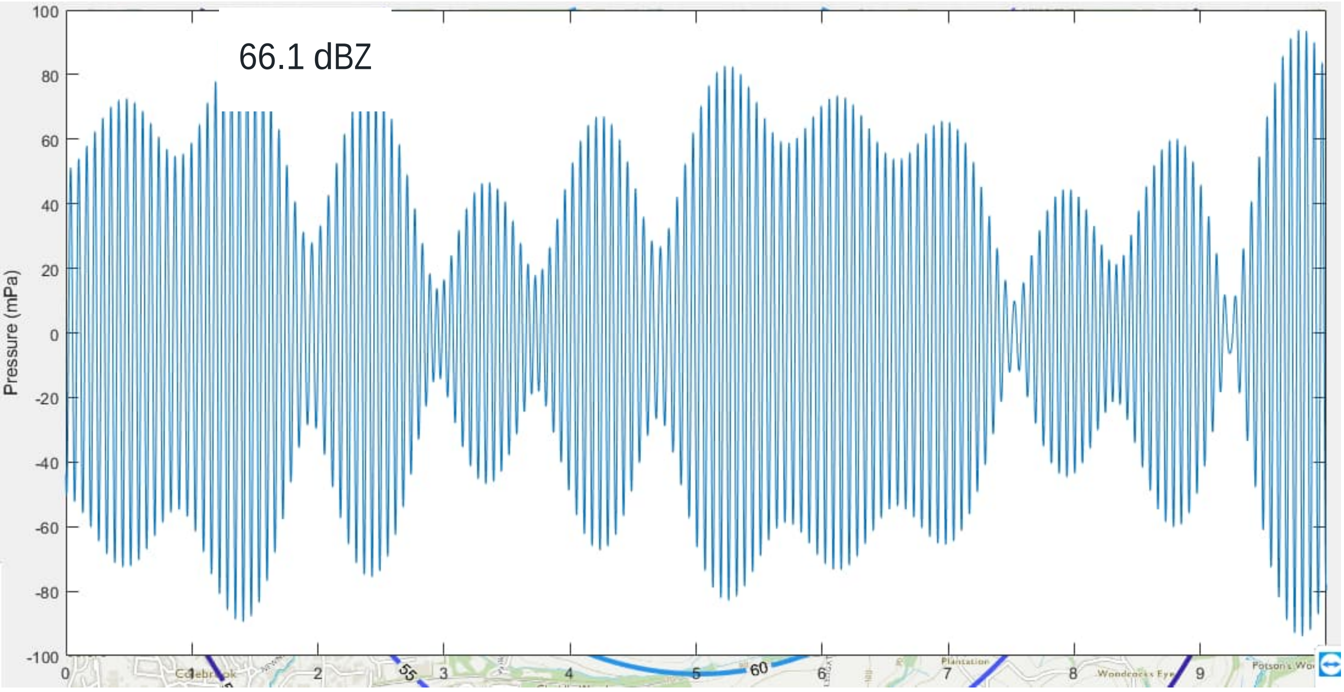
7.3 BEATING EFFECTS

7.3.1. Item h of the Schedule 5 states:

-*"Slight differences in operating frequencies will also introduce beating patterns at distant locations, repeating changes to the interference pattern over short periods of time. We need to understand if and how the chosen model accounts for this, and how this is likely to affect sound pressure levels which will be experienced at distant locations."*

7.3.2. The time domain noise model is able to produce a waveform which shows the screens interacting and, therefore, the beating effect. Figure 7-1 below shows the time waveform with background noise removed; it is the waveform from four screens operating in the process building.

Figure 7-1 - Time waveform showing Beating Effect



7.3.3. It is common knowledge that the variation in sound pressure level due to the operation of the screens causes annoyance. The model does not include a correction for annoyance relating to the beating. However, Broner in his paper *"A Simple Criterion for Low Frequency Noise Emission Assessment"*[14] states:

"If the measured LFN SPL is fluctuating at least +/- 5 dBC, then a "penalty' of 5 dBC to the proposed criteria (ie a reduction in the proposed limit) is recommended."

[14] Broner, N, 2010. A Simple Criterion for Low Frequency Noise Emission Assessment. Journal of Low Frequency Noise, Vibration and Active Control.

7.3.4. It would be appropriate to consider a penalty of +5 dB where beating is expected to be noticeable. To present a conservative assessment, it has been assumed that beating would be noticeable at all assessment locations. However, linking back to the Schedule 5 Notes section included above, it is the noise level reduction that is of importance as the beating effects would have been present during Wolf Mineral operations and, as shown in Figure 7-1 above, are expected to be present in future operations.

7.4 AMPLIFICATION OF LOW FREQUENCY NOISE IN DWELLINGS

7.4.1. Item g of the Schedule 5 states:

"Provide an assessment of amplification within the receptors, or provide a justification for why this has not been provided.

Amplification has not been considered within the NVIA, although you have acknowledged in your previous submissions that this can occur. The potential for this will be considered by the Environment Agency when we determine the potential impact. Therefore, should you want to provide further information with regards to amplification that shall support your application, please do so.

The absence of any further recognition or assessment within the NVIA of the risks presented by this manifestation of increased sound pressure levels at certain low frequencies within residential properties is a serious omission in the NVIA."

7.4.2. Appendix N provides a full justification for not including an assessment of amplification of LFN in dwellings. This is based on a review of published research on outside to inside low frequency sound transmission into buildings, a consideration of available research on vibration transmission into and through buildings, a review of the potential for resonance effects and room modes, and a review of the available measurement data obtained during previous operations by Wolf Minerals.

7.4.3. In summary, this review has found:

- Published research on outside to inside low frequency sound transmission into buildings shows that the sound reduction afforded by the building envelope at the low frequencies under consideration (12.5 Hz and 16 Hz) is small or even negligible. However, no instances of amplification within the building have been shown.
- Consideration of available research on vibration transmission into and through buildings also indicates that effects will be small or negligible. The laws of physics (conservation of energy) determine that no amplification in sound energy can occur.
- Measurement surveys undertaken at receptor locations at and around Hemerdon mine have shown a variation in sound pressure levels measured at various locations within individual receptor buildings. However, these results do not demonstrate any amplification effects within the building, and the research suggests that amplification effects will not occur. Resonance effects (e.g. from windows) can occur, but will only serve to negate any sound attenuation that might otherwise have been provided by the building façade / envelope.
- For the purposes of the low frequency sound prediction model, a worst case assumption would be that there are no amplification effects but there will also be no sound reduction provided by the building envelope, i.e. that the building structure is effectively 'invisible' to low frequency sound.

7.5 CONTEXT

7.5.1. Whilst the impact assessment has discussed the reduction in noise levels achieved from the acoustic enclosure with a discharge chute and the deck venting, the context of how the LFN at the assessment locations is also important.

7.5.2. It can be seen from the spectrograms in Section 5 that there are other screens and LFN sources in the area which contribute to the background LFN levels – i.e. those in the absence of DRL operations.

7.5.3. Section 1.4 shows that neither the county council nor the local district council have received any LFN complaints in the last 12 months. This strongly suggests that the background LFN is acceptable at the assessment locations.

7.5.4. The spectrograms in Section 5.2 for the far field results with the acoustic enclosure and discharge chute demonstrate that the screen is not visible amongst the background noise. As the screens are unlikely to be discernible above the background noise, it is a clear indication that there is likely to be a low impact at the assessment locations.

7.5.5. As the processing plant will work 24 hours a day and seven days a week, it is important to provide context of the night time noise impacts. The background noise levels at night-time have been analysed from data gathered at the three long-term far field noise monitoring locations (Portworthy Farmhouse, Dartmoor Zoo and Windwhistle) and a sample of the spectrograms are shown below. Note that it is the spectrograms which show background LFN which have been selected; background LFN is not continuously present at these receptors. It should be noted that no test work was being undertaken at Hemerdon at the times these spectrograms were recorded. The spectrograms show that there is other equipment operating at 12.5 Hz that contributes to the background LFN climate.

Figure 7-2 - Portworthy Farmhouse Night-time Spectrogram (16.06.2023 at 02:00 hours)

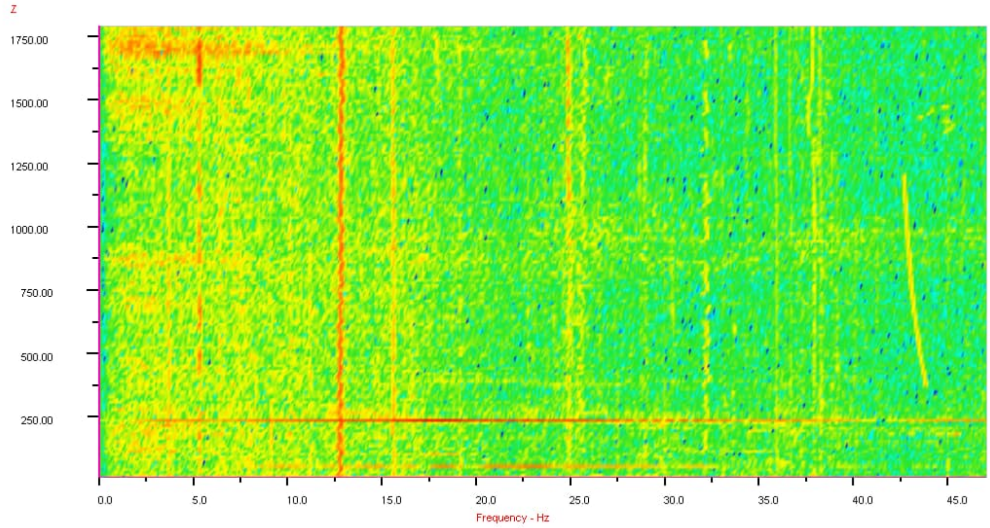


Figure 7-3 - Dartmoor Zoo Night-time Spectrogram (22.06.2023 at 02:00 hours)

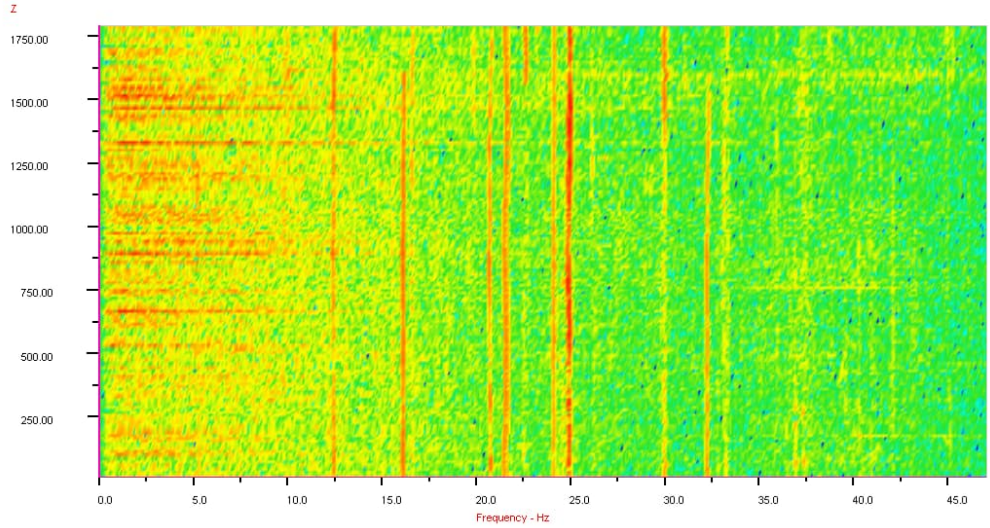
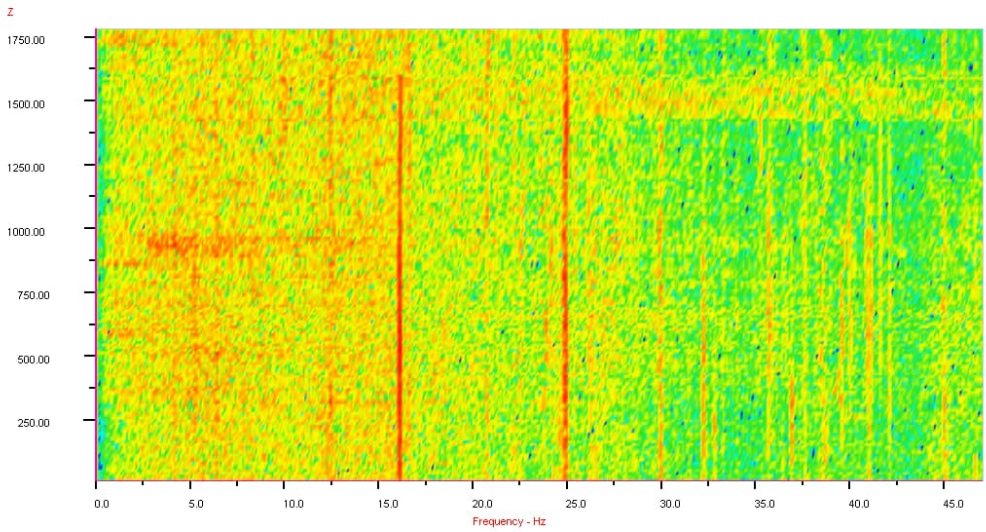


Figure 7-4 – WindwhistleFarm Night-time Spectrpgram (22.06.2023 02:00 hours)



7.5.6. It can be clearly seen that there is a night-time background LFN component at the far field receptors. This is likely to be due to other plant operating in the area.

7.6 CONCLUSION

7.6.1. Section 7.2 details a demonstrable noise level reduction due to the acoustic enclosures of 11 dB at the fundamental frequency and with an open area for the infeed and a discharge chute. A further reduction of 6 dB is achieved by deck venting, resulting in an overall reduction of 17 dB. This, in combination with the reduced total screen area, in comparison to those used by Wolf Minerals, results in levels which are in the order of 23 dBZ lower. This is a significant noise reduction which in WSP's professional opinion effectively reduces and minimises LFN to a level which should be deemed acceptable.

7.6.2. It is clear from the data which were analysed from the far field monitoring locations that LFN is present in the underlying background. The degree to which this is present differs amongst the three noise monitoring locations.

8 MITIGATION / NOISE CONTROL

8.1 INTRODUCTION

8.1.1. Whilst the Noise Impact Assessment section above details how acoustic enclosures and deck venting have been identified as inherent mitigation, it is also important that additional mitigation is considered in the form of secondary and tertiary mitigation. This allows for mitigation with a proven LFN reduction to be proactively selected and, if needed, implemented during operation.

8.2 OPTIONS APPRAISAL AND NOISE MANAGEMENT PLAN

8.2.1. An options appraisal exercise has been undertaken and a report detailing the findings is provided with the application documents (see WSP report *Options Appraisal Report*, dated August 2023). The report screens all mitigation options submitted in the Wolf Minerals options appraisal, (dated 2018) and takes forward appropriate mitigation options and dismisses those which are no longer relevant. The final five options appraised and ranked in the 2023 options appraisal exercise are:

- Acoustic enclosure to reduce noise levels at the fundamental frequency of the screen.
- Deck venting to reduce the acoustic efficiency of the screen and reduce noise levels at the fundamental frequency of the screen.
- Active noise control which generates a pressure waveform of the same magnitude but in anti-phase with the pressure being generated by the screen.
- Acoustic enclosure (as above) with Kingspan cladding to reduce noise levels at the second harmonic.
- Underpan venting to open the transmission path between the upper and lower surfaces to create a cancelling effect. This option was subsequently dismissed as it does not work in combination with deck venting.

8.2.2. The option scoring highest in the appraisal exercise has been included as inherent mitigation, along with secondary mitigation in the form of deck venting, which is also included as inherent mitigation. The remaining options either considered as secondary or tertiary mitigation are detailed in the following sections.

8.3 INHERENT MITIGATION

Acoustic Enclosure

8.3.1. The acoustic enclosure to reduce noise levels at the fundamental frequency is included as inherent mitigation. A reduction in noise level at the fundamental frequency has been proven during the LFN trials (see Section 5) as 11 dB.

8.3.2. All screens will be enclosed and operate with an 11 dB reduction due to the acoustic enclosure.

8.3.3. An enclosure was designed and built for the purpose of the trial. The design of the structure, including the material and its mass, was based on achieving a natural frequency of at least 20% more than that of the screen itself. The acoustic enclosures for the screens will all be designed to achieve a natural frequency of at least 20% above that of the screen it houses.

8.3.4. DRL has undertaken a hazard and operability review for the enclosure to ensure it is a practical solution. The acoustics enclosure will have a carefully designed openable door which will not compromise the noise reduction it provides. The door is to allow operator access for checks and maintenance. For the safety of the operator, all enclosures will be fitted with cameras and lighting. The screen itself will operate unhindered by the mitigation and this has been confirmed by suppliers.

Deck Venting

8.3.5. The deck venting mitigation option increases the open area of the screen by including a diamond shaped “chimney” (see the figure below). It mitigates noise by reducing the acoustic efficiency of the screen which reduces its sound pressure level.

8.3.6. A reduction in noise levels at the fundamental frequency of 6 dB has been proven via testing undertaken by Eatec Dynamics. The test report is included in Appendix O.

Figure 8-1 - Deck Venting

SECONDARY AND TERTIARY MITIGATION

8.3.7. The options appraisal ranked the acoustic enclosure with Kingspan cladding as being the most favoured option apart from the inherent mitigation measures as detailed above.

Acoustic Enclosure with Kingspan Cladding (Secondary Mitigation)

8.3.8. As detailed in the Options Appraisal Report, this mitigation is targeted at reducing noise levels at the second harmonic. Whilst measurements and predictions show that the second harmonic is not visible at the assessment locations, DRL considered it appropriate to have a tested and proven solution for mitigating noise levels at the second harmonic, should it be needed.

8.3.9. The Kingspan product included in the LFN trial is the same as that recommended in the SLR audible noise assessment (see Table 5-2 of the SLR report) submitted with the application.

8.3.10. The Kingspan product information does not include noise level reductions at the low frequencies and, through the LFN trial, its reduction has been proven to be at least 4.2 dB at the second harmonic (see Section 5).

Tertiary Mitigation

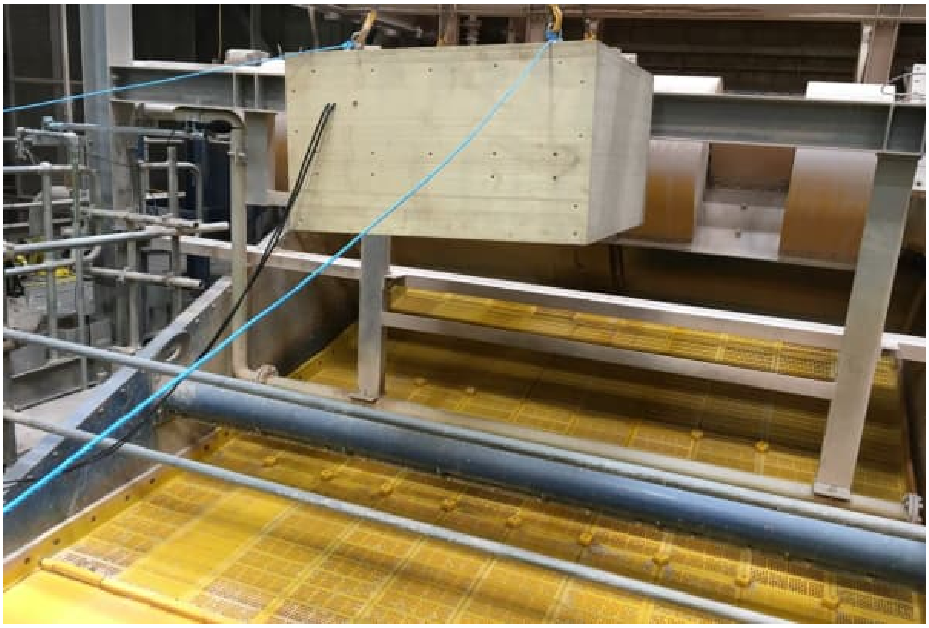
8.3.11. Active noise control has been identified in the Options Appraisal Report as tertiary mitigation.

8.3.12. This will be considered if, following operation and implementation of the secondary mitigation, LFN is substantiated to be impacting noise sensitive receptors.

8.3.13. Active noise control is a noise cancelling system which generates a pressure waveform close to the screen deck that is of the same magnitude and in anti-phase with the pressure being generated from the screen. It is a solution which has a proven reduction of 10dB at the running frequency.

8.3.14. The figure below shows the active noise control system during the trial undertaken by Eatec Dynamics. The Eatec Dynamics test report is provided in Appendix P.

Figure 8-2 - Active Noise Control



8.3.15. It is considered as tertiary mitigation as it is an active system which is least preferred. However, DRL is committed to it being implemented, should it be identified as necessary.

8.4 MAINTENANCE

8.4.1. The screens need to be proactively maintained to ensure, amongst other things, that they continue to operate as expected as poorly maintained equipment can increase noise levels.

8.4.2. Each area of the plant has a number of process control loops which allow the equipment within that area to be operated under controlled and steady state conditions. Also, for each area there are critical control parameters for operating the equipment. Field instrumentation including pressure, flow, mass, density, and speed transmitters feed to the Supervisory Control and Data Acquisitioning (SCADA) via the programmable logic controller (PLC). These real time inputs are programmed to perform certain control decisions based on data collected. Control functions may include turning power on/off, adjusting temperature, decreasing, or increasing speed, and regulating a variety of processes.

8.4.3. An example of the feed control to 140-SN-01 is shown below.

DMS FEEDER 1 & 2 SPEED CONTROL (WIC14014)

8.4.4. The DMS feeders 1 and 2 (140-FE-01/02) speeds are controlled by the measured DMS circuit throughput (WIT14014). The DMS feeder 1 and 2 speed control may be operated in either “Man” or “Auto” modes of control. In “Auto” mode of control, the feeders will run at 30% on start up for 30 seconds before enabling the control loop WIC14014 to allow feed to reach the weightometer

(WIT14014). The control loop (WIC14014) operates according to the following when in “Auto” mode:

Table 8-1 – Control Loop Auto Mode Operating

Control Loop	Description	Process Variable (PV)	Input – Set-point (SP)	Output – Control Variable (CV)
WIC14014	DMS circuit feed rate control	DMS circuit feed rate measured by weightometer (WIT 14014) in t/h	Desired DMS circuit feed rate set by operator in t/h	Vibrating feeder (140-FE-01 and 140-FE-02) speed in %

9 UNCERTAINTIES

9.1 INTRODUCTION

9.1.1. This section details and, where possible, quantifies the uncertainties in this assessment and discusses how they may influence the findings of this report.

9.1.2. Uncertainty is an unavoidable feature of measurements in the field, which can be subject to many factors. Uncertainty is also unavoidable in the prediction of sound levels, where naturally, before the scenario being considered becomes a reality, a number of assumptions need to be relied upon. There is also the uncertainty of people's reactions, which can be influenced by a number of factors, not just the magnitude or character of the sound in question.

9.1.3. Whilst LFN is outside the scope of British Standard 4142, the Standard includes a robust approach to uncertainty and this has, in part, been used to inform this assessment of uncertainty.

9.1.4. Crucially, measurements have been undertaken by suitably qualified staff, using state of the art, equipment, in a number of locations, over a period deemed sufficient for this impact assessment, and experiencing a range of weather conditions, including wind speed and direction.

9.1.5. The prediction and assessment of noise levels have also been undertaken by suitably qualified staff, whilst using the best available information and undertaking research where there are not go-to industry methods available and it is necessary to better understand an issue.

9.1.6. Appendix Q details all of the issues considered in the assessment of uncertainty. In this Appendix, the items in red are those which need to be quantified and this exercise is presented in the following sections. A summary of the issues is presented in Table 9-1.

Table 9-1 – Summary of Uncertainty Considerations

	Uncertainty Measure	Comments
Measurement		
1	Measure under different operating conditions relevant to your assessment / adopt worst case if known	Achieved by using different ply coverings during the LFN trial
2	Evaluate any difference in noise level which might results between using manufacturer noise levels versus measured noise levels	Yes. The assessment is based on manufacturer source data for some screens. For some screens, a comparison of measured versus manufacturer data has been undertaken and measured levels are lower.
Noise Modelling Prediction		
3	Obtain data which allow a robust acoustic efficiency value to be derived	Yes, although a cautious approach has been taken
4	Use measurement data at different distances/locations to verify propagation	Yes, although it has identified the need to undertake more research on LFN and wind effects
5	Where mitigation is included in the noise model, ensure it is tested with proven results available.	Yes, although assessment uses a cautious approach to quantifying the reduction from inherent mitigation
Receptors		
6	Assess any amplification effects of LFN in buildings	Yes – no amplification has been assumed within the building and, cautiously, no attenuation from the building structure is assumed
7	Quantify and assess the effects of beating caused by more than one screen operating	Yes – a +5dB correction can be applied for beating

9.1.7. Each of the above uncertainty measures is expanded upon below and, where possible, the uncertainty in the assessment is quantified.

9.2 MEASUREMENTS

MEASUREMENT UNDER DIFFERENT OPERATING CONDITIONS

9.2.1. The LFN trial included measurements with various plywood arrangements which were representative of the differing amounts of material on the screen deck.

9.2.2. As expected, the highest noise levels were measured with a full ply covering and it is these levels which have been used in the assessment.

9.2.3. This is a conservative approach to the assessment and, whilst close to a realistic scenario, is does overestimate the noise level from the screen.

9.3 NOISE MODEL

ACOUSTIC EFFICIENCY VALUE

9.3.1. The noise model includes noise levels for the screens which have been measured on many occasions with little variation. The source data are considered to include negligible levels of uncertainty.

9.3.2. The acoustic efficiency of the screens is detailed in Section 6.3 and shows that a conservative value of 0.3 has been used, as opposed to 0.1 being used for the Wolf Minerals modelling. This results in the likelihood of the modelled noise levels being overpredicted by up to 8 dB.

VERIFYING PROPAGATION

9.3.3. The model validation process is as described in Section 6. The validation of the model against measurements at the far field locations has highlighted that wind effects for downwind receptors can result in higher than anticipated noise levels, particularly at receptors at distance from the site. For example, measurements at Yondertown during downwind conditions (i.e. when the wind is westerly, blowing from the site towards the receptor) are higher by 6.4 dB than the levels predicted in the model, albeit that the model has neutral wind conditions. The on-site meteorological station shows an average wind speed of 2 m/s and gusts of up to 5 m/s during the measurement at Yondertown. Analysis of the wind rose data (see Figure 5-36) shows that Yondertown is in downwind conditions for 5% of the time (i.e. westerly winds occur for 5% of the time) and, therefore this increase in noise levels will be experienced for only 5% of the time.

9.3.4. Whilst the theory of wind propagation of LFN is understood, understanding the extent to which it influences noise levels at the assessment locations requires further work.

9.3.5. Wind speeds from the on-site meteorological station are presented in the wind rose in Figure 5-36 and include data gathered over the last 13 months. The dominant wind direction is south-westerly and, over the last 13 months, the wind was from this direction (SSW, SW and WSW) for 42% of the time and the average wind speed in this direction ranged from 0 m/s to 13 m/s with most data being captured in the 3-4 m/s range.

9.3.6. This suggests that, of the receptors considered, those to the north-east will most regularly experience noise levels which are higher than those predicted by the noise model. These receptors include those represented by East of Lee Moor and those in the northern areas of Lutton and Cornwood. Fortunately, this is the least densely populated area around the mine. However, other receptors will also experience downwind conditions and DRL proposes to research wind effects and LFN upon operation. The study would aim to identify the extent of the increases experienced at assessment locations during a range of typical conditions. The findings of the research would assist DRL during the complaints process, if it were needed, and would be shared with the EA.

9.3.7. To conclude, it is recognised that wind effects are known to result in increased noise levels of up to 6.4 dB and that further research is required to better quantify the LFN variation in the area due to wind speed and direction. However, the Schedule 5 states the following:

"A reduction from the current proposed levels would need to be demonstrated within the NVIA for us to consider issuing an environmental permit authorising operation of the proposed Mineral Processing Facility."

9.3.8. Regardless of wind effects, which DRL acknowledges are important and do need to be further researched, the reduction in noise levels from the acoustic enclosures in comparison to Wolf Minerals' operation is 11 dB, with a further reduction of 6 dB obtained from deck venting. The overall reduction, including the removal and replacement of operational screens, is in the region of 23 dB. The same wind effects would have been present when the mine was operated by Wolf Minerals.

PROVEN REDUCTION FROM MITIGATION

9.3.9. The LFN trial with the acoustic enclosure to reduce noise levels at the fundamental frequency had a discharge chute and an open infeed inlet measuring 1175 x 558 mm. In practice, there would be an infeed chute as well as a discharge chute. The inclusion of an inlet chute is likely to result in a further reduction as the open area of the enclosure would be reduced, therefore enhancing the performance of the enclosure at the natural frequency.

9.3.10. It is difficult to quantify the reduction expected from the additional chute on the infeed. However, this is a conservative approach to the assessment which will overpredict the noise levels at the assessment locations.

9.4 RECEPTORS

AMPLIFICATION OF LOW FREQUENCY NOISE IN DWELLINGS

9.4.1. Item 1.g of the March 2023 Schedule 5 requests consideration of amplification of low frequency noise within the receptors. A review of published technical literature and previous investigations at Hemerdon Mine and nearby receptors has been undertaken and is included in the technical memo in Appendix N.

9.4.2. The technical note provides the following summary:

- Published research on outside to inside low frequency sound transmission into buildings shows that the sound reduction afforded by the building envelope at the low frequencies under consideration (12.5 Hz and 16 Hz) is small or even negligible. However, no instances of amplification within the building have been shown.
- Consideration of available research on vibration transmission into and through buildings also indicates that effects will be small or negligible. The laws of physics (conservation of energy) determine that no amplification in sound energy can occur.
- Measurement surveys undertaken at receptor locations at and around Hemerdon mine have shown a variation in sound pressure levels measured at various locations within individual receptor buildings. However, these results do not demonstrate any amplification effects within the building, and the research suggests that amplification effects will not occur. Resonance effects (e.g. from windows) can occur, but will only serve to negate any sound attenuation that might otherwise have been provided by the building façade / envelope.
- For the purposes of the low frequency sound prediction model, a worst case assumption is that there are no amplification effects but there will also be no sound reduction provided by the building envelope, i.e. that the building structure is effectively 'invisible' to low frequency sound

9.4.3. It is therefore not considered appropriate to include an uncertainty correction for amplification of LFN in dwellings.

BEATING EFFECTS AT DWELLINGS

9.4.4. As detailed in Section 7.5, the Broner 2010 paper (Ref 13) suggests a +5 dB penalty where the LFN sound pressure level is fluctuating at least ±5 dBC. This has been assumed for all receptors and the penalty is to reflect the annoyance associated with the beating effect. There are no other identified research papers which provide a penalty for beating. As such, the Broner penalty is considered to be appropriate.

9.5 SUMMARY OF UNCERTAINTY IN THE ASSESSMENT

9.5.1. Table 9-2 below summarises the uncertainty discussed above.

Table 9-2 – Summary of Uncertainty

	Uncertainty Measure	Effect on the NIA Outcomes	Quantify	Outcome/ Recommendations
1	Measure under different operating conditions relevant to your assessment / adopt worst case if known	Overpredicts LFN	Unknown	Acknowledged as an unquantified value which very slightly overpredicts LFN
2	Evaluate any difference in noise level which might results between using manufacturer noise levels versus measured noise levels	Overpredicts LFN	Approximately 2 dB	Model overpredicts LFN
3	Obtain data which allow a robust acoustic efficiency value to be derived	Overpredicts LFN	Up to 8 dB	Considerably overpredicts LFN
4	Use measurement data at different distances/locations to verify propagation	Underpredict LFN during downwind conditions	Extent of the underprediction is unknown, although 6.4 dB has been measured	Underpredicts noise levels and potentially by a considerable value at some receptors during downwind conditions
5	Where mitigation is included in the noise model, ensure it is tested with proven results available.	Overpredicts LFN	Unknown and to be quantified upon operation.	Acknowledged as an unquantified value which overpredicts LFN
6	Assess any amplification effects of LFN in buildings	Overpredicts	Unknown	Acknowledged as an unquantified value which is likely to very slightly overpredict LFN
7	Quantifying and assessing the effects of beating caused by more	N/A	N/A	Beating penalty of +5 dB to be added to the assessment

	than one screen operating			

9.5.2. The uncertainty now needs to be considered in terms of its potential impact on the assessment outcomes. As uncertainty measures numbered 1 and 6 in the table are considered minor, they have been discounted from further consideration.

9.5.3. Uncertainty measures 2 and 3 result in a combined uncertainty of 10.3 dB overprediction of modelled noise levels. The uncertainty value for the noise model underpredicting is 6.4 dB, or more. Taking these values and including a penalty to the noise levels of +5 dB for beating results in a 1.1 dB increase in the DRL predicted sound pressure levels shown in Table 6-3 in Section 6.6 and at least a 17.9 dB reduction when compared to the Wolf Minerals operation. However, this could be considered an unfair comparison as the modelled sound pressure levels from Wolf Minerals do not include wind effects or beating. With these effects removed from the DRL predicted levels in Table 6-3 (but including uncertainty of -10.3 dB for uncertainty measures 2 and 3) results in a reduction of at least 30 dB when compared to the Wolf Minerals operation. This is a considerable and impressive reduction in noise levels and only confirms the conclusion of the noise impact assessment.

10 CONCLUSIONS AND NEXT STEPS

CONCLUSIONS

10.1.1. This Noise Impact Assessment has been prepared in response to the Schedule 5 notice issued by the Environment Agency (EA) dated 1st March 2023. The Schedule 5 notice is specifically in relation to low frequency noise (LFN) from the Minerals Processing Facility (MPF). A satisfactory response to the Schedule 5 notice is required to enable the EA to issue an Environmental Permit for the operation of the mine.

10.1.2. The Noise Impact Assessment has considered:

- The history of LFN emissions from the site, which is summarised in Section 1 of this Report.
- The relevant legislation, policy, guidance and standards pertaining to LFN, and the available research on the generation, propagation and effects of LFN, which is summarised in Section 2 of this Report.
- The locations and receptors that could be affected by LFN emissions from the MPF, which is summarised in Section 3 of this Report.
- The results of measurement surveys (including measurements of LFN and meteorological conditions) to determine typical background levels of LFN in the absence of operations at Hemerden.
- The measurement results from on site trials to quantify the reductions in LFN emissions that can be achieved from various mitigation interventions, including the implementation of acoustics enclosures and deck venting applied to the screens. This is summarised in Sections 4 and 5 of this Report.
- The results of a LFN noise modelling exercise to calculate the levels of LFN that would likely be experienced within the community surrounding the Hemerdon mine, should the MPF become operational upon implementation of appropriate LFN mitigation measures as identified in Section 5 of this Report. The results of this modelling exercise are presented in Section 6.
- An assessment of the predicted LFN levels in the context of their acceptability, using comparisons with the previous Wolf Minerals operations and the existing (i.e. excluding Hemerdon mine operations) LFN in the area. The results are presented in Section 7 of this Report.
- The possibility of implementing further mitigation measures upon operation, should it be deemed necessary. This is presented in Section 8 of this Report.
- A consideration of uncertainties in the assessment, including the noise measurements, data analysis, noise model predictions and assessment, how these have been minimised and the degree to which they have influenced the outcome of the assessment. This is summarised in Section 9.

10.1.3. The results of this assessment are that:

- The background noise climate as measured at various residential locations includes LFN from sources external to the Hemerdon site. The measured background data suggests that there are other sites in the area operating screens or other equipment with a similar operating speed / frequency to the screens proposed for Hemerdon MPF.
- The results from on site trials has demonstrated that the implementation of acoustic enclosures (including outlet chutes) provides a reduction of 11 dB compared to the situation without

enclosures (which was the case when the mine was operating under the control of Wolf Minerals as the previous operator).

- On site trials have also demonstrated that a further reduction in LFN of 6 dB can be achieved through the use of deck venting to the screens.
- The implementation of both acoustic enclosures and deck venting is proposed for Hemerdon MPF. The combined effect of these measures will be a reduction of 17 dB compared to the previous situation when the site was operating under the control of Wolf Minerals.
- Furthermore, the proposed future operations at Hemerdon will utilise a set of screens with a lower overall screening area than was used previously under Wolf Minerals.
- The combined effect of these measures is that the expected levels of LFN at receptor locations in the community surrounding Hemerdon will be of the order of 23 dB lower than was the case when the site was operated by Wolf Minerals.
- There will be beating effects associated with the LFN as experienced at locations within the community surrounding Hemerdon mine. This was the case under previous operation by Wolf Minerals and is an inevitable consequence of having multiple screens in operation. However, the reduction in overall levels of LFN ought to make beating effects less noticeable.
- There are some known uncertainties associated with the LFN predictions. In particular, LFN if experienced within the neighbouring community will vary depending on meteorological conditions. This was the case under previous operation of the Hemerdon site by Wolf Minerals, and will remain the case under operation by DRL. The potential uncertainties have been quantified in Section 9 of this Report and, in summary, the assessment is considered to be conservative in its approach.

RECOMMENDATIONS AND NEXT STEPS

10.1.4. This noise impact assessment has demonstrated that upon implementation of the proposed mitigation measures (use of acoustic enclosures and deck venting applied to the screens), LFN will be reduced by 17 dB compared to the previous situation when the site was operated by Wolf Minerals. Additionally, changes to the proposed operation of the MPF including the use of new screens with a lower total screening area (compared to the Wolf Minerals operations) are projected to result in a total combined reduction of 23 dB.

10.1.5. This represents a substantial reduction in levels of LFN. As such, it is recommended that an Environmental Permit be issued for operation of the mine.

10.1.6. DRL has committed to the implementation of additional control measures (identified as secondary and tertiary control measures in Section 8 of this Report) if, following operation and implementation of the inherent mitigation, LFN is substantiated to be impacting noise sensitive receptors.

10.1.7. The Noise Management Plan, submitted alongside this Noise Impact Assessment, identifies the future LFN monitoring protocols that will be implemented should the MPF become operational following receipt of the necessary permits. The results from this monitoring will be used to identify the need for further control measures as required.

10.1.8. The results of future LFN measurements, alongside data obtained from the on site meteorological station, can be used to further investigate the LFN prediction uncertainties associated with meteorological conditions.

Appendix A

ENVIRONMENT AGENCY
SCHEDULE 5 NOTICE (MARCH 2023)

CONFIDENTIAL

Notice of request for more information

The Environmental Permitting (England & Wales) Regulations 2016

Drakelands Restoration Limited

Company Secretary
Shakespeare Martineau Llp
6th Floor
60 Gracechurch Street
London
EC3V 0HR

Application number: **EPR/AP3203ML/A001**

The Environment Agency, in exercise of its powers under paragraph 4 of Part 1 of Schedule 5 of the above Regulations, requires you to provide the information detailed in the attached schedule. The information is required in order to determine your application for a permit duly made on 16/09/2021.

Send the information to either the email or postal address below by 23/03/2023. If we do not receive this information by the date specified then we may treat your application as having been withdrawn or it may be refused. If this happens you may lose your application fee.

Email address: psc@environment-agency.gov.uk.

Postal address:
Permitting Support, NPS Sheffield
Quadrant 2
99 Parkway Avenue
Parkway Business Park
Sheffield
S9 4WF

Name	Date
Jake Walker	01/03/2023

Authorised on behalf of the Environment Agency

Notes

These notes do not form part of this notice.

The notes in italics that appear after information requests in the attached schedule do not form part of the notice. The notes are intended to assist you in providing a full response.

General Comments

On 16th February 2022 we issued a Schedule 5 request with regards to the former low frequency Noise and Vibration Impact Assessment (NVIA. A substantially new NVIA (Reference: PS134446) was provided by the Applicant to the Environment Agency on 1st December 2022.

The new NVIA does not satisfactorily address all of the points requested in the 16th February 2022 Schedule 5. The internal sound levels predicted in the report are within 5dB of those polluting levels previously measured by the Environment Agency in 2017. This, together with the source and modelling uncertainties, means we do not currently have sufficient confidence that the emissions from the proposed operation will be prevented or sufficiently minimised.

We noted in February 2022 that the uncertainties associated with the modelling, the criteria and the confusing proposed mitigation, we have yet to be convinced that the measures the Applicant is suggesting will sufficiently avoid the risk of pollution. This position has not changed.

We also noted in February 2022 that given our concern about the magnitude of the proposed LFN/infrasound emissions, and the risks presented to the local population, the Applicant needed to assess further control options so the cumulative effect could be quantified. This has not yet been done.

A reduction from the current proposed levels would need to be demonstrated within the NVIA for us to consider issuing an environmental permit authorising operation of the proposed Mineral Processing Facility.

A satisfactory response to this Schedule 5 is essential for your application to continue.

Outstanding Questions

Some of the unsatisfied requests from the 16th February 2022 Schedule 5 have been amended, and included in the attached Schedule 5. The Schedule 5 dated 16th February 2022 is therefore deemed closed.

Schedule

NOISE AND VIBRATION IMPACT ASSESSMENT, Ref PS134446 dated 29/11/2022 (referred to from here on as NVIA).

1. Please provide a revised NVIA to address the following issues:

a. Within the NVIA report, provide a non-technical summary and conceptual plan of the proposal with regards to low frequency noise impact, covering the following areas:
  - The potential sources of low frequency noise, and location;
  - New equipment at the site, the location and mitigation;
  - Disused equipment at the site, and location; and,
  - Main mitigation measures.

This summary is needed to provide additional clarity to identify historic changes to the site and proposals. We acknowledge that some of this information is currently provided within the NVIA report, and will also likely be in the Noise Management Plan, but a summary at the front of the NVIA report would be useful for both members of the Environment Agency, and also members of the public that may read the NVIA.

b. Amend the NVIA to include all potential sources of low frequency noise, or provide a justification for the exclusion of potential sources of noise from the assessment.

You have stated that Tungsten West has updated the BS4142 background noise assessment to consider the impact of noise from a proposed Primary Jaw and Secondary Cone crushing arrangement. This does not justify its exclusion from the NVIA.

All potential sources need to be included in the NVIA, or provide a written justification as to why it is not. The new proposed jaw crushers are expected to be significant sources of LFN/infrasound. It is not known at what mechanical frequency those items of plant operate, nor the sound power at those frequencies. Any effects from these additional sources are therefore not currently quantified or understood.

c. Amend the NVIA to include the impact at 20Hz 1/3 octave band for completeness.

d. Provide further information to justify the chosen acoustic radiation efficiency of 0.1 for all screens, or justify and use a more conservative assumption for the assessment.

Table 17 of in the previous NVIA report (Ref TWL-CP-PA-EN-006.2.23 dated 18/08/2021) identified an Acoustic Efficiency (AE) range of 0.005 to 0.819. Whilst it is understood that J5510B and J5645B screens are excluded, it is not clear why the higher AE figures from Table 17 have not been considered.

e. Include additional mitigation options within the NVIA.

A previous Schedule 5 notification (dated 16/02/2022) requested a more comprehensive appraisal (including consideration of costs and benefits) of all available control options.

You have stated that this written appraisal shall be included as part of the Noise Management Plan. We also require these options to be assessed within the NVIA to justify your selection of appropriate measures to prevent or where that is not practicable minimise emissions of infrasound/low frequency noise.

It is noted that previously discussed mitigation measures such as antiphase speakers, enclosure of sources, and Innova J57 building cladding proposed under previous operation, have not yet been considered for the assessment, and the currently modelled insertion loss of the proposed double-layer concrete building cladding system is zero for sound frequencies in the 12.5 Hz, 16 Hz, and 25 Hz third octave bands.

f. Provide additional information on the proposed cladding, and ensure that this is consistent with the BS4142 assessment and any Noise Management Plan.

It is currently unclear what cladding is proposed for the different Mineral Processing Facility buildings, equipment housing or extensions. Whilst we expect that further detail shall be provided in the Noise Management Plan, it must be ensured that this information is also clear in the NVIA. The BS4142 assessment and NVIA currently contain insufficient and conflicting detail on the proposed cladding. You must identify clearly in the Application what control measures are proposed in order to enable us to make a determination.

g. Provide an assessment of amplification within the receptors, or provide a justification for why this has not been provided.

Amplification has not been considered within the NVIA, although you have acknowledged in your previous submissions that this can occur. The potential for this will be considered by the Environment Agency when we determine the potential impact. Therefore, should you want to provide further information with regards to amplification that shall support your application, please do so.

The absence of any further recognition or assessment within the NVIA of the risks presented by this manifestation of increased sound pressure levels at certain low frequencies within residential properties is a serious omission in the NVIA.

h. Provide consideration and quantification of the uncertainty of the propagation model, including the source sound power uncertainties and directivities. Consider the quantitative effect of constructive and destructive interference at different locations at distance arising from operation of coherent, or nearly coherent (as opposed to non-coherent) sound sources operating at low frequencies. Consider the worst-case scenarios, and what impact these would have on the identified receptors.

Uncertainty has not been considered within the NVIA. We are concerned that the known uncertainty of the measured acoustic efficiencies, together with the unknown uncertainty of the propagation model, could fail to correctly identify the impact on receptors. Operation of coherent sound sources (e.g. large mechanical screens running at the same low frequencies) will generate interference patterns of areas of constructive and destructive interference (higher and lower sound pressure level) at distance at those sound frequencies.

Slight differences in operating frequencies will also introduce beating patterns at distant locations, repeating changes to the interference pattern over short periods of time. We need to understand if and how the chosen model accounts for this, and how this is likely to affect sound pressure levels which will be experienced at distant locations.

Appendix B

CREDENTIALS OF THOSE INVOLVED IN COMPILING THE REPORT

Louise Beamish: WSP, Director (BSc, MIOA)
Louise is a Director and the Head of Profession for acoustics at WSP. Louise has 23 years of experience working in environment and engineering consultancies and specialises in environmental acoustics. Louise's experience extends to many sectors including infrastructure, residential, commercial, mining and renewable energy. Louise typically leads large and/or complex projects and, more recently, these include Development Consent Orders for a new interconnector and widenings of the A1 in Sunderland. She has also provided expert evidence at public enquiries and planning hearings. Louise is actively involved in the acoustics industry, having served as a Council member for the Institute of Acoustics for seven years and she is currently a board member of the Association of Noise Consultants and its vice chair.
Keith Jefferson: WSP, Associate Director (MSc, MIOA, CPhys, MInstP)
Keith is a senior acoustics and vibration specialist with 29 years' experience in the calculation, assessment and control of environmental noise and vibration. He has undertaken numerous noise and vibration impact assessments for a wide range of commercial, industrial and transportation developments and has managed noise and vibration impacts from major infrastructure projects. Keith's role at WSP includes the mentoring and technical development of colleagues and provision of specialist training on all aspects of environmental noise and vibration.
Alex West: WSP, Senior Engineer (BA, MIOA)
Alex has been working in the field of acoustics for eleven years, with experience working both in the United Kingdom and New Zealand. As an acoustic Engineer he has contributed to many environmental noise projects associated with mining and quarrying, natural gas production, complex industrial facilities, energy and hospitality development sectors.
Yasmin Hall: WSP, Apprentice
Yasmin is an Apprentice with four years' experience working in the field of environmental consultancy including one year in Acoustics. She has contributed to projects across the UK and internationally in sectors such as infrastructure, energy and transportation. Yasmin is proficient in GIS mapping software and undertaking noise measurement data analysis.
Brian Jarvis: Eatec Dynamics, Director (CEng FIMechE MIOA)
Brian is the director of Eatec Dynamics with 47 years' experience in theoretical and experimental noise and vibration. He was previously a director of PAFEC Ltd responsible for the dynamics coding in commercial finite element software. Brian ran the Bristol office of PAFEC, responsible for consultancy projects mainly in the aerospace and marine sectors before setting up Eatec Ltd to expand the operations into experimental testing and to include other industry sectors. In 2015, Eatec Dynamics was formed to expand into new areas of application of dynamics to investigate structural integrity of historic buildings.

Brian is a member of the Dynamics and Testing Working Group of NAFEMS and is active in research for control of airborne and underwater radiated noise. He has provided the technical input for a number of patents in the fields of vibration and acoustics.

Appendix C

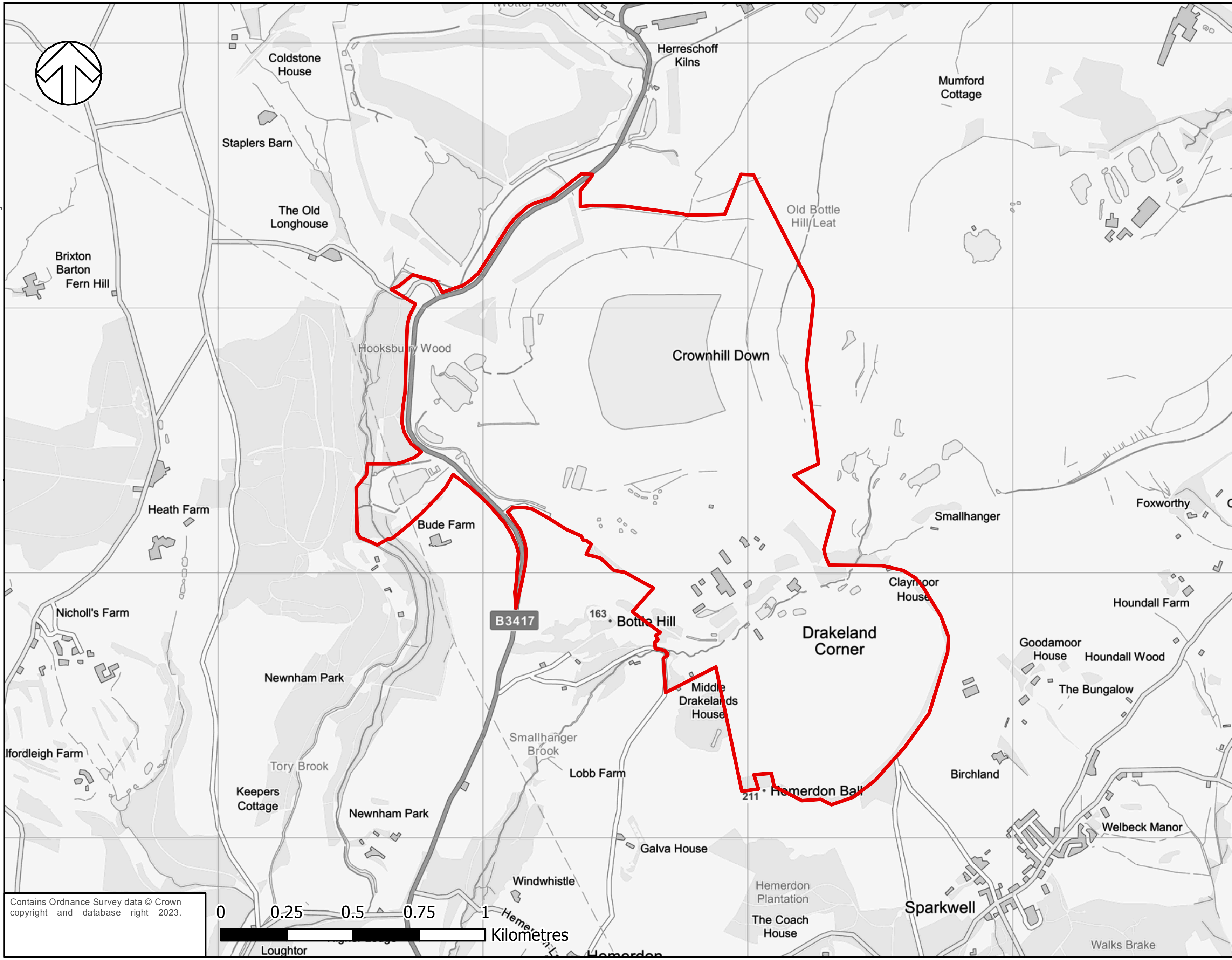
GLOSSARY OF ACOUSTIC TERMINOLOGY

Sound Pressure	Sound, or sound pressure, is a fluctuation in air pressure over the static ambient air pressure.
Sound Pressure Level (Sound Level)	The sound level is the sound pressure relative to a standard reference pressure of 20μPa (20×10^{-6} Pascals) on a decibel scale.
Decibel (dB)	A scale for comparing the ratios of two quantities, including sound pressure and vibration velocity. The difference in level between two sounds s_1 and s_2 is given by $20 \log_{10} (s_1 / s_2)$. The decibel can also be used to measure absolute quantities by specifying a reference value that fixes one point on the scale. For sound pressure, the reference value is 20μPa. For vibration velocity the reference value is 10^{-6} mms^{-1}.
A-weighting, dB(A) G-weighting, dB(G)	The unit of sound level, weighted according to the A-scale, which takes into account the increased sensitivity of the human ear at some frequencies. The G weighting specifically applies to low frequency sound and is weighted to account for human sensitivity to how the sound is *felt* rather than heard.
Noise	Any unwanted sound.
Free-field	Far from the presence of sound reflecting objects (except the ground), usually taken to mean at least 3.5m.
Façade	At a distance of 1m in front of a large sound reflecting object such as a building façade.
Octave Band, Third Octave band	An octave band refers to a range of frequencies whose upper limit is twice the frequency of the lower limit. An octave band is sometimes divided into a one third octave band to allow for more detailed analysis.
Sound Reduction Index, R	A measure of the airborne sound insulating properties, in a particular frequency band, of a material in the form of a panel or partition, or of a building element such as a wall, window or floor. Measured in decibels. Also sometimes referred to as transmission loss.
Weighted Sound Reduction Index, R_W	A single figure value of sound reduction index, derived according to procedures given in BS5821. Used for rating and comparing partitions based on the values of sound reduction index at different frequencies.
Displacement, Acceleration and Velocity Root Mean Square (r.m.s.) and Peak Values	Vibration is an oscillatory motion. The magnitude of vibration can be defined in terms of displacement (how far from the equilibrium position that something moves), velocity (how fast something moves), or acceleration (the rate of change of velocity). When describing vibration, one must specify whether peak values are used (i.e. the maximum displacement or maximum velocity) or r.m.s. values (effectively an average value) are used.
Root Mean Square (r.m.s.)	The r.m.s. value of a set of numbers is the square root of the average of the squares of the numbers. For a sound or vibration waveform, the r.m.s. value over a given time period is the square root of the average value of the square of the waveform over that time period.
Frequency (Hz), Frequency Spectrum	Sound and vibration occurs over a range of frequencies (cycles per second, or Hz), referred to as the frequency spectrum. The range of human hearing can extend as low as 20Hz and as high as 16kHz. However, in the case of low frequency sound, the sound can be felt via other mechanisms apart from the human ear.

Attenuation	A general term used to indicate the reduction of noise or vibration, or the amount (in decibels) by which it is reduced.

Appendix D

SITE LOCATION



Key

Approximate Site Boundary

wsp

TITLE:

SITE LOCATION

FIGURE No:

Drawn By: YH Date Modified: 09/08/2023

File: \\uk.wspgroup.com\central data\Projects\70108xxx\70108756 - Tungsten Mine - LFN03 WIP\7. Models\01 GIS

Appendix E

SIMPLIFIED LAYOUT OF PROCESSING PLANT

REFERENCE DRAWING	DRAWING NUMBER	REV	DATE	REVISION	DRN	CHK	TECH	PROJ
		A	04/08/2023	FOR INFORMATION ONLY	DA			

WHEN IN DOUBT – ASK
DO NOT SCALE

TUNGSTEN WEST
Tungsten West plc
Hemerdon Mine
Drakelands
Devon PL7 5BS
tungstenwest.com

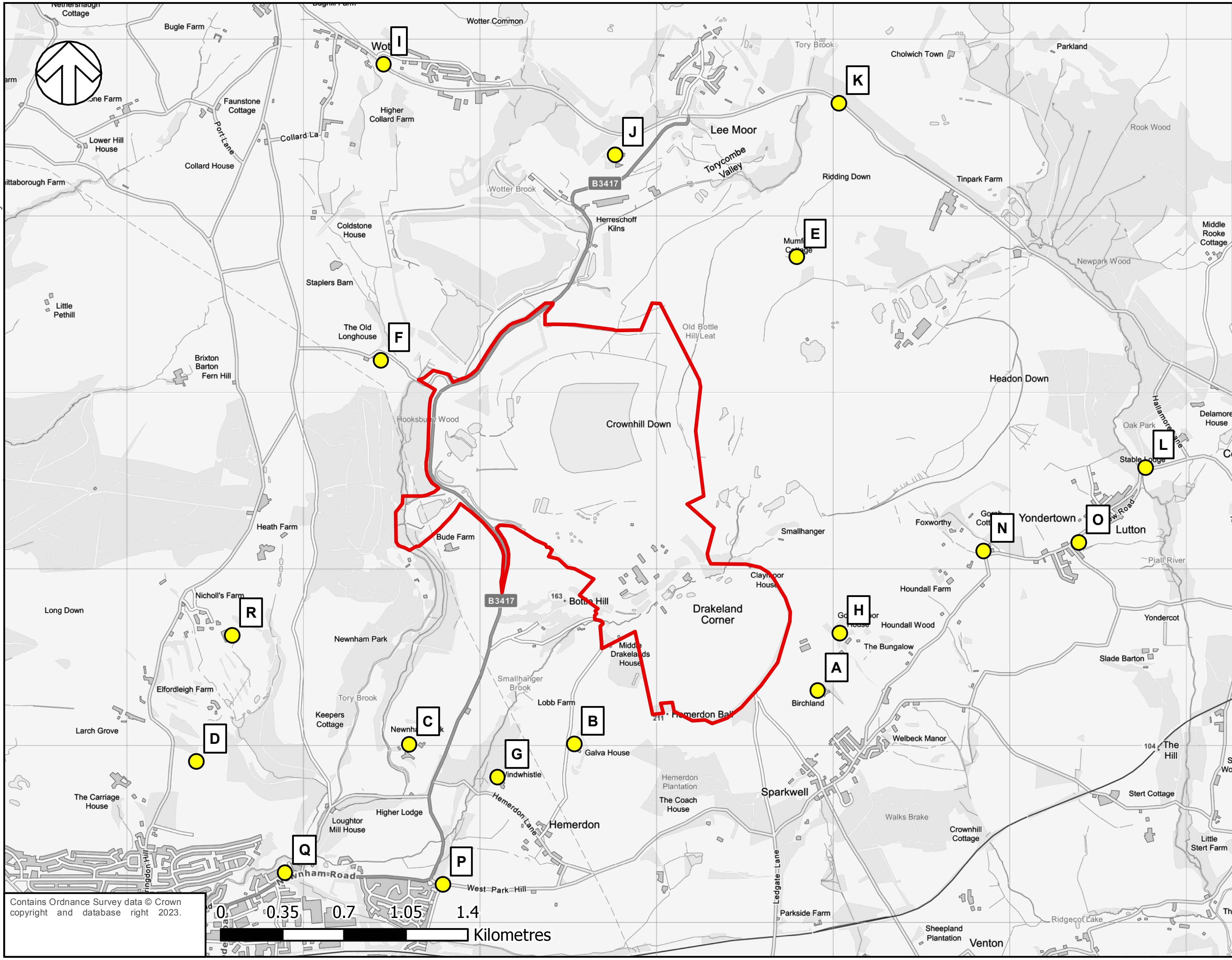
DRAWN	DJA	04/08/2023
CHECKED		
DESIGNED		
TECH APP		
PROJ APP		
CLIENT APP		

TUNGSEN WEST PLC
HEMERDON RESTART PROJECT
PROCESS PLANT LAYOUT
PLAN

A1	SCALE N.T.S.	JOB No -----	DWG No TWL 100-L-001	REV A

Appendix F

RECEPTOR AND ASSESSMENT LOCATION



Key

- Noise Sensitive Receptor
- Approximate Site Boundary

TITLE:

NOISE SENSITIVE RECEPTORS

FIGURE No:

Date Modified: 09/08/2023

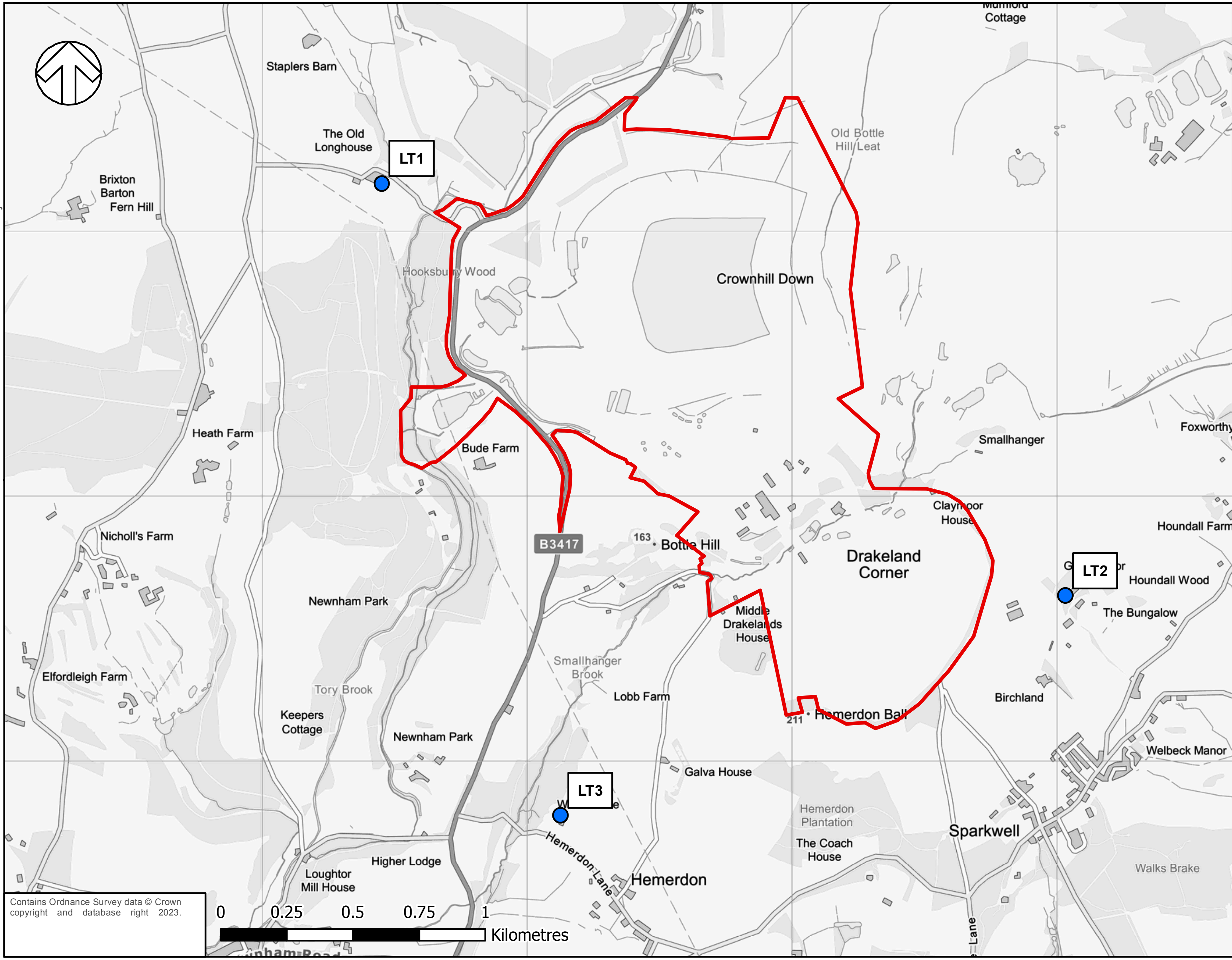
Drawn By: YH

File: \\uk.wspgroup.com\central data\Projects\70108xxx\70108756 - Tungsten Mine - LFN03 WIP\7. Models\01 GIS

Receptor Reference	Land Use	Compass Direction from the Site	Approximate Distance to Closest Site Boundary (m)	Approximate Distance to the Mineral Processing Facility (m)
A: Birchland Farm	Residential	South-east	300	1,100
B: Galva House	Residential	South-west	480	950
C: Newnham House	Residential	South-west	1,000	1,475
D: Boringdon Hall	Hotel and spa	South-west	760	3,000
E: Mumford Cottage	Residential	North-east	820	2,000
F: Portworthy Farmhouse	Residential	North-west	200	1,900
G: Windwhistle Farm	Residential property and hotel	South-west	950	1,400
H: Dartmoor Zoo	Zoo	South-east	320	1,250
I: Wotter	Residential	North-west	1,640	3,245
J: Broadoaks Cottages	Residential	North	990	2,390
K: East of Lee Moor	Public land	North-east	1,520	2,900
L: Lutton	Residential	East	2,120	2,930
M:Cornwood Inn	Pub and restaurant	East	3,050	3,820
N: Gorah Cottages	Residential	East	1,150	1,950
O: Yondertown	Residential	East	1,680	2,490
P: Road Junction	Public land	South-west	1,530	2,070
Q: Colebrook	Public land	South-west	1,150	2,480
R: Elfordleigh Hotel	Hotel	West	1,070	2,340

Appendix G

MONITORING LOCATIONS



Key

Far Field Monitoring Location

Approximate Site Boundary

wsp

TITLE:

FAR FIELD MONITORING LOCATIONS

FIGURE No:

FIGURE X

File: \\uk.wspgroup.com\central data\Projects\70108xxx\70108756 - Tungsten Mine - LFN03 WIP\7. Models\01 GIS

Drawn By: YH

Date Modified: 07/08/2023

Appendix H

CALIBRATION CERTIFICATES

CONFIDENTIAL

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

DATE OF ISSUE: 17 April 2023 CERTIFICATE NUMBER: **1143383**

BS EN ISO 9001:2015 APPROVED BY **LRQA**

CERT No 10045223

11 Frensham Road
Norwich
Norfolk
NR3 2BT

Tel: +44 1603 279557

Approved Signatory

Electronically Authorised Document

- ☐ P K CLARK
- ☐ R J WADE
- ☐ M A FROST
- ☒ M S PARDOE
- ☐ J FRYER
- ☐ M FOY

Customer	**EATEC DYNAMICS LIMITED**
Order No	**EDP/1048/1**
Equipment Description	**CALIBRATION EXCITER**
Manufacturer	**IMI**
Model	**699A02**
Serial No	**977**
Ident No	**NOT KNOWN**
Date Of Calibration	**17 APRIL 2023**

INSTRUMENT CONDITION

Adjustments Made	**NO**
Repairs Made	**NO**

ENVIRONMENT

The instrument was placed in the laboratory environment for a minimum period of 4 hours and was operated prior to calibration.

Measurements were made in ambient conditions of 22 °C ± 3 °C and 45 %RH ± 15 %RH.

PROCEDURE

Measurements were performed in accordance with the in house laboratory procedure 0153
All equipment used has been calibrated/verified against measurement standards or reference equipment traceable to International or National Measurement Standards as specified in our control procedure WI64
The results attached to this certificate refer to measurements made at the time of test and not to the instrument's ability to maintain calibration.
The attached results are a true record of the levels required to confirm the instrument meets the original stated manufacturer's specification and accuracy where shown.

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

BS EN ISO 9001:2015 APPROVAL CERTIFICATE No. 10045223

CERTIFICATE NUMBER
1143383

Calibration Equipment Used:

Cert Number	Ident Number	Model	Serial Number	Test Equipment Calibration Due
1121190IH	273	353B04	LW160893	4 Jan 2024
1136735IH	093	2001	0890250	1 Dec 2023
1137693IH	190	480E09	17252	21 Dec 2023

Notes:

Measurement Uncertainties

The expanded uncertainty quoted refers to the measured values only, with no account being taken of the instruments ability to maintain its calibration. The expanded uncertainties are based on a standard uncertainty multiplied by a coverage factor $k = 2$, providing a level of confidence of approximately 95%.

PARAMETER	RANGE	EXPANDED UNCERTAINTY
d.c. Resistance	0.01Ω - 400MΩ	± 409ppm
	400MΩ - 1TΩ	± 1%
d.c. Voltage	0V – 1kV	± 79ppm
d.c. Voltage	1.01kV-15kV	± 2.2%
d.c. Current	0mA – 20A	± 437ppm
a.c. Voltage	0mV – 1.05kV	± 1.2%
a.c. Current	0mA – 20A	± 0.5%
Frequency	0.5Hz – 20GHz	± 0.1ppm
Capacitance	0.5nF – 40mF	± 1.1%
Time	0 - 1 Hour	± 1s
Distortion	10mV - 100V	± 1.4mV
Temperature (Dry Block)	-30°C - 350°C	± 1%
Temperature (Simulation)	-270°C - 1800°C	± 0.57%
Pressure	10mBar - 35Bar	± 0.04%
Dynamic Pressure	1.38 - 103.5MPa	± 5.0%
Torque	0.1 - 1100Nm	± 1.5%
Weight	2g - 157kg	± 0.03%
Humidity	0% - 90%	± 1%
Shock & Impulse Hammers		± 4%
Spring Hammers		± 0.015J
Sound	Frequency	± 0.06%
Sound	Level	± 0.16dB
Tachometers	60rpm - 96000rpm	± 0.1%
Anemometers	2.5m/s to 15m/s	± 2.0%
Vibration Meters	10Hz - 1kHz	± 5%
Vibration Calibrators		± 3%
Mechanical Measurement	<200mm	± 0.01µm
	>200mm	± 0.002mm
Inductance		± 0.1%
Power (VA)		± 1%
Power (RF)		± 0.5dB
Light Meters	20-2000Lux	±3.5%
Force (Compression)	0.25N - 50kN	±0.25%

These uncertainties are only applicable if no uncertainties are shown on the result sheet.

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

CERTIFICATE NUMBER

1143383

RESULT SHEET 0153 – 699A02 CALIBRATION EXCITER

BATTERIES REPLACED **NO**

AS FOUND

1) ACCELERATION

	Output		Measured mV	Calibration Sensitivity	Limits	Measured Level		Error %
RMS	9.8	ms^{-2}	100.331	1.0160	±3.0%	**9.875**	ms^{-2}	0.77
Peak	9.8	ms^{-2}	71.066	0.7184	±3.0%	**9.892**	ms^{-2}	0.94

2) FREQUENCY

Frequency	Limits	Measured Output	Units	Error %
159.2	±1.0%	159.22	Hz	0.01

3) TEST POINT VOLTAGE

Voltage	Limits	Measured Output	Units	Error %
100.0	5.0%	100.305	mVac	0.31

COMMENTS

TEST ENGINEER **R J WADE** **DATE 17 APRIL 2023**

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

DATE OF ISSUE: 18 April 2023 CERTIFICATE NUMBER: **1143382**

BS EN ISO 9001:2015 APPROVED BY **LRQA**

CERT No 10045223

11 Frensham Road
Norwich
Norfolk
NR3 2BT

Tel: +44 1603 279557

Approved Signatory

Electronically Authorised Document

- ☐ P K CLARK
- ☐ R J WADE
- ☐ M A FROST
- ☒ M S PARDOE
- ☐ J FRYER
- ☐ M FOY

Customer	**EATEC DYNAMICS LIMITED**
Order No	**EDP/1048/1**
Equipment Description	**ACOUSTICAL CALIBRATOR**
Manufacturer	**BRUEL & KJAER**
Model	**4231**
Serial No	**2136424**
Ident No	**NOT KNOWN**
Date Of Calibration	**18 APRIL 2023**

INSTRUMENT CONDITION

Adjustments Made	**NO**
Repairs Made	**NO**

ENVIRONMENT

The instrument was placed in the laboratory environment for a minimum period of 4 hours and was operated prior to calibration.

Measurements were made in ambient conditions of 22 °C ± 3 °C and 45 %RH ± 15 %RH.

PROCEDURE

Measurements were performed in accordance with the in house laboratory procedure 0224
All equipment used has been calibrated/verified against measurement standards or reference equipment traceable to International or National Measurement Standards as specified in our control procedure WI64
The results attached to this certificate refer to measurements made at the time of test and not to the instrument's ability to maintain calibration.
The attached results are a true record of the levels required to confirm the instrument meets the original stated manufacturer's specification and accuracy where shown.

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

BS EN ISO 9001:2015 APPROVAL CERTIFICATE No. 10045223

CERTIFICATE NUMBER
1143382

Calibration Equipment Used:

Cert Number	Ident Number	Model	Serial Number	Test Equipment Calibration Due
1132959IH	557	12AQ	300811	5 Oct 2024
1137393IH	562	Indigo 500	U4930263	3 Dec 2023
1139519IH	554	40AG	500911	1 Feb 2024
1139624IH	334	26AK	292032	2 Feb 2024
1141335IH	546	PXI-4461	01C9BAFA	7 Mar 2024
1141922IH	CMR561	42AA	16296	8 Mar 2024

Notes:

Referenced Standards BS EN 60942 (Acoustic Calibrators)

Measurement Uncertainties

The expanded uncertainty quoted refers to the measured values only, with no account being taken of the instruments ability to maintain its calibration. The expanded uncertainties are based on a standard uncertainty multiplied by a coverage factor *k* = 2, providing a level of confidence of approximately 95%.

PARAMETER	RANGE	EXPANDED UNCERTAINTY
d.c. Resistance	0.01Ω - 400MΩ	± 409ppm
	400MΩ - 1TΩ	± 1%
d.c. Voltage	0V – 1kV	± 79ppm
d.c. Voltage	1.01kV-15kV	± 2.2%
d.c. Current	0mA – 20A	± 437ppm
a.c. Voltage	0mV – 1.05kV	± 1.2%
a.c. Current	0mA – 20A	± 0.5%
Frequency	0.5Hz – 20GHz	± 0.1ppm
Capacitance	0.5nF – 40mF	± 1.1%
Time	0 - 1 Hour	± 1s
Distortion	10mV - 100V	± 1.4mV
Temperature (Dry Block)	-30°C - 350°C	± 1%
Temperature (Simulation)	-270°C - 1800°C	± 0.57%
Pressure	10mBar - 35Bar	± 0.04%
Dynamic Pressure	1.38 - 103.5MPa	± 5.0%
Torque	0.1 - 1100Nm	± 1.5%
Weight	2g - 157kg	± 0.03%
Humidity	0% - 90%	± 1%
Shock & Impulse Hammers		± 4%
Spring Hammers		± 0.015J
Sound	Frequency	± 0.06%
Sound	Level	± 0.16dB
Tachometers	60rpm - 96000rpm	± 0.1%
Anemometers	2.5m/s to 15m/s	± 2.0%
Vibration Meters	10Hz - 1kHz	± 5%
Vibration Calibrators		± 3%
Mechanical Measurement	<200mm	± 0.01µm
	>200mm	± 0.002mm
Inductance		± 0.1%
Power (VA)		± 1%
Power (RF)		± 0.5dB
Light Meters	20-2000Lux	±3.5%
Force (Compression)	0.25N - 50kN	±0.25%

These uncertainties are only applicable if no uncertainties are shown on the result sheet.

CERTIFICATE OF CALIBRATION

ISSUED BY: **CALIBRATION MAINTENANCE & REPAIR LTD**

Certificate No. 1143382
Page No. 3

Device Under Test

Manufacturer	Bruel & Kjaer
Model Number:	4231
Class	1
Measurements	As Found

Environmental Conditions

	Environmental Conditions		Reference Conditions	
Temperature:	21.09	C	23.00	C
Humidity:	39.42	% r.h	50.00	% r.h
Ambient Pressure:	1027.02	hPa	1013.00	hPa

Measured Level

The levels shown are corrected for reference conditions.
dB relative to 20µPa

Level dB	Freq Hz	Result 1	Result 2	Result 3	Result 4	Result 5	Average dB	Limits
94	1000	93.7879	93.7897	93.7897	93.789	93.7884	**93.79**	±0.25dB
114	1000	113.7934	113.794	113.7952	113.7944	113.7945	**113.79**	±0.25dB

Measured Frequency

Frequency Hz	Hz	Limits
1000	999.826	±7Hz

Measured Distortion

Level dB	THD+N %	Limits
94	0.6543	±2.5%
114	0.2586	±2.5%

Short Term Fluctuation

Level stability measured sampling 60 readings over a period of 60s

Level dB	Freq Hz	Minimum	Maximum	Mean	Fluctuation	Limits
94	1000	93.9242	93.9331	93.9286	**0.0089**	±0.07dB
114	1000	113.7778	113.7959	113.7868	**0.0181**	±0.07dB

Notes

Results relate only to the item being calibrated

Referenced Standard - BS EN 60942

Test Engineer Ross Osborne **Date** 18 April 2023

CERTIFICATE OF CALIBRATION

MEASUREMENT SYSTEMS

0653

Date of Issue: 26 September 2022

Certificate Number: UCRT22/2144

Calibrated at & Certificate issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
Milton Keynes MK5 8HL
Telephone 01908 642846 Fax 01908 642814
E-Mail: info@noise-and-vibration.co.uk
Web: www.noise-and-vibration.co.uk
Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory

B. Bogdan

CUSTOMER	WSP UK Ltd WSP House 70 Chancery Lane London WC2A 1AF
ORDER No	20151294 Job No UKAS22/09601
DATE OF RECEIPT	26 September 2022
PROCEDURE	Procedure TP 1 Calibration of Sound Calibrators
IDENTIFICATION	Sound Calibrator 01dB type CAL21 serial number 34344461(2014) with one-inch housing and adapter type BAC21 for half-inch microphone
CALIBRATED ON	26 September 2022
PREVIOUS CALIBRATION	Calibrated on 01 September 2021, Certificate No. UCRT21/2063 issued by this laboratory.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No 0653

MEASUREMENTS

The sound pressure level generated by the Sound Calibrator in its half-inch configuration was measured using a B&K type 4134 microphone with the protective grid in position. The microphone sensitivity was traceable to National Standards.

RESULTS

The mean level of the calibrator output, corrected to the standard atmospheric pressure of 101.3 kPa using manufacturers' data, was

94.05 ± 0.10 dB rel 20 µPa

The fundamental frequency of the sound output was 1003.43 ± 0.12 Hz,
and its total distortion was (1.22 ± 0.09) %.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor *k* =2, providing a coverage probability of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

During the measurements the laboratory environmental conditions were:

Temperature: 22 to 24 ºC
Atmospheric pressure: 99.0 to 99.2 kPa
Relative humidity: 43 to 54 %

The tests carried out were based on Annex B of BS EN 60942:2003, but with five determinations of sound pressure level, and limited to the above level(s) & freq(s). This is a subset of the tests specified in Annex B of BS EN 60942:1998. The mean level, frequency and total distortion of the sound output as measured meet the Class 1 requirements of BS EN 60942:1998 for the environmental conditions under which the tests were performed. This does not imply that the sound calibrator meets this standard under any other conditions. However it has successfully undergone pattern evaluation to the earlier Standard IEC 942:1988

The results on this certificate only relate to the items calibrated as identified above.

Calibrator adjusted NO END R 1

CERTIFICATE OF CALIBRATION

0653

Date of Issue: 26 September 2022

Certificate Number: UCRT22/2141

Calibrated at & Certificate issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
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Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory

B. Bogdan

CUSTOMER	WSP UK Ltd WSP House 70 Chancery Lane London WC2A 1AF		
ORDER No	20151294	Job No	UKAS22/09601
DATE OF RECEIPT	26 September 2022		
PROCEDURE	Procedure TP 1 Calibration of Sound Calibrators		
IDENTIFICATION	Sound Calibrator 01dB type CAL21 serial number 34924010(2012) with one-inch housing and adapter type BAC21 for half-inch microphone		
CALIBRATED ON	26 September 2022		
PREVIOUS CALIBRATION	Calibrated on 01 September 2021, Certificate No. UCRT21/2064 issued by this laboratory.		

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No 0653

MEASUREMENTS

The sound pressure level generated by the Sound Calibrator in its half-inch configuration was measured using a B&K type 4134 microphone with the protective grid in position. The microphone sensitivity was traceable to National Standards.

RESULTS

The mean level of the calibrator output, corrected to the standard atmospheric pressure of 101.3 kPa using manufacturers' data, was

94.00 ± 0.10 dB rel 20 µPa

The fundamental frequency of the sound output was 1002.11 ± 0.12 Hz,
and its total distortion was (1.23 ± 0.09) %.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor *k* =2, providing a coverage probability of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

During the measurements the laboratory environmental conditions were:

Temperature: 22 to 24 ºC
Atmospheric pressure: 99.1 to 99.2 kPa
Relative humidity: 43 to 58 %

The tests carried out were based on Annex B of BS EN 60942:2003, but with five determinations of sound pressure level, and limited to the above level(s) & freq(s). This is a subset of the tests specified in Annex B of BS EN 60942:1998. The mean level, frequency and total distortion of the sound output as measured meet the Class 1 requirements of BS EN 60942:1998 for the environmental conditions under which the tests were performed. This does not imply that the sound calibrator meets this standard under any other conditions. However it has successfully undergone pattern evaluation to the earlier Standard IEC 942:1988

The results on this certificate only relate to the items calibrated as identified above.

Calibrator adjusted NO END R 1

CERTIFICATE OF CALIBRATION

0653

Date of Issue: 15 May 2023

Certificate Number: UCRT23/1652

Calibrated at & Certificate issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
Milton Keynes MK5 8HL
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E-Mail: info@noise-and-vibration.co.uk
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Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory

K. Mistry

CUSTOMER	WSP UK Ltd WSP House 70 Chancery Lane London WC2A 1AF United Kingdom

ORDER No 20161234 Job No UKAS23/05333

DATE OF RECEIPT 11 May 2023

PROCEDURE Procedure TP 1 Calibration of Sound Calibrators

IDENTIFICATION Sound Calibrator 01dB type CAL21 serial number 34924053(2012) with one-inch housing and adapter type BAC21 for half-inch microphone

CALIBRATED ON 15 May 2023

PREVIOUS CALIBRATION Calibrated on 13 May 2022, Certificate No. UCRT22/1648 issued by this laboratory.

MEASUREMENTS

The sound pressure level generated by the Sound Calibrator in its half-inch configuration was measured using a B&K type 4134 microphone with the protective grid in position. The microphone sensitivity was traceable to National Standards.

RESULTS

The mean level of the calibrator output, corrected to the standard atmospheric pressure of 101.3 kPa using manufacturers' data, was

94.14 ± 0.10 dB rel 20 µPa

The fundamental frequency of the sound output was 1001.99 ± 0.12 Hz,
and its total distortion was (1.61 ± 0.11) %.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor *k* =2, providing a coverage probability of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

During the measurements the laboratory environmental conditions were:

Temperature: 22 to 23 ºC
Atmospheric pressure: 101.0 to 101.1 kPa
Relative humidity: 36 to 47 %

The tests carried out were based on Annex B of BS EN 60942:2003, but with five determinations of sound pressure level, and limited to the above level(s) & freq(s). This is a subset of the tests specified in Annex B of BS EN 60942:1998. The mean level, frequency and total distortion of the sound output as measured meet the Class 1 requirements of BS EN 60942:1998 for the environmental conditions under which the tests were performed. This does not imply that the sound calibrator meets this standard under any other conditions. However it has successfully undergone pattern evaluation to the earlier Standard IEC 942:1988

The results on this certificate only relate to the items calibrated as identified above.

Calibrator adjusted No END

CERTIFICATE OF CALIBRATION

0653

Date of Issue: 18 May 2023

Certificate Number: UCRT23/1677

Calibrated at & Certificate issued by:
ANV Measurement Systems
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Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory

K. Mistry

CUSTOMER	WSP UK Ltd WSP House 70 Chancery Lane London WC2A 1AF United Kingdom
ORDER No	20161234 Job No UKAS23/05333
DATE OF RECEIPT	11 May 2023
PROCEDURE	Calibration Engineer's Handbook, section 25: periodic testing of sound level meters to IEC 61672-3:2006 (BS EN 61672-3:2006) as modified by UKAS TPS 49
IDENTIFICATION	Sound level meter 01dB type DUO serial No 10616 connected via an extension lead type RAL135-10M and preamplifier type PRE 22 serial No 10180 to a half-inch microphone type GRAS 40CD serial No 154423 fitted with a 'DMK01' weatherproof outdoor windshield including nosecone type RA 0208. Associated calibrator 01dB type CAL21 serial No 34924053(2012) with a one-inch housing and adapter type BAC21 for half-inch microphone.
CALIBRATED ON	18 May 2023
PREVIOUS CALIBRATION	Calibrated on 01 June 2021, Certificate No. UCRT21/1686 issued by this laboratory.

The sound level meter was set up using the type CAL21 sound calibrator supplied; it was set to frequency weighting A, and initially read 94.0 dB. It was then adjusted to read 93.9 dB (corresponding to 93.9 dB at standard atmospheric pressure). This reading was derived from Calibration Certificate no. UCRT23/1652 supplied by this laboratory and manufacturers' information on the free-field response of the sound level meter when fitted with the windshield. The calibration check frequency was 1kHz.

Procedures from IEC 61672-3:2006 (BS EN 61672-3:2006) as modified by UKAS TPS 49 were used to perform the periodic tests.

RESULTS

The sound level meter submitted for testing has successfully completed the class 1 periodic tests of IEC 61672-3:2006 (BS EN 61672-3:2006), for the environmental conditions under which the tests were performed. As public evidence was available, from an independent testing organization responsible for approving the results of pattern evaluation tests performed in accordance with IEC 61672-2 : 2003 (BS EN 61672-2 : 2003), to demonstrate that the model of sound level meter fully conformed to the requirements in IEC 61672-1 : 2002 (BS EN 61672-1 : 2003), the sound level meter submitted for testing conforms to the class 1 requirements of IEC 61672-1 : 2002 (BS EN 61672-1 2003).

The self-generated noise recorded with the microphone replaced by the electrical input device was:

12.1 dB (A)   14.3 dB (C)   18.9 dB (Z)

The environmental conditions recorded at the start and end of testing were:

Start: 21 to 23 ºC, 47 to 57 %RH and 101.8 to 101.9 kPa
End: 22 to 23 ºC, 45 to 55 %RH and 101.7 to 101.8 kPa

Technical information including adjustment data specified in the manufacturers' User Manual DOC1112 - May 2015 H with further clarification from 01dB has been used to carry out this verification. These data include manufacturer-specified uncertainties for case reflections and windshield, but NOT for the microphone response.

Publicly-available evidence has been found that this configuration of the 01dB DUO sound level meter design has successfully undergone pattern evaluation in accordance with IEC 61672-2:2002 (BS EN 61672-2:2003) by Physikalisch-Technische Bundesanstalt (PTB), an independent testing organisation responsible for pattern approvals.

All measurement data are held at ANV Measurement Systems for a period of at least six years.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor *k* =2, providing a coverage probability of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

NOTES

Any opinions or interpretations which may be expressed in the following notes are not UKAS Accredited.

1 The high pass filter was set to 10 Hz, the mic correction to 90° and the nosecone usage to "Yes".

2 No suitable microphone frequency response information was supplied with the instrument. It was therefore measured by this laboratory using the electrostatic actuator method. This response in isolation is not UKAS accredited.

3 The instrument was running application firmware version 2.34 and metrology firmware version 2.10 on hardware version 3F2D3D

4 These periodic tests are valid ONLY for the instrument configuration shown on page 1 of this certificate and for 90° incidence of sound on the microphone.

5 When set up to read correctly in response to the sound calibrator, the sound level meter stored a calibration correction of 0.17 dB and a microphone sensitivity of 49 mV/Pa

6 Typical case reflection factors (for the DMK01 unit) specified by the manufacturer have been used for this verification.

The results on this certificate only relate to the items calibrated as identified above.

END

CERTIFICATE OF CALIBRATION

0653

Date of Issue: 28 September 2022

Certificate Number: UCRT22/2158ATR

Calibrated at & Certificate issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
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Web: www.noise-and-vibration.co.uk
Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory

B. Bogdan

CUSTOMER	WSP UK Ltd WSP House 70 Chancery Lane London WC2A 1AF
ORDER No	20151294 Job No UKAS22/09601
DATE OF RECEIPT	26 September 2022
PROCEDURE	Calibration Engineer's Handbook, section 25: periodic testing of sound level meters to IEC 61672-3:2006 (BS EN 61672-3:2006) as modified by UKAS TPS 49 Edition 2:June 2009
IDENTIFICATION	Sound level meter 01dB type CUBE serial No 10630 connected via an extension lead type RAL135-10M and preamplifier type PRE 22 serial No 10261 to a half-inch microphone type GRAS 40CD serial No 231588 fitted with a 'DMK01' weatherproof outdoor windshield including nosecone type RA 0208. Associated calibrator 01dB type CAL21 serial No 34344461(2014) with a one-inch housing and adapter type BAC21 for half-inch microphone.
CALIBRATED ON	28 September 2022
PREVIOUS CALIBRATION	Calibrated on 21 October 2021, Certificate No. UCRT21/2302 issued by this laboratory.

The sound level meter was set up using the type CAL21 sound calibrator supplied; it was set to frequency weighting A, and initially read 93.6 dB. It was then adjusted to read 93.9 dB (corresponding to 93.9 dB at standard atmospheric pressure). This reading was derived from Calibration Certificate no. UCRT22/2144 supplied by this laboratory and manufacturers' information on the free-field response of the sound level meter when fitted with the windshield. The calibration check frequency was 1kHz.

Procedures from IEC 61672-3:2006 (BS EN 61672-3:2006) as modified by UKAS TPS 49 Edition 2:June 2009 were used to perform the periodic tests.

RESULTS

The sound level meter submitted for testing has successfully completed the class 1 periodic tests of IEC 61672-3:2006 (BS EN 61672-3:2006), for the environmental conditions under which the tests were performed. As public evidence was available, from an independent testing organization responsible for approving the results of pattern evaluation tests performed in accordance with IEC 61672-2 : 2003 (BS EN 61672-2 : 2003), to demonstrate that the model of sound level meter fully conformed to the requirements in IEC 61672-1 : 2002 (BS EN 61672-1 : 2003), the sound level meter submitted for testing conforms to the class 1 requirements of IEC 61672-1 : 2002 (BS EN 61672-1 2003).

The self-generated noise recorded with the microphone replaced by the electrical input device was:

12.1 dB (A) 12.2 dB (C) 18.0 dB (Z)

The environmental conditions recorded at the start and end of testing were:

Start: 23 to 24 ºC, 41 to 51 %RH and 99.0 to 99.1 kPa
End: 22 to 23 ºC, 44 to 54 %RH and 99.0 to 99.1 kPa

Technical information including adjustment data specified in the manufacturers' User Manual DOC1112 - May 2015 H with further clarification from 01dB has been used to carry out this verification. These data include manufacturer-specified uncertainties for case reflections and windshield, but NOT for the microphone response.

Publicly-available evidence has been found that this configuration of the 01dB CUBE sound level meter design has successfully undergone pattern evaluation in accordance with IEC 61672-2:2002 (BS EN 61672-2:2003) by Physikalisch-Technische Bundesanstalt (PTB), an independent testing organisation responsible for pattern approvals.

All measurement data are held at ANV Measurement Systems for a period of at least six years.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor *k* =2, providing a coverage probability of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

NOTES

Any opinions or interpretations which may be expressed in the following notes are not UKAS Accredited.

1 The high pass filter was set to 10 Hz, the mic correction to 90° and the nosecone usage to "Yes".

2 No suitable microphone frequency response information was supplied with the instrument. It was therefore measured by this laboratory using the electrostatic actuator method. This response in isolation is not UKAS accredited.

3 The instrument was running application firmware version 2.40, metrology firmware version 2.12 and modem firmware version 12.00.005 on hardware version LIS001A

4 These periodic tests are valid ONLY for the instrument configuration shown on page 1 of this certificate and for 90° incidence of sound on the microphone.

5 When set up to read correctly in response to the sound calibrator, the sound level meter stored a calibration correction of 0.54 dB and a microphone sensitivity of 47 mV/Pa

6 Typical case reflection factors (for the DMK01 unit) specified by the manufacturer have been used for this verification.

7 Prior to calibration the instrument's microphone and pre-amp were replaced.

8 Amendment to report:- This certificate has been amended due to incorrect serial numbers of the"preamp and microphone", which were corrected.

The results on this certificate only relate to the items calibrated as identified above.

CERTIFICATE OF CALIBRATION

0653

Date of Issue: 22 October 2021

Certificate Number: UCRT21/2304

Calibrated at & Certificate issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
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Telephone 01908 642846 Fax 01908 642814
E-Mail: info@noise-and-vibration.co.uk
Web: www.noise-and-vibration.co.uk
Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory

K. Mistry

CUSTOMER	WSP UK Ltd WSP House 70 Chancery Lane London WC2A 1AF
ORDER No	20134892 Job No UKAS21/10697
DATE OF RECEIPT	18 October 2021
PROCEDURE	Calibration Engineer's Handbook, section 25: periodic testing of sound level meters to IEC 61672-3:2006 (BS EN 61672-3:2006) as modified by UKAS TPS 49 Edition 2:June 2009
IDENTIFICATION	Sound level meter 01dB type DUO serial No 10617 connected via an extension lead type RAL135-10M and preamplifier type PRE 22 serial No 10324 to a half-inch microphone type GRAS 40CD serial No 162071 fitted with a 'DMK01' weatherproof outdoor windshield including nosecone type RA 0208. Associated calibrator 01dB type CAL21 serial No 34924010(2012) with a one-inch housing and adapter type BAC21 for half-inch microphone.
CALIBRATED ON	22 October 2021
PREVIOUS CALIBRATION	Calibrated on 14 October 2019, Certificate No. UCRT19/2145 issued by this laboratory.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No 0653

The sound level meter was set up using the type CAL21 sound calibrator supplied; it was set to frequency weighting A, and initially read 93.7 dB. It was then adjusted to read 93.8 dB (corresponding to 93.8 dB at standard atmospheric pressure). This reading was derived from Calibration Certificate no. UCRT21/2064 supplied by this laboratory and manufacturers' information on the free-field response of the sound level meter when fitted with the windshield. The calibration check frequency was 1kHz.

Procedures from IEC 61672-3:2006 (BS EN 61672-3:2006) as modified by UKAS TPS 49 Edition 2:June 2009 were used to perform the periodic tests.

RESULTS

The sound level meter submitted for testing has successfully completed the class 1 periodic tests of IEC 61672-3:2006 (BS EN 61672-3:2006), for the environmental conditions under which the tests were performed. As public evidence was available, from an independent testing organization responsible for approving the results of pattern evaluation tests performed in accordance with IEC 61672-2 : 2003 (BS EN 61672-2 : 2003), to demonstrate that the model of sound level meter fully conformed to the requirements in IEC 61672-1 : 2002 (BS EN 61672-1 : 2003), the sound level meter submitted for testing conforms to the class 1 requirements of IEC 61672-1 : 2002 (BS EN 61672-1 2003).

The self-generated noise recorded with the microphone replaced by the electrical input device was:

14.3 dB (A) 14.8 dB (C) 19.9 dB (Z)

The environmental conditions recorded at the start and end of testing were:

Start: 21 to 22 ºC, 42 to 52 %RH and 100.7 to 100.8 kPa
End: 21 to 22 ºC, 41 to 51 %RH and 100.7 to 100.8 kPa

Technical information including adjustment data specified in the manufacturers' User Manual DOC1112 - May 2015 H with further clarification from 01dB has been used to carry out this verification. These data include manufacturer-specified uncertainties for case reflections and windshield, but NOT for the microphone response.

Publicly-available evidence has been found that this configuration of the 01dB DUO sound level meter design has successfully undergone pattern evaluation in accordance with IEC 61672-2:2002 (BS EN 61672-2:2003) by Physikalisch-Technische Bundesanstalt (PTB), an independent testing organisation responsible for pattern approvals.

All measurement data are held at ANV Measurement Systems for a period of at least six years.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor *k* =2, providing a coverage probability of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

NOTES

Any opinions or interpretations which may be expressed in the following notes are not UKAS Accredited.

1 The high pass filter was set to 10 Hz, the mic correction to 90° and the nosecone usage to "Yes".

2 No suitable microphone frequency response information was supplied with the instrument. It was therefore measured by this laboratory using the electrostatic actuator method. This response in isolation is not UKAS accredited.

3 The instrument was running application firmware version 2.34, metrology firmware version 2.10 and modem firmware version 08.01.107 on hardware version 3F2D3D

4 These periodic tests are valid ONLY for the instrument configuration shown on page 1 of this certificate and for 90° incidence of sound on the microphone.

5 When set up to read correctly in response to the sound calibrator, the sound level meter stored a calibration correction of -0.28 dB and a microphone sensitivity of 51.6 mV/Pa

6 Typical case reflection factors (for the DMK01 unit) specified by the manufacturer have been used for this verification.

The results on this certificate only relate to the items calibrated as identified above.

END

Appendix I

LFN TRIAL OBJECTIVES AND METHODOLOGY

Tungsten West

LOW FREQUENCY NOISE TRIAL

Objectives and Methodology

MAY 2023

CONFIDENTIAL

Tungsten West

LOW FREQUENCY NOISE TRIAL

Objectives and Methodology

TYPE OF DOCUMENT (VERSION) CONFIDENTIAL

PROJECT NO. 70108756

DATE: MAY 2023

WSP

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6 Devonshire Square
London
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WSP.com

QUALITY CONTROL

Issue/revision	First issue	Revision 1	Revision 2	Revision 3
Remarks	Draft for comment	Final_Rev1		
Date	26.04.2023	17.05.223		
Prepared by	Louise Beamish	Louise Beamish		
Signature				
Checked by	Keith Jefferson	Keith Jefferson		
Signature				
Authorised by	Keith Jefferson	Keith Jefferson		
Signature				
Project number	70108756	70108756		
Report number	Draft	Rev 1		
File reference				

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APPENDICES

APPENDIX A

TERTIARY CRUSHER DEWATERING SCREEN

APPENDIX B

ENCLOSURE DRAWING AND TRIAL LOCATION

1 INTRODUCTION

1.1.1. Tungsten West, the operator of the Hemerdon mine in Plymouth, is preparing a noise and vibration impact assessment and noise management plan for submission to the Environment Agency (EA) in response to a Schedule 5 notice for additional information.

1.1.2. This document focuses on a trial to test the effectiveness of enclosures in reducing noise at specific frequencies. The outcomes of the trial will be used to inform the strategy to mitigate low frequency noise from the screens at the mine, in addition to validating models for the prediction of noise in the local community.

1.1.3. The trial involves the design and fabrication of enclosures and the testing of their effectiveness in reducing noise levels at specific frequencies. As this process involves collaboration across the Tungsten West project team, contributions to this document have been sought from:

- Tungsten West (Mine Operator)
- WSP (Acoustics Engineers)
- Fairport (Project Engineers)
- Eatec Dynamics (Acoustics Engineer)

1.1.4. This document provides in Section 2 a description of the operating plant and enclosures that will be used in the trial whilst Section 3 details the trial measurement methodology. Section 4 includes details of proposed stakeholder engagement.

1.1.5. Tungsten West has confirmed the following timetable for the trial.

Table 1-1 – Timetable for Low Frequency Noise Trial

	Start Date	End Date
Confirmation of drawings for fabrication		28.04.2023
Fabrication of enclosure(s)	01.05.2023	18.06.2023
Low frequency noise trial	26.06.2023	28.07.2023

2 THE OPERATING PLANT AND ENCLOSURES

2.1 THE ENCLOSURES

2.1.1. Two enclosures are likely to be fabricated and tested to determine their effectiveness in reducing noise at the fundamental frequency of the screen operating within it and at higher frequencies to capture the first and second harmonics of the operating frequency.

ENCLOSURE 1

2.1.2. The walls and roof of the enclosure will be constructed of 6mm steel plate spanning between channel rails. The rails span between columns which, along with beams between them at roof level, form a stable structure.

2.1.3. All elements have been designed to have a natural frequency above that of the screen and its 1st harmonic (see following section for details of the screen) and most are at a conservative level of approximately 1.4 times that of the screen.

2.1.4. Enclosure 1 is also likely to be tested with Kingspan insulation (or similar) and the exact details of this aspect of the trial are in the process of being finalised. The aim of conducting the trial with Kingspan insulation (or similar) will be to determine whether Enclosure 1 would be able to mitigate the 2nd harmonic.

2.1.5. The openings for infeed and outfeed total 8% of the area of roof and walls combined. These are plated in with removeable panels which can be removed in full or part, as required.

ENCLOSURE 2

2.1.6. Enclosure 2 is intended to be similar in construction with additional rails being inserted to raise the natural frequency of the walls such that it is sufficient to mitigate the 2nd harmonic. However, the performance of Enclosure 1, with the inclusion of Kingspan insulation (or similar) may negate the need for a second enclosure to fabricated and tested. The need for Enclosure 2 is being explored as part of the ongoing study.

2.2 OPERATING PLANT

2.2.1. The enclosure is being designed to accommodate a screen which would be in operation at the mine. The screen to be tested is 130-SN-13 Tertiary Crusher Dewatering Screen which would sit on a concrete slab for the trial. Further details on the screen are provided below and shown on the drawing in Appendix A.

- Screen deck dimension – 6.0m long x 3.0m wide
- Screen deck media – polyurethane panels with 0.8mm x 12mm slotted apertures
- Screen mass – 16,000kg
- Subframe mass – 8,000kg
- Operating amplitude – 15mm
- Screen speed – 740 rpm (12.3Hz)
- Natural frequency – 12.3Hz
- Acceleration – 45 m/s2

2.2.2. The final location for the screen, upon operation of the mine, will be Building 130A (Tertiary Crusher Dewatering Screen Building).

2.3 TRIAL LOCATION

2.3.1. The trial area is shown in the top right of the drawing in Appendix B and is within the dense media separation (DMS) area to the west of the existing processing building. The drawing also shows details of the enclosure.

3 NOISE MEASUREMENT METHODOLOGY

3.1 TIMETABLE

3.1.1. The noise measurements are planned to commence on Monday 26th June 2023 for a period of up to two weeks. During this period, the trials will be conducted during the working day and no plant will be operational during the evening and night-time hours.

3.2 MEASUREMENT METHODOLOGY

3.2.1. Measurements will be conducted in the nearfield (close to the enclosures) and in the far-field at receptors in the surrounding area within a 2km radius. The proposed monitoring locations are provided below, although these are yet to be agreed with the property owners and are, therefore, subject to change.

3.2.2. The following measurements will be undertaken and can be adapted to suit any reasonable additional requests from the EA.

- Nearfield:
  - Microphone inside the enclosure and 1 metre above the screen deck.
  - Microphones at six locations around the enclosure at a radius of approximately 50 metres.
  - One accelerometer on the screen deck.
  - Five accelerometers; one on each panel of the enclosure. These are likely to be slightly off the centre of the panel.
- Far field:
  - Three measurement locations in the far field at receptors in the area of Windwhistle Farm (to the south-west of the mine), Portworthy Farmhouse (to the north-west of the mine) and Sparkwell (measurements have previously been undertaken at East Dartmoor Zoo).
  - One measurement location in the far field will also include a meteorological station.

3.2.3. The measurements will be undertaken for the following scenarios:

- Screen operating without an enclosure.
- For each of the two enclosures (assuming two are fabricated), measurements will be undertaken with an 8% open area (equal to the infeed and outfeed) and Tungsten West will also trial a range of percentage open areas in order to explore the relationship between the percentage open area of the enclosure and its effectiveness to mitigate noise.
- Sampling will be undertaken in bursts of 5 minutes at a rate of 256 samples per second per channel. The seven microphones and six accelerometers to be used will be sampled simultaneously.

3.2.4. The data gathered during the surveys will include the following weightings: dB(C) dB(Z) and dB(G). Raw unweighted time histories will also be recorded.

3.2.5. A meteorological station will be deployed at one of the far field noise monitoring locations and will record data for the duration of the noise survey. The meteorological data will include wind speed and direction, humidity, temperature and rainfall.

3.2.6. Modal testing of the enclosure(s) will also be undertaken in addition to the above measurements. This will confirm the natural frequency of the enclosure.

3.3 POST-PROCESSING OF MEASUREMENT DATA

3.3.1. The post processing of measurement data will include:

- High resolution FFTs
- Spectrograms for each five minute burst
- Waveform analysis to check for stationarity

3.3.2. The data will be presented in a summary report which will be shared with the EA.

3.4 MEASUREMENT EQUIPMENT

3.4.1. A Digital Acquisition system (DAQ) will be used during the measurements. It will consist of 32 channels of 24 bit accuracy inputs with voltage and Integrated Electronic Piezo-Electric (IEPE) inputs.

3.4.2. There will be a total of six accelerometers for use on the screen and enclosure and approximately four noise monitoring kits for use in the near field. Three additional sets of noise monitoring equipment will be available for use in the far field measurements. These will have remote access and will be capable of continuous measurement.

3.4.3. All microphones will be capable of measuring low frequency noise and the measurement equipment will have been calibrated by a UKAS-accredited laboratory within the preceding two years.

4 STAKEHOLDER ENGAGEMENT

4.1 ENVIRONMENT AGENCY

4.1.1. The EA is invited to comment on the proposed methodology and any reasonable requests for additional measurements will be considered.

4.1.2. Tungsten West has invited the EA to attend the low frequency noise trial with a view to being open and collaborative in approach.

4.1.3. The findings of the trial will be summarised in a report which will be shared with the EA.

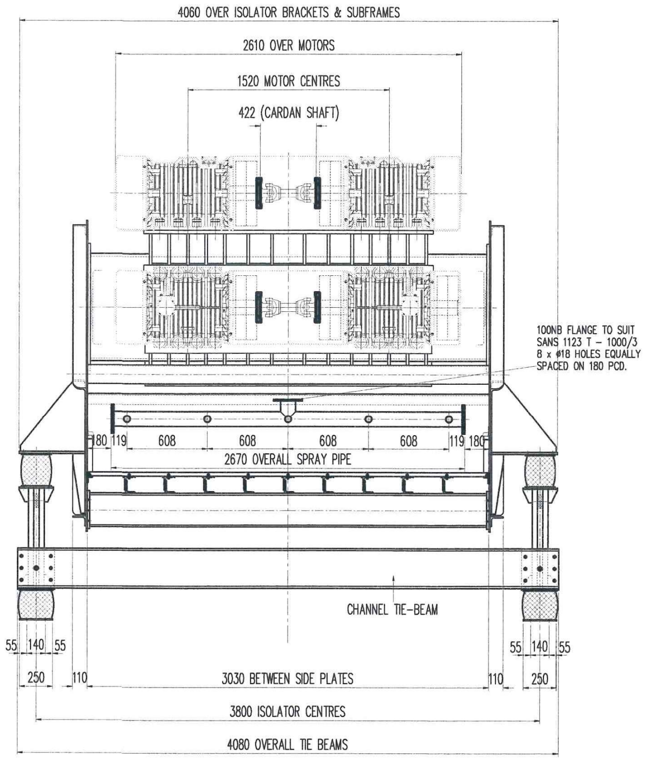
4.2 LOCAL COMMUNITY

4.2.1. Due to the apprehension surrounding LFN within the local communities, Tungsten West has highlighted the importance of informing local stakeholders of the proposed trial. As such Tungsten West is proposing to notify the residents of Shaugh Prior, Cornwood and Sparkwell Parish Councils in the June monthly parish council meetings which are attended by both the ESG Manager and Stakeholder Engagement Lead.

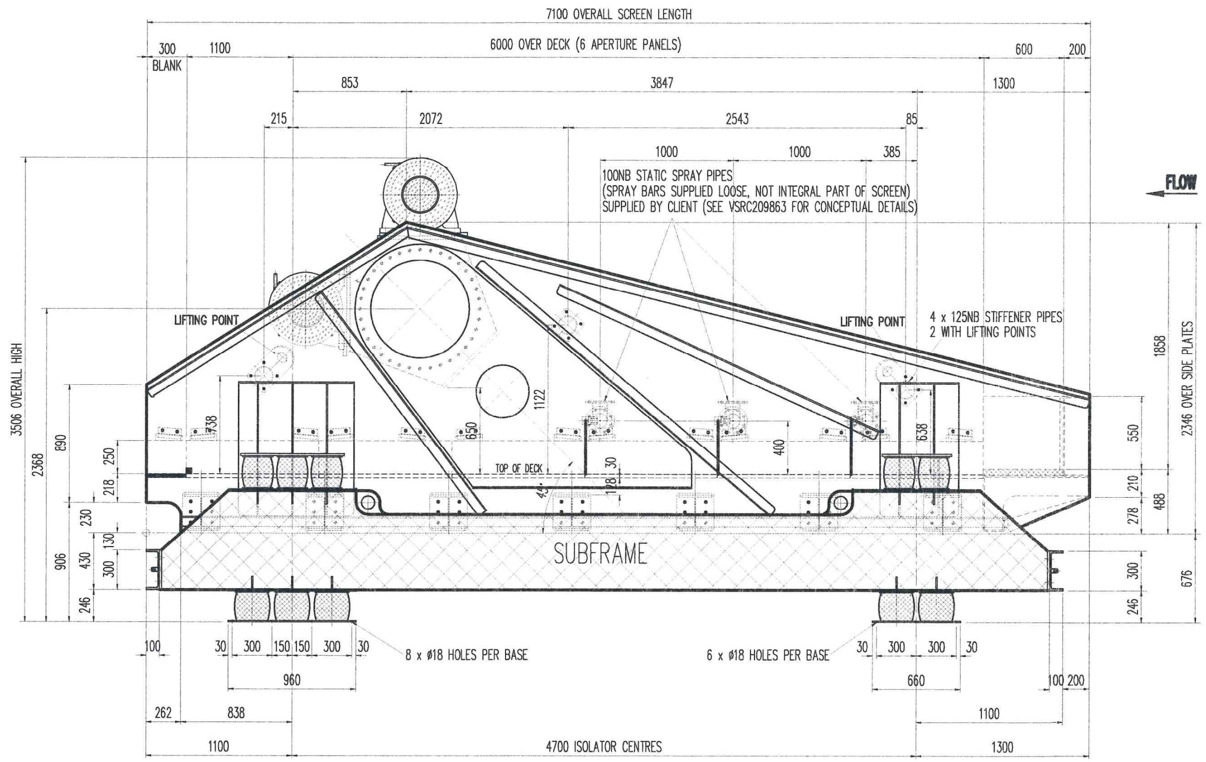
4.2.2. The detail of this communication is to be shared and agreed with the EA prior to the Parish Council Meetings to ensure consistency and alignment in the messaging between Tungsten West and its regulatory stakeholders. In addition to the communication of the trial, Parish Councils will be offered the opportunity to put forward representatives to a 'Low Frequency Noise Working Group' in which TW will share further detail on the trial and be able to answer any questions raised.

Appendix A

TERTIARY CRUSHER DEWATERING SCREEN



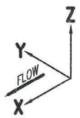
VIEW ON DISCHARGE



SIDE ELEVATION

		DYNAMIC COMPONENT PER CORNER			
		SUBFRAME DYNAMIC COMP.		ISOLATOR STIFFNESS	
		VERTICAL	HORIZONTAL	VERTICAL	HORIZONTAL
RUNNING	FEED END	1586N	794N	700N/mm	350N/mm
	DISCHARGE END	2379N	1191N	NATURAL FREQUENCY	
STARTING	FEED END	3172N	2160N	3Hz	
	DISCHARGE END	4758N	2382N		
STOPPING	FEED END	4758N	2382N		
	DISCHARGE END	7137N	3573N		

CLEARANCE DIMENSIONS					
SCREEN CLEARANCES			SUBFRAME CLEARANCES		
LONGITUDINAL (X)	LATERAL (Y)	VERTICAL (Z)	LONGITUDINAL (X)	LATERAL (Y)	VERTICAL (Z)
75mm	35mm	75mm	50mm	25mm	50mm



APPROVED
TUNGSTEN WEST
Warren Monaghan
18/03/2022

GENERAL NOTES!

MOTORS – 4 x KEEH 170–8 XCS ; 11 kW EACH (400 V/50 Hz).
SCREEN SPEED – 740 RPM. (12.3 Hz)
SCREEN MASS – 16000 kg.
SUBFRAME MASS – 8000 kg.
SCREEN ISOLATORS – 10 x VB50 RUBBER BUFFERS.
SUBFRAME ISOLATORS – 10 x VB70 RUBBER BUFFERS.
ALLOW 75mm OPERATING CLEARANCE.
ISOLATOR CENTRES, PADS AND FIXING HEIGHTS
TO BE WITHIN ±2mm OF INDICATED DIMENSIONS.
FOR DECK LAYOUT REFER TO VSRC114686_1.DWG
SURFACE PROTECTION AS PER VIBRAMECH HEAVY DUTY PAINT SPECIFICATION : VIB–HD–PS–VIBR–PAINT 008 (Rev 00)

VIBRAMECH
CERTIFIED CORRECT FOR MANUFACTURE
By: HA Arlow
Signed: Arlow
Date: 10-03-2022

TAG No and Equipment Name modified as per Project TRIDENT
Tertiary Crusher Dewatering Screen
TAG No. 130-SN-13

HEMERDON RESTART PROJECT
~~PRODUCT SCREEN~~
TAG No.: ~~120-SN-13~~

VIBRAMECH
Email: vibramech@vibramech.co.za Tel: +27 (11) 762 5501/5 Fax: +27 (11) 762 7463

REV.	DATE	DESCRIPTION	COM. BY
G	18.01.2022	DRIVE MOTOR DESCRIPTION AND NOTE FOR STATIC SPRAY BARS UPDATED.	AHA
F	15.12.2021	DECK COMPONENTS FINALIZED (LINERS, WEDGES, RUNNER STRIPS, ETC).	AHA
E	19.09.2021	SIDE PLATE FILLER STRIP MODIFIED.	AHA
D	11.05.2021	PANEL/SIDE LINER DETAILS UPDATED. SURFACE PROTECTION & ISOLATOR INFO ADDED.	AHA
		STATIC SPRAY BARS AND WEIR BAR AT DISCHARGE END ADDED	
C	12.04.2021	SIDE LINER / PANEL CONFIGURATION UPDATED ON GA	AHA
B	23.03.2021	SCREEN LOWERED INTO SUBFRAME BY 260mm.	AHA

REV.	DATE	DESCRIPTION	COM. BY
H	02.02.2022	WEDGE DETAIL UPDATED	AHA

QTY.	DESCRIPTION	DRG. No./MATERIAL	LENGTH	ITEM No.	MASS

TITLE: GENERAL ARRANGEMENT
H1-60-30

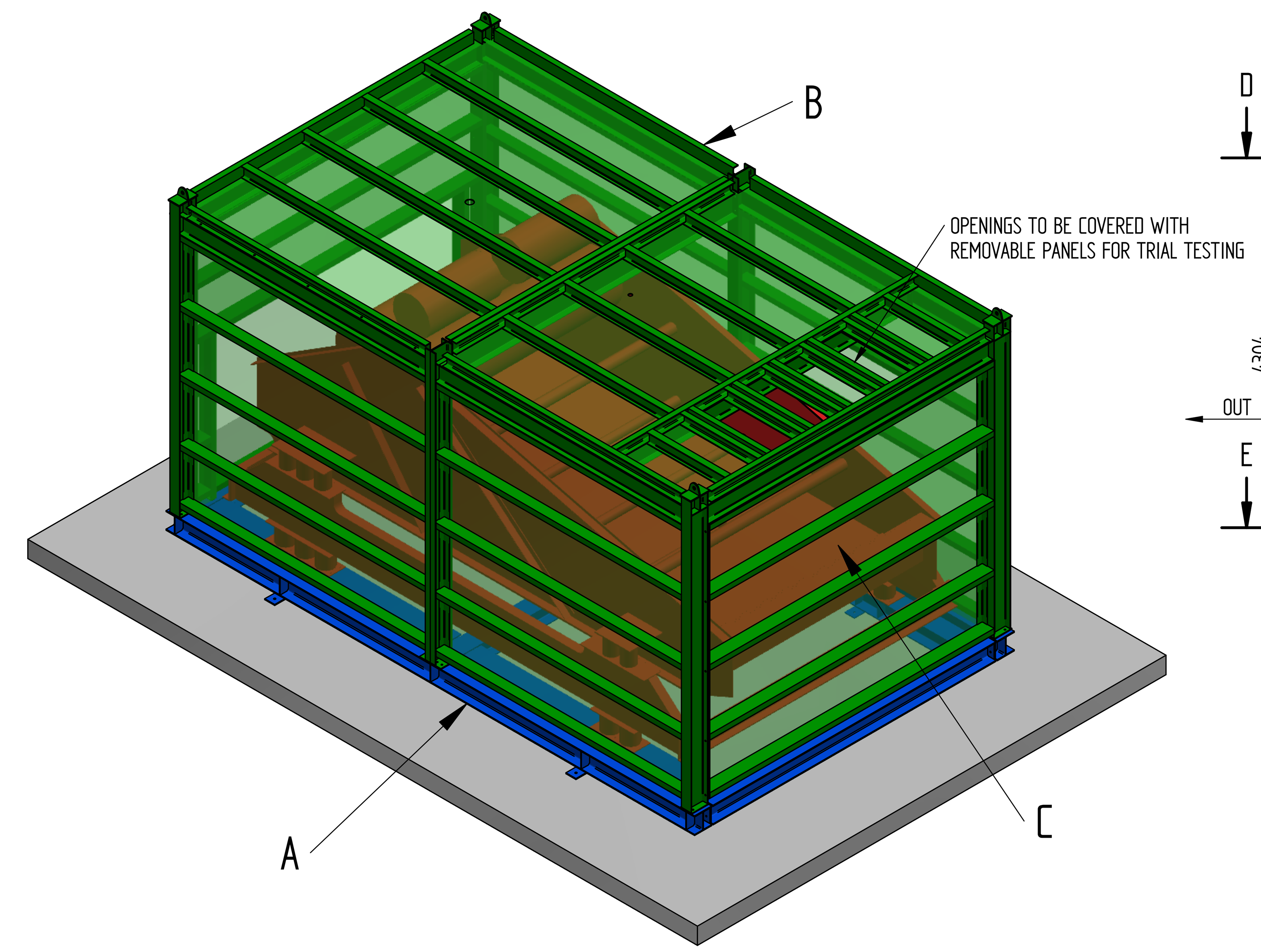
DRAWN	DATE	CHECKED	SCALE
AHA	12.03.2021	D.S.M.	1:20

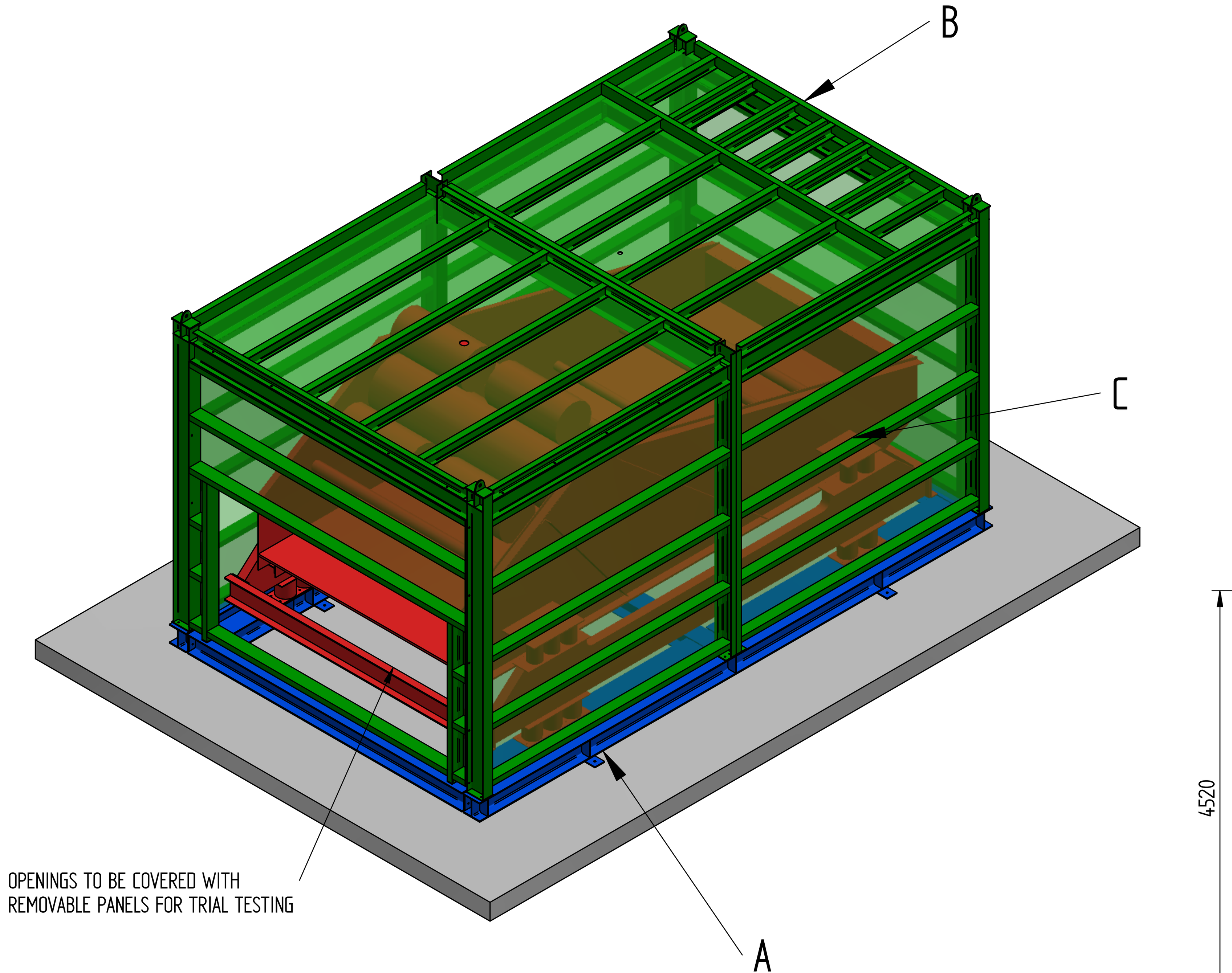
Job Ref.#
DRG. No.: VSRC114686
REV. H

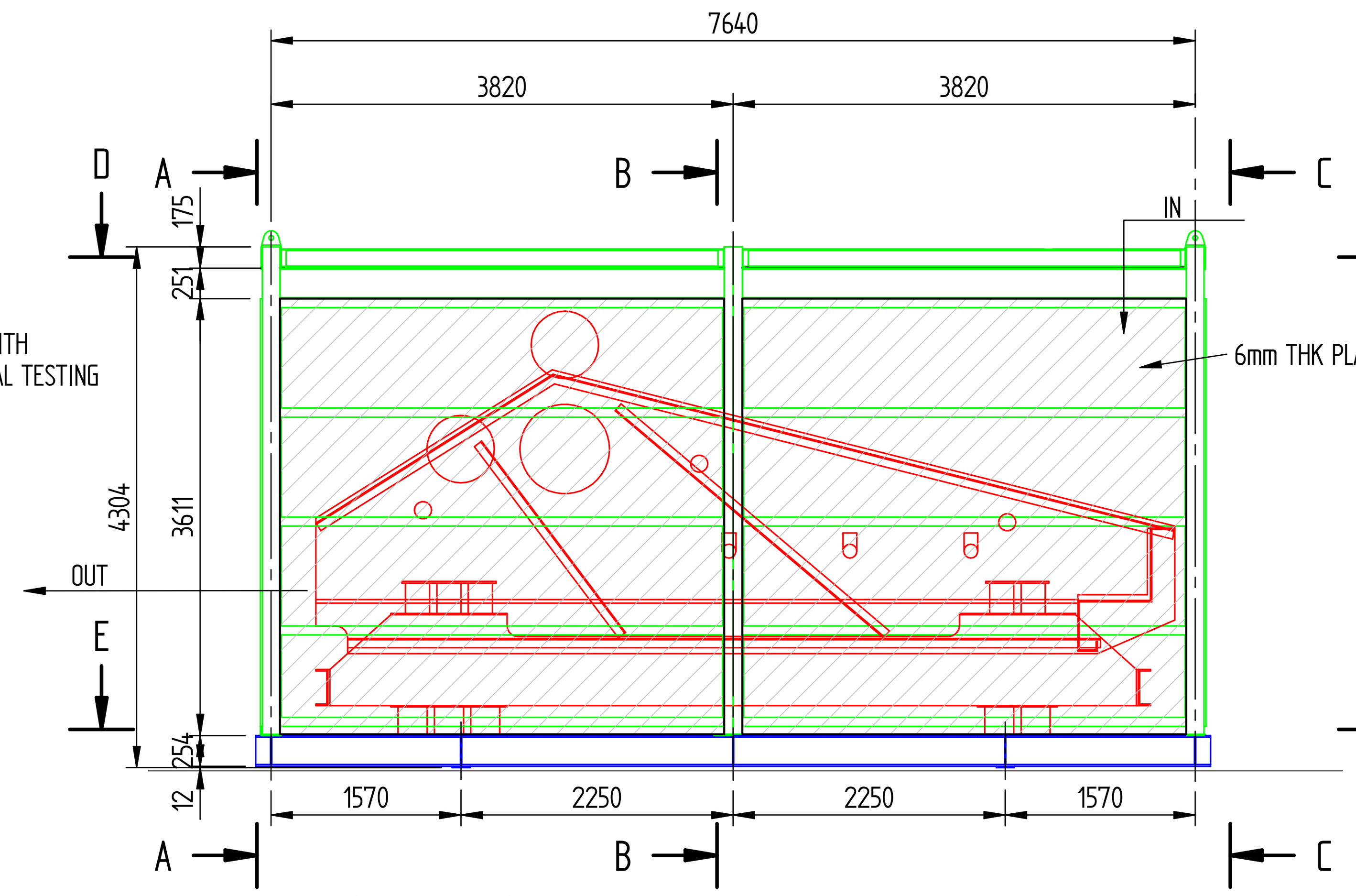
Appendix B

ENCLOSURE DRAWING AND TRIAL LOCATION

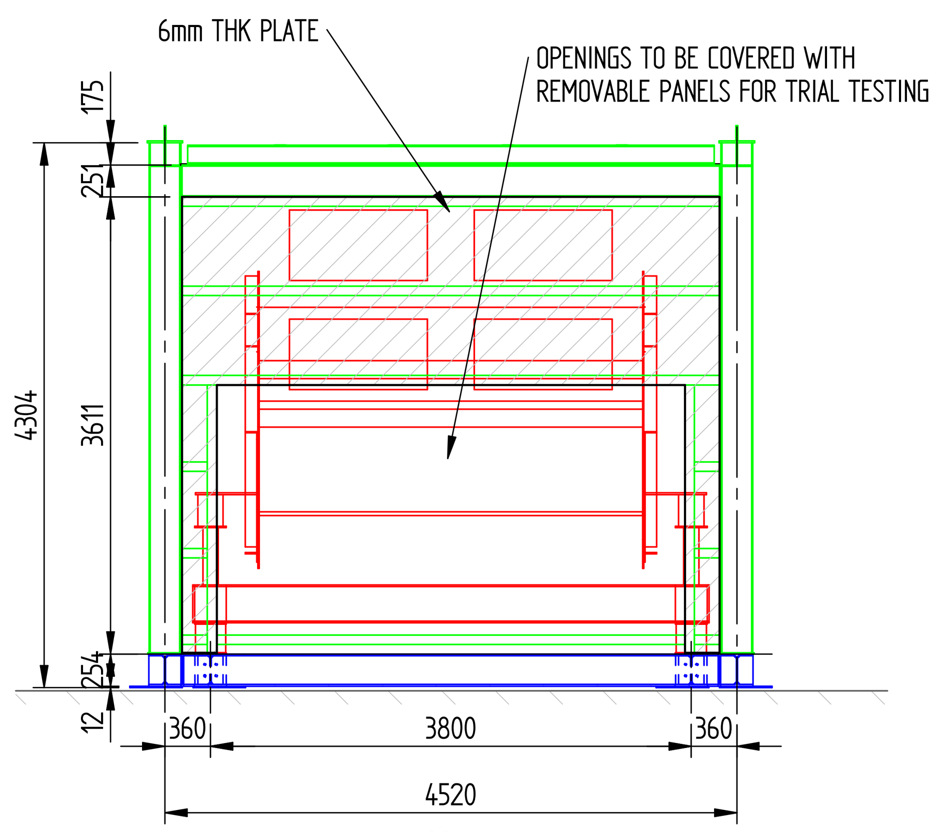
ALL DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE STATED



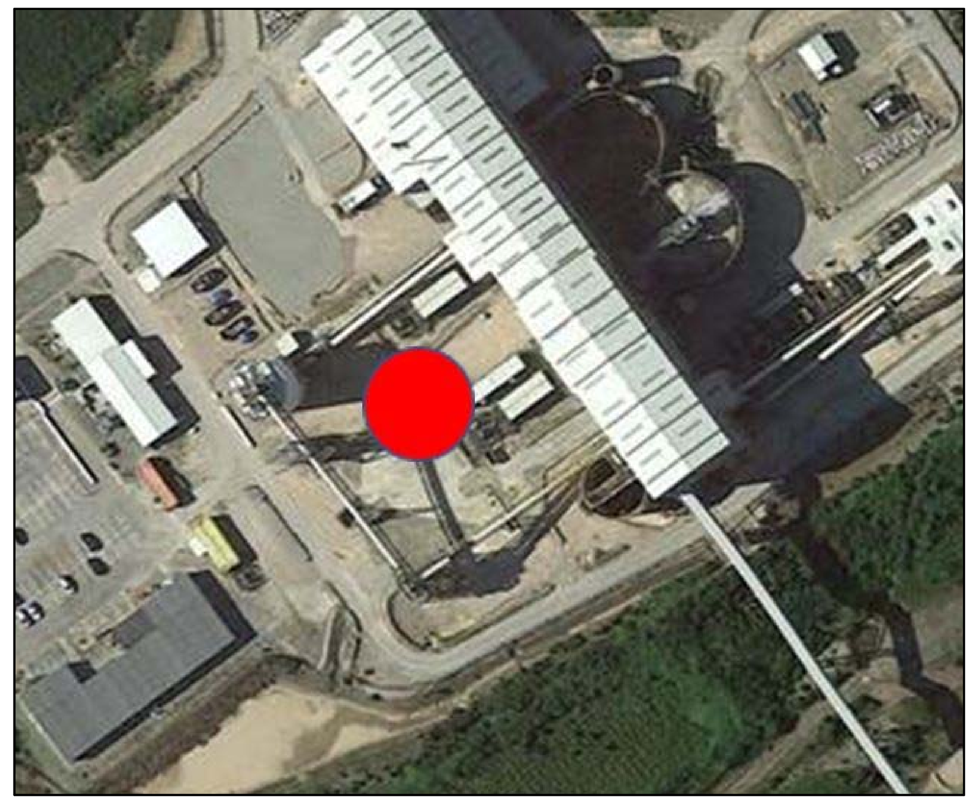




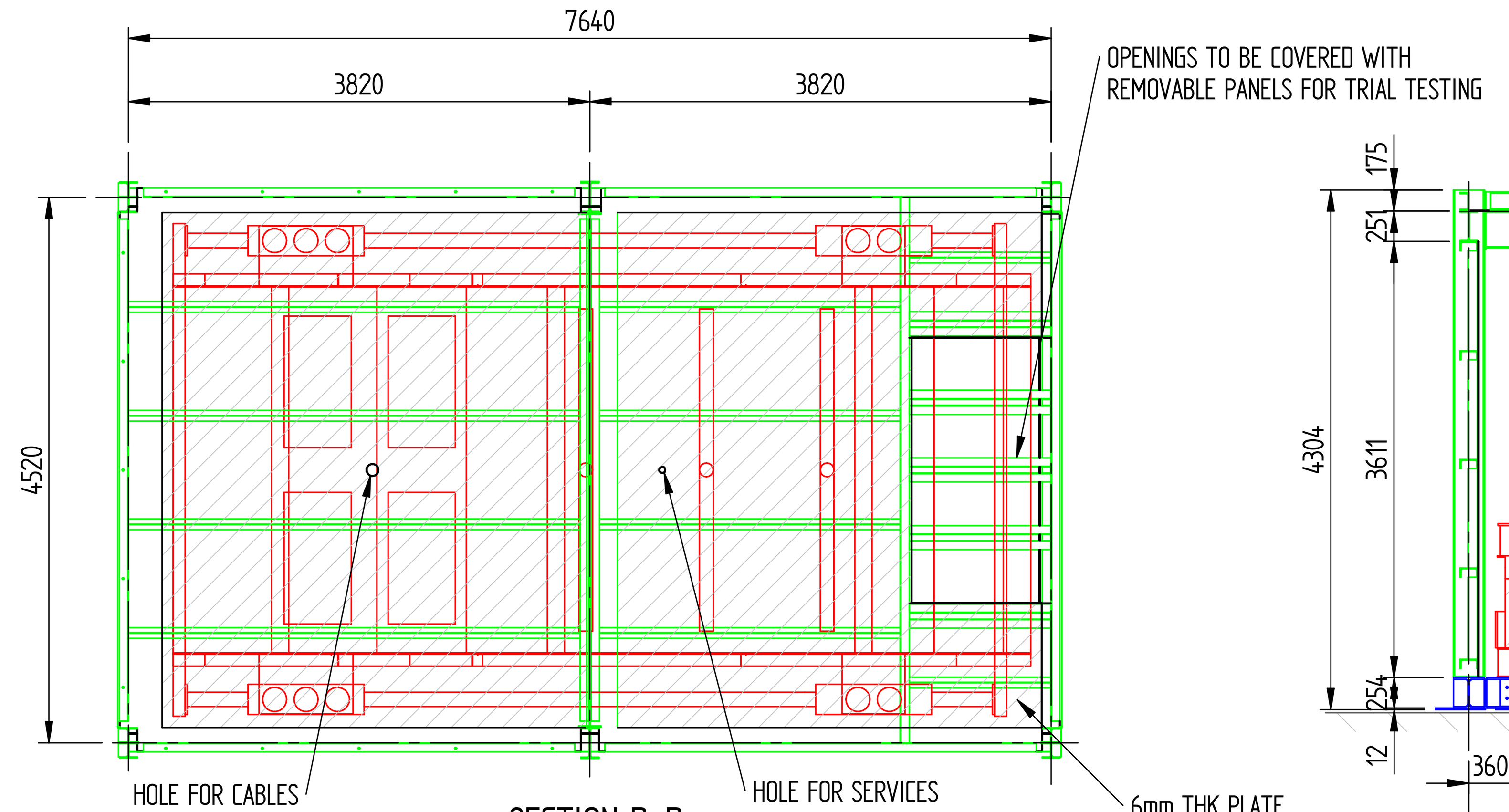
MAIN SIDE ELEVATION OF FULL TRIAL SUB FRAME, SCREEN AND ENCLOSURE



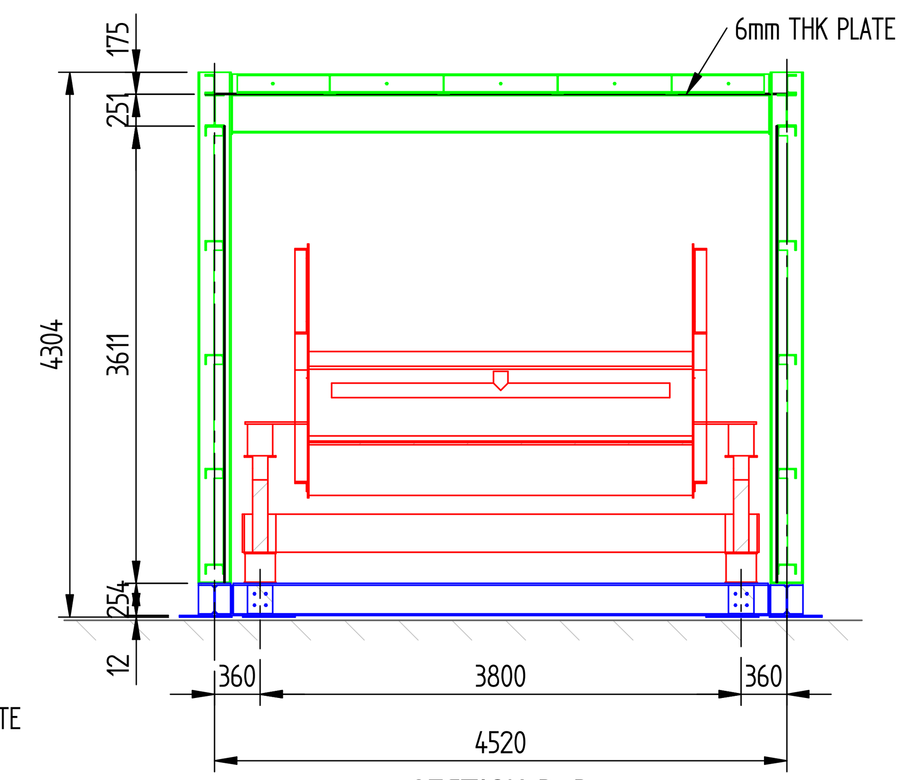
SECTION A-A
FRONT ELEVATION OF FULL TRIAL SUB FRAME, SCREEN AND ENCLOSURE



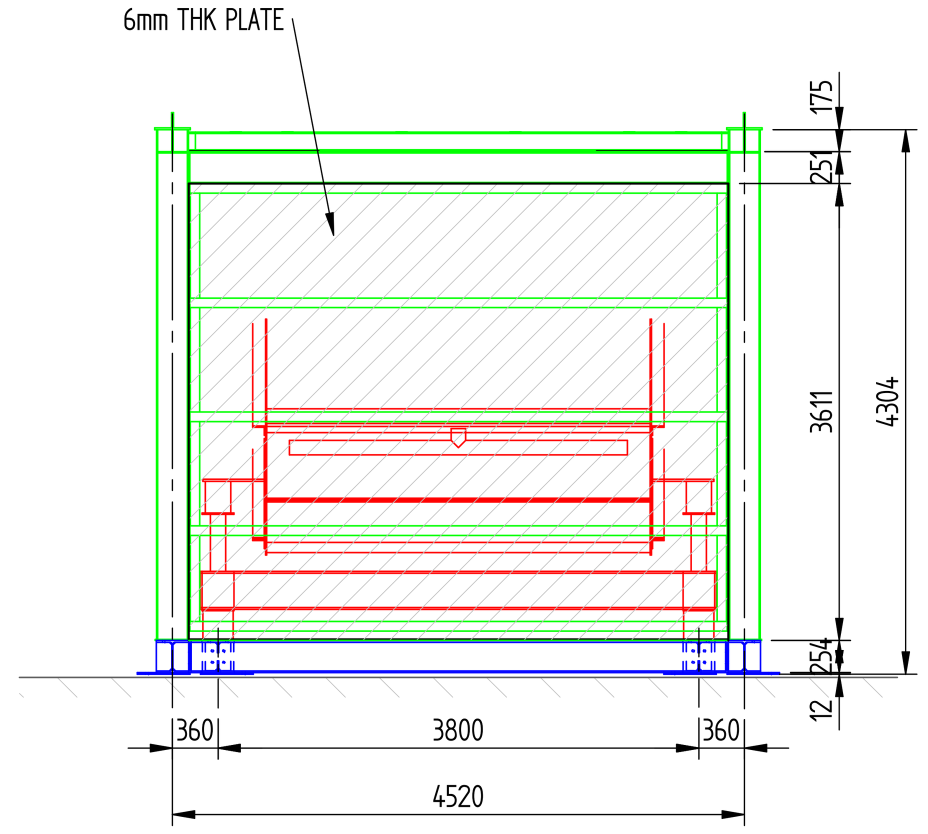
APPROX SITE LOCATION FOR TRIAL
NORTHING: 58905.1542
EASTING: 256877.7847



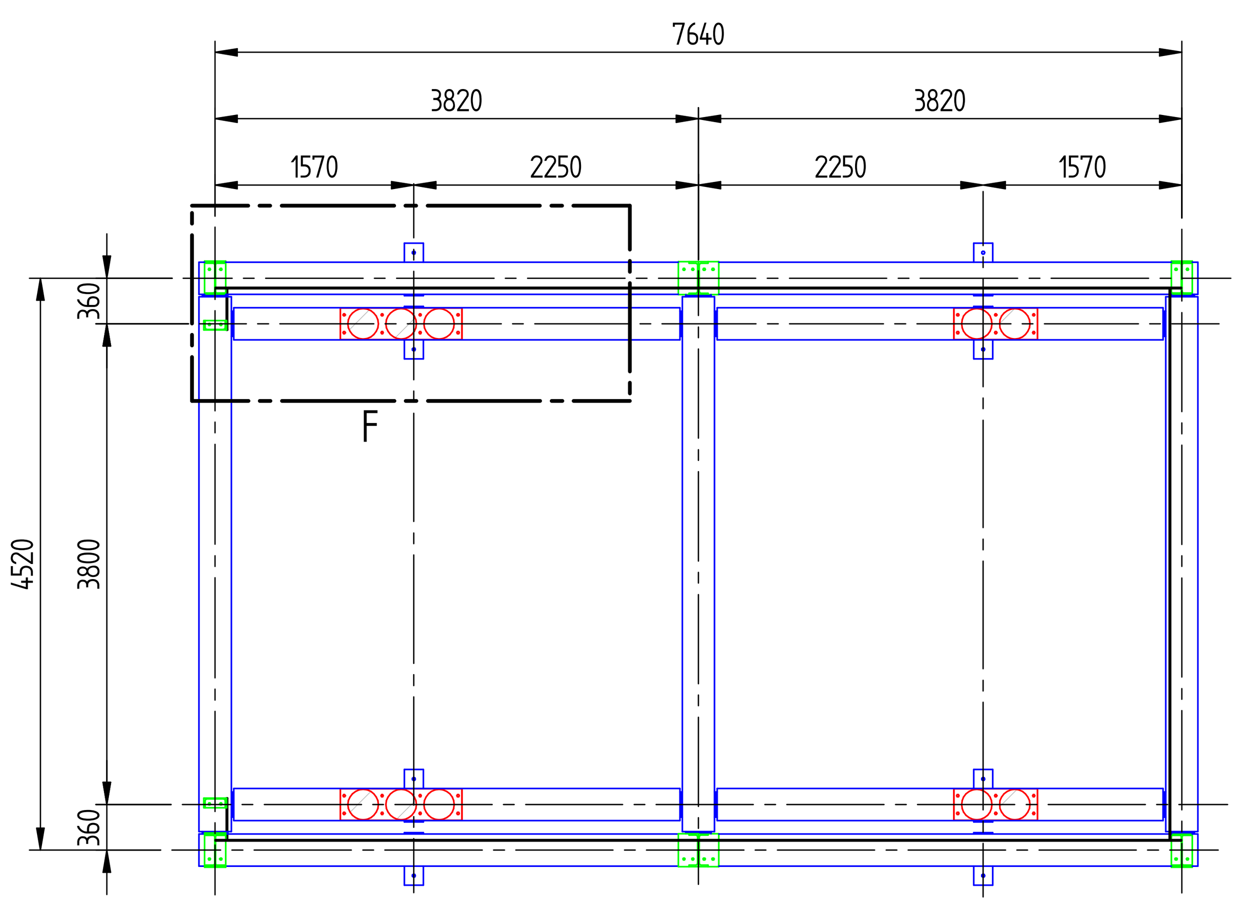
SECTION D-D
PLAN VIEW ON TRIAL SCREEN AND ENCLOSURE



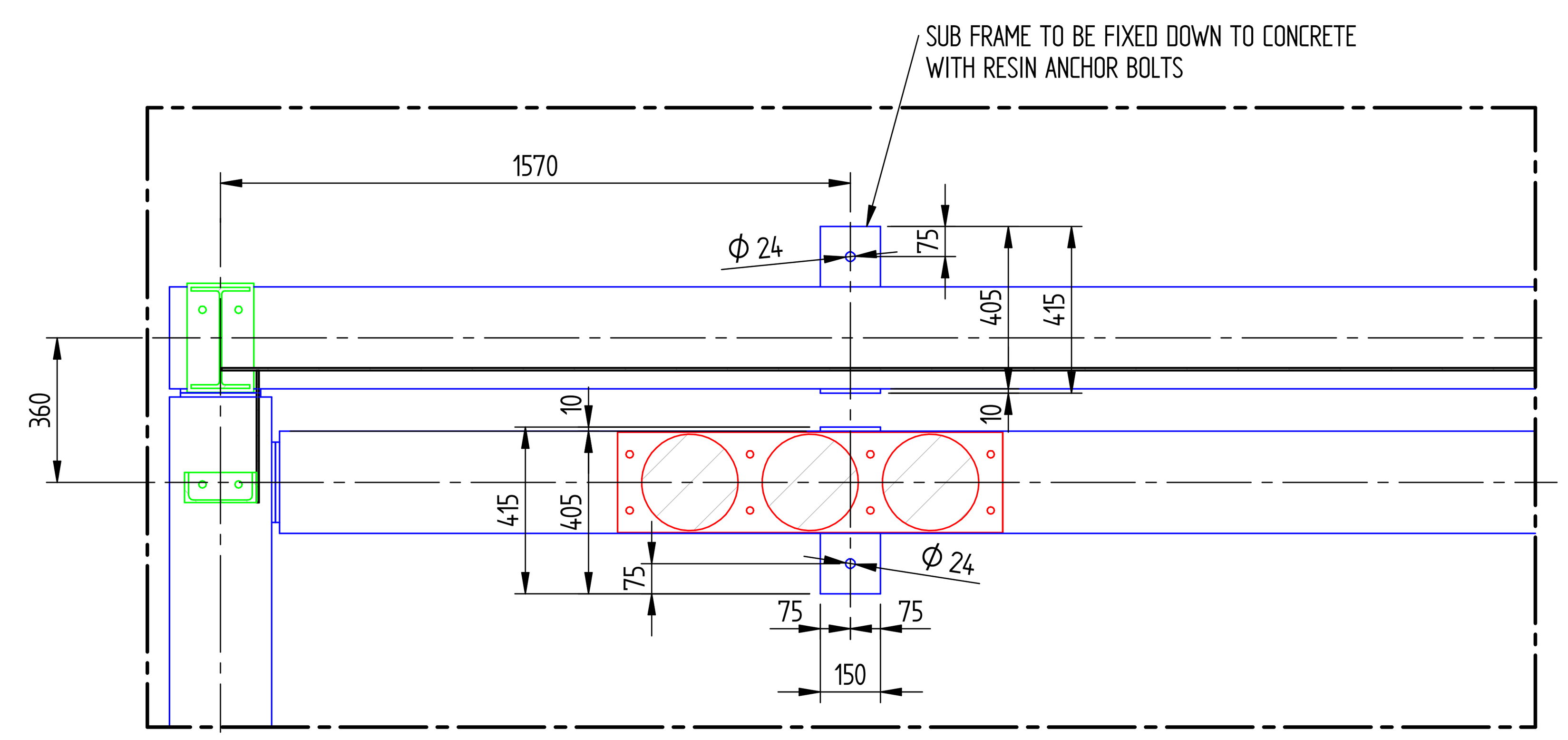
SECTION B-B
SECTION THROUGH OF FULL TRIAL SUB FRAME, SCREEN AND ENCLOSURE



SECTION C-C
REAR ELEVATION OF FULL TRIAL SUBFRAME, SCREEN AND ENCLOSURE



SECTION E-E
PLAN VIEW ON SUB FRAME



DETAIL F
SHOWING BASE PLATE DETAILS

LEGEND:
A – SUB FRAME TO SUPPORT SCREEN AND ENCLOSURE FOR TRIAL
B – ENCLOSURE FOR NOISE MITIGATION FREQUENCY TRIALS
C – TRIAL SCREEN 130-SN-13 TERTIARY CRUSHER DEWATERING SCREEN

TUNGSTEN WEST

fairport
partnership - resource - accountability

REVISIONS

REV	DRAWN	DATE	CHECK	DATE	DESCRIPTION
--					
--					
--					
--					
--					
A1	CC	19/04/23	SG	19/04/23	UPDATED TO SUIT CALCULATIONS
A	CC	14/04/23	SG	14/04/23	FIRST ISSUE

REV	DRAWN	DATE	CHECK	DATE	DESCRIPTION
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--					
--					
--					
--					

REF. DRAWINGS

DRAWING REFERENCE	DRAWING NUMBER
	--
	--
	--
	--
	--
	--
	--

DO NOT SCALE.
IF IN DOUBT - ASK

DRN	CC	SCALE @ A1	-:---
DATE	14/04/23		
CHKD	SG	APPD	SG
DATE	14/04/23	DATE	14/04/23
PROJECT/PLANT AREA		PROJ.No.	7257

HEMERDON RESTART PROJECT
LFN TRIAL

Fairport Engineering Ltd
2nd Floor, Fairclough House
Church Street
Adlington
Chorley
PR7 4EX
TEL: +44 (0) 01257 484000
www.fairport.co.uk/www.pxlimited.com
Registered in England, Reg. No. 6534289

TITLE:- LOW FREQUENCY NOISE
SCREEN 130-SN-13 TRIAL ENCLOSURE

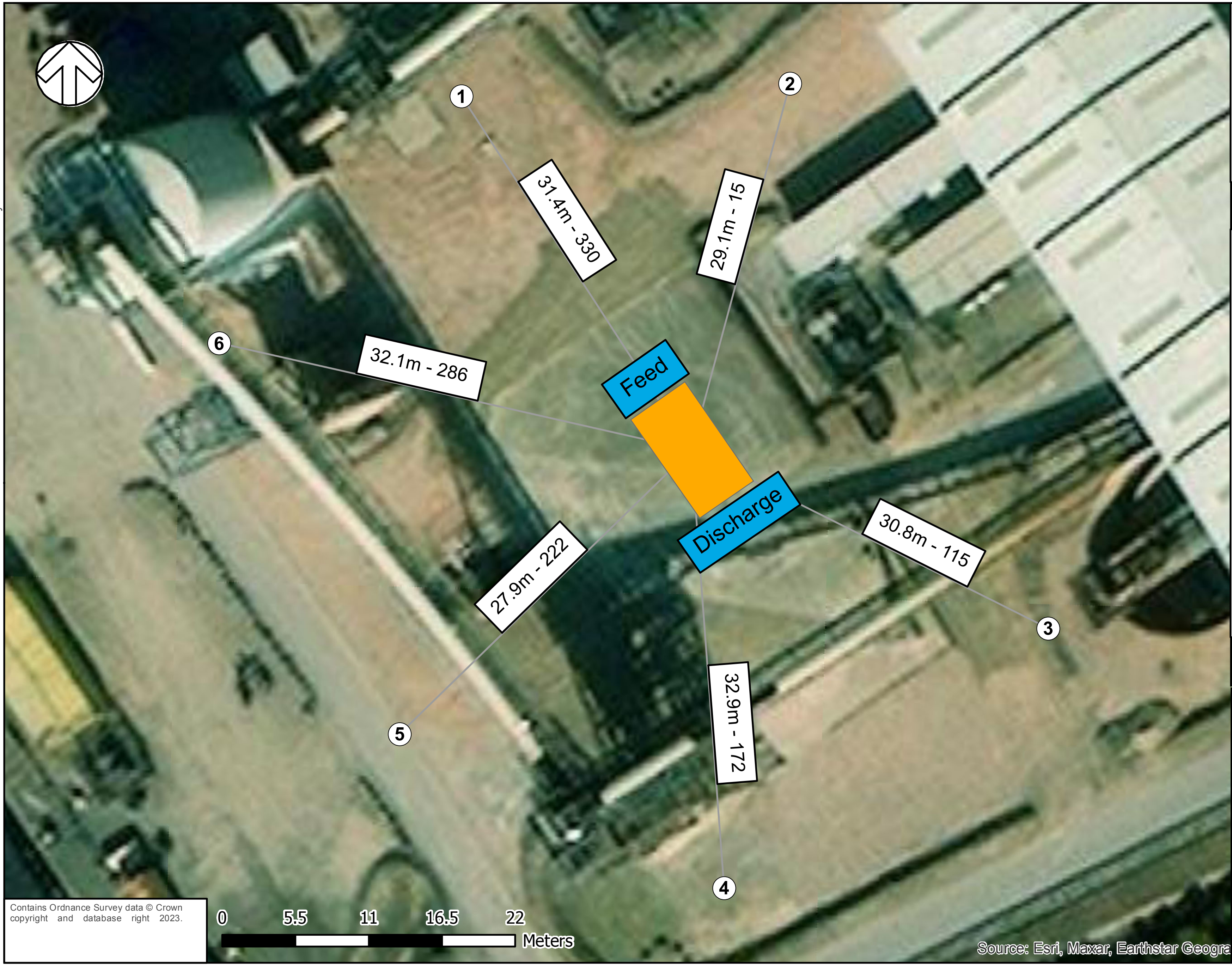
DRG No 7257-SK-LFN-001 REV. A1

4th Floor
6 Devonshire Square
London
EC2M 4YE

wsp.com

Appendix J

LFN TRIAL MEASUREMENT LOCATIONS (NEAR FIELD)



Legend

Nearfield Measurement Location

Screen Location

wsp

TITLE:

NEARFIELD TESTING ARRANGEMENT

FIGURE No:

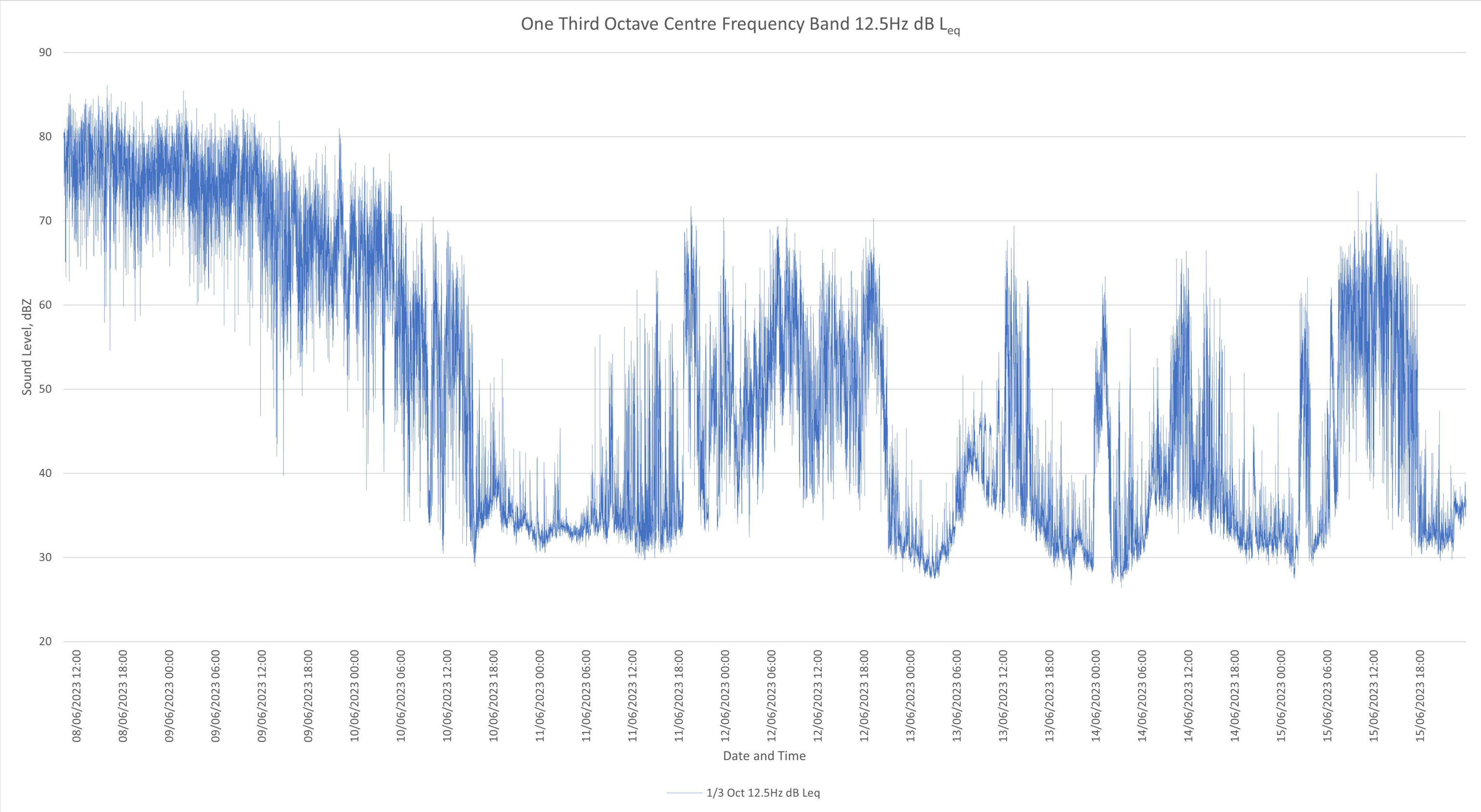
FIGURE X

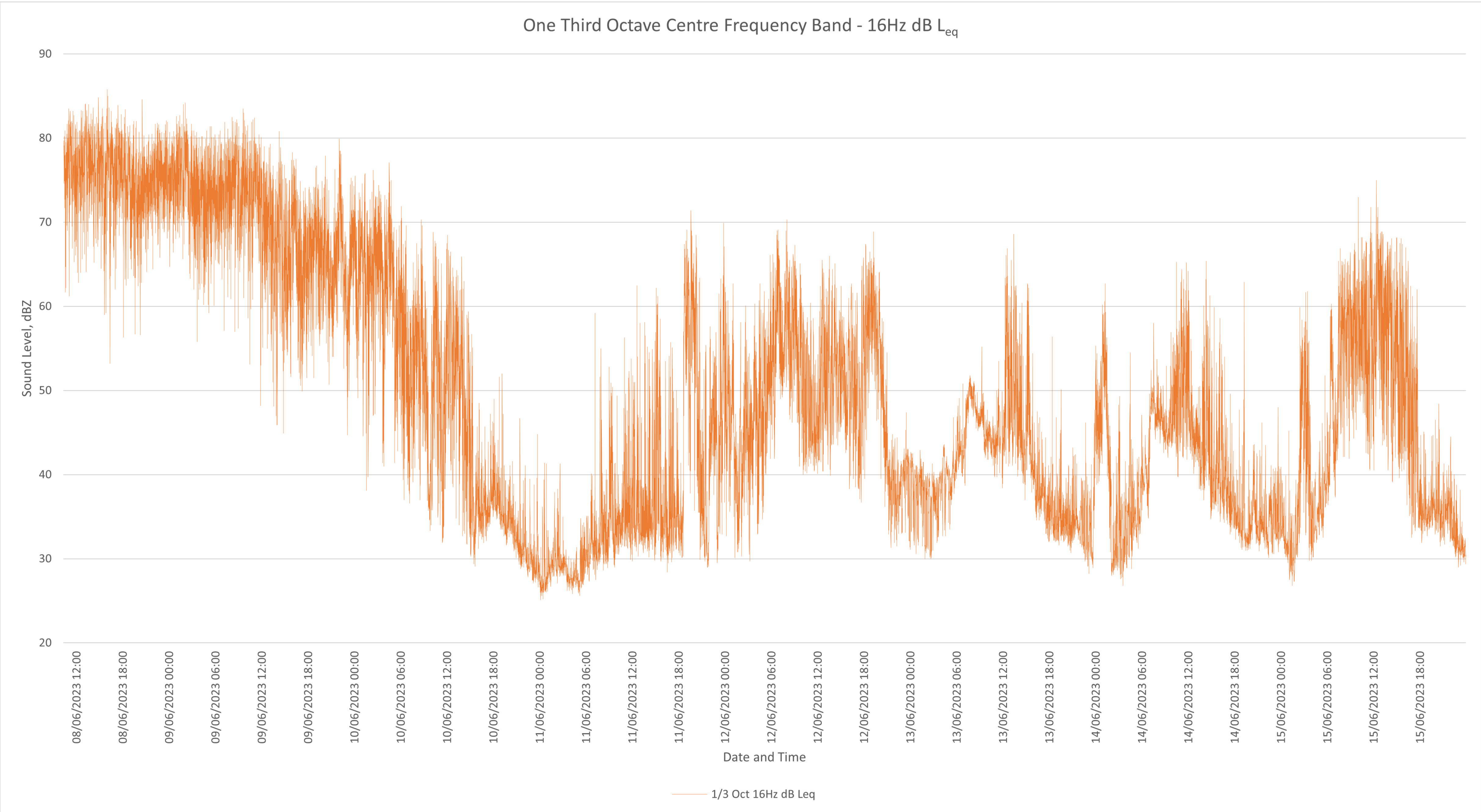
Date Modified: 03/08/2023
Drawn By: YH
File: \\uk.wspgroup.com\central data\Projects\70108xxx\70108756 - Tungsten Mine - LFN\03 WIP\7. Models\01 GIS

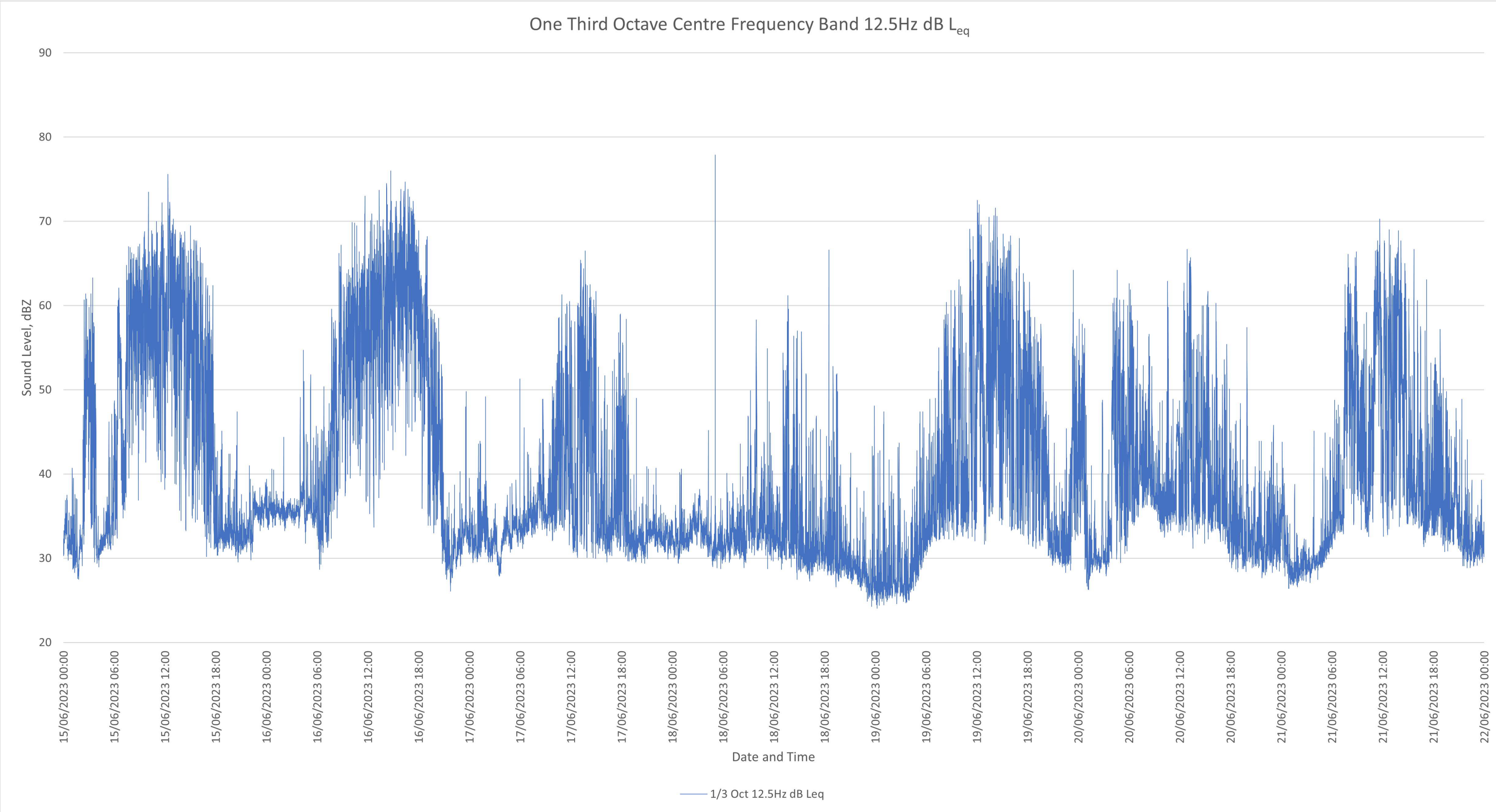
Appendix K

RAW NOISE AND WEATHER DATA

LT1: Noise Monitoring Graphs






One Third Octave Centre Frequency Band 12.5Hz dB L_{eq}
Sound Level, dBZ
90
80
70
60
50
40
30
20
15/06/2023 00:00
15/06/2023 06:00
15/06/2023 12:00
15/06/2023 18:00
16/06/2023 00:00
16/06/2023 06:00
16/06/2023 12:00
16/06/2023 18:00
17/06/2023 00:00
17/06/2023 06:00
17/06/2023 12:00
17/06/2023 18:00
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19/06/2023 00:00
19/06/2023 06:00
19/06/2023 12:00
19/06/2023 18:00
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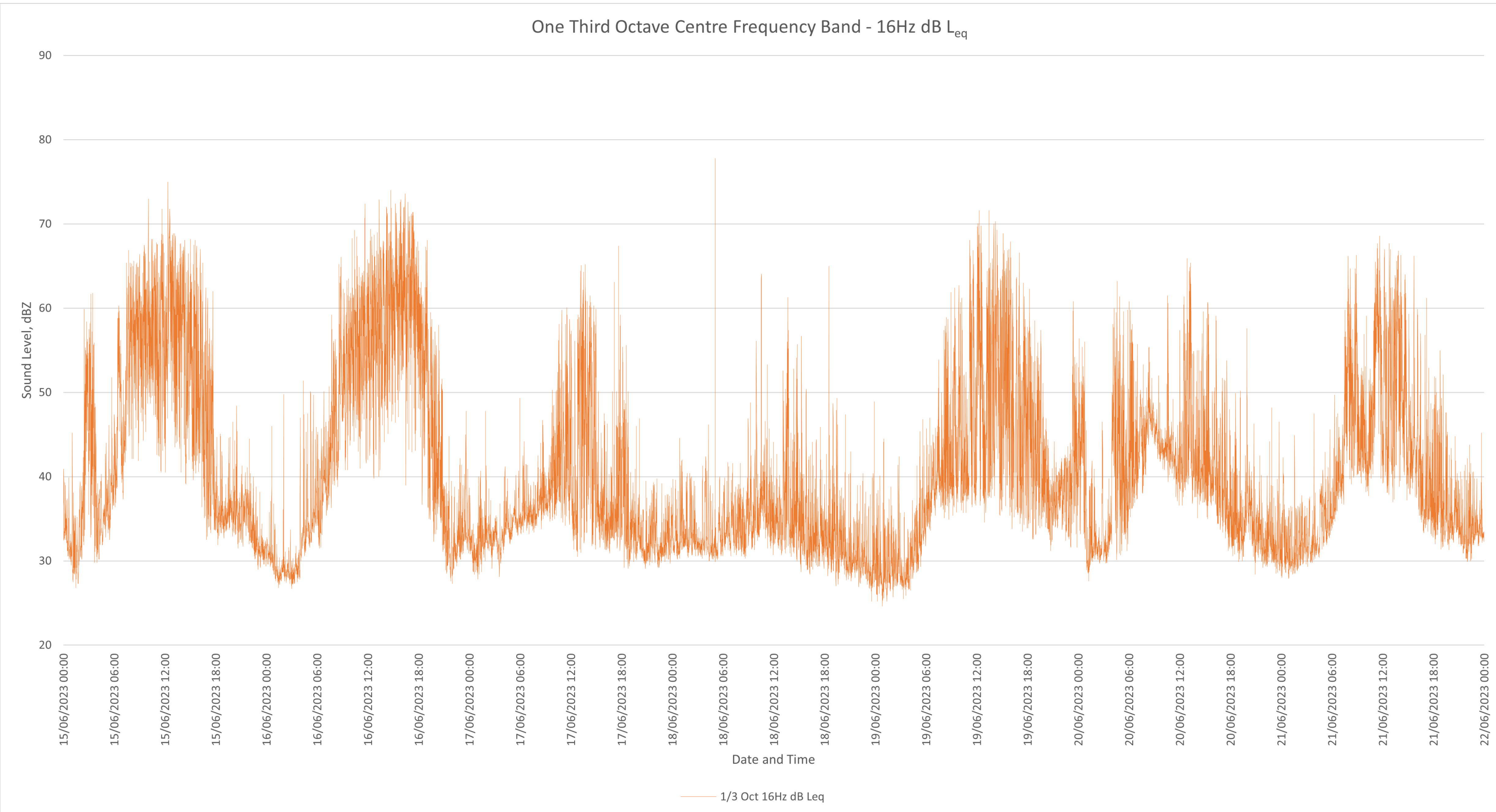
20/06/2023 06:00
20/06/2023 12:00
20/06/2023 18:00
21/06/2023 00:00
21/06/2023 06:00
21/06/2023 12:00
21/06/2023 18:00
22/06/2023 00:00
Date and Time
1/3 Oct 12.5Hz dB Leq


One Third Octave Centre Frequency Band - 16Hz dB L_{eq}
Sound Level, dBZ
90
80
70
60
50
40
30
20
15/06/2023 00:00
15/06/2023 06:00
15/06/2023 12:00
15/06/2023 18:00
16/06/2023 00:00
16/06/2023 06:00
16/06/2023 12:00
16/06/2023 18:00
17/06/2023 00:00
17/06/2023 06:00
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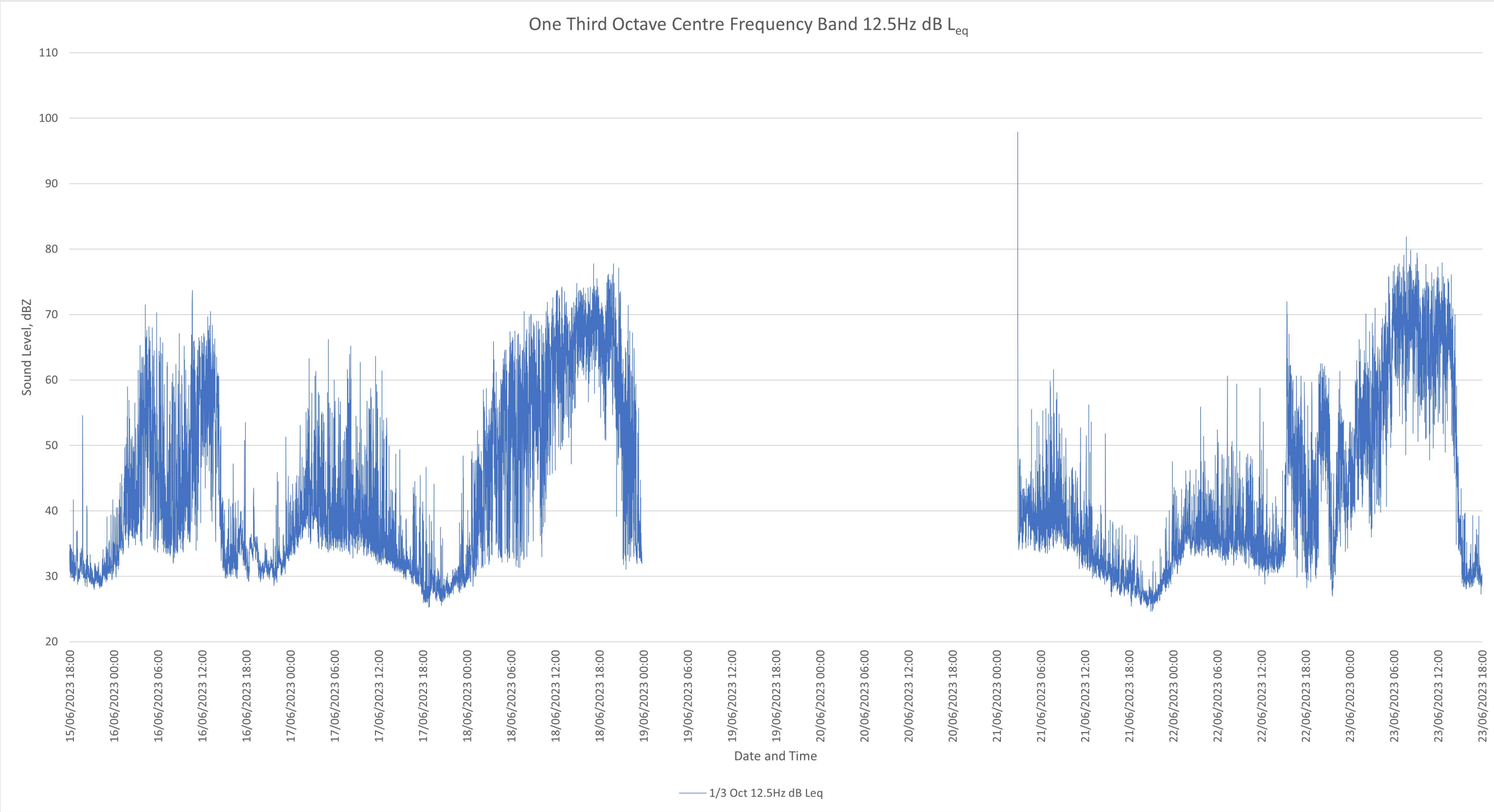
Date and Time
1/3 Oct 16Hz dB Leq


One Third Octave Centre Frequency Band 12.5Hz dB L_{eq}
Sound Level, dBZ
110
100
90
80
70
60
50
40
30
20
15/06/2023 18:00
16/06/2023 00:00
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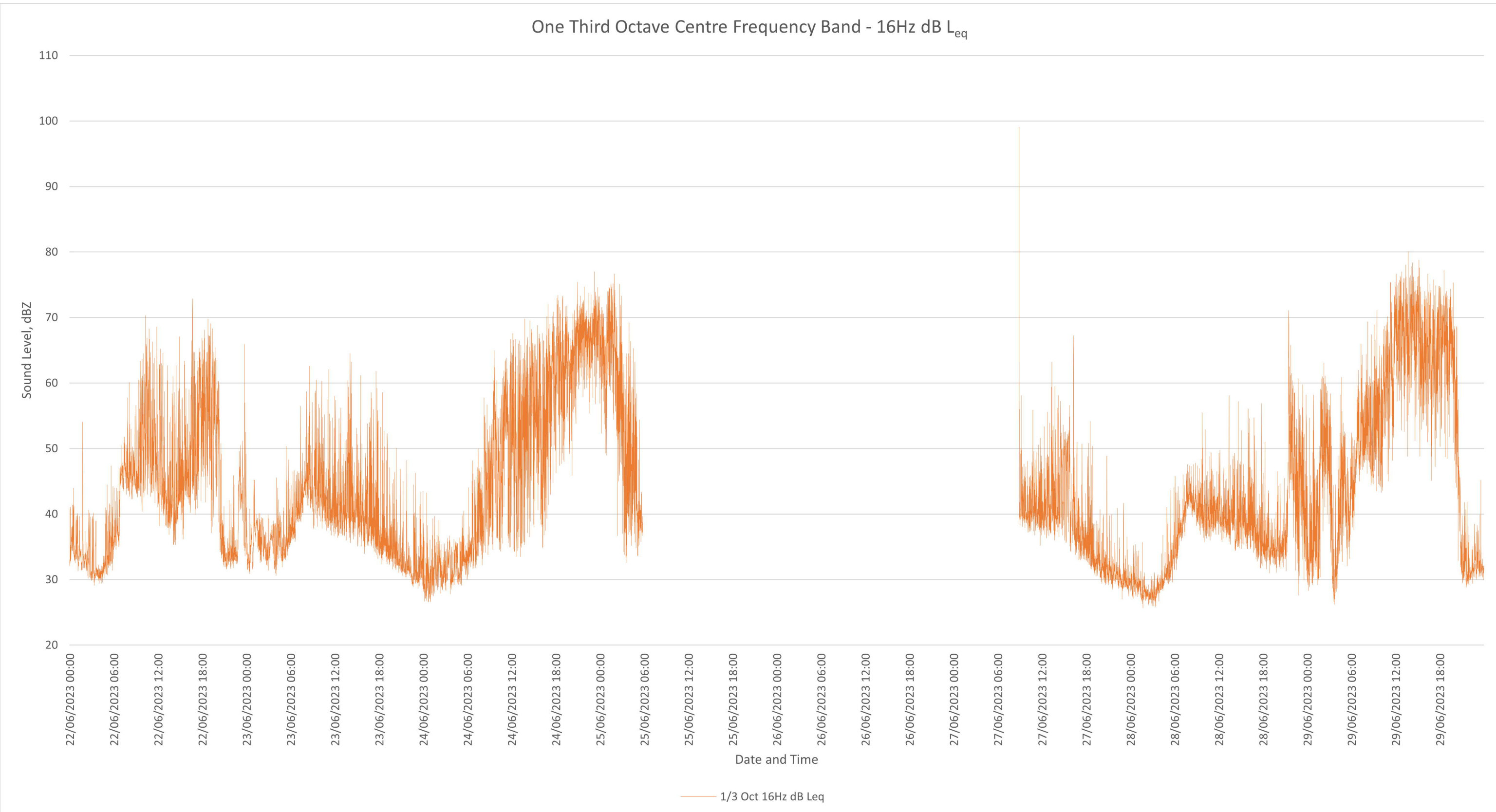
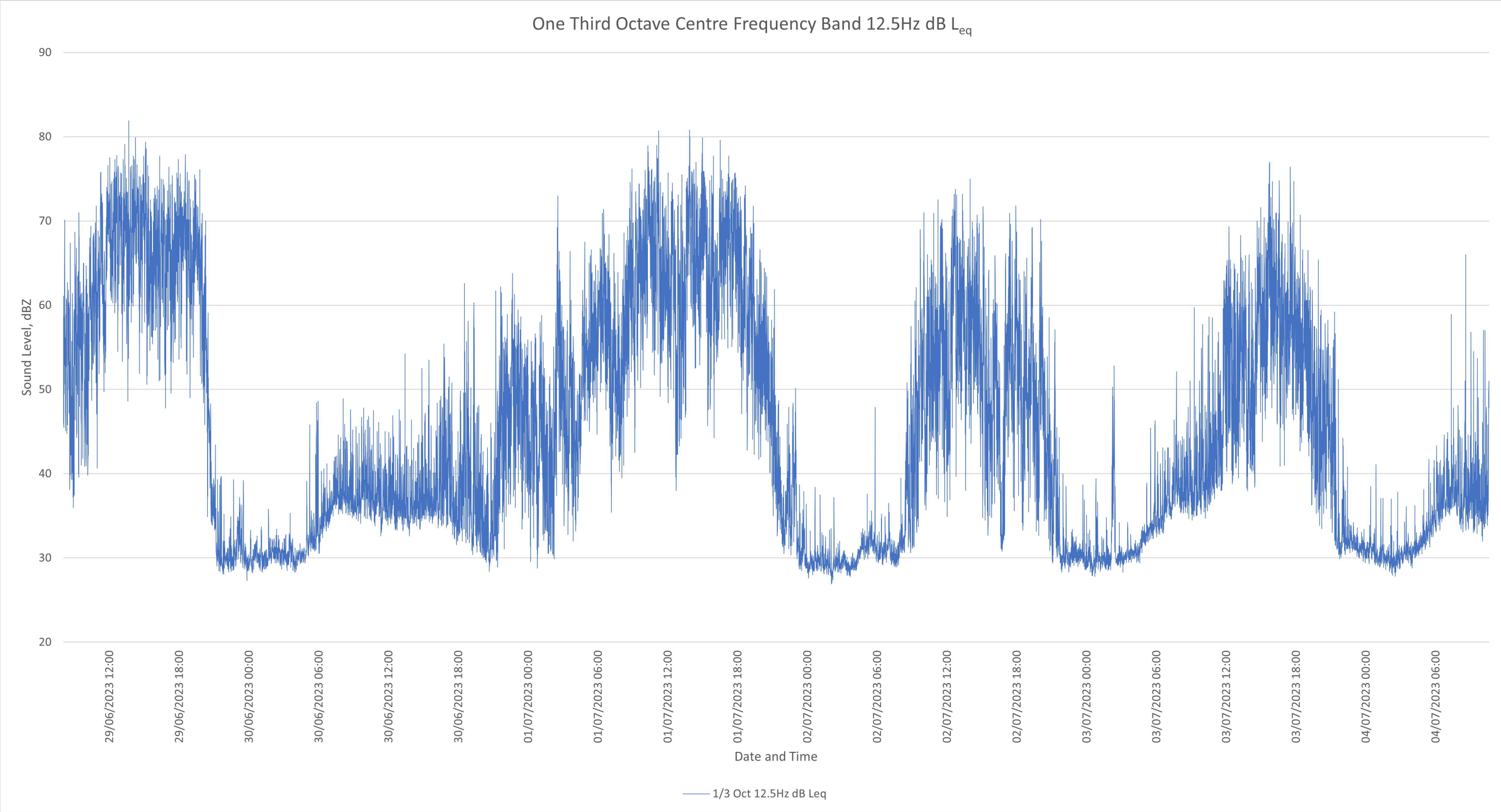
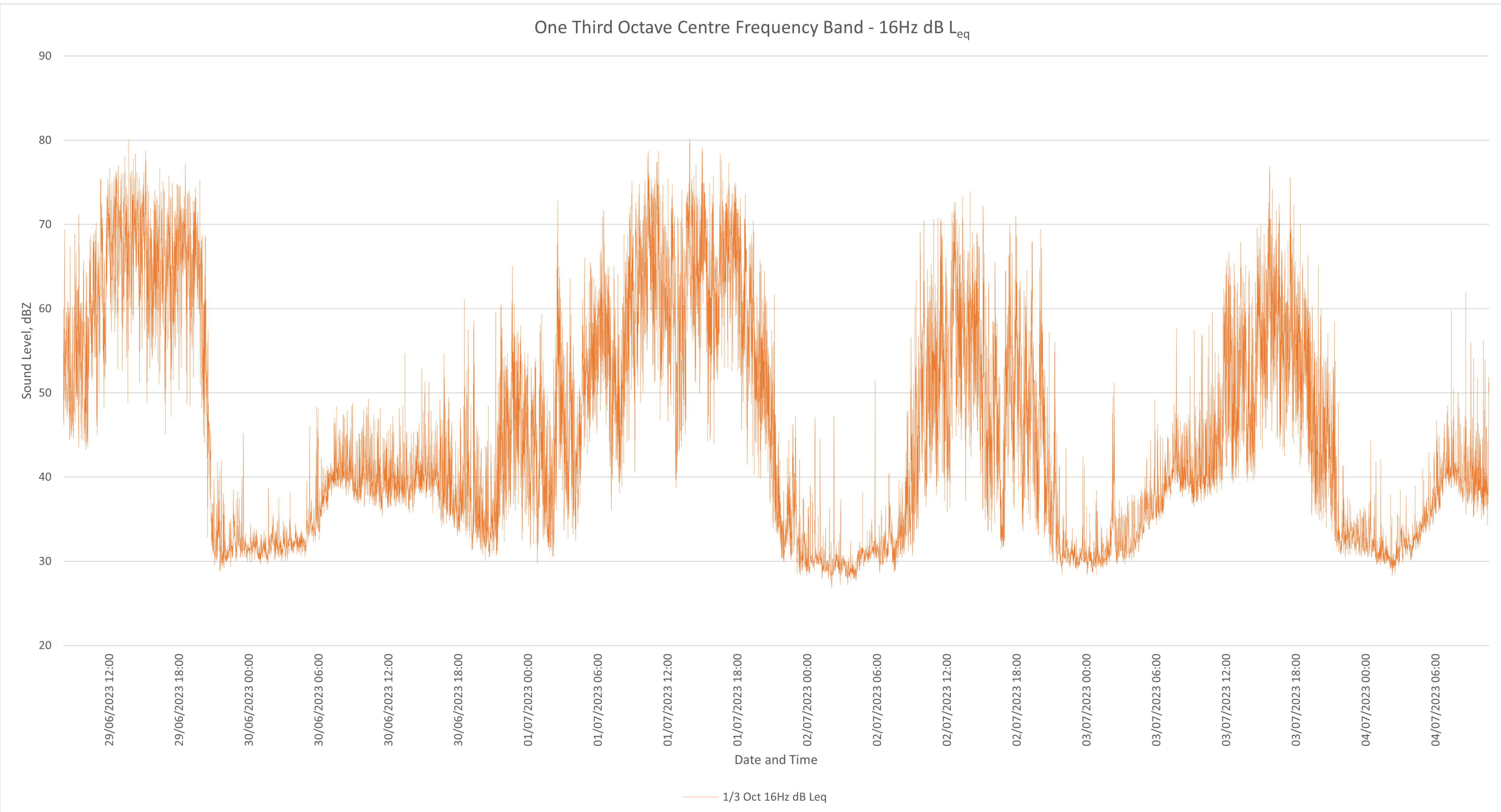
22/06/2023 00:00
22/06/2023 06:00
22/06/2023 12:00
22/06/2023 18:00
23/06/2023 00:00
23/06/2023 06:00
23/06/2023 12:00
23/06/2023 18:00
Date and Time
1/3 Oct 12.5Hz dB Leq


One Third Octave Centre Frequency Band - 16Hz dB L_{eq}
Sound Level, dBZ
110
100
90
80
70
60
50
40
30
20
22/06/2023 00:00
22/06/2023 06:00
22/06/2023 12:00
22/06/2023 18:00
23/06/2023 00:00
23/06/2023 06:00
23/06/2023 12:00
23/06/2023 18:00
24/06/2023 00:00
24/06/2023 06:00
24/06/2023 12:00
24/06/2023 18:00
25/06/2023 00:00
25/06/2023 06:00
25/06/2023 12:00
25/06/2023 18:00
26/06/2023 00:00
26/06/2023 06:00
26/06/2023 12:00
26/06/2023 18:00
27/06/2023 00:00
27/06/2023 06:00
27/06/2023 12:00
27/06/2023 18:00
28/06/2023 00:00
28/06/2023 06:00
28/06/2023 12:00
28/06/2023 18:00
29/06/2023 00:00
29/06/2023 06:00
29/06/2023 12:00
29/06/2023 18:00
Date and Time
1/3 Oct 16Hz dB Leq

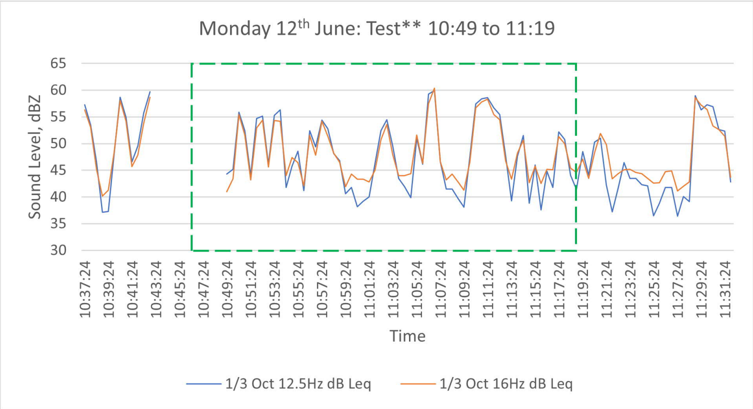


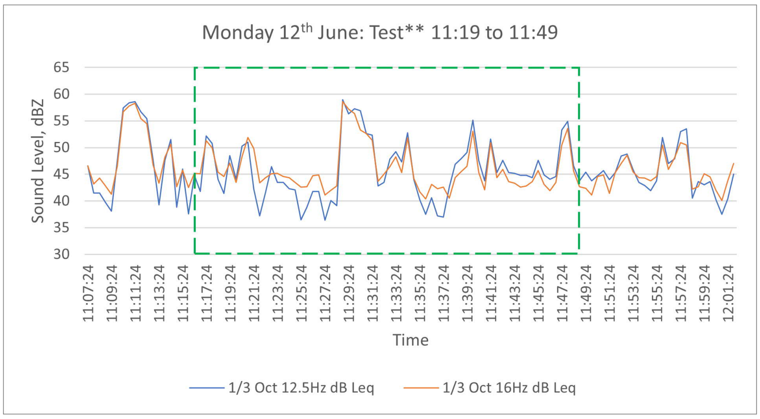
One Third Octave Centre Frequency Band 12.5Hz dB L_{eq}
Sound Level, dBZ
90
80
70
60
50
40
30
20
29/06/2023 12:00
29/06/2023 18:00
30/06/2023 00:00
30/06/2023 06:00
30/06/2023 12:00
30/06/2023 18:00
01/07/2023 00:00
01/07/2023 06:00
01/07/2023 12:00
01/07/2023 18:00
02/07/2023 00:00
02/07/2023 06:00
02/07/2023 12:00
02/07/2023 18:00
03/07/2023 00:00
03/07/2023 06:00
03/07/2023 12:00
03/07/2023 18:00
04/07/2023 00:00
04/07/2023 06:00
Date and Time
1/3 Oct 12.5Hz dB Leq

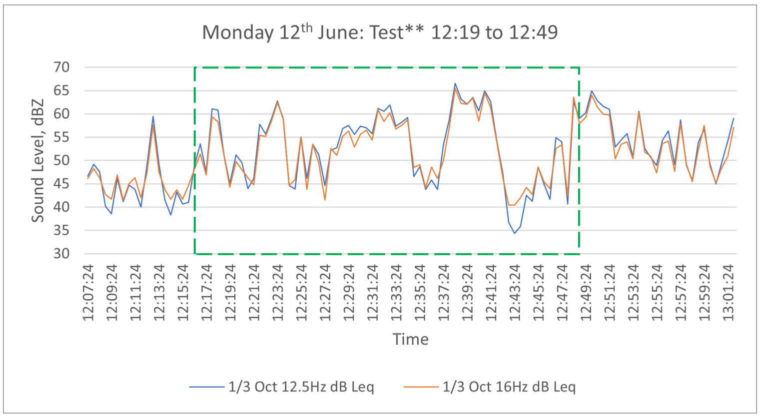


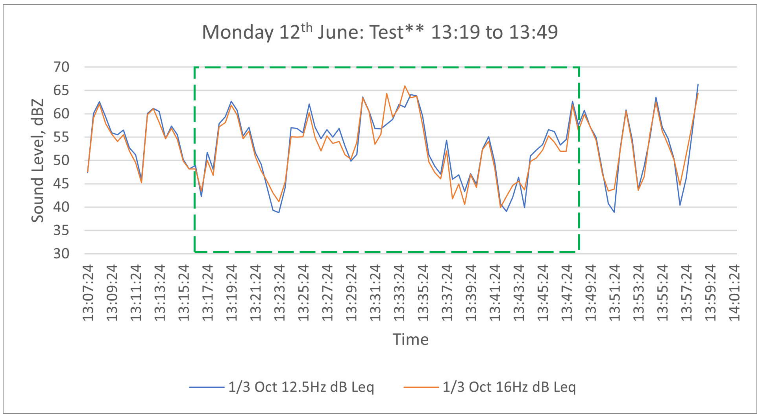
One Third Octave Centre Frequency Band - 16Hz dB L_{eq}
Sound Level, dBZ
90
80
70
60
50
40
30
20
29/06/2023 12:00
29/06/2023 18:00
30/06/2023 00:00
30/06/2023 06:00
30/06/2023 12:00
30/06/2023 18:00
01/07/2023 00:00
01/07/2023 06:00
01/07/2023 12:00
01/07/2023 18:00
02/07/2023 00:00
02/07/2023 06:00
02/07/2023 12:00
02/07/2023 18:00
03/07/2023 00:00
03/07/2023 06:00
03/07/2023 12:00
03/07/2023 18:00
04/07/2023 00:00
04/07/2023 06:00
Date and Time
1/3 Oct 16Hz dB Leq

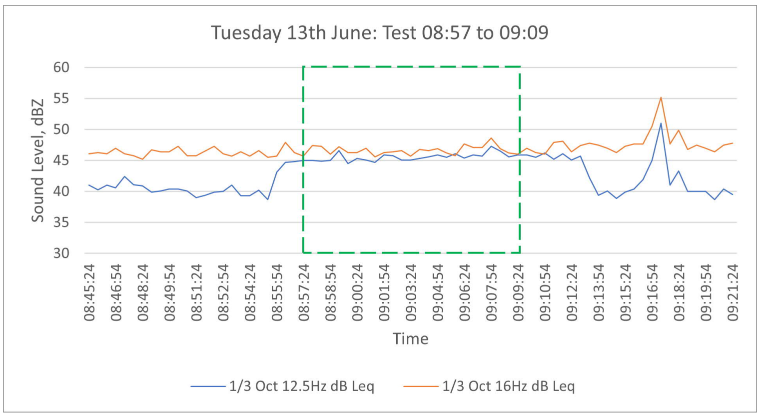
LT1: LFN Trial Graphs

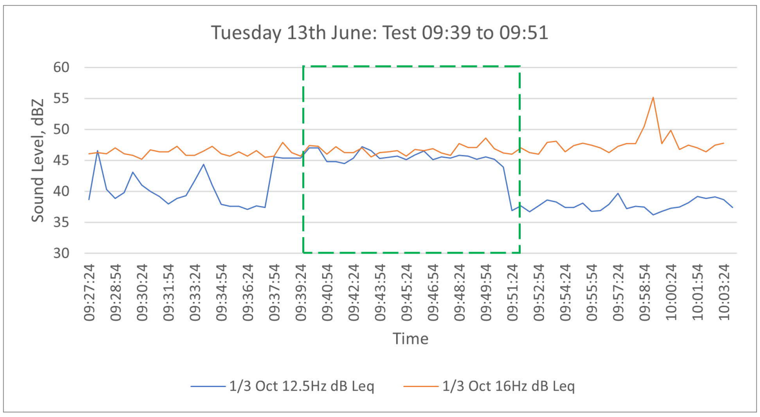


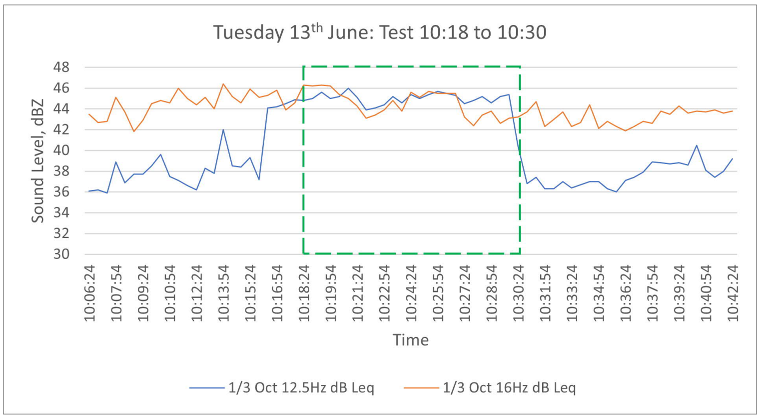


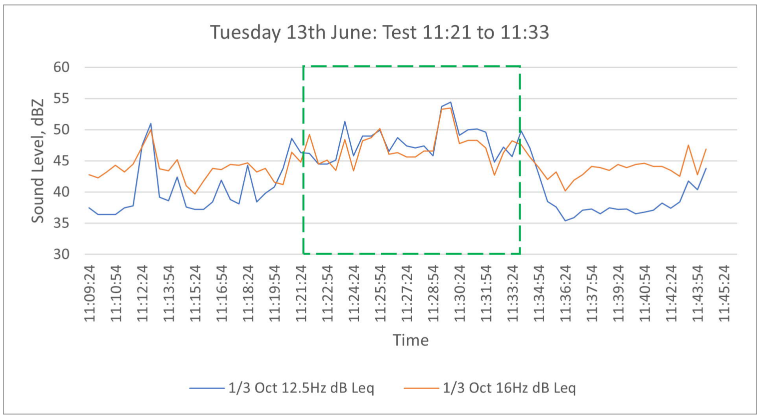


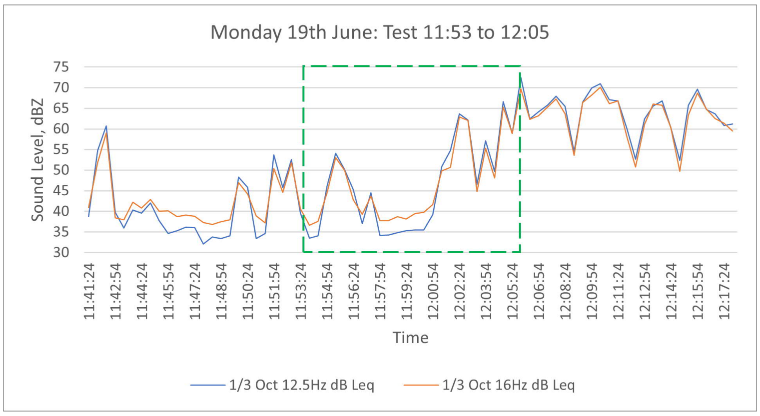


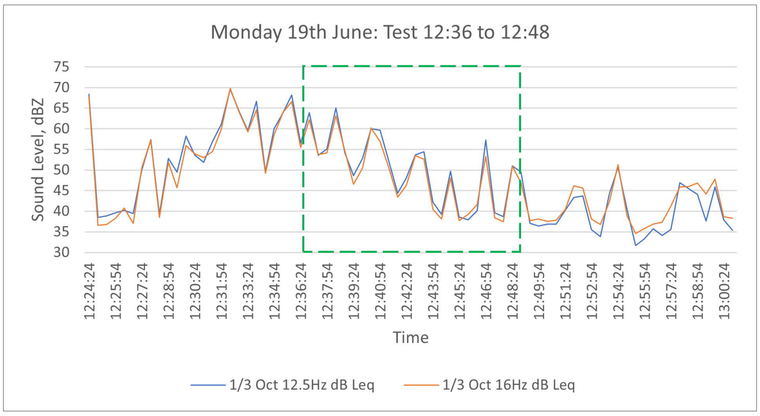


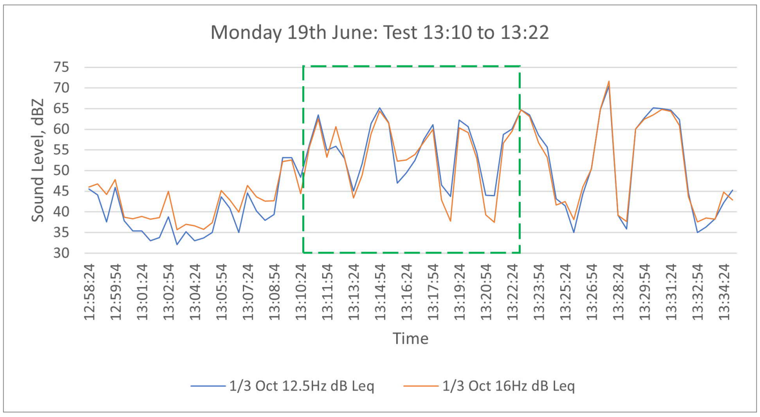


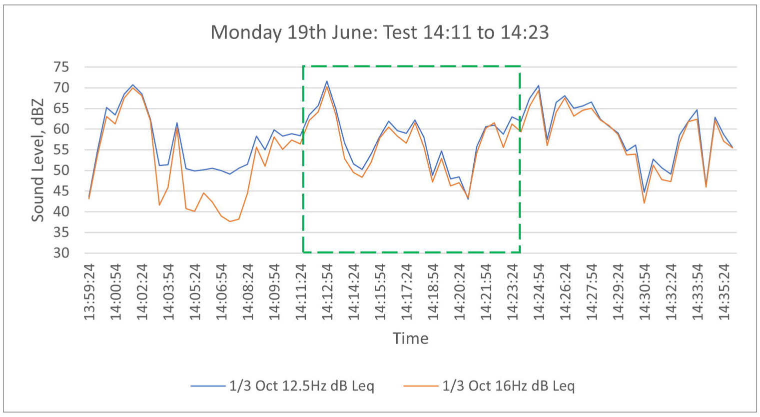

Tuesday 13th June: Test 10:18 to 10:30
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

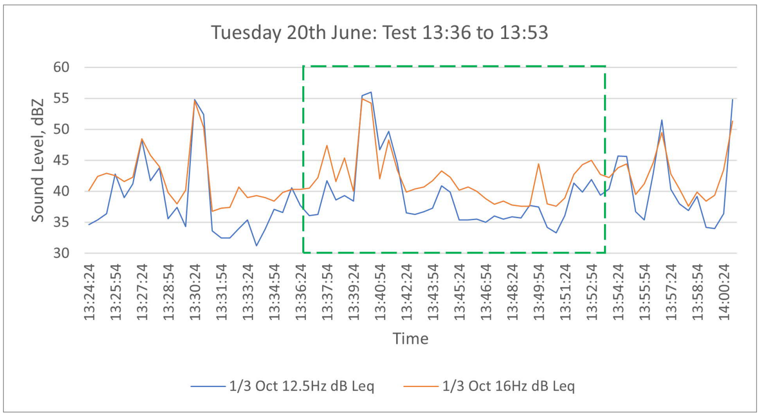

Tuesday 13th June: Test 11:21 to 11:33
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

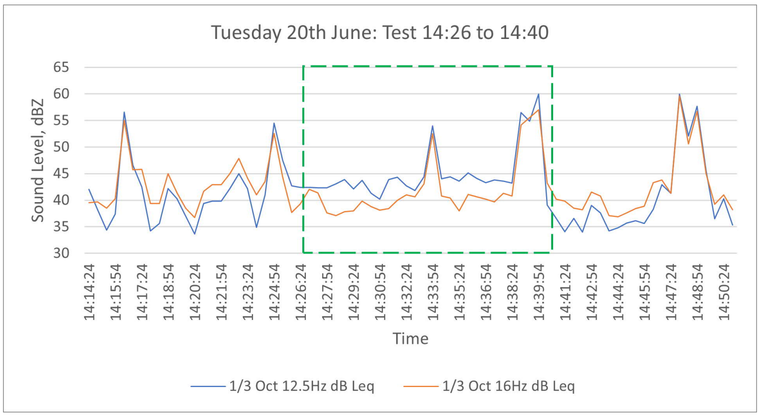

Monday 19th June: Test 11:53 to 12:05
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

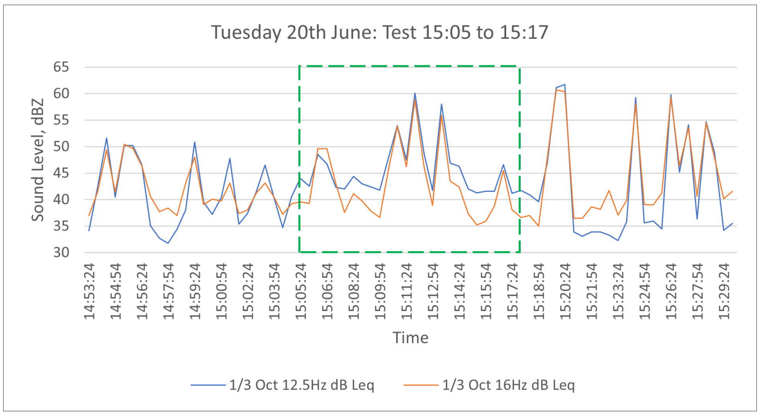

Monday 19th June: Test 12:36 to 12:48
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

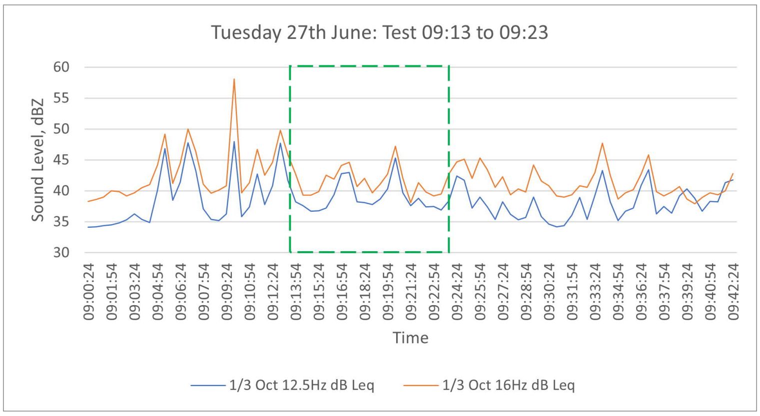

Monday 19th June: Test 13:10 to 13:22
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

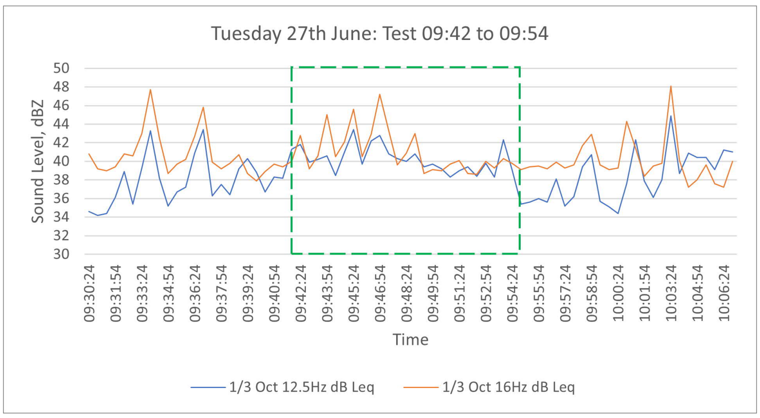

Monday 19th June: Test 14:11 to 14:23
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

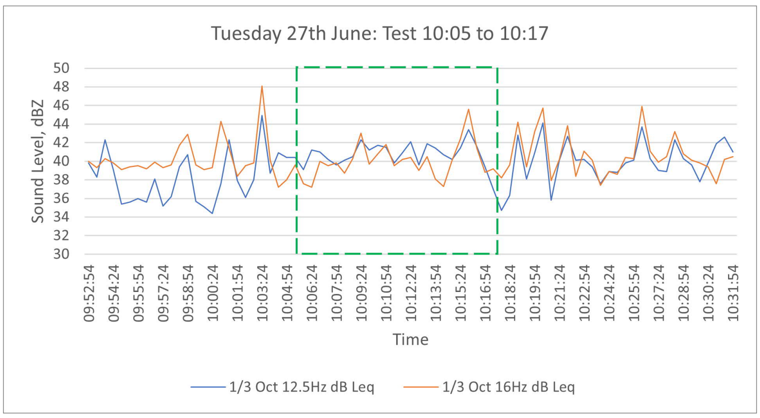

Tuesday 20th June: Test 13:36 to 13:53
Sound Level, dBZ
60
55
50
45
40
35
30
13:24:24
13:25:54
13:27:24
13:28:54
13:30:24
13:31:54
13:33:24
13:34:54
13:36:24
13:37:54
13:39:24
13:40:54
13:42:24
13:43:54
13:45:24
13:46:54
13:48:24
13:49:54
13:51:24
13:52:54
13:54:24
13:55:54
13:57:24
13:58:54
14:00:24
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

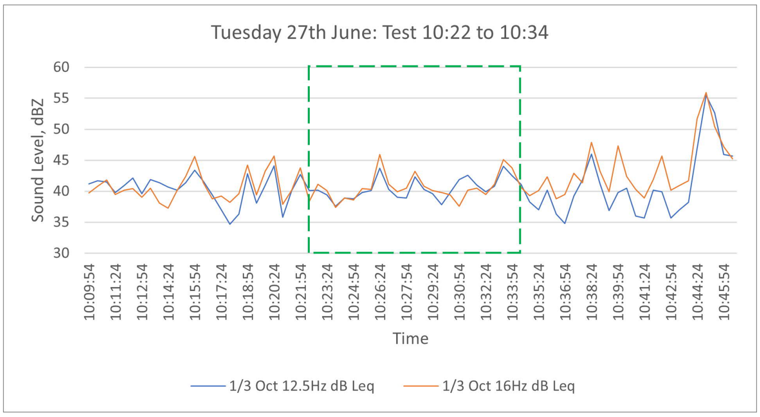

Tuesday 20th June: Test 14:26 to 14:40
Sound Level, dBZ
65
60
55
50
45
40
35
30
14:14:24
14:15:54
14:17:24
14:18:54
14:20:24
14:21:54
14:23:24
14:24:54
14:26:24
14:27:54
14:29:24
14:30:54
14:32:24
14:33:54
14:35:24
14:36:54
14:38:24
14:39:54
14:41:24
14:42:54
14:44:24
14:45:54
14:47:24
14:48:54
14:50:24
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

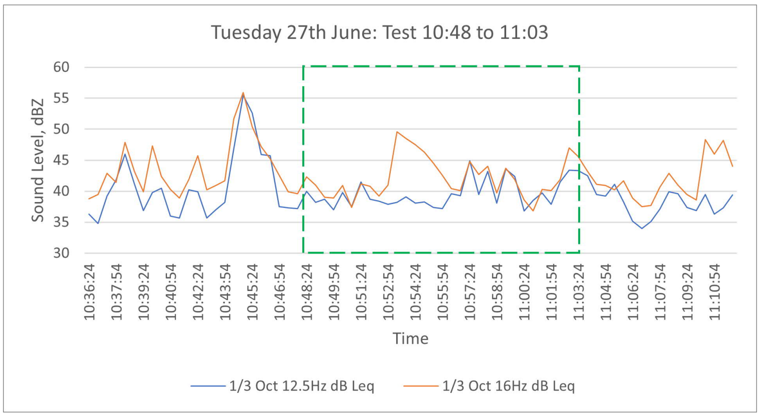

Tuesday 20th June: Test 15:05 to 15:17
Sound Level, dBZ
65
60
55
50
45
40
35
30
14:53:24
14:54:54
14:56:24
14:57:54
14:59:24
15:00:54
15:02:24
15:03:54
15:05:24
15:06:54
15:08:24
15:09:54
15:11:24
15:12:54
15:14:24
15:15:54
15:17:24
15:18:54
15:20:24
15:21:54
15:23:24
15:24:54
15:26:24
15:27:54
15:29:24
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

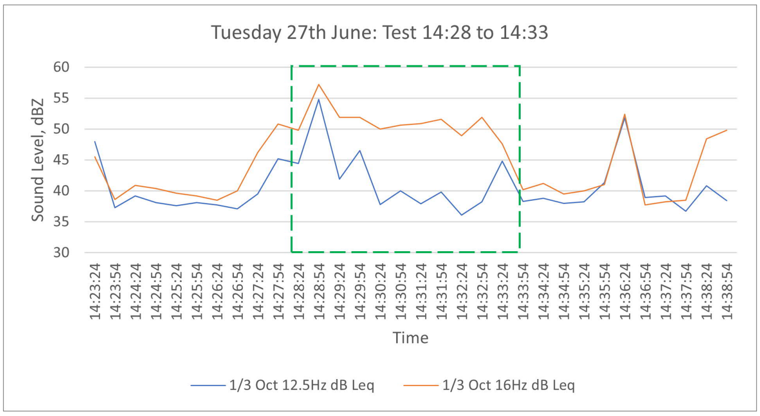

Tuesday 27th June: Test 09:13 to 09:23
Sound Level, dBZ
60
55
50
45
40
35
30
09:00:24
09:01:54
09:03:24
09:04:54
09:06:24
09:07:54
09:09:24
09:10:54
09:12:24
09:13:54
09:15:24
09:16:54
09:18:24
09:19:54
09:21:24
09:22:54
09:24:24
09:25:54
09:27:24
09:28:54
09:30:24
09:31:54
09:33:24
09:34:54
09:36:24
09:37:54
09:39:24
09:40:54
09:42:24
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

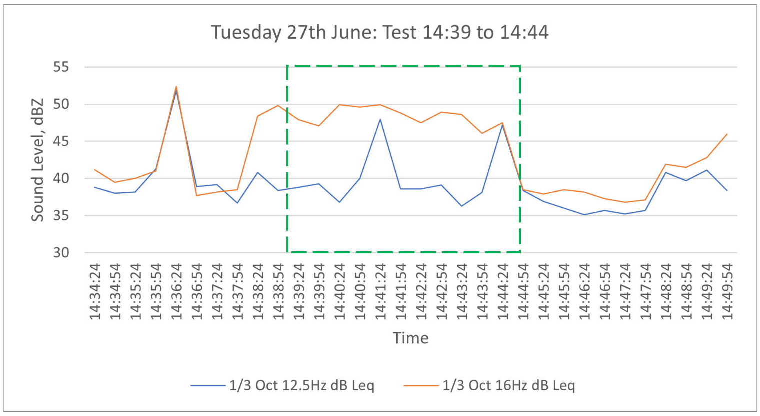

Tuesday 27th June: Test 09:42 to 09:54
Sound Level, dBZ
50
48
46
44
42
40
38
36
34
32
30
09:30:24
09:31:54
09:33:24
09:34:54
09:36:24
09:37:54
09:39:24
09:40:54
09:42:24
09:43:54
09:45:24
09:46:54
09:48:24
09:49:54
09:51:24
09:52:54
09:54:24
09:55:54
09:57:24
09:58:54
10:00:24
10:01:54
10:03:24
10:04:54
10:06:24
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

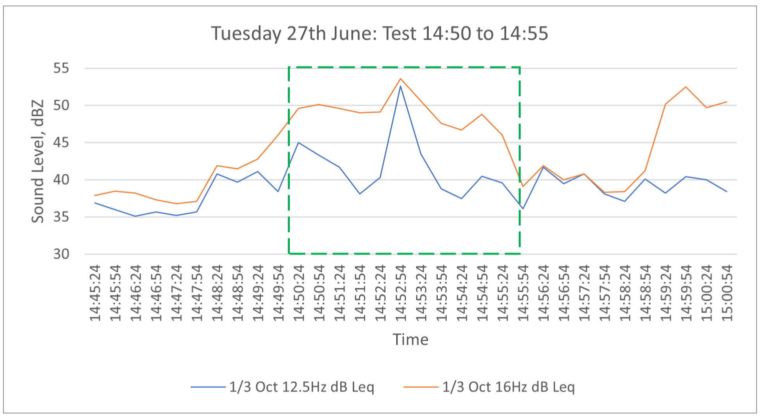

Tuesday 27th June: Test 10:05 to 10:17
Sound Level, dBZ
50
48
46
44
42
40
38
36
34
32
30
09:52:54
09:54:24
09:55:54
09:57:24
09:58:54
10:00:24
10:01:54
10:03:24
10:04:54
10:06:24
10:07:54
10:09:24
10:10:54
10:12:24
10:13:54
10:15:24
10:16:54
10:18:24
10:19:54
10:21:24
10:22:54
10:24:24
10:25:54
10:27:24
10:28:54
10:30:24
10:31:54
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

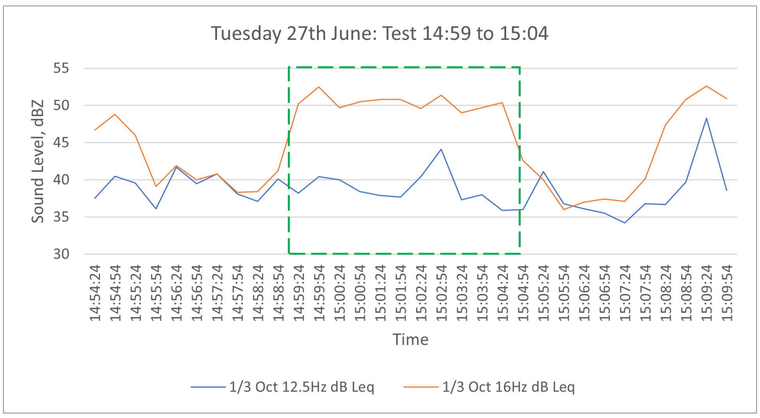

Tuesday 27th June: Test 10:22 to 10:34
Sound Level, dBZ
60
55
50
45
40
35
30
10:09:54
10:11:24
10:12:54
10:14:24
10:15:54
10:17:24
10:18:54
10:20:24
10:21:54
10:23:24
10:24:54
10:26:24
10:27:54
10:29:24
10:30:54
10:32:24
10:33:54
10:35:24
10:36:54
10:38:24
10:39:54
10:41:24
10:42:54
10:44:24
10:45:54
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

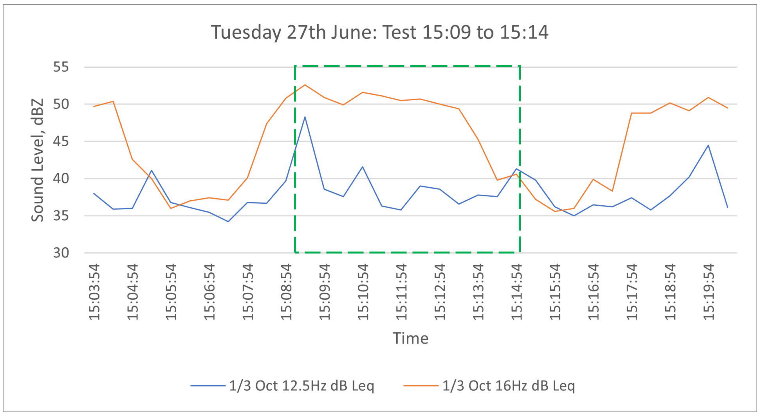

Tuesday 27th June: Test 10:48 to 11:03
Sound Level, dBZ
60
55
50
45
40
35
30
10:36:24
10:37:54
10:39:24
10:40:54
10:42:24
10:43:54
10:45:24
10:46:54
10:48:24
10:49:54
10:51:24
10:52:54
10:54:24
10:55:54
10:57:24
10:58:54
11:00:24
11:01:54
11:03:24
11:04:54
11:06:24
11:07:54
11:09:24
11:10:54
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

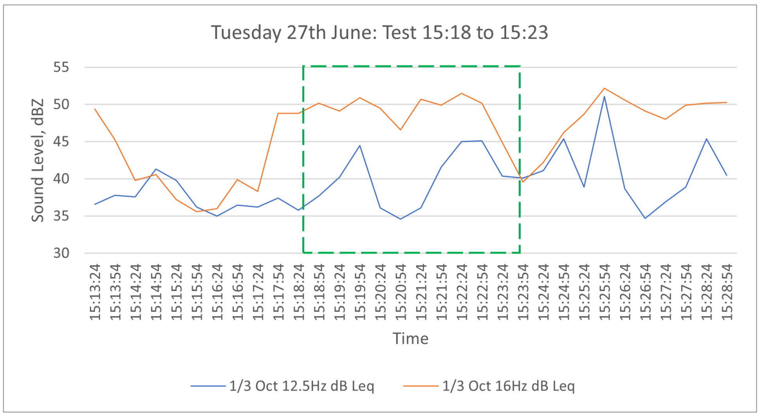

Tuesday 27th June: Test 14:28 to 14:33
Sound Level, dBZ
60
55
50
45
40
35
30
14:23:24
14:23:54
14:24:24
14:24:54
14:25:24
14:25:54
14:26:24
14:26:54
14:27:24
14:27:54
14:28:24
14:28:54
14:29:24
14:29:54
14:30:24
14:30:54
14:31:24
14:31:54
14:32:24
14:32:54
14:33:24
14:33:54
14:34:24
14:34:54
14:35:24
14:35:54
14:36:24
14:36:54
14:37:24
14:37:54
14:38:24
14:38:54
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

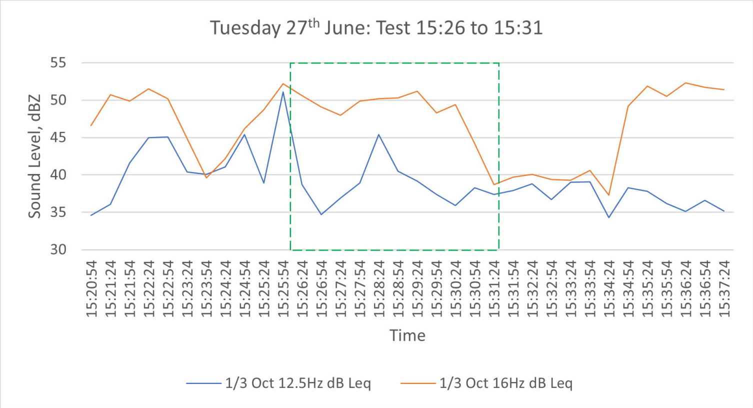

Tuesday 27th June: Test 14:39 to 14:44
Sound Level, dBZ
55
50
45
40
35
30
14:34:24
14:34:54
14:35:24
14:35:54
14:36:24
14:36:54
14:37:24
14:37:54
14:38:24
14:38:54
14:39:24
14:39:54
14:40:24
14:40:54
14:41:24
14:41:54
14:42:24
14:42:54
14:43:24
14:43:54
14:44:24
14:44:54
14:45:24
14:45:54
14:46:24
14:46:54
14:47:24
14:47:54
14:48:24
14:48:54
14:49:24
14:49:54
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

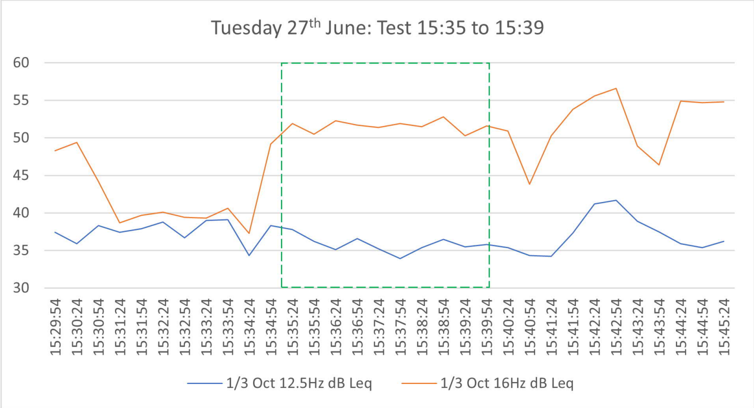

Tuesday 27th June: Test 14:50 to 14:55
Sound Level, dBZ
55
50
45
40
35
30
14:45:24
14:45:54
14:46:24
14:46:54
14:47:24
14:47:54
14:48:24
14:48:54
14:49:24
14:49:54
14:50:24
14:50:54
14:51:24
14:51:54
14:52:24
14:52:54
14:53:24
14:53:54
14:54:24
14:54:54
14:55:24
14:55:54
14:56:24
14:56:54
14:57:24
14:57:54
14:58:24
14:58:54
14:59:24
14:59:54
15:00:24
15:00:54
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

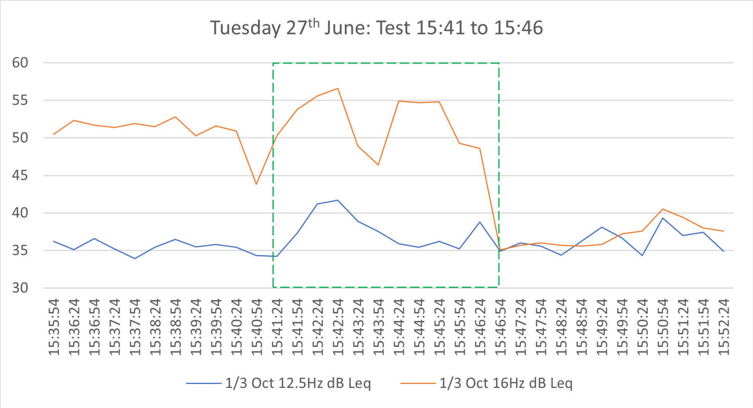

Tuesday 27th June: Test 14:59 to 15:04
Sound Level, dBZ
55
50
45
40
35
30
14:54:24
14:54:54
14:55:24
14:55:54
14:56:24
14:56:54
14:57:24
14:57:54
14:58:24
14:58:54
14:59:24
14:59:54
15:00:24
15:00:54
15:01:24
15:01:54
15:02:24
15:02:54
15:03:24
15:03:54
15:04:24
15:04:54
15:05:24
15:05:54
15:06:24
15:06:54
15:07:24
15:07:54
15:08:24
15:08:54
15:09:24
15:09:54
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq


Tuesday 27th June: Test 15:09 to 15:14
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

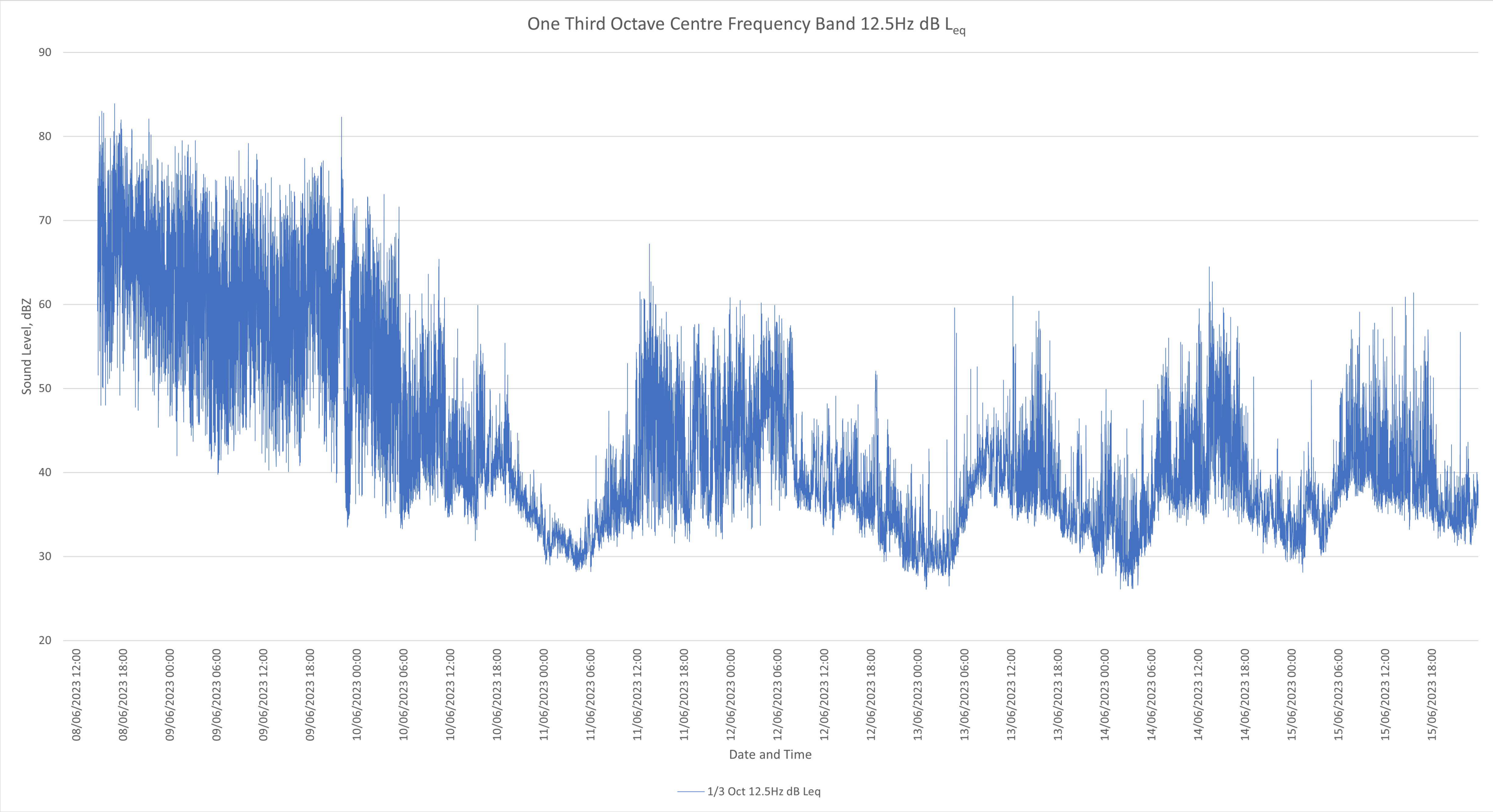

Tuesday 27th June: Test 15:18 to 15:23
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

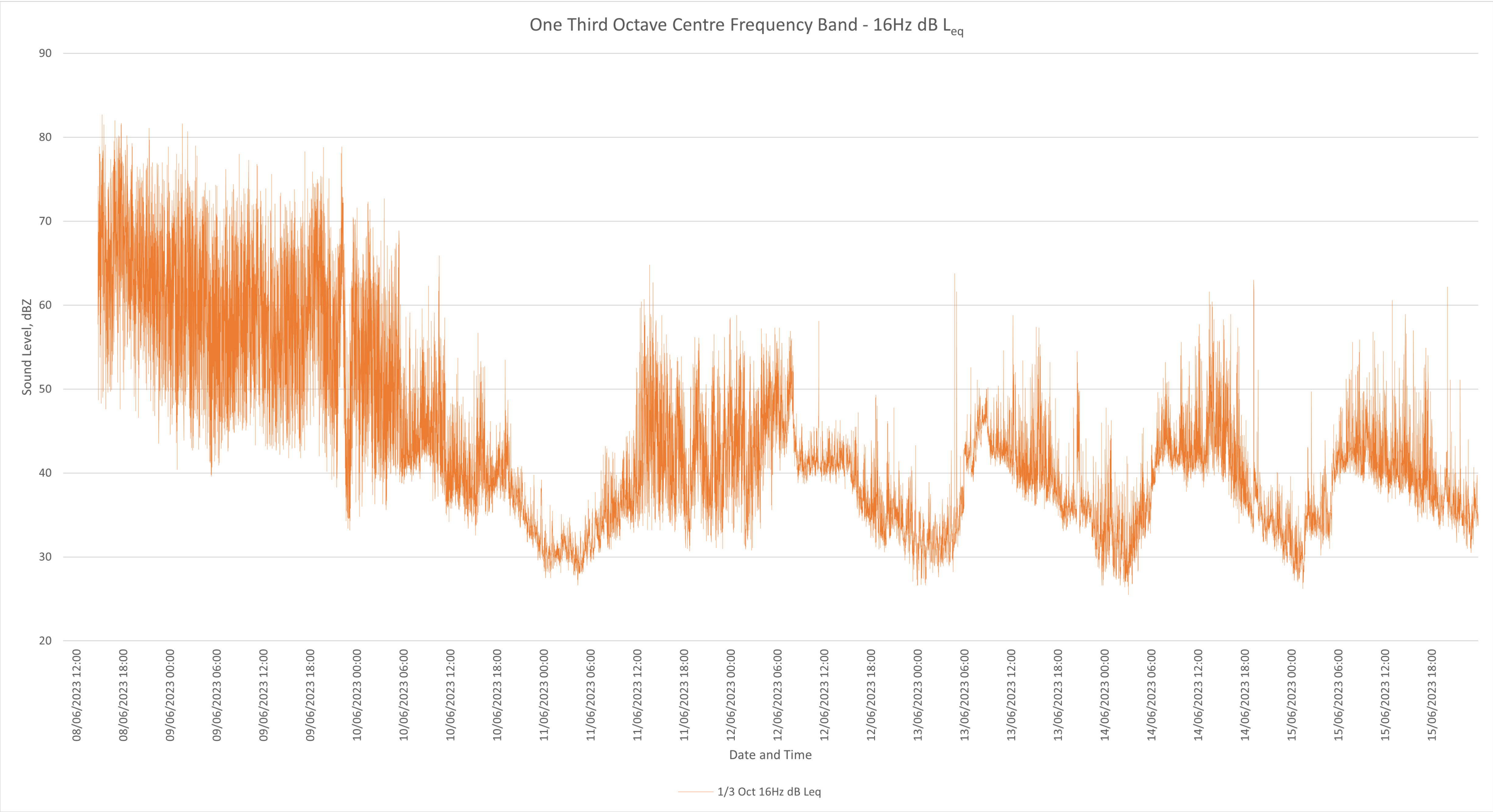

Tuesday 27th June: Test 15:26 to 15:31
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

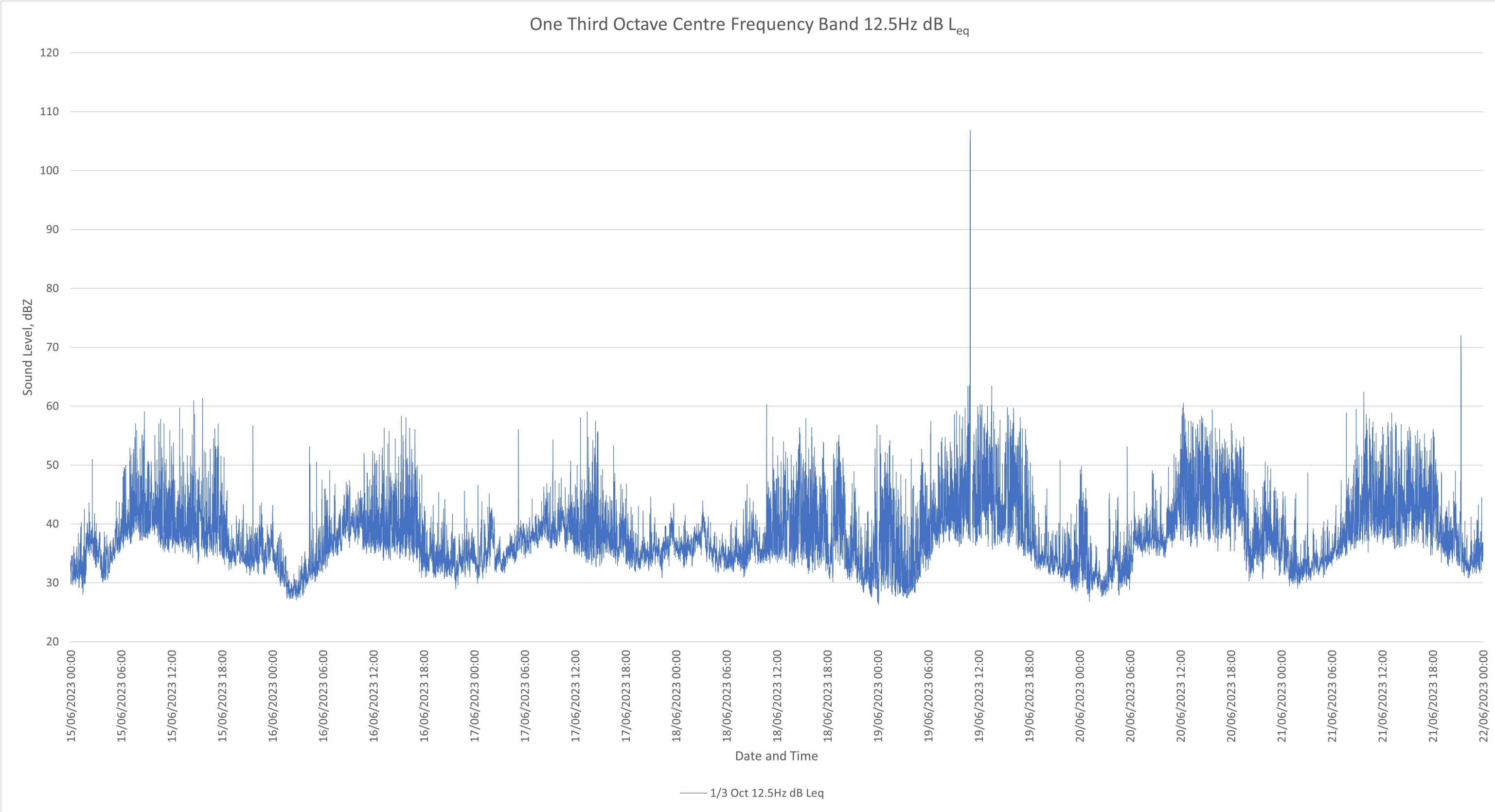

Tuesday 27th June: Test 15:35 to 15:39
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq


Tuesday 27th June: Test 15:41 to 15:46
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

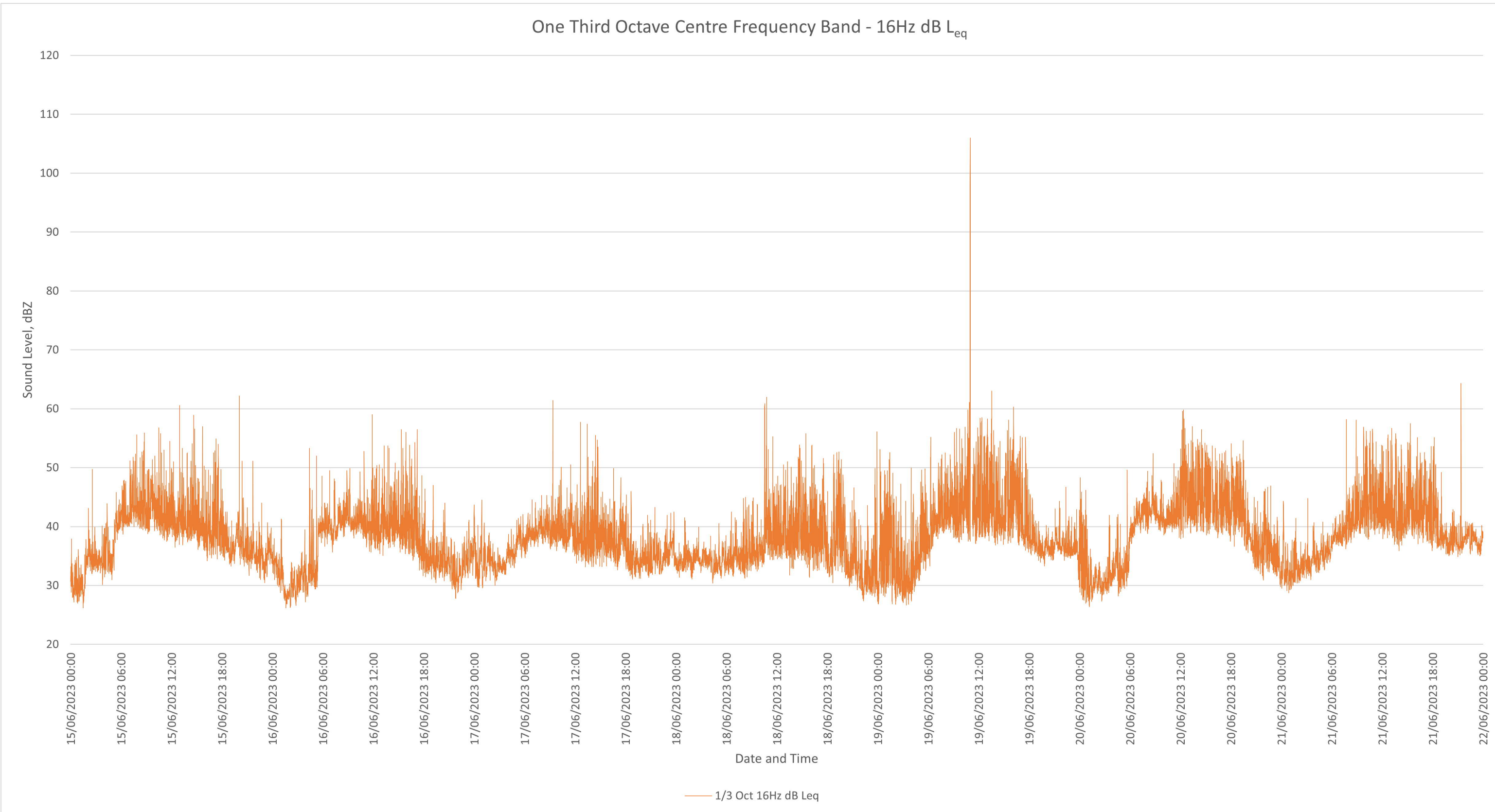
LT2: Noise Monitoring Graphs



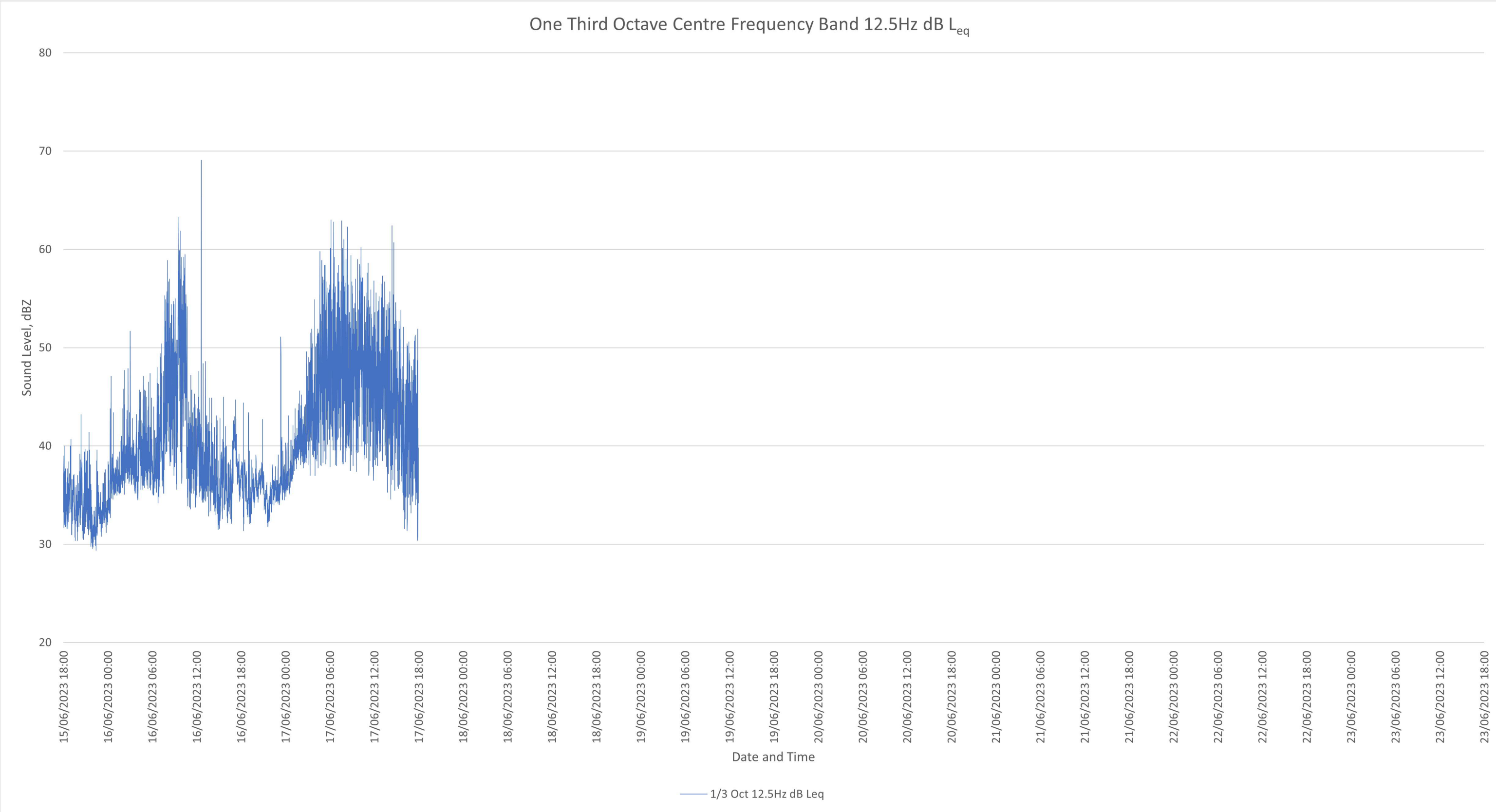




One Third Octave Centre Frequency Band 12.5Hz dB Leq
Sound Level, dBZ
120
110
100
90
80
70
60
50
40
30
20
15/06/2023 00:00
15/06/2023 06:00
15/06/2023 12:00
15/06/2023 18:00
16/06/2023 00:00
16/06/2023 06:00
16/06/2023 12:00
16/06/2023 18:00
17/06/2023 00:00
17/06/2023 06:00
17/06/2023 12:00
17/06/2023 18:00
18/06/2023 00:00
18/06/2023 06:00
18/06/2023 12:00
18/06/2023 18:00
19/06/2023 00:00
19/06/2023 06:00
19/06/2023 12:00
19/06/2023 18:00
20/06/2023 00:00
20/06/2023 06:00
20/06/2023 12:00
20/06/2023 18:00
21/06/2023 00:00
21/06/2023 06:00
21/06/2023 12:00
21/06/2023 18:00
22/06/2023 00:00
Date and Time
1/3 Oct 12.5Hz dB Leq



One Third Octave Centre Frequency Band - 16Hz dB Leq
Sound Level, dBZ
120
110
100
90
80
70
60
50
40
30
20
15/06/2023 00:00
15/06/2023 06:00
15/06/2023 12:00
15/06/2023 18:00
16/06/2023 00:00
16/06/2023 06:00
16/06/2023 12:00
16/06/2023 18:00
17/06/2023 00:00
17/06/2023 06:00
17/06/2023 12:00
17/06/2023 18:00
18/06/2023 00:00
18/06/2023 06:00
18/06/2023 12:00
18/06/2023 18:00
19/06/2023 00:00
19/06/2023 06:00
19/06/2023 12:00
19/06/2023 18:00
20/06/2023 00:00
20/06/2023 06:00
20/06/2023 12:00
20/06/2023 18:00
21/06/2023 00:00
21/06/2023 06:00
21/06/2023 12:00
21/06/2023 18:00
22/06/2023 00:00
Date and Time
1/3 Oct 16Hz dB Leq



One Third Octave Centre Frequency Band 12.5Hz dB L_{eq}
Sound Level, dBZ
80
70
60
50
40
30
20
15/06/2023 18:00
16/06/2023 00:00
16/06/2023 06:00
16/06/2023 12:00
16/06/2023 18:00
17/06/2023 00:00
17/06/2023 06:00
17/06/2023 12:00
17/06/2023 18:00
18/06/2023 00:00
18/06/2023 06:00
18/06/2023 12:00
18/06/2023 18:00
19/06/2023 00:00
19/06/2023 06:00
19/06/2023 12:00
19/06/2023 18:00
20/06/2023 00:00
20/06/2023 06:00
20/06/2023 12:00
20/06/2023 18:00
21/06/2023 00:00
21/06/2023 06:00
21/06/2023 12:00
21/06/2023 18:00
22/06/2023 00:00
22/06/2023 06:00
22/06/2023 12:00
22/06/2023 18:00
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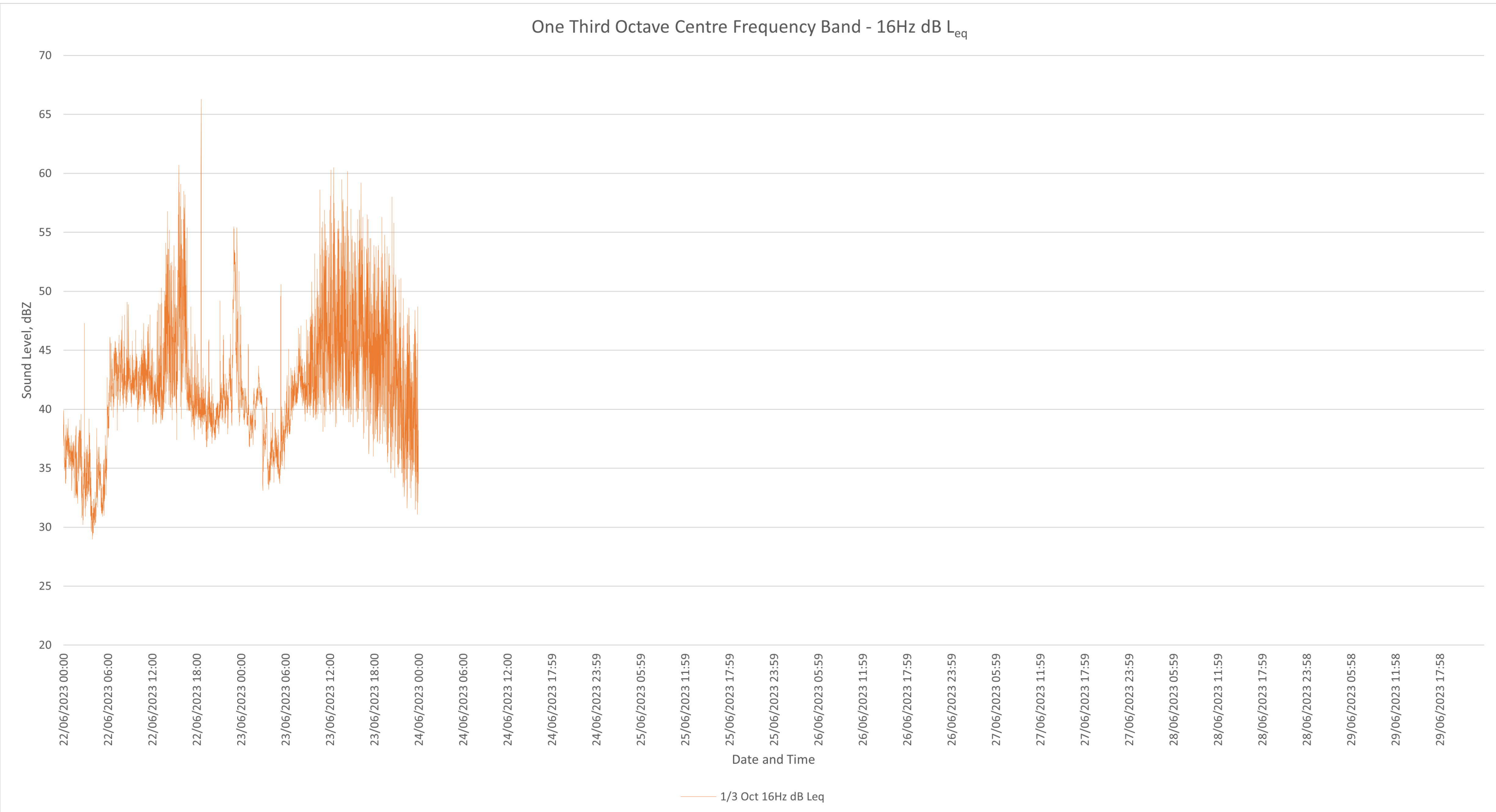
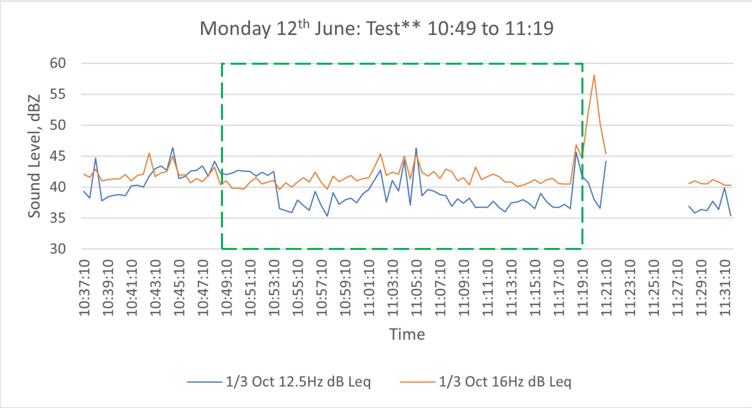
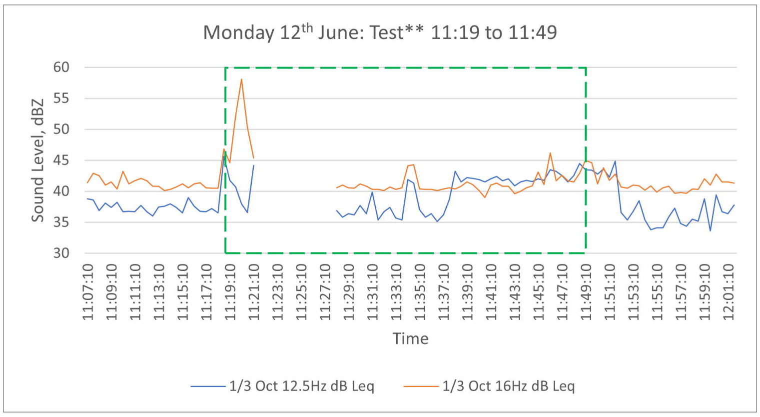
23/06/2023 18:00
Date and Time
1/3 Oct 12.5Hz dB Leq

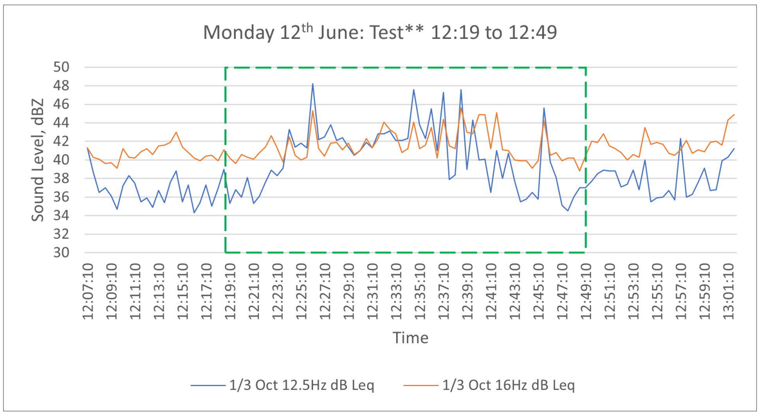


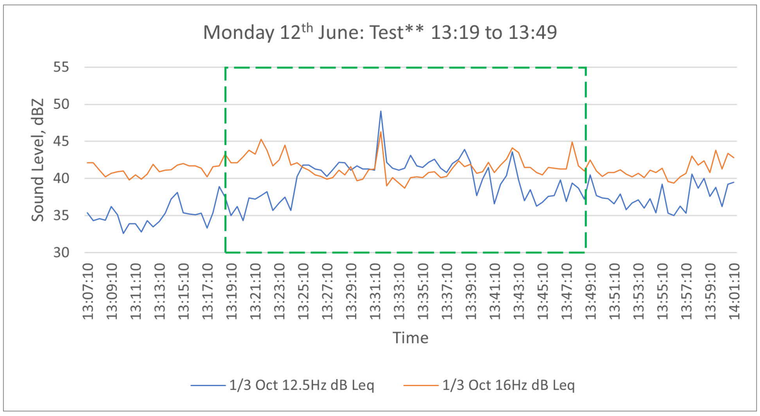
One Third Octave Centre Frequency Band - 16Hz dB L_{eq}
Sound Level, dBZ
70
65
60
55
50
45
40
35
30
25
20
22/06/2023 00:00
22/06/2023 06:00
22/06/2023 12:00
22/06/2023 18:00
23/06/2023 00:00
23/06/2023 06:00
23/06/2023 12:00
23/06/2023 18:00
24/06/2023 00:00
24/06/2023 06:00
24/06/2023 12:00
24/06/2023 17:59
24/06/2023 23:59
25/06/2023 05:59
25/06/2023 11:59
25/06/2023 17:59
25/06/2023 23:59
26/06/2023 05:59
26/06/2023 11:59
26/06/2023 17:59
26/06/2023 23:59
27/06/2023 05:59
27/06/2023 11:59
27/06/2023 17:59
27/06/2023 23:59
28/06/2023 05:59
28/06/2023 11:59
28/06/2023 17:59
28/06/2023 23:58
29/06/2023 05:58
29/06/2023 11:58
29/06/2023 17:58
Date and Time
1/3 Oct 16Hz dB Leq

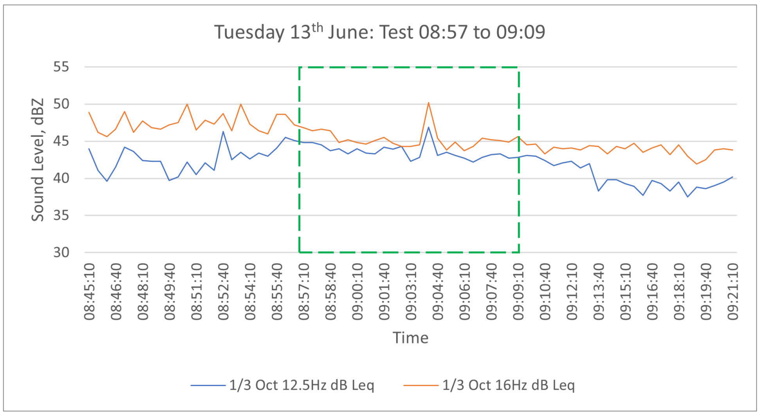
LT2: LFN Trial Graphs

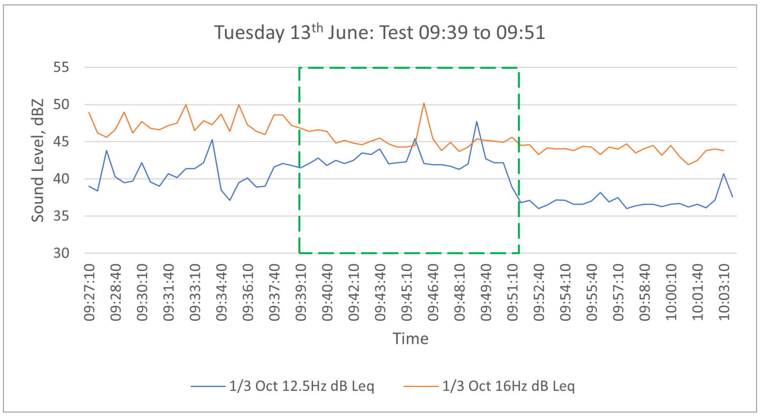


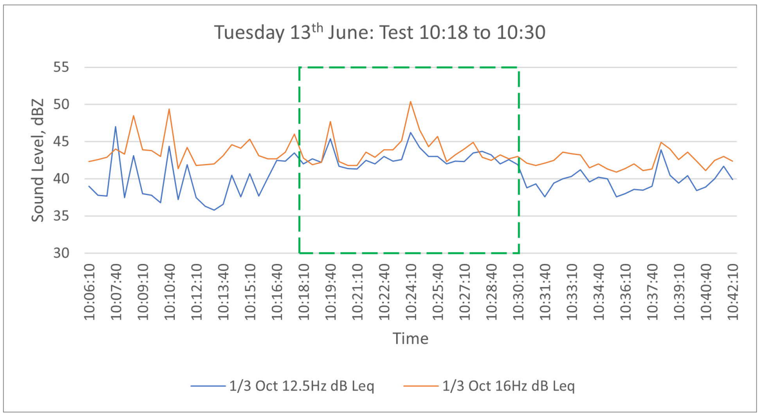


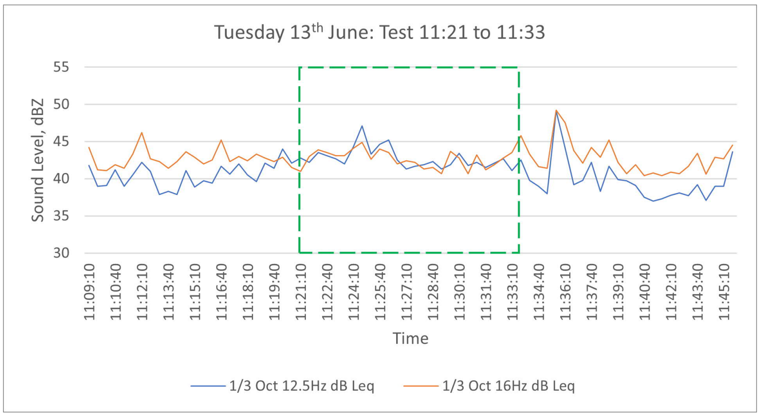


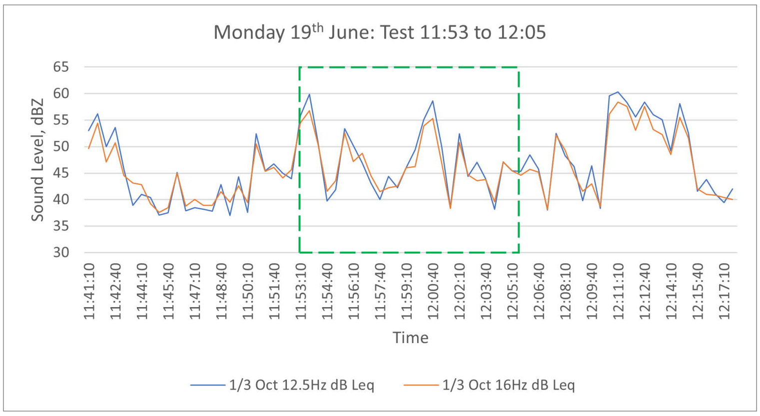


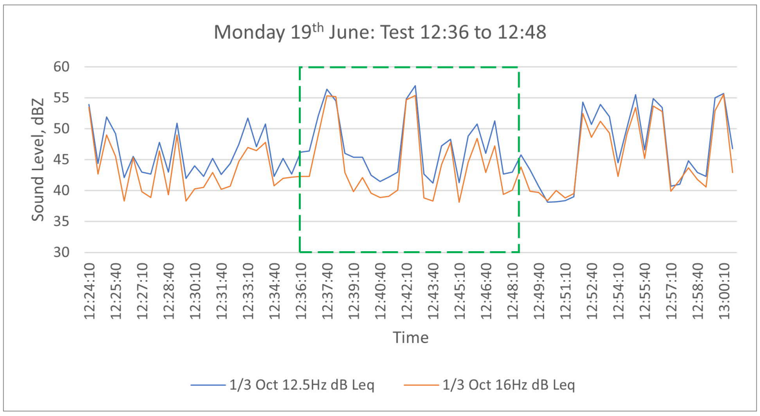


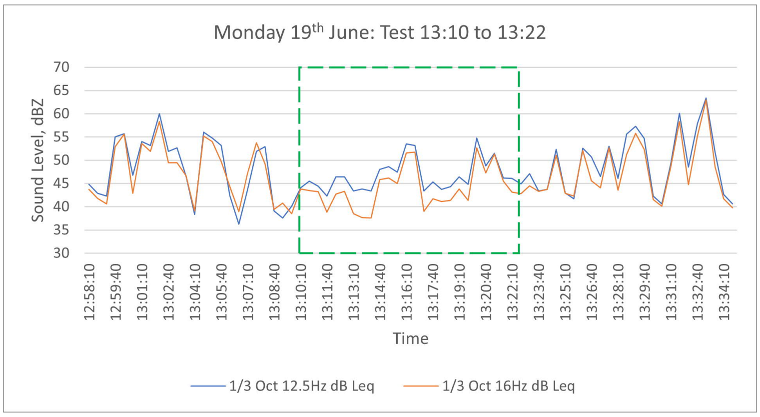


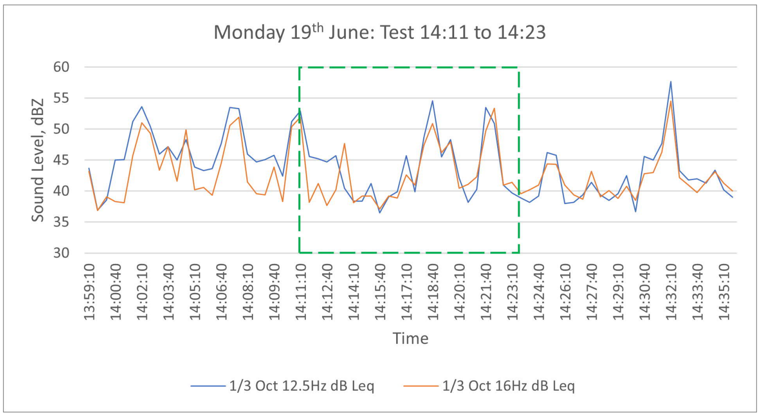

Tuesday 13th June: Test 10:18 to 10:30
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

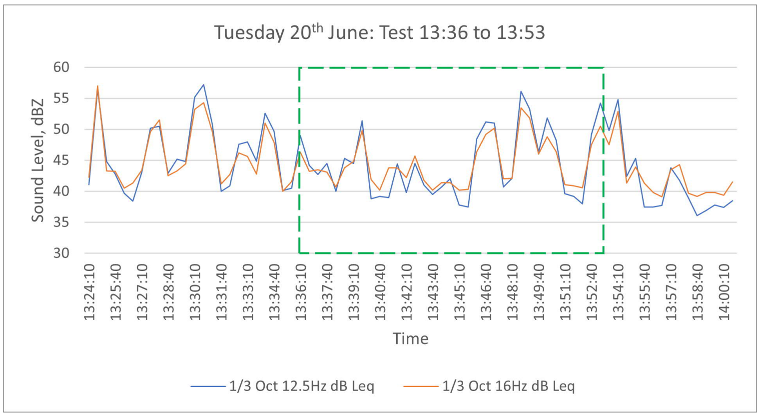

Tuesday 13th June: Test 11:21 to 11:33
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

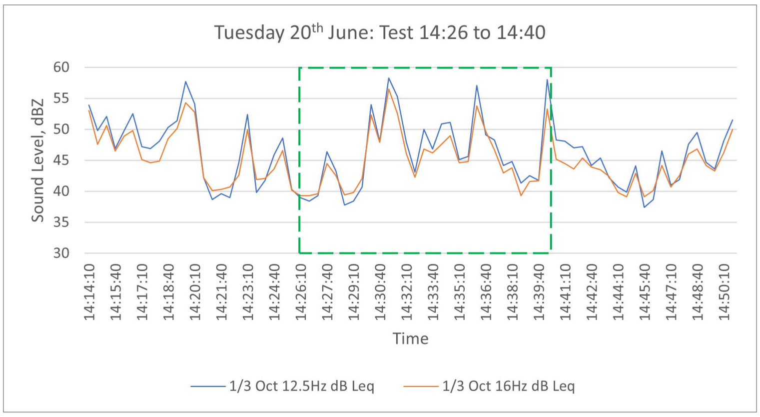

Monday 19th June: Test 11:53 to 12:05
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

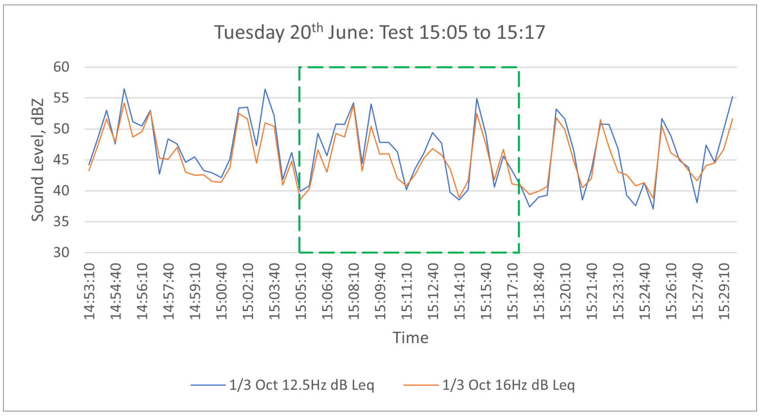

Monday 19th June: Test 12:36 to 12:48
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq


Monday 19th June: Test 13:10 to 13:22
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

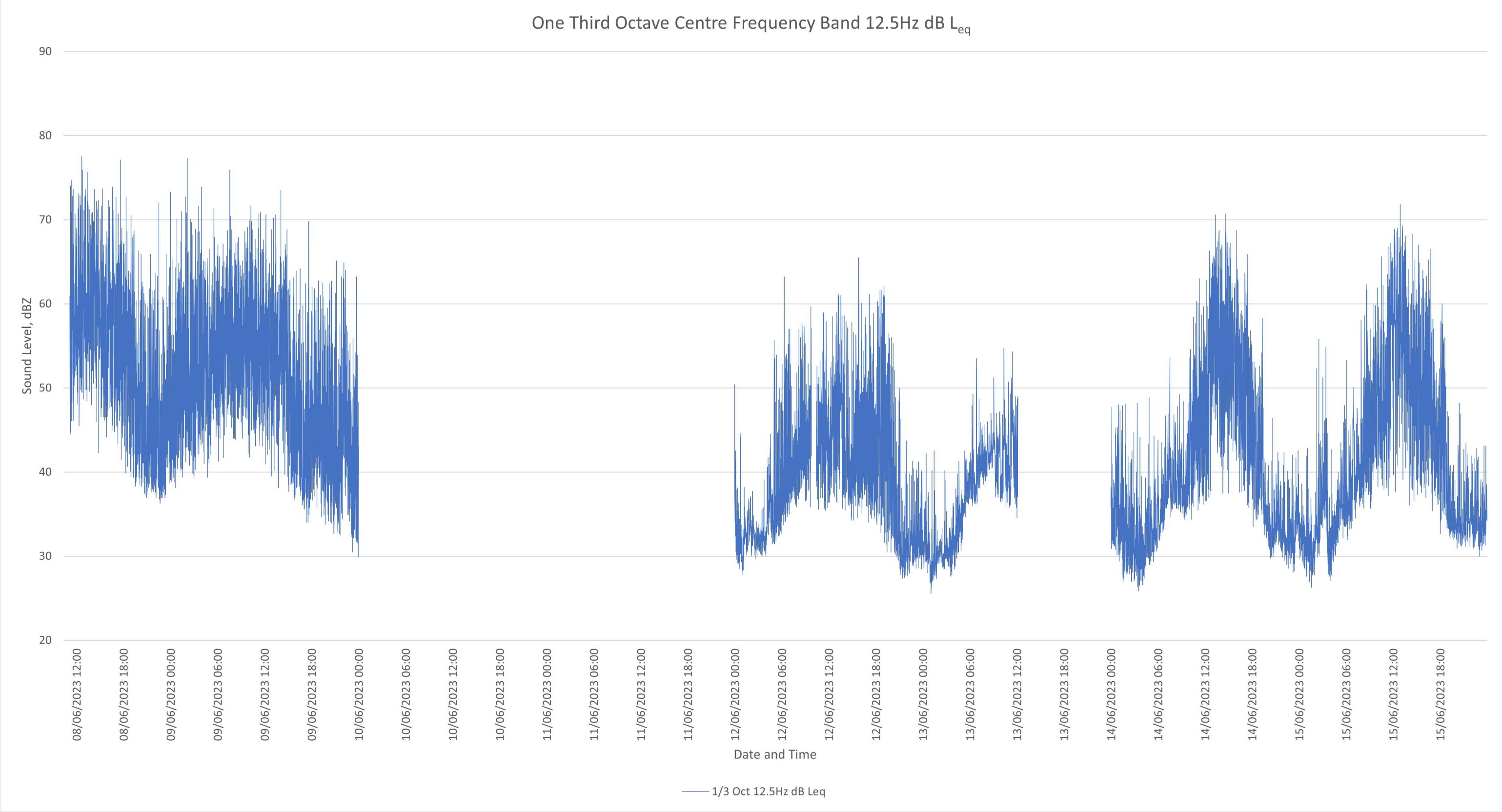

Monday 19th June: Test 14:11 to 14:23
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

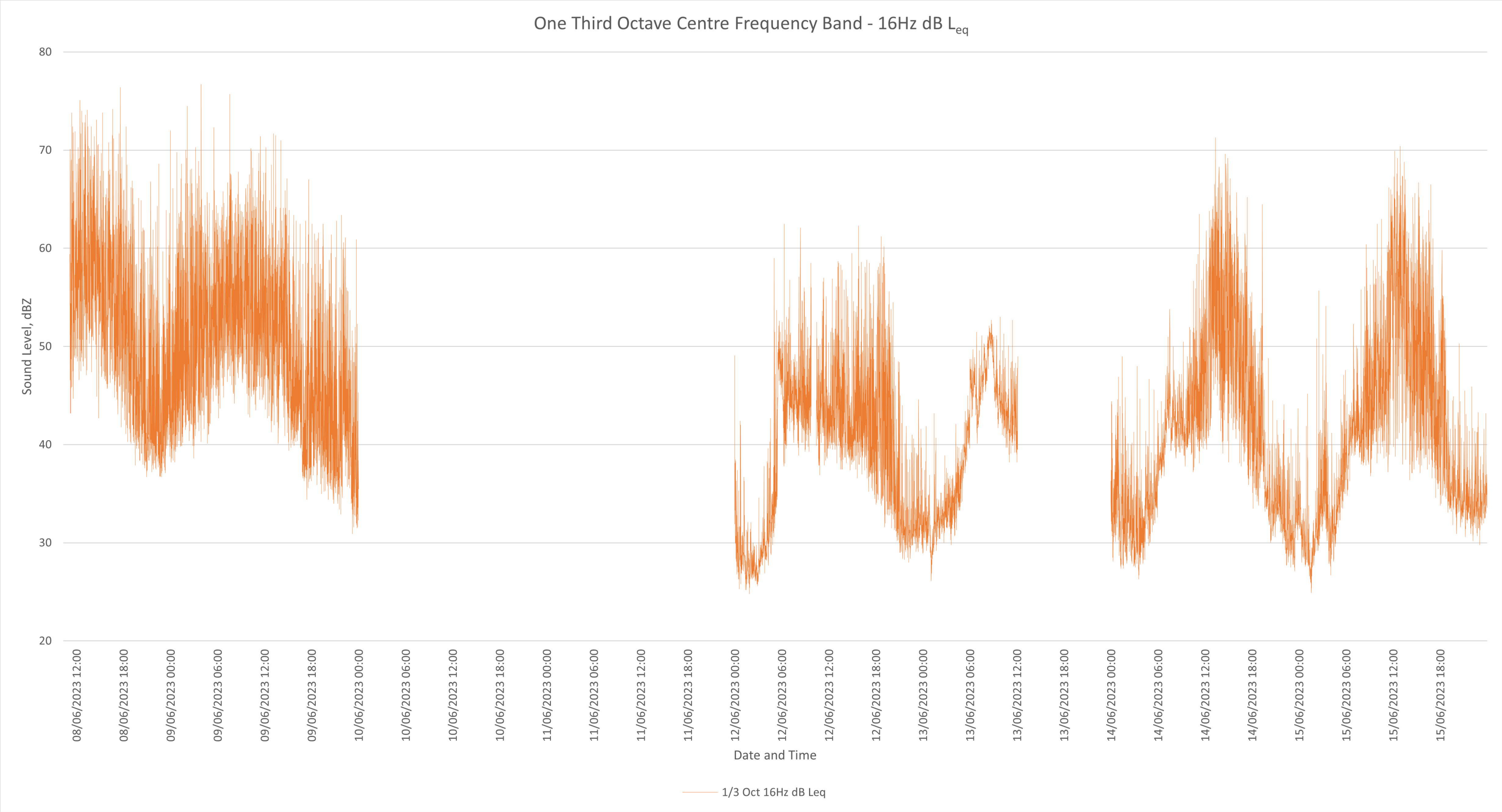

Tuesday 20th June: Test 13:36 to 13:53
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

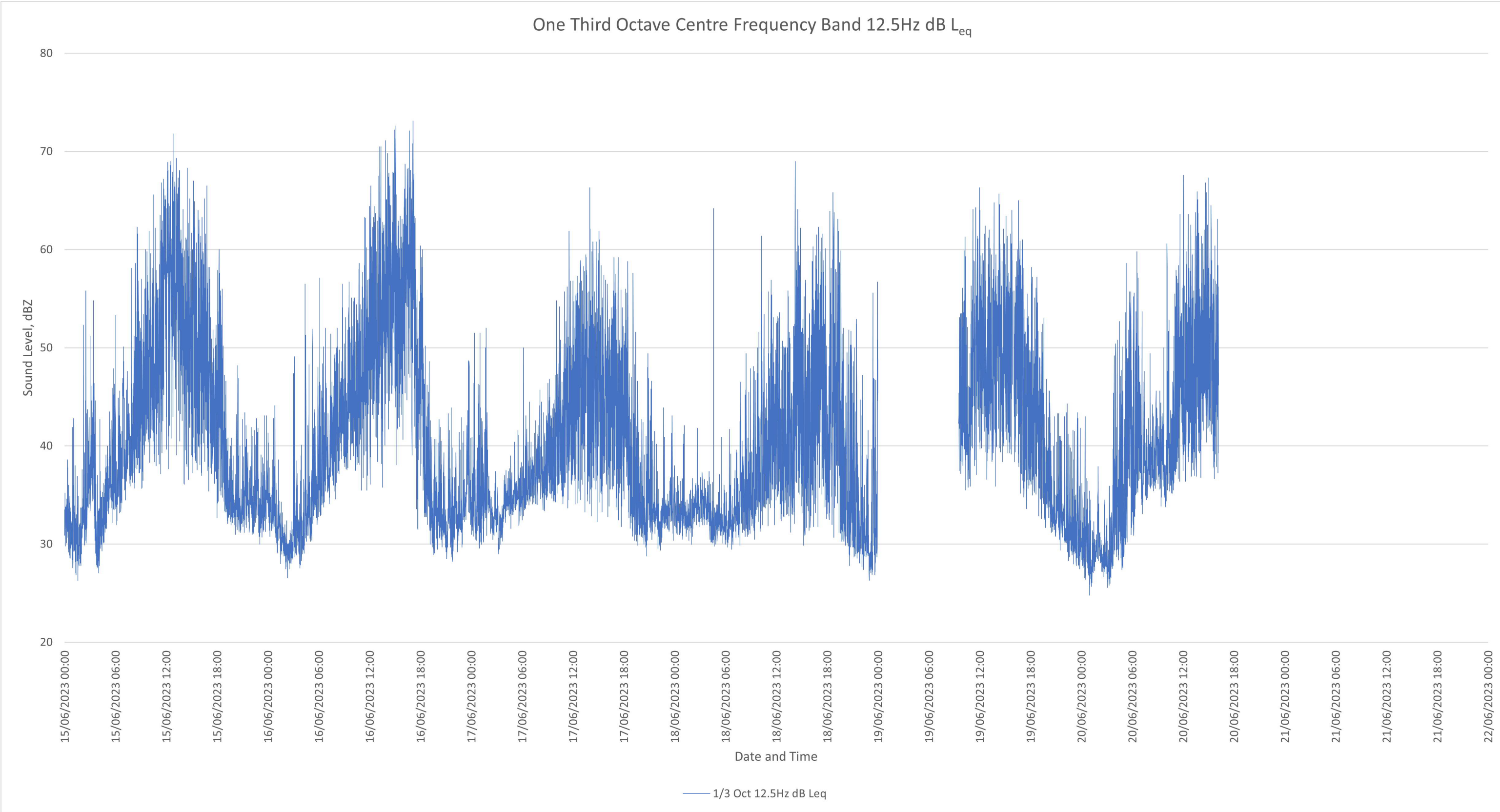

Tuesday 20th June: Test 14:26 to 14:40
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

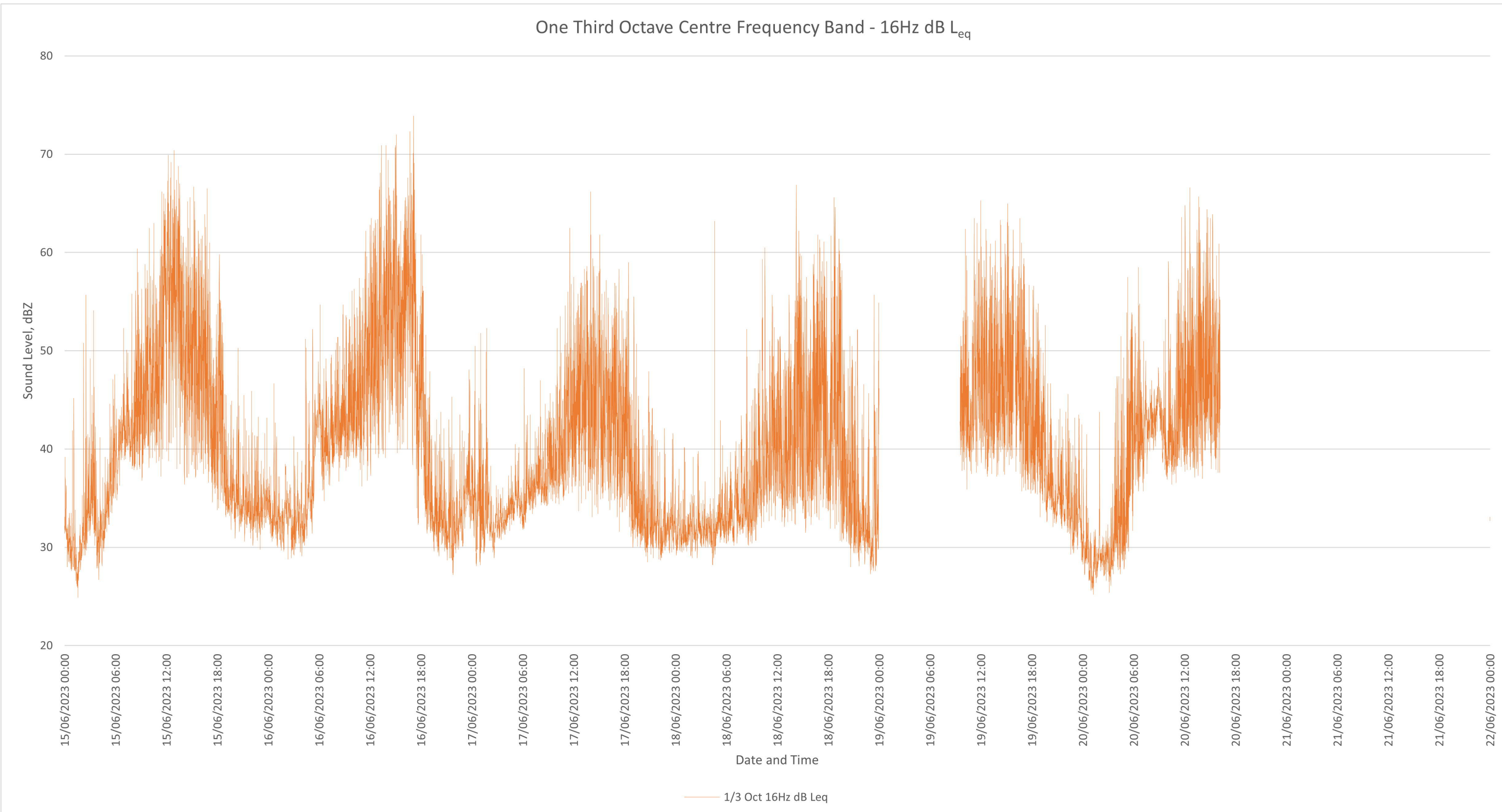

Tuesday 20th June: Test 15:05 to 15:17
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

LT3: Noise Monitoring Graphs






One Third Octave Centre Frequency Band 12.5Hz dB Leq
Sound Level, dBZ
80
70
60
50
40
30
20
15/06/2023 00:00
15/06/2023 06:00
15/06/2023 12:00
15/06/2023 18:00
16/06/2023 00:00
16/06/2023 06:00
16/06/2023 12:00
16/06/2023 18:00
17/06/2023 00:00
17/06/2023 06:00
17/06/2023 12:00
17/06/2023 18:00
18/06/2023 00:00
18/06/2023 06:00
18/06/2023 12:00
18/06/2023 18:00
19/06/2023 00:00
19/06/2023 06:00
19/06/2023 12:00
19/06/2023 18:00
20/06/2023 00:00
20/06/2023 06:00
20/06/2023 12:00
20/06/2023 18:00
21/06/2023 00:00
21/06/2023 06:00
21/06/2023 12:00
21/06/2023 18:00
22/06/2023 00:00
Date and Time
1/3 Oct 12.5Hz dB Leq


One Third Octave Centre Frequency Band - 16Hz dB Leq
Sound Level, dBZ
80
70
60
50
40
30
20
15/06/2023 00:00
15/06/2023 06:00
15/06/2023 12:00
15/06/2023 18:00
16/06/2023 00:00
16/06/2023 06:00
16/06/2023 12:00
16/06/2023 18:00
17/06/2023 00:00
17/06/2023 06:00
17/06/2023 12:00
17/06/2023 18:00
18/06/2023 00:00
18/06/2023 06:00
18/06/2023 12:00
18/06/2023 18:00
19/06/2023 00:00
19/06/2023 06:00
19/06/2023 12:00
19/06/2023 18:00
20/06/2023 00:00
20/06/2023 06:00
20/06/2023 12:00
20/06/2023 18:00
21/06/2023 00:00
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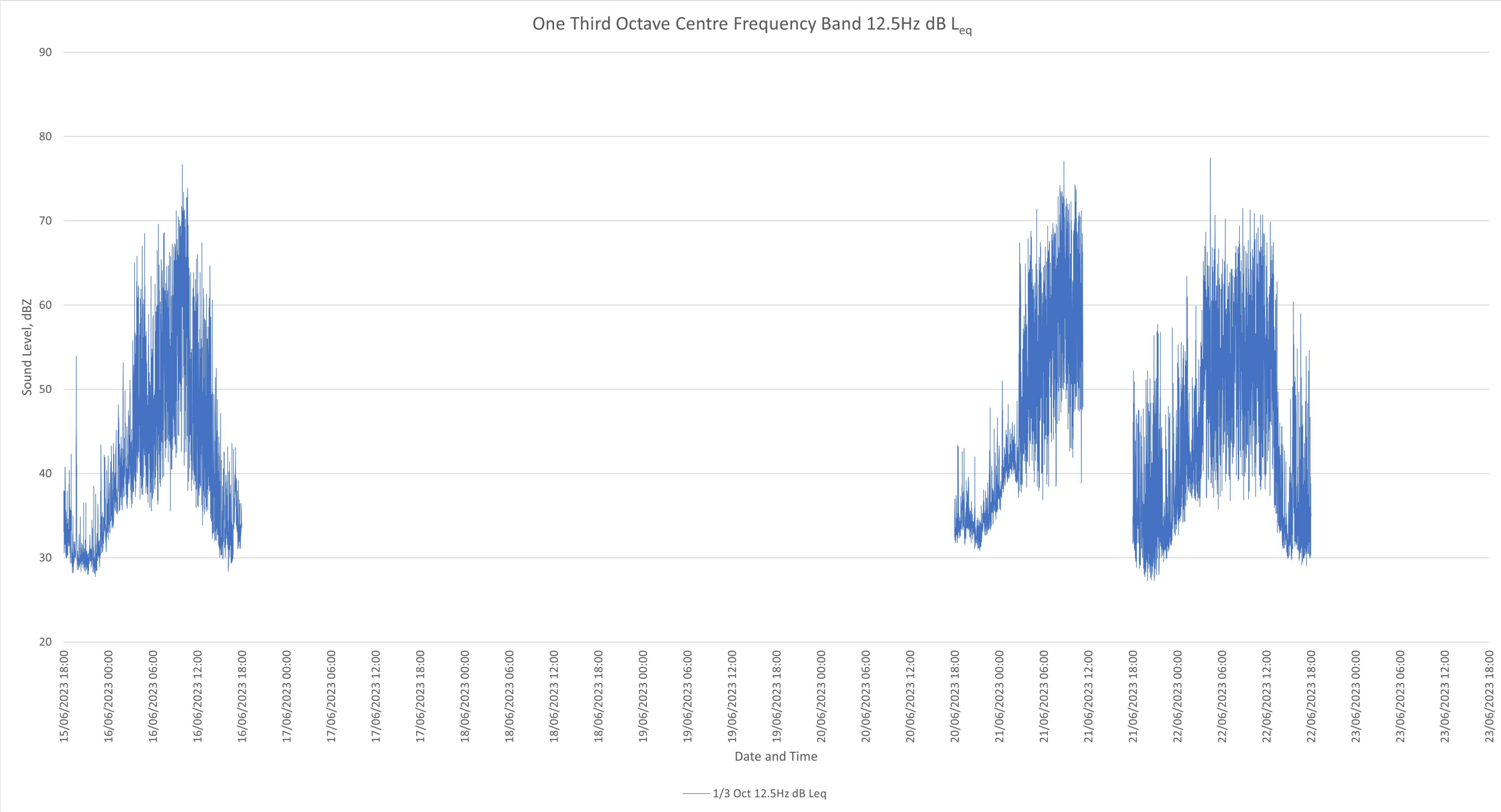
21/06/2023 18:00
22/06/2023 00:00
Date and Time
1/3 Oct 16Hz dB Leq



One Third Octave Centre Frequency Band 12.5Hz dB Leq
Sound Level, dBZ
90
80
70
60
50
40
30
20
15/06/2023 18:00
16/06/2023 00:00
16/06/2023 06:00
16/06/2023 12:00
16/06/2023 18:00
17/06/2023 00:00
17/06/2023 06:00
17/06/2023 12:00
17/06/2023 18:00
18/06/2023 00:00
18/06/2023 06:00
18/06/2023 12:00
18/06/2023 18:00
19/06/2023 00:00
19/06/2023 06:00
19/06/2023 12:00
19/06/2023 18:00
20/06/2023 00:00
20/06/2023 06:00
20/06/2023 12:00
20/06/2023 18:00
21/06/2023 00:00
21/06/2023 06:00
21/06/2023 12:00
21/06/2023 18:00
22/06/2023 00:00
22/06/2023 06:00
22/06/2023 12:00
22/06/2023 18:00
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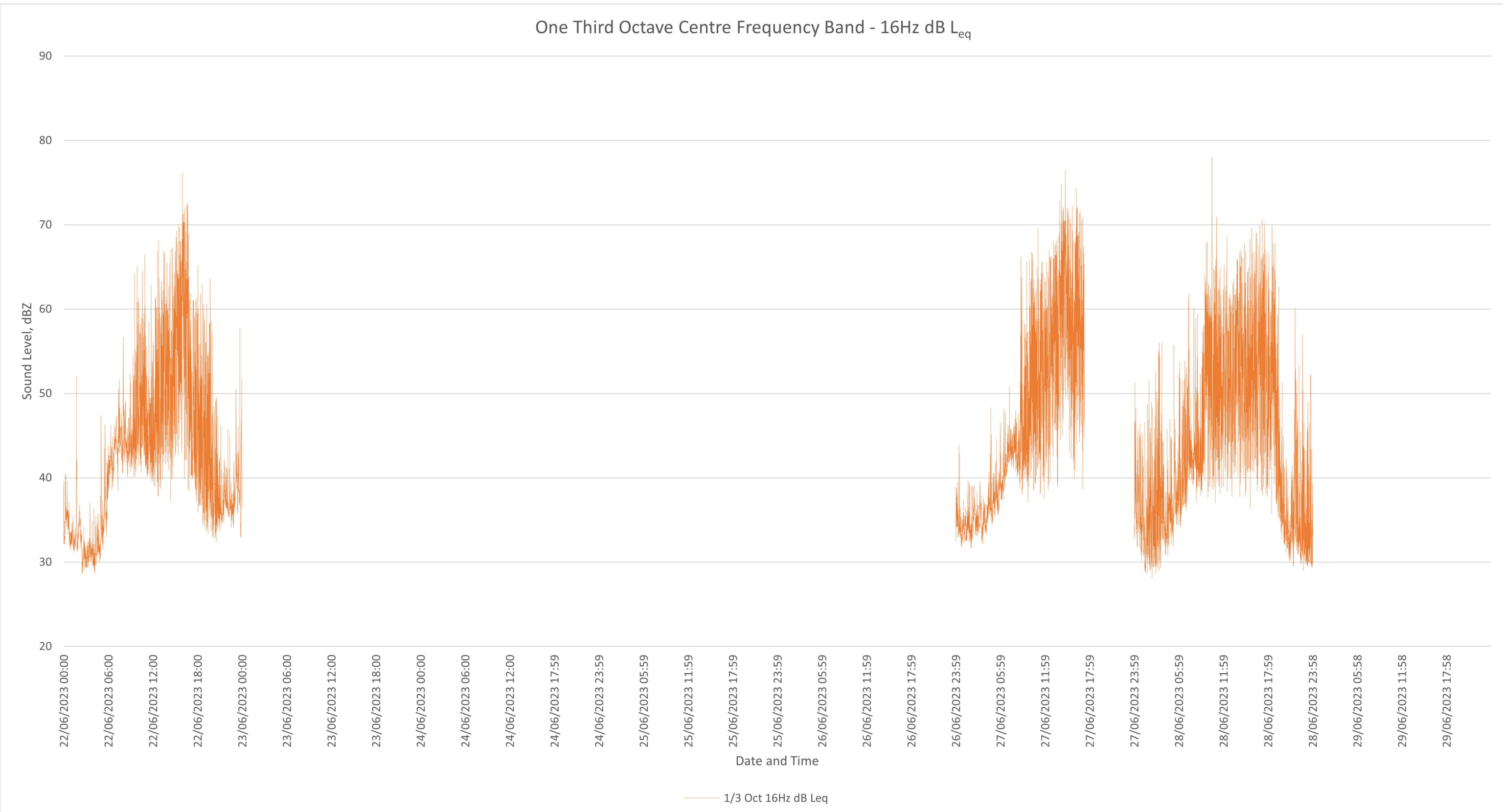
23/06/2023 18:00
Date and Time
1/3 Oct 12.5Hz dB Leq



One Third Octave Centre Frequency Band - 16Hz dB Leq
Sound Level, dBZ
90
80
70
60
50
40
30
20
22/06/2023 00:00
22/06/2023 06:00
22/06/2023 12:00
22/06/2023 18:00
23/06/2023 00:00
23/06/2023 06:00
23/06/2023 12:00
23/06/2023 18:00
24/06/2023 00:00
24/06/2023 06:00
24/06/2023 12:00
24/06/2023 17:59
24/06/2023 23:59
25/06/2023 05:59
25/06/2023 11:59
25/06/2023 17:59
25/06/2023 23:59
26/06/2023 05:59
26/06/2023 11:59
26/06/2023 17:59
26/06/2023 23:59
27/06/2023 05:59
27/06/2023 11:59
27/06/2023 17:59
27/06/2023 23:59
28/06/2023 05:59
28/06/2023 11:59
28/06/2023 17:59
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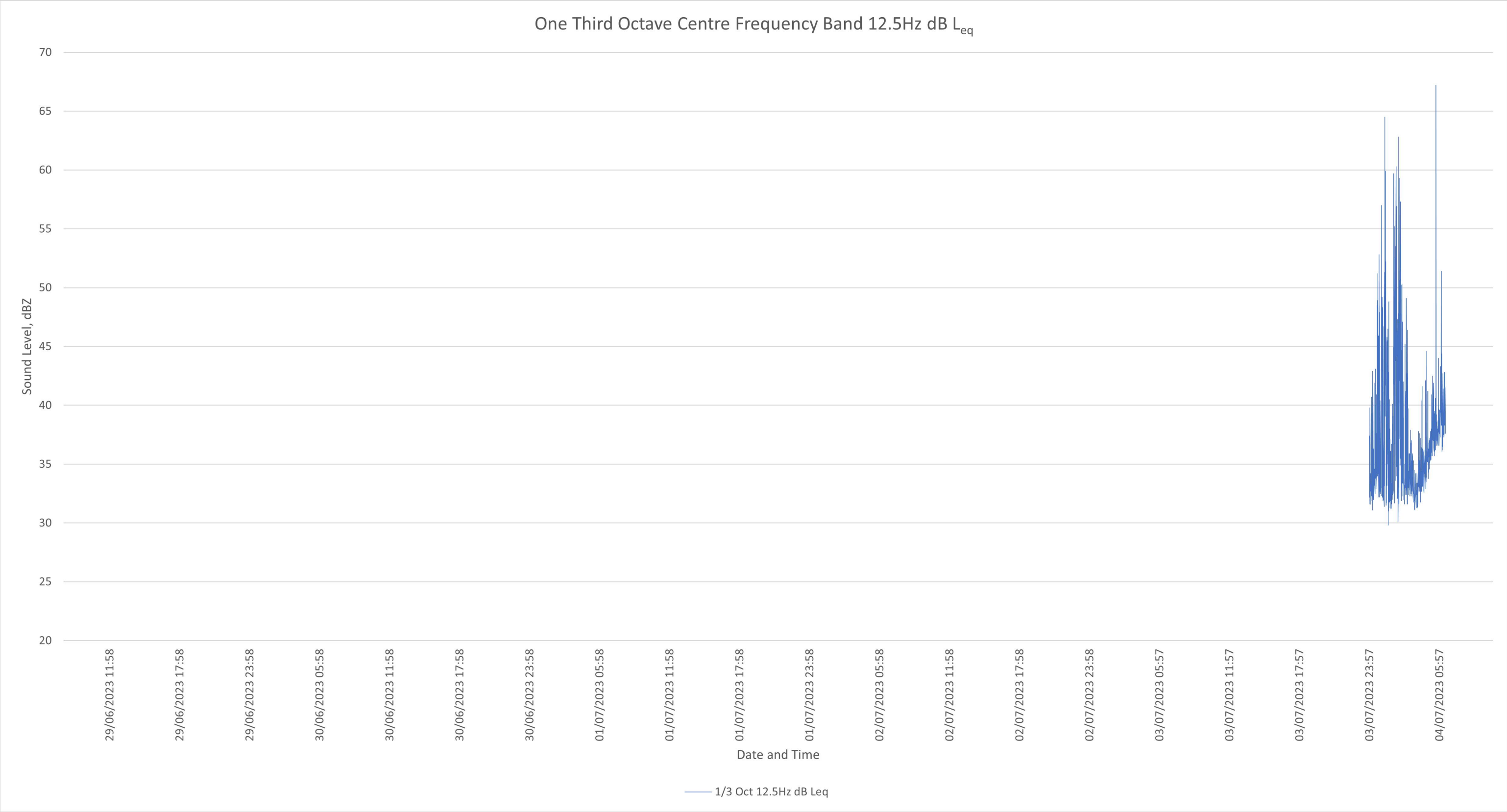
29/06/2023 11:58
29/06/2023 17:58
Date and Time
1/3 Oct 16Hz dB Leq



One Third Octave Centre Frequency Band 12.5Hz dB L_{eq}
Sound Level, dBZ
70
65
60
55
50
45
40
35
30
25
20
29/06/2023 11:58
29/06/2023 17:58
29/06/2023 23:58
30/06/2023 05:58
30/06/2023 11:58
30/06/2023 17:58
30/06/2023 23:58
01/07/2023 05:58
01/07/2023 11:58
01/07/2023 17:58
01/07/2023 23:58
02/07/2023 05:58
02/07/2023 11:58
02/07/2023 17:58
02/07/2023 23:58
03/07/2023 05:57
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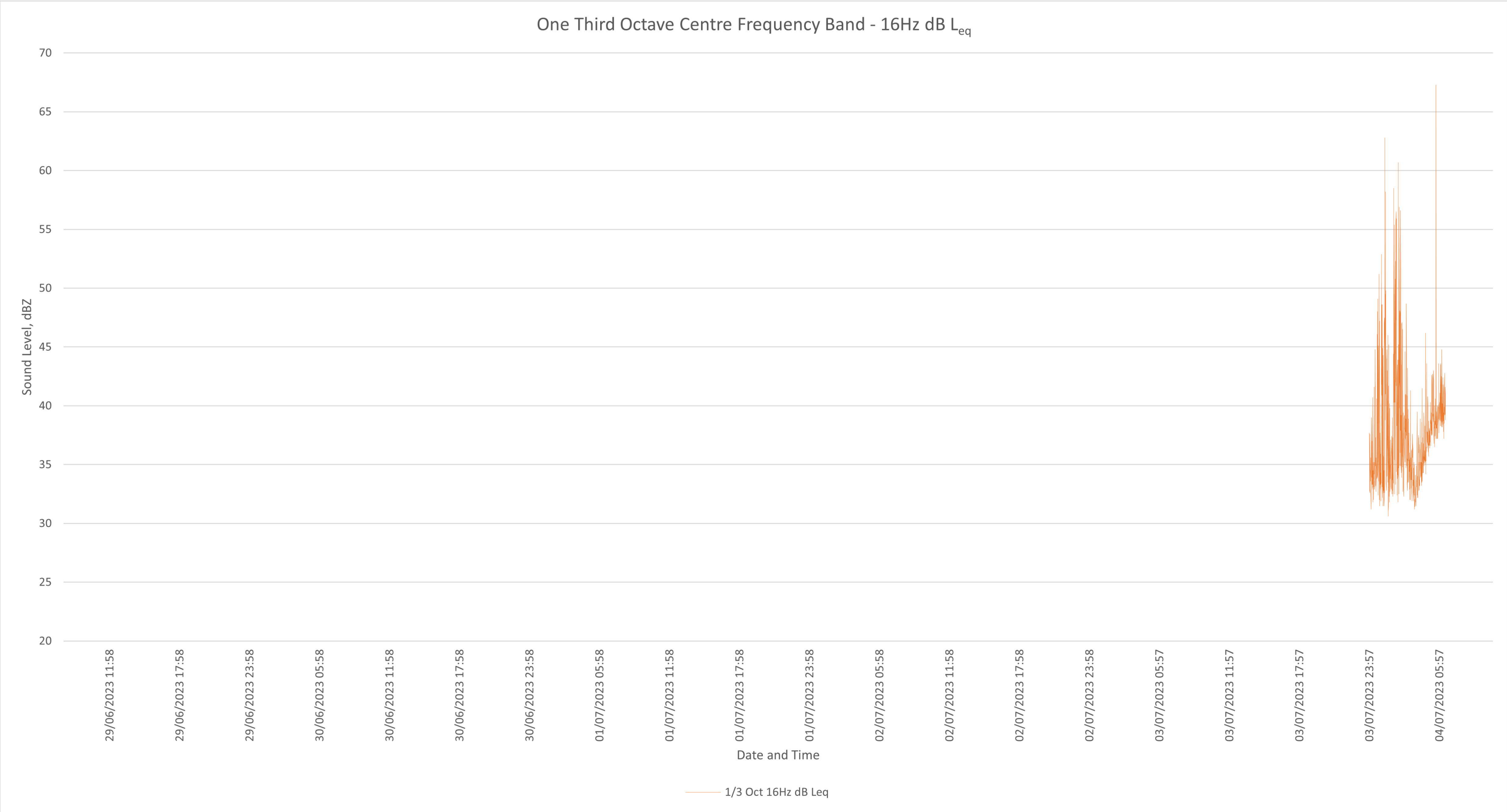
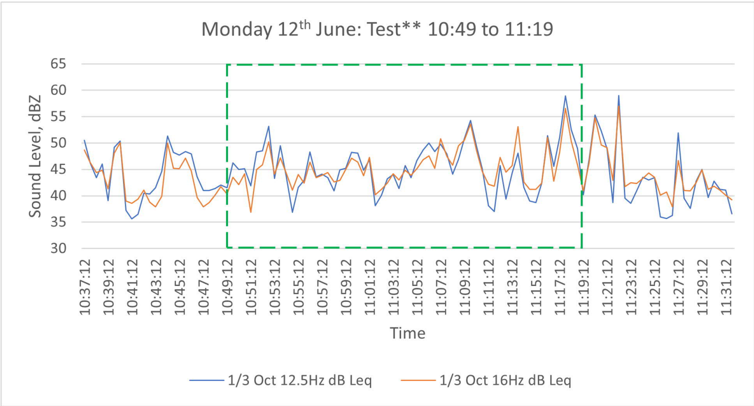
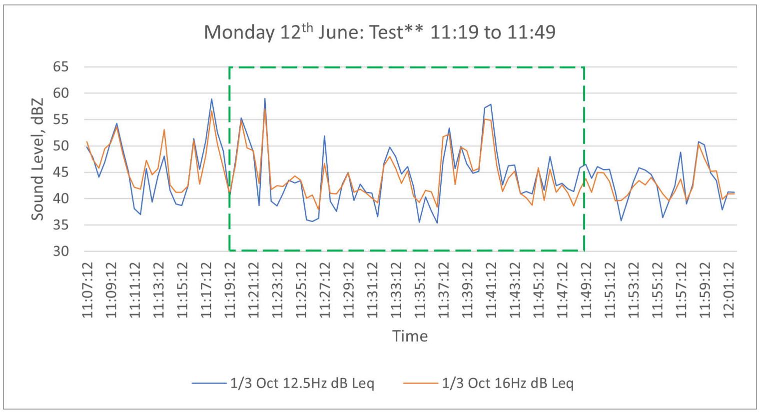
04/07/2023 05:57
Date and Time
1/3 Oct 12.5Hz dB Leq

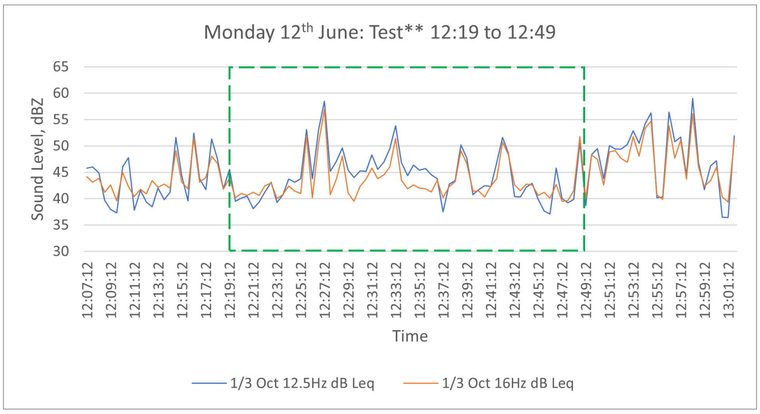


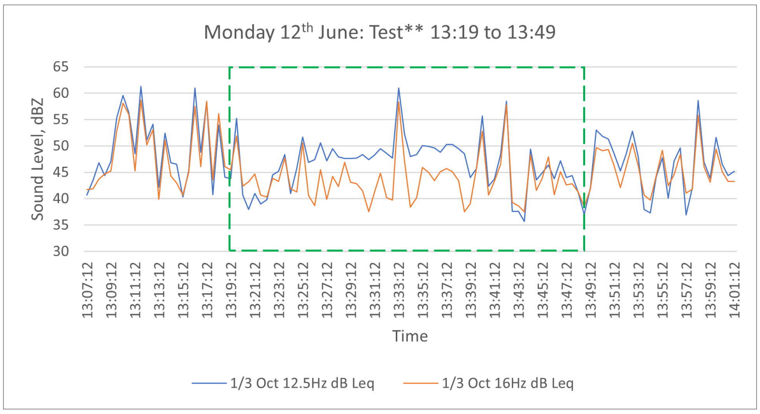
One Third Octave Centre Frequency Band - 16Hz dB L_{eq}
Sound Level, dBZ
70
65
60
55
50
45
40
35
30
25
20
29/06/2023 11:58
29/06/2023 17:58
29/06/2023 23:58
30/06/2023 05:58
30/06/2023 11:58
30/06/2023 17:58
30/06/2023 23:58
01/07/2023 05:58
01/07/2023 11:58
01/07/2023 17:58
01/07/2023 23:58
02/07/2023 05:58
02/07/2023 11:58
02/07/2023 17:58
02/07/2023 23:58
03/07/2023 05:57
03/07/2023 11:57
03/07/2023 17:57
03/07/2023 23:57
04/07/2023 05:57
Date and Time
1/3 Oct 16Hz dB Leq

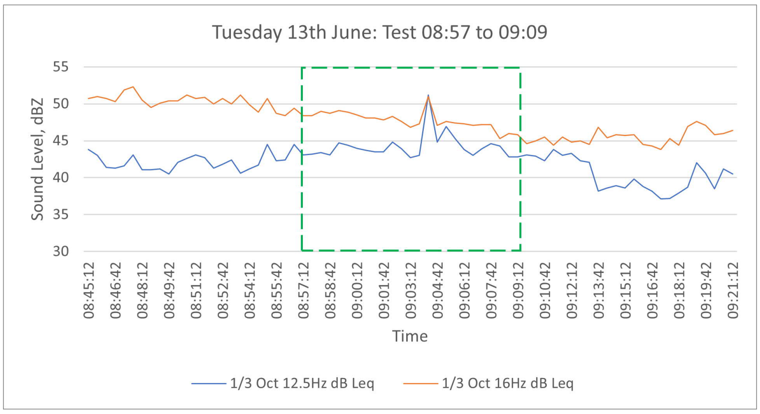
LT3: LFN Trial Graphs

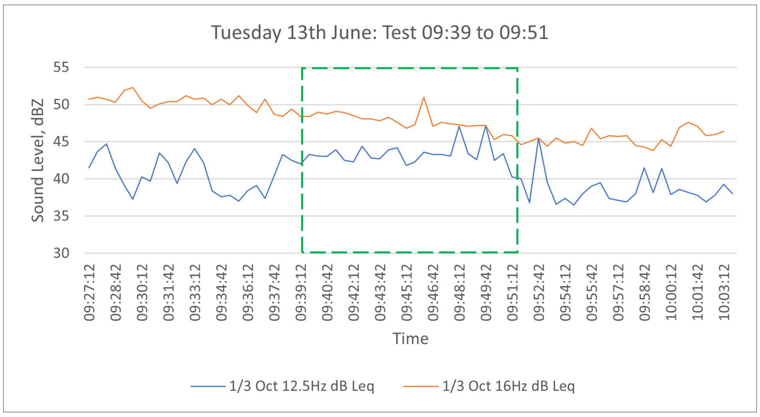


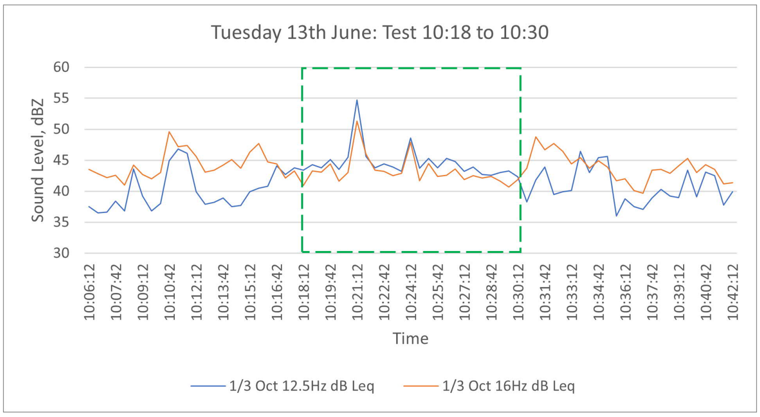


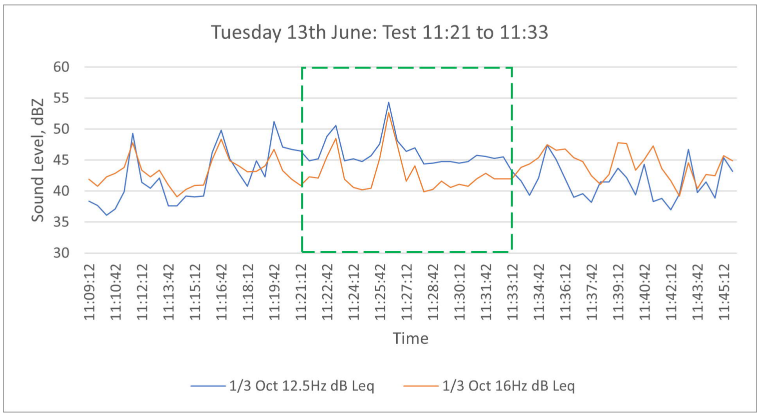


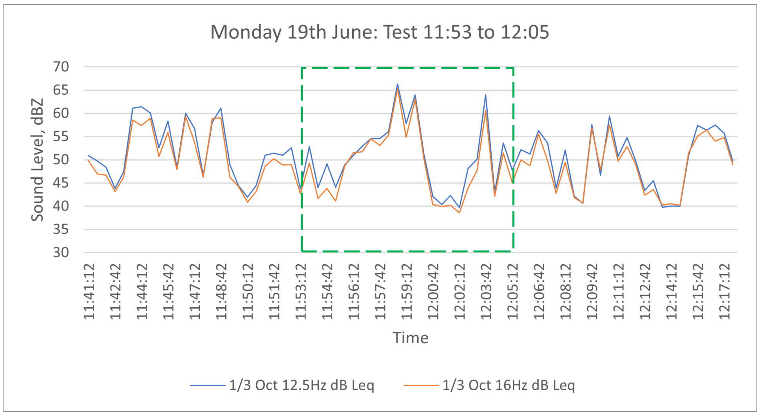


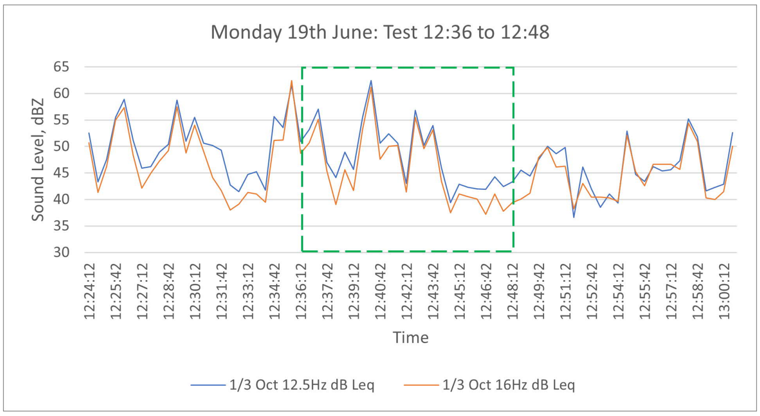


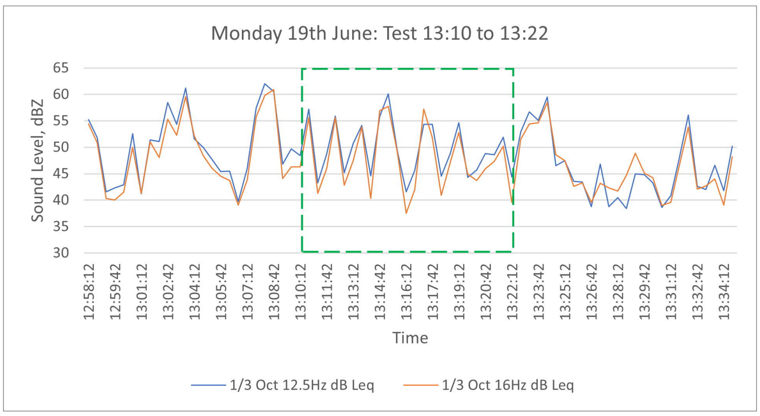


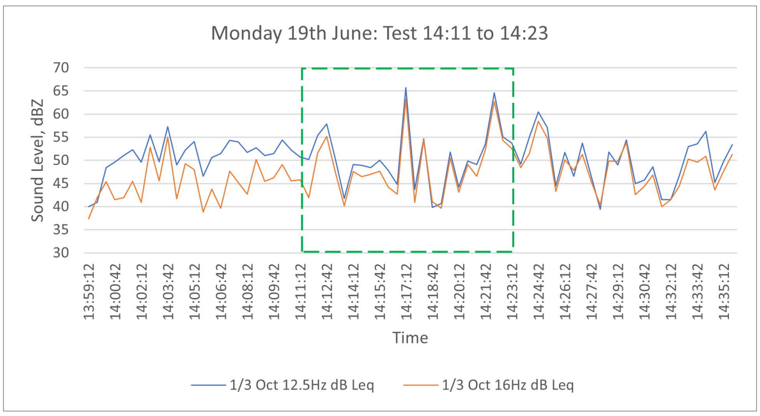

Tuesday 13th June: Test 10:18 to 10:30
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

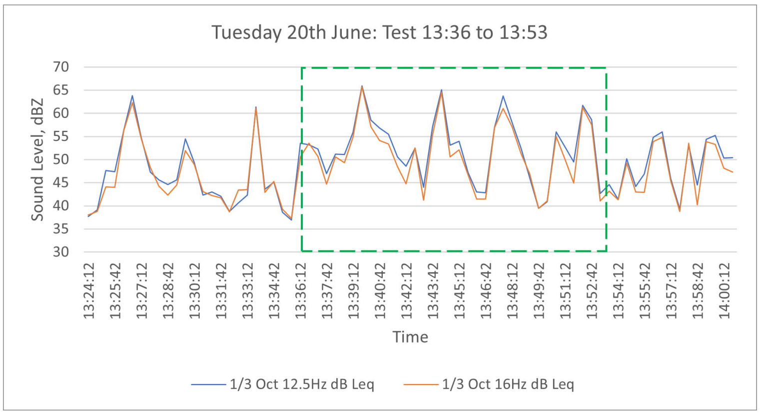

Tuesday 13th June: Test 11:21 to 11:33
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

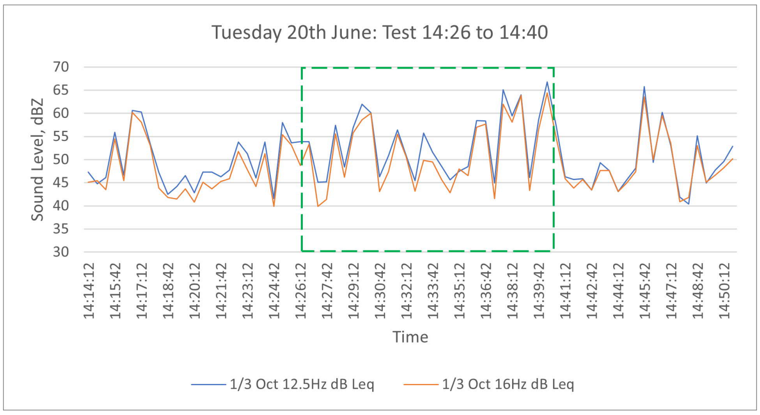

Monday 19th June: Test 11:53 to 12:05
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

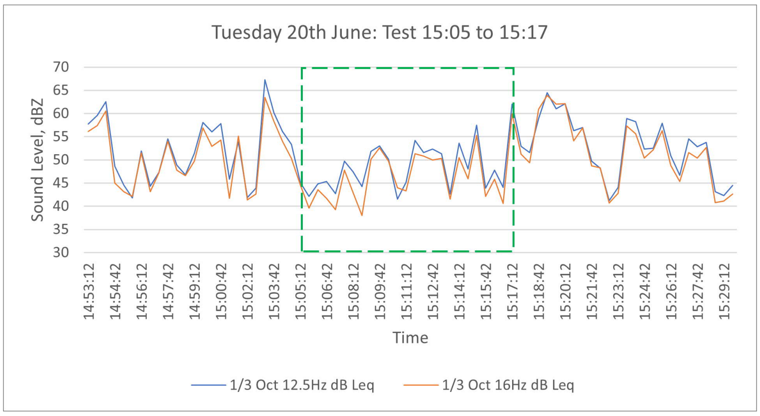

Monday 19th June: Test 12:36 to 12:48
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

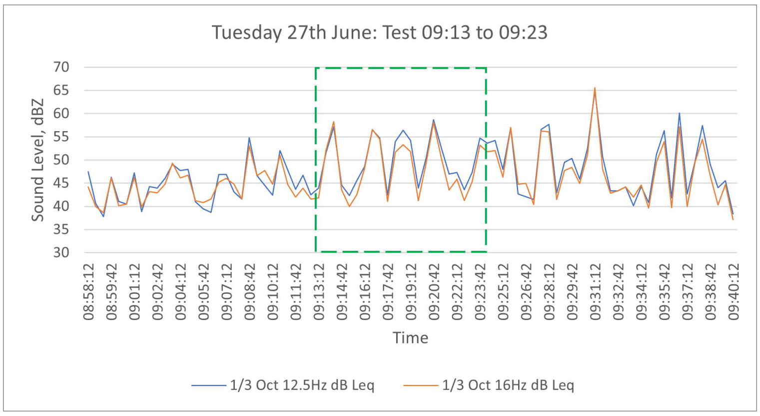

Monday 19th June: Test 13:10 to 13:22
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

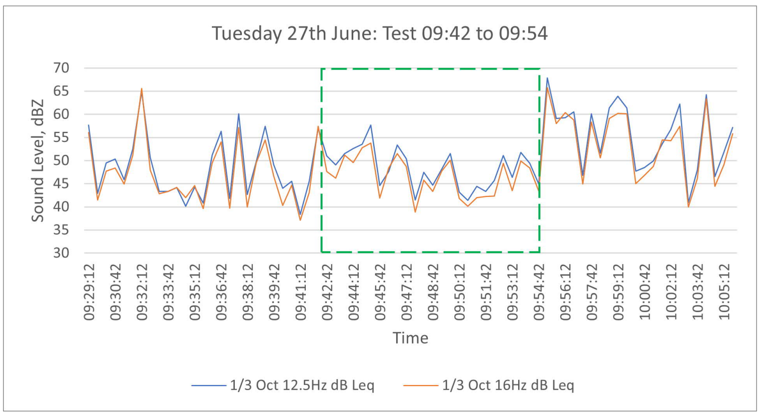

Monday 19th June: Test 14:11 to 14:23
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

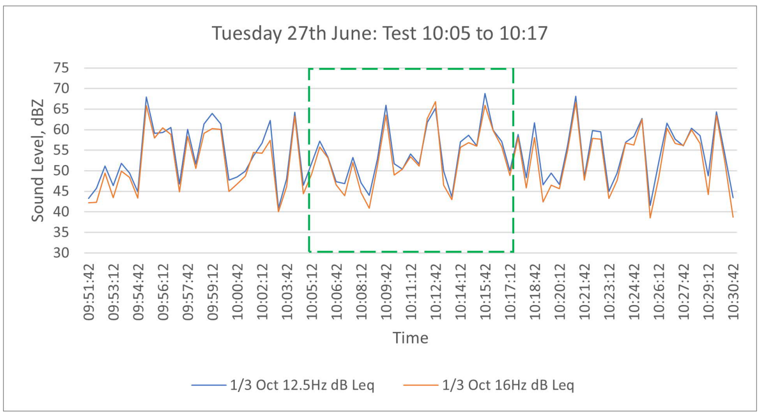

Tuesday 20th June: Test 13:36 to 13:53
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

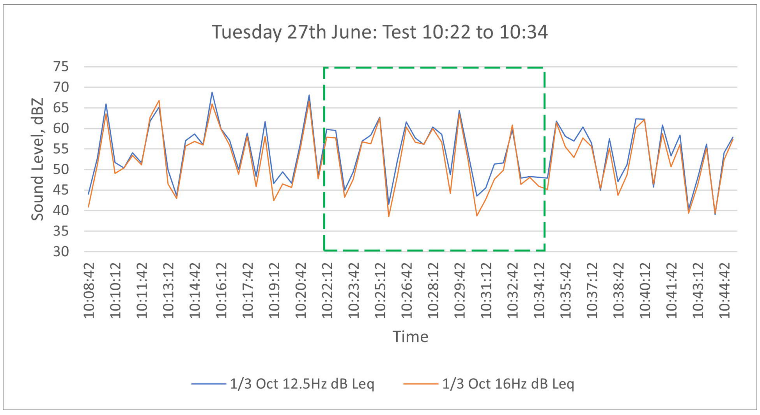

Tuesday 20th June: Test 14:26 to 14:40
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

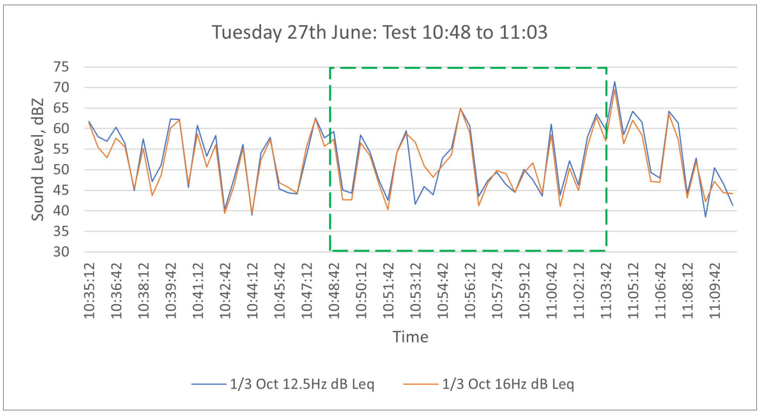

Tuesday 20th June: Test 15:05 to 15:17
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

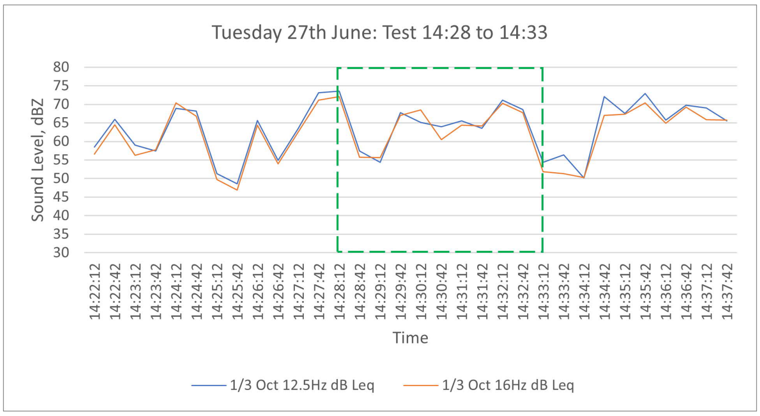

Tuesday 27th June: Test 09:13 to 09:23
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

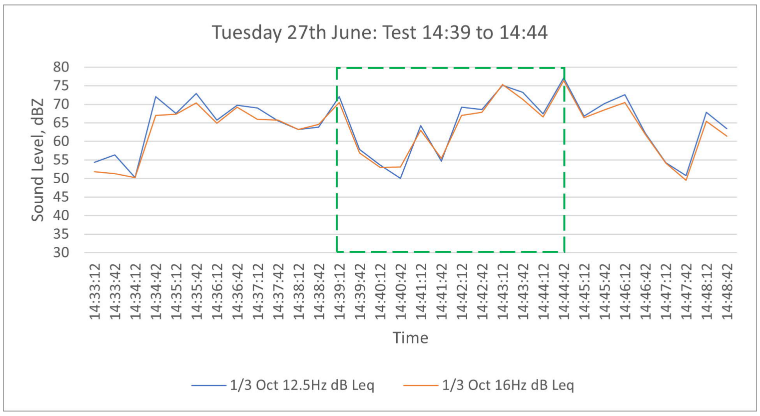

Tuesday 27th June: Test 09:42 to 09:54
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

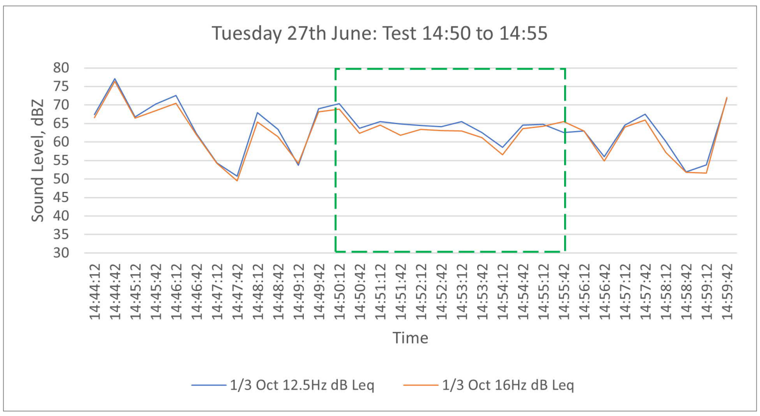

Tuesday 27th June: Test 10:05 to 10:17
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

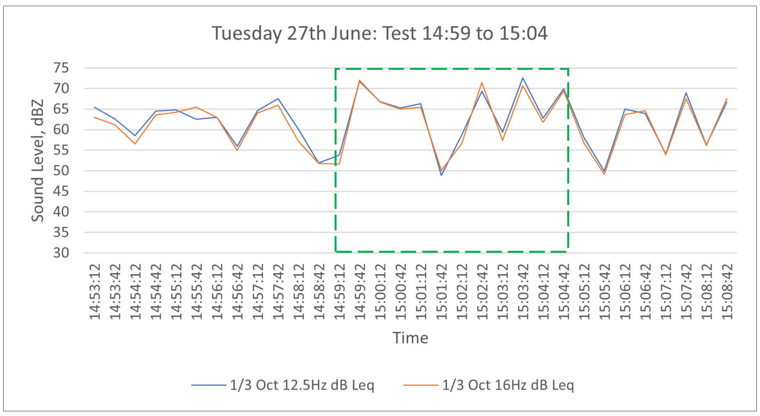

Tuesday 27th June: Test 10:22 to 10:34
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

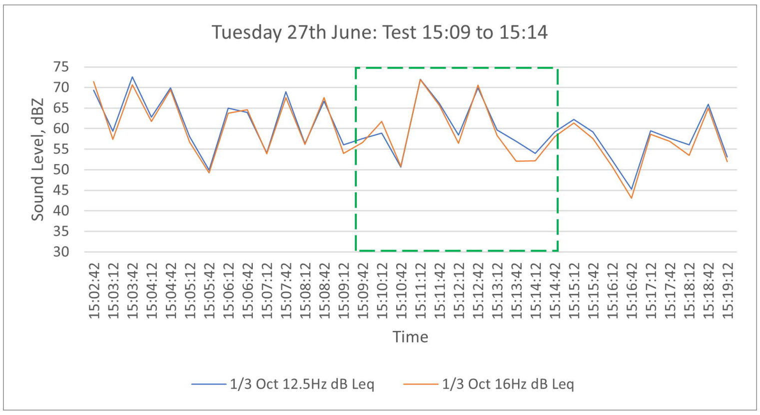

Tuesday 27th June: Test 10:48 to 11:03
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq


Tuesday 27th June: Test 14:28 to 14:33
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

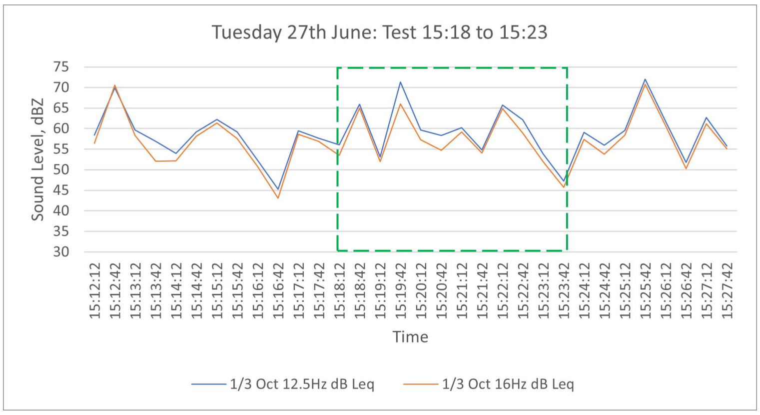

Tuesday 27th June: Test 14:39 to 14:44
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq


Tuesday 27th June: Test 14:50 to 14:55
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

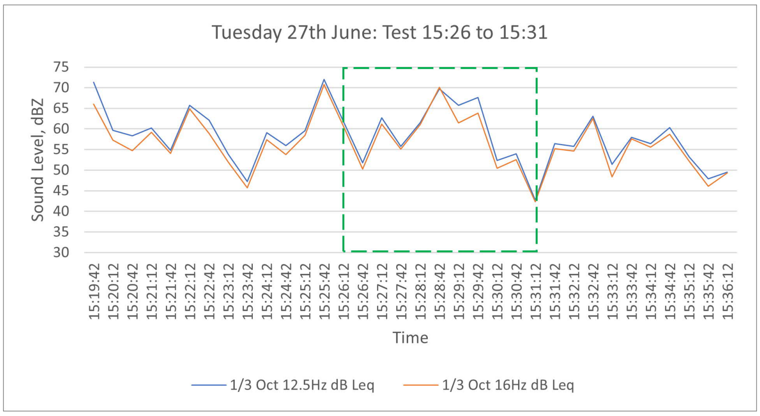

Tuesday 27th June: Test 14:59 to 15:04
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq



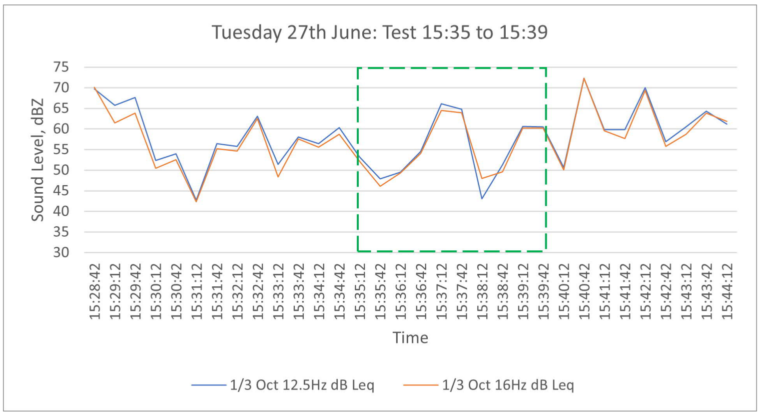
Tuesday 27th June: Test 15:09 to 15:14
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq



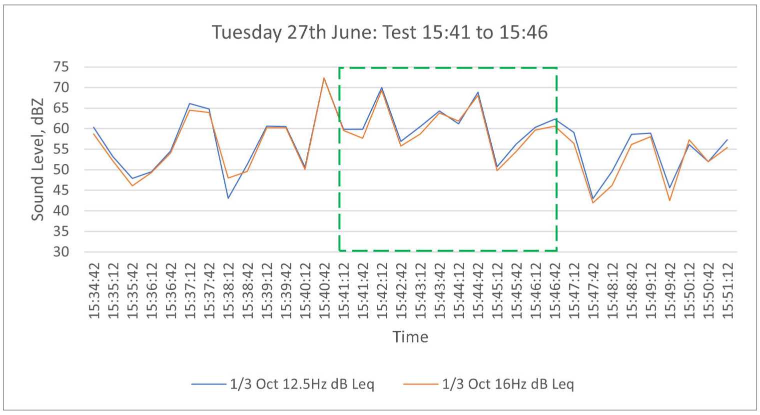
Tuesday 27th June: Test 15:18 to 15:23
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq



Tuesday 27th June: Test 15:26 to 15:31
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq



Tuesday 27th June: Test 15:35 to 15:39
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq



Tuesday 27th June: Test 15:41 to 15:46
Sound Level, dBZ
Time
1/3 Oct 12.5Hz dB Leq
1/3 Oct 16Hz dB Leq

Appendix L

PROPAGATION CALCULATIONS OR PREDICTIONS

The information in this Appendix is presented in two parts.

The first part presents the results of a review into the requirements of the low frequency sound propagation model used to predict the potential impacts of future operations at Hemerdon mine, with particular emphasis on the propagation mechanisms that need to be included and the suitability of available prediction techniques.

The second part presents details of the low frequency sound propagation model adopted for the prediction of impacts associated with the operation of Hemerdon mine.

PART 1: REVIEW OF LOW FREQUENCY SOUND PROPAGATION

Background

A review has been undertaken to determine the requirements of the low frequency sound propagation model used to predict the potential impacts of future operations affecting residential locations in the vicinity of the Hemerdon mine. As part of this review, published research on the physical sound propagation mechanisms relevant to the situation at Hemerdon mine has been reviewed. This Appendix sets out details of the sound propagation mechanisms that have been included in the model and the mechanisms that have safely been excluded from the model (with technical justification) to avoid the model becoming over-complicated.

Conventional Sound Propagation Models and their Unsuitability for the Prediction of Low Frequency Noise from Hemerdon Mine

The conventional sound prediction model used for the assessment of potential noise impacts arising from minerals processing facilities such as that at Hemerdon mine is that set out in ISO 9613-2: *Acoustics - Attenuation of Sound during Propagation Outdoors - Part 2: General Method of Calculation*[15]. Other noise prediction models, such as CONCAWE[16] are available, and are very similar to the ISO 9613-2 model.

However, the ISO 9613-2 model (and similar models such as CONCAWE) is unsuitable for use in the prediction of low frequency noise at Hemerdon, for two reasons:

- The ISO 9613-2 model specifically relates to, and has been validated for, the prediction of audible noise in the frequency range 63 Hz to 16 kHz. The method does not consider noise at the very low frequencies (12.5 Hz and 16 Hz fundamental frequencies and first / second harmonics thereof) that are of interest for the low frequency noise assessment. Furthermore, the research base upon which the ISO 9613-2 method has been derived does not include robust data at very low frequencies, and it would be extremely dangerous to extrapolate the method to cover the frequency range below 63 Hz, for which the model has not been validated.
- The ISO 9613-2 method is based on an empirical (or semi-empirical) model which includes the application of correction factors to account for acoustical phenomena such as ground effects,

[15] ISO 9613 - Part 2: 1996. *Acoustics - Attenuation of Sound during Propagation Outdoors - Part 2: General Method of Calculation*. International Organisation for Standardisation. 1996
[16] Manning, C J. *The Propagation of Noise from Petroleum and Petrochemical Complexes to Neighbouring Communities*. CONCAWE. 1981

barrier effects and meteorological effects, to numerical values for the source sound power level. As such, ISO 9613-2 cannot be used to calculate an expected sound waveform, which would only be possible by adopting a wave-based approach to the prediction model. The inability to calculate or predict a sound waveform means that the ISO 9613-2 method cannot be used to predict effects such as beating (associated with multiple low frequency noise sources operating at the same frequency or at a very close frequency), which is known to occur at Hemerdon.

We must therefore conclude that ISO-9613-2 and similar sound propagation models are not appropriate to assess the low frequency noise emissions at Hemerdon and that an alternative wave based prediction model must be applied. In the absence of a standard wave-based model, a bespoke model has been derived, based on acoustical theory and, where possible, measurement data and the available published research.

Requirements of the Low Frequency Sound Propagation Model for Hemerdon

The elements that need to be considered in any sound propagation model (and are included, for example, in conventional models such as ISO 9613-2) include:

- Characterisation of the source. This is usually via specification of a sound power level for each source and a directivity factor to account for the fact that the source may not radiate sound equally in all directions. Usually, the sound power level will be expressed in octave or one third octave frequency bands.
- Quantification of the sound attenuation during propagation from the source to the receptor location. The attenuation effects that should be considered include:
- Attenuation due to geometrical wave spreading;
- Attenuation due to atmospheric absorption;
- Attenuation (or amplification) due to ground effects;
- Attenuation due to barrier (or screening) effects;
- Corrections due to meteorological effects; and
- Corrections due to sound reflections (for example, at a building façade).
- Consideration of the effects of the receptor location (e.g. whether outside or inside a building, and quantification of the effects of the building in terms of sound insulation provided by the building envelope and the potential attenuation or amplification effects associated with room modes or resonances with building elements such as walls and floors).

For the situation at Hemerdon, each of the above factors needs to take into account the very low frequency content of the sound emissions. Some of the effects listed above can be safely removed from the model specifically because the sound is of such low frequency. This is discussed further below.

Characterisation of the Source

The screens at Hemerdon are to be installed within purpose built enclosures. Effectively, the radiating sound source will be the walls and roof of the enclosure. Within the acoustic near field, the enclosure will act as a ‘plane’ source, with no attenuation due to geometrical spreading. In the acoustic far-field, the attenuation due to geometrical spreading will be such that the enclosure will act as a point source, with an attenuation of 6dB per doubling of distance. In the intermediate region between the acoustic near field and far field (often referred to as the geometric near field), the attenuation with distance will be approximately 3dB per doubling of distance.

The distance from the enclosure beyond which the characteristics of the source are such that it will radiate as a point source is a/π, where a is the largest dimension of the enclosure[17]. For the enclosures being studied, the largest dimension, a, is 7.64m. Sound radiation from the enclosures will therefore follow the physics of point source radiation at distances beyond approximately 2.4m. Given the distances to the nearest receptor locations, which are typically beyond 1km from the source, only an extremely small (and insignificant) part of the propagation path will not follow the rules of point source radiation. One could argue that for those (enclosed) screens within the process building, the process building itself will become the effective sound source. Even then, given the largest dimensions of the process building (approx. 126m long x 39m wide x 29m high), sound radiation from the building will follow the physics of point source radiation at distances beyond approximately 40m. It is therefore concluded that, to all intents and purposes, the screens will effectively act as acoustic point sources as seen from receptor locations outside of the site.

In terms of quantifying the magnitude of the sound emissions and the effects of directivity, this has been achieved via a series of measurement exercises undertaken during site trials to assist the design of acoustic enclosures, as reported by Eatec Dynamics[18]. For simplicity, Eatec has characterised the source strength in terms of a characteristic pressure, $p_{sc}(t)$, defined as the sound pressure experienced at a hypothetical distance of 1m from the source. The advantage of using this method to characterise the source (rather than the more conventional method of specifying a sound power level) is that it allows for the calculation or prediction of sound pressure time histories for use in a wave based prediction model, which would not be possible if the source were characterised as a sound power level.

Sound emissions from the screens may exhibit some directionality, even when the screens are contained within an acoustics enclosure. This is an inevitable consequence of requiring apertures (whether open or ducted via chutes) to allow material throughput. This is shown by the on-site measurement data, as reported by Eatec, which involved the measurement of the sound pressure time history at 6 locations around the test screen (and at 6 different directions from the screen centre). However, source directivity is less prominent for low frequency sound compared to the higher audible frequencies. Furthermore, there will be multiple screens operating at Hemerdon and they will not be oriented in the same direction, such that the overall directivity from the combined sources will be much diluted. For the purposes of the sound propagation model, a worst case scenario has been adopted which adjusts the magnitude of the characteristic pressure, $p_{sc}(t)$, according to the results obtained from the mitigation trials (which involved measurements on site and at the far field receptor locations) to represent the worst case measurement data. The magnitude of the characteristic pressure is adjusted via the choice of the assumed ‘acoustic efficiency’.

[17] Rathe, E J. *Note on Two Common Problems of Sound Propagation*. Journal of Sound and Vibration, 10 (3) pp 472-479 (1969)
[18] Included in the Appendices to this NIA.

Sound Propagation - Attenuation due to Geometrical Wave Spreading

As detailed above, the screens can be modelled as a point source. The *intensity* of the sound pressure will then reduce in proportion of the square of the distance between the source and receptor, and the sound pressure will reduce linearly (in proportion with the distance). The phase of the pressure waveform will also change along the propagation path, the phase change being dependent on the wavelength and the speed of sound in air.

The pressure waveform at the receptor location (assumed to be free-field) will then be given by

$p_r(t,r) = p_{sc} \sin(2 \pi f t - (2 \pi f r / c)) / r$

This is based on the fundamental physics relating to spherical wave propagation.

Sound Propagation - Attenuation due to Atmospheric Absorption

The latest theory relating to sound attenuation during propagation through the atmosphere due to molecular absorption is described by Bass et al[19]. The theory of Bass et al, which was used to derive the atmospheric attenuation coefficients in ISO 9613-1[20], describes the attenuation of sound due to atmospheric absorption through the following equations:

attenuation, α (in nepers/m) = $p_s F^2 \{1.84\times10^{-11}(T/T_0)^{1/2} p_{s0} + (T/T_0)^{-5/2} \times [0.01275(e^{-2239.1/T})/(F_{r,o}+F^2/F_{r,o}) + 0.1068(e^{-3352/T})/(F_{r,N}+F^2/F_{r,N})]\}$

where

F	=	scaled frequency = f/p_s
f	=	frequency (Hz)
p_s	=	atmospheric pressure
T	=	temperature (Kelvin)
T_0	=	reference atmospheric temperature = 293.15 K
$F_{r,o}$	=	scaled relaxation frequency of oxygen = $(1/p_{s0}) \{24+4.04\times10^4 h(0.02+h)/(0.391+h)\}$
$F_{r,N}$	=	scaled relaxation frequency of nitrogen = $(1/p_{s0})(T_0/T)^{1/2} \{9+280h \exp\{-4.17[(T_0/T)^{1/3}-1]\}\}$
h	=	molar concentration of water vapour = $h_r (p_{sat}/p_{s0}) / (p_s/p_{s0}) = (p_{s0} h_r p_{sat}) / (p_s p_{s0})$ %
h_r	=	relative humidity (%)
p_{s0}	=	reference value for atmospheric pressure = 1×10^5 Pa

[19] Bass H E; Sutherland L C; Zuckerwar A J; Blackstock D T; and Hester D M: *Atmospheric Absorption of Sound – Further Developments*. Journal of the Acoustical Society of America Vol 97 Part 1 (Jan 1995) plus erratum Vol 99 Part 2 (Feb 1996)
[20] ISO9613-1: 1993. *Acoustics - Attenuation of Sound during Propagation Outdoors - Part 1: Calculation of the Absorption of Sound by the Atmosphere*. International Organisation for Standardisation. 1993

T_{01} = triple point isotherm temperature = 273.16 K

and the saturated vapour pressure p_{sat} is given by:

$$Log_{10} (p_{sat} / p_{s0}) = 10.79586 [1-(T_{01} / T)] - 5.02808 Log_{10}(T / T_{01}) + 1.50474 \times 10^{-4} (1-10^{-8.29692[(T / T01) -1]}) - 4.2873 \times 10^{-4} (1-10^{-4.76955[(T01 / T) -1]}) - 2.2195983$$

Note that the attenuation coefficient α is in Nepers per meter where:

1 Neper= $20 \log_{10} e$ dB = 8.68589 dB

The above equations can be used to derive a set of curves as shown in Figure AL-1 below. Note that in this figure the frequency and absorption coefficients shown in the abscissa are scaled by atmospheric pressure and the curves are presented for a range of relative humidities and for a temperature of 20°C. Similar curves can be derived for other temperatures.

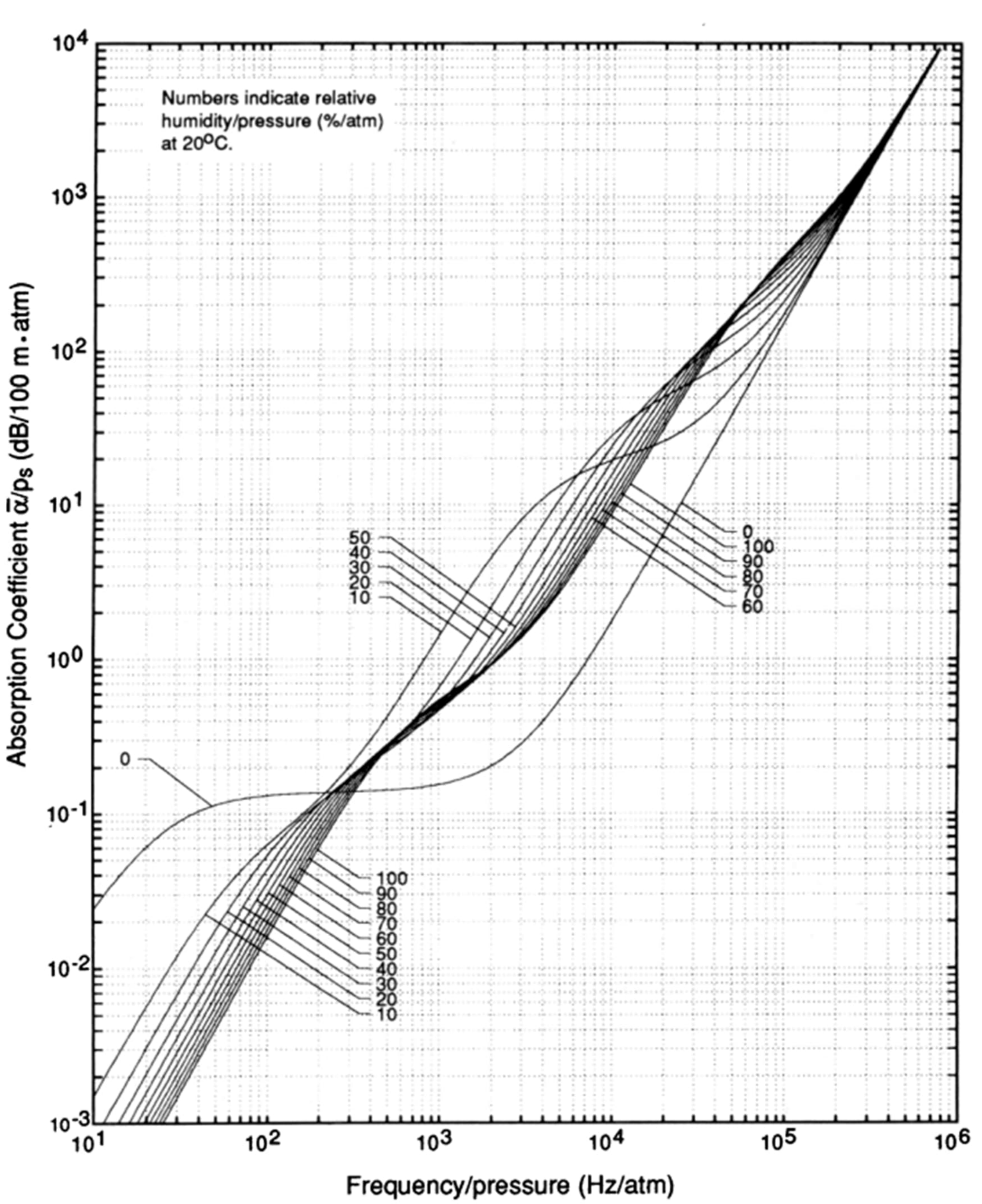


Figure AL-1: Sound absorption coefficient per atmosphere for air at 20°C (reproduced from Bass et al)

For the situation at Hemerdon, where the fundamental frequencies and harmonics under consideration are all below 50Hz, the area of interest is in the far bottom left corner of the graph in Figure AL-1. It can be seen that the atmospheric absorption coefficients will be of the order of 0.001 to 0.01 dB per 100m.

More accurate calculations can be undertaken using the equations above (the National Physical Laboratory provides an online tool to do this[21]).

Considering the more distant receptor locations that we need to consider, which are approximately 2.5 km from the source, the atmospheric attenuation over the entire propagation path would be as follows:

Atmospheric Conditions	Attenuation (dB/m)		Total Attenuation (dB)	
	12.5 Hz	48 Hz	12.5 Hz	48 Hz
Warm and dry (20ºC / 50% RH)	0.000005	0.000072	0.0125	0.18
Warm and humid (20ºC / 95% RH)	0.000003	0.000039	0.0075	0.0975
Cold and dry (0ºC / 50% RH)	0.00001	0.000119	0.025	0.2975
Cold and humid (0ºC / 95% RH)	0.00005	0.000075	0.125	0.1875

Table AL-1: Atmospheric attenuation over 2.5 km propagation path.

In the above table, the figures relate to air at standard atmospheric pressure (taken as $1x10^5$ Pa). Typical variation in the UK between low pressure and high pressure weather systems would be plus or minus 3% of standard atmospheric pressure and would lead to a similar variation in the figures quoted in the above table. Figures are presented to cover the range of frequencies that are of concern at Hemerdon, from the lowest fundamental screen frequency (12.5 Hz) to the second harmonic of the screens with an operating frequency of 16 Hz (i.e. second harmonic at 48 Hz).

It can be seen from the results presented in Table AL-1 that, for the situation at Hemerdon, the effects of atmospheric absorption in the propagation path would result in, at most, an attenuation of small a fraction of a decibel.

It is therefore concluded that the effects of atmospheric absorption can be safely excluded for the sound prediction model.

Sound Propagation - Attenuation (or Amplification) due to Ground Effects

It should be noted from the outset that in the propagation of sound there is an interaction between ground effects, barrier effects, and meteorological effects, resulting in a situation where any sound attenuation due to ground effects can be diminished or even entirely removed if there are sound "barriers" in the propagation path or if the prevailing meteorological conditions are favourable to the

[21] http://resource.npl.co.uk/acoustics/techguides/absorption

propagation of sound. For the analysis that follows, a simplified situation is considered whereby there are no sound barriers in the propagation path and the meteorological conditions are neutral (meteorological conditions are considered in more detail below). The situation is simplified further by assuming a flat ground profile.

The theory of sound attenuation due to ground effects is based on interference (which can be a combination of constructive and destructive interference) between the direct sound path and a sound path that is reflected by the ground (as shown in Figure AL-2). The theory is mathematically complicated because the interference patterns are highly dependent on the phase change that happens upon reflection at the ground surface, which in turn is highly dependent on the geometry of the sound paths and the properties of the ground (especially the flow resistivity of the soil and the soil depth / profile). As an example, Figure AL-3 shows the attenuation due to ground effects for various source to receiver distances of up to 1.5km where the reflecting ground is a grass surface. Figure AL-4 shows the same data for a single source to receiver distance (of 150m) but showing the effect of the flow resistivity of the soil (where the soil depth is assumed to be infinite). Figure AL-5 shows the same data again, but with a situation where the soil is a thin layer (5cm thick) over a harder rock. In these figures, the ground attenuation is defined by comparison with the free-field situation (i.e. assuming the ground is not present).

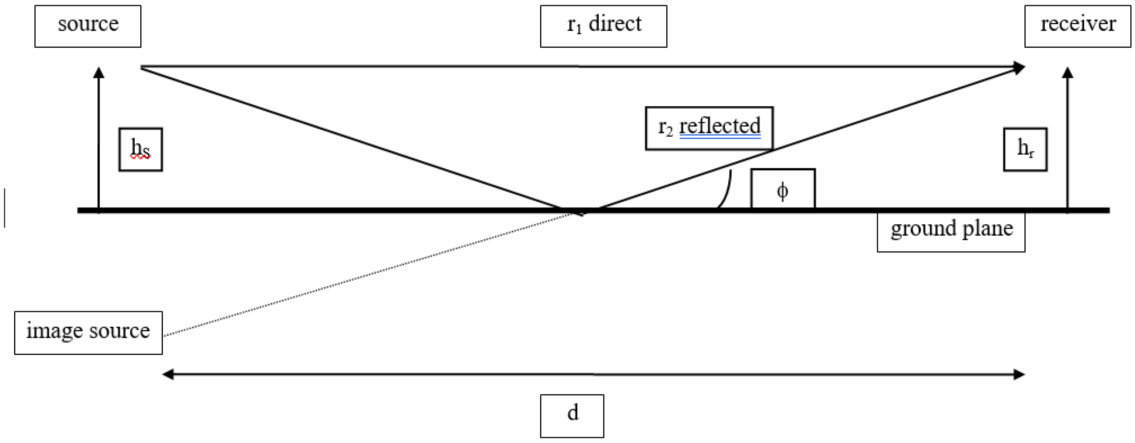


Figure AL-2: Interaction of direct and ground-reflected sound paths

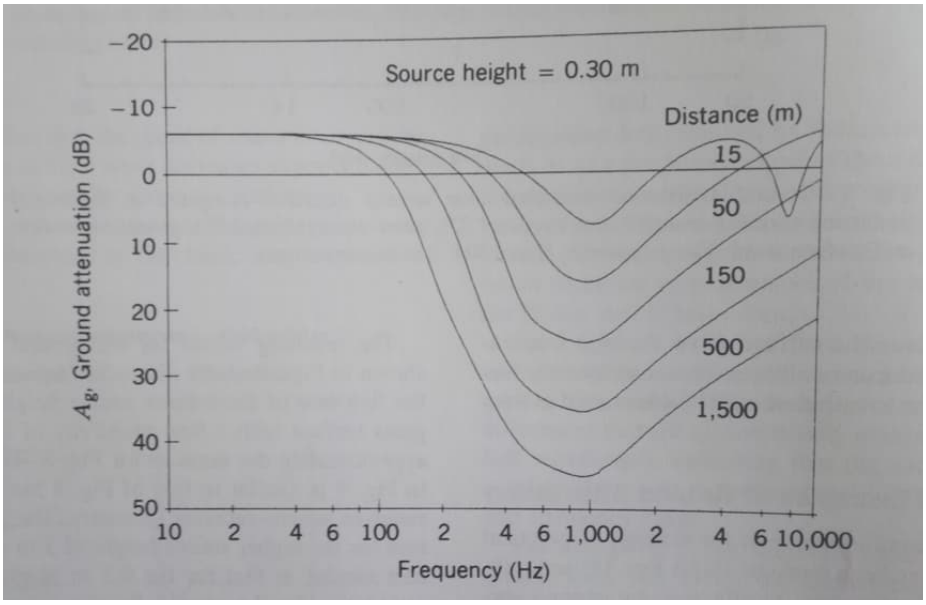


Figure AL-3: Predicted ground attenuation for average grass surface using Delany-Bazley impedance model for receiver height 1.2m (from Sutherland and Daigle[22])

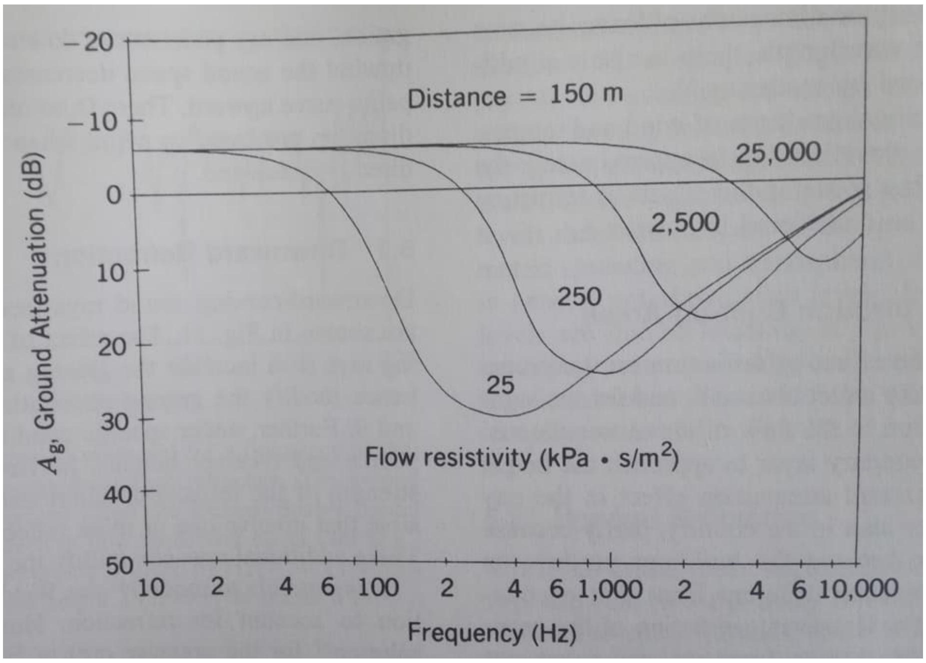


Figure AL-4: Predicted ground attenuation for different surfaces using Delany-Bazley impedance model for receiver height 1.2m and assuming semi-infinite ground (from Sutherland and Daigle - see ref. 22)

[22] Sutherland, L C and Daigle G A: *Atmospheric Sound Propagation*. Presented in the *Encyclopedia of Acoustics* edited by Crocker, M J, Vol 1 pp341-356. Wiley (1997)

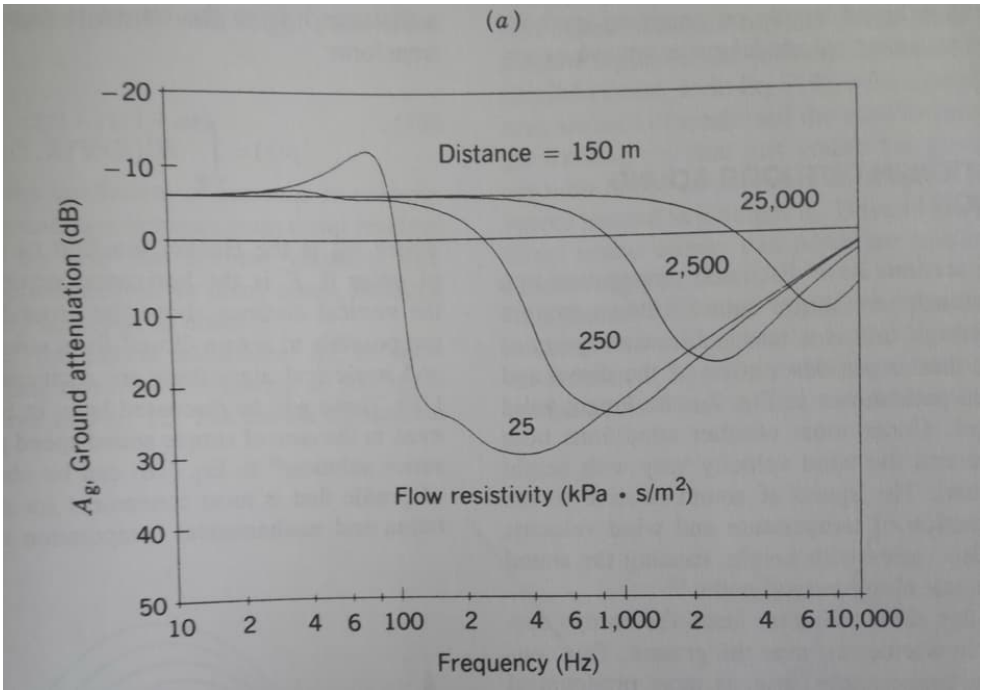


Figure AL-5: Predicted ground attenuation for different surfaces using Delany-Bazley impedance model for receiver height 1.2m and assuming 0.05 thick soil layer over a hard backing (from Sutherland and Daigle – see ref. 22)

In summary, the situation is complicated (at least at audible frequencies), and precise calculations will, in most circumstances, be impossible because it would require detailed information on soil / ground properties that will not be available. However, it is worth noting from the above figures what is happening at the low frequencies that are of concern at Hemerdon. At low frequencies (typically below 50 to 100Hz), the attenuation due to ground effects converges at +6dB. In effect, this is an amplification and would be equivalent to perfectly constructive interference between the direct and reflected sound waves.

It is worth investigating specific research that has been undertaken into ground effects at low frequencies (below 50Hz). Figure AL-6 shows predictions from a study[23] using numerical modelling techniques to investigate sound propagation in a system of fluid layers (representing the air) and porous elastic layers (representing the ground). The results show the same trend as described above (a ground effect of +6dB) but with ‘dips’ at specific and very narrow frequency ranges. The frequency at which the dips occur was found to depend slightly on the assumed speed of sound in the air, and the depth of the dip was found to depend slightly on the source to receiver distance. The dips occurred between 2Hz and 3.5Hz and between 20Hz and 30Hz, neither of which coincide with the fundamental frequencies of the screens at Hemerdon. The physical mechanism that caused the

[23] Tooms, S, Taherzadeh, S and Attenborough, K: *Sound Propagation in a Refracting Fluid above a Layered Porous and Elastic Medium*. Journal of the Acoustical Society of America, 93 (1) pp 173-181 (1993). The results are presented in Attenborough, K; Li, K M; and Horoshenkov, K: *Predicting Outdoor Sound*. Taylor and Francis (2007).

dips was explained as acoustic to seismic coupling (e.g. energy transfer from the sound wave to groundborne vibration). However, this should not be a cause of concern. The same authors (ref 23) modelled the effects of this acoustic to seismic coupling, which was later compared to measurement data by Harrop[24]. The results are shown in Figure AL-7 and show that the induced groundborne vibration was at all frequencies less than $10^{-5}ms^{-2}Pa^{-1}$. For the range of sound pressures previously measured at Hemerdon, any induced groundborne vibration would be an order of magnitude lower than the threshold of human perception.

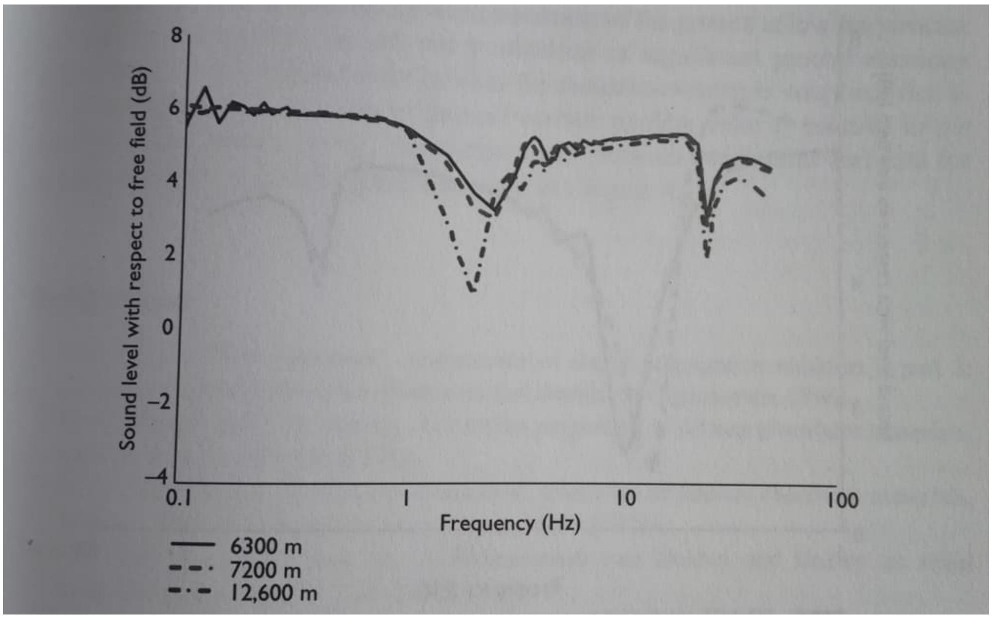


Figure AL-6: Ground attenuation spectra for various distance ranges, with assumed source height = 2.0m, receiver height = 1.0m and sound speed in air of 332m/s.

[24] Harrop, N D: *The Exploitation of Acoustic to Seismic Coupling for the Determination of Soil Properties*. PhD thesis. The Open University (2000). The results are presented in Attenborough, K; Li, K M; and Horoshenkov, K: *Predicting Outdoor Sound.* Taylor and Francis (2007).

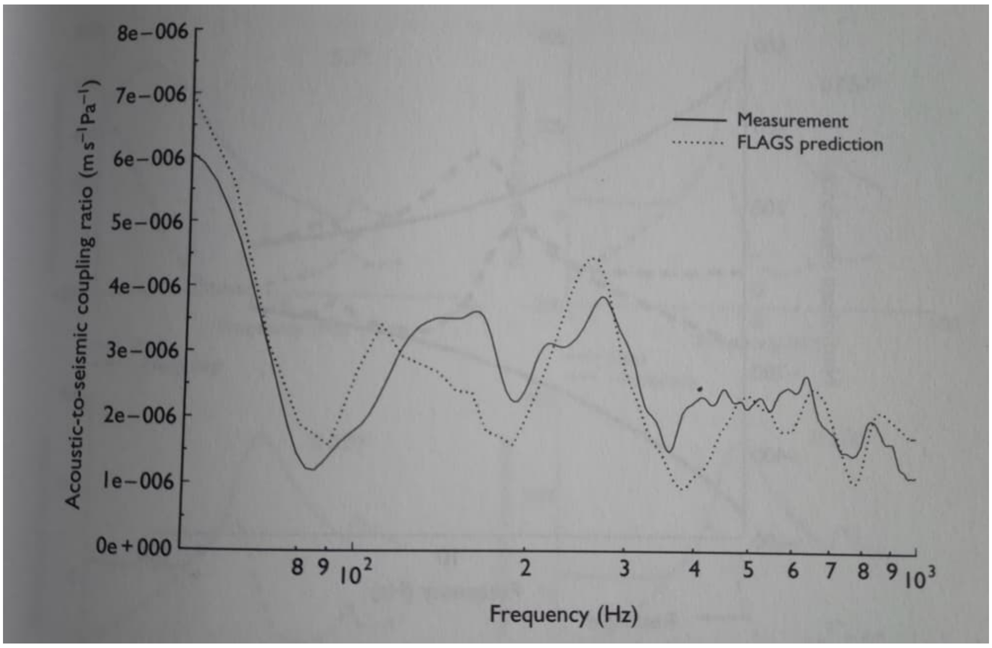


Figure AL-7: Measured and predicted acoustic to seismic coupling ratio for a layered soil.

To summarise, the available research on ground effects leads us to conclude that, at the low frequencies of concern at Hemerdon, the sound attenuation due to ground effects converges to a value of +6dB as experienced at the receptor location. In effect, this is an amplification and would be equivalent to perfectly constructive interference between the direct and reflected sound waves which could be modelled by assuming hemispherical propagation rather than spherical propagation. It is noted, however, that this analysis is based on an assumed simplified situation with flat ground (no intervening barriers or terrain) and neutral meteorological conditions. The influences of these effects, and how they might affect ground attenuation, are considered below.

Sound Propagation – Barrier Attenuation due to Ground Terrain / Topography

The calculation methods for sound barrier attenuation as contained within conventional sound propagation models such as ISO 9613-2 are largely based on the work of Maekawa[25]. However, the implementation of these barrier calculation methods assume that the methods are to be used for the audible frequency spectrum (63Hz and above in ISO 9613-2) associated with typical sources of environmental noise, and that the sound barriers in question are purpose designed barriers such as, for example, those used alongside roads and railways or around factories. It is widely recognised that in such circumstances the sound reduction performance of such barriers is very small at lower frequencies and that this is due to the fact that sound barriers will only be effective where the height / size of the sound barrier is greater than the wavelength of the sound to be attenuated. This is demonstrated in Figure AL-8 below, which is taken from the original paper by Maekawa. At 63Hz (the lower bounds of the ISO 9613-2 model), the wavelength is of the order of 5.4m, which will in

[25] Maekawa, Z: *Noise Reduction by Screens*. Applied Acoustics, 1, pp 157-173 (1968)

most circumstances be greater than the height of conventional purpose built noise barriers; hence the assumption that sound barriers will always be ineffective at low frequencies.

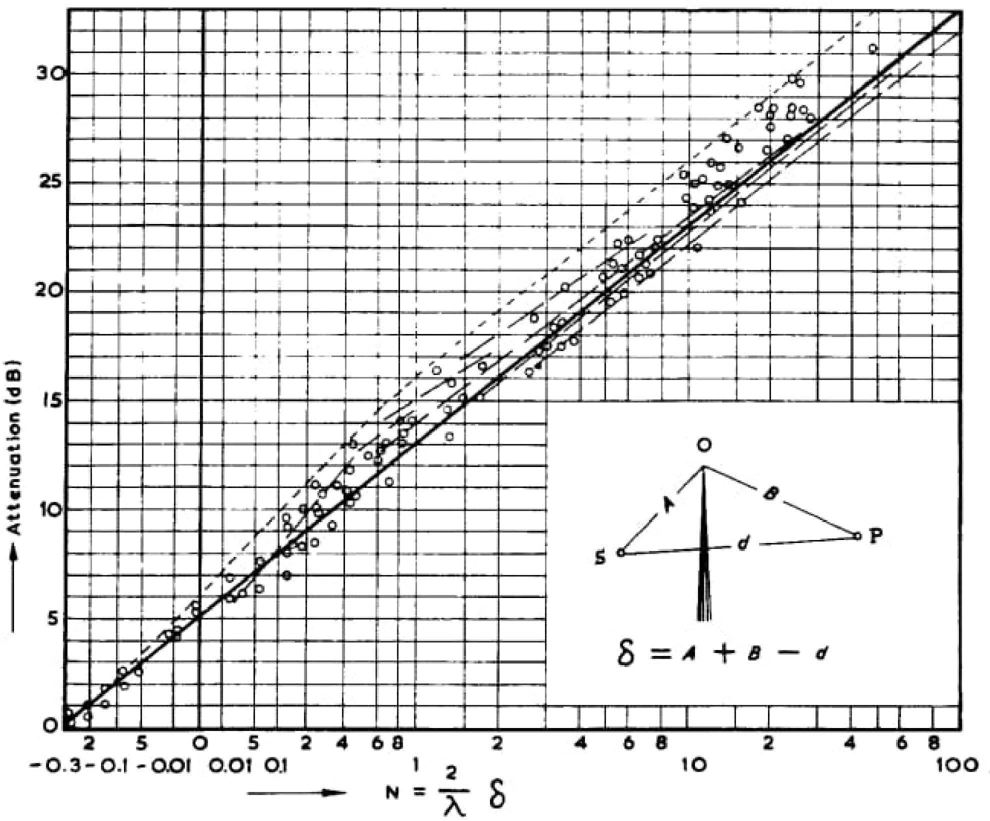


Figure AL-8: Sound attenuation by a semi-infinite screen in free space (from Maekawa – Ref 25)

However, Maekawa notes that the method would be equally applicable to situations where the sound barrier is not in the form of a purpose built 'thin wall', but instead is in the form of a thick barrier (e.g. a building) or in the form of a hillside, a deep cutting or even a mountain. In these situations, the barrier geometry shown in the inset to Figure AL-8 should be adapted as shown in Figure AL-9 below.

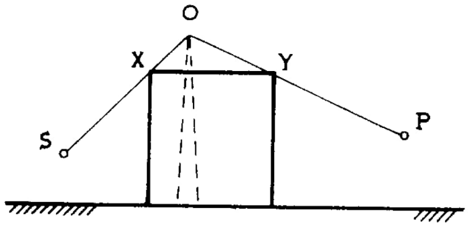


Fig. 14. Approximation of the banks or buildings to a thin wall.

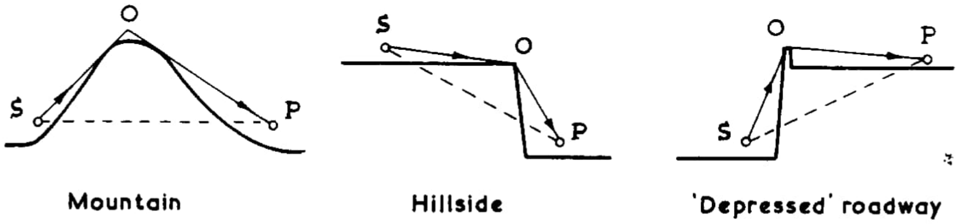


Fig. 15. Effective barriers for noise reduction between the source S and the receiver P.

Figure AL-9: Equivalent geometry for substantial (non-fence) sound barriers (original figures from Maekawa – Ref 25)

Subsequent investigations by Lam[26] have found that the approach adopted by Maekawa (that the coefficients used in Maekawa's equations for thin barriers can be adapted using the geometries shown in Figure AL-9 for 'thick' barriers) is adequate. Bies and Hansen[27] propose a slight amendment in the situation where the ground terrain includes more than one peak, as shown in Figure AL-10 below. In this situation, the geometry used by Maekawa (δ = A+B-d, as shown in the inset to Figure AL-8) is replaced by δ = A+B+C-d, as shown in Figure AL-10.

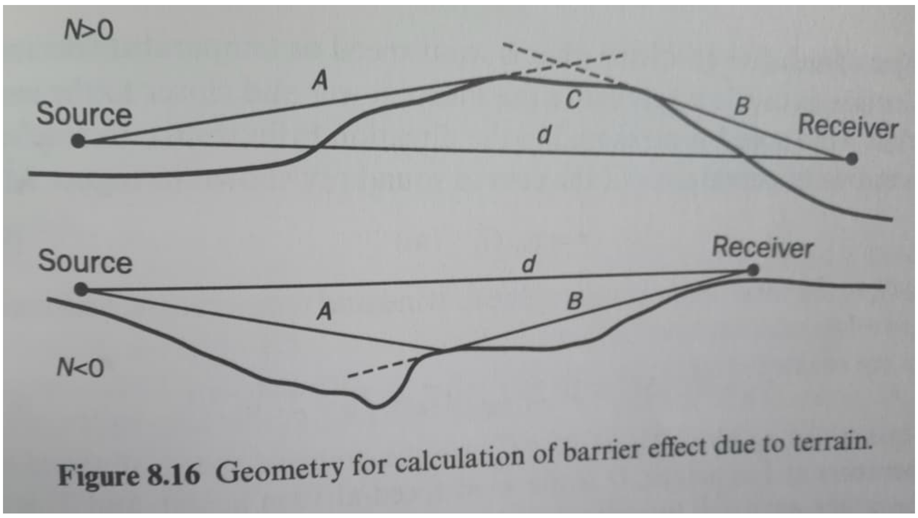


Figure AL-10: Geometry for calculation of barrier effects due to terrain (from Bies and Hansen)

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[26] Lam, Y W: *On The Modelling of the Effect of Ground Terrain Profile in Environmental Noise Calculations*. Applied Acoustics 42, pp 99-123 (1994)
[27] Bies, D A and Hansen, C A: *Engineering Noise Control - 2nd Edition*. E&FN Spon. 1996

Applying this to the situation at Hemerdon, the wavelengths of concern are of the order of 27m at 12.5Hz and 21m at 16Hz (the fundamental operating frequencies of the screens). Any obstacles in the propagation path of less than about 20 to 30m in height will therefore provide no significant attenuation of sound. However, any obstacles (hills) of greater than 20 to 30m in height (compared to the source – receiver line) might provide some useful attenuation of sound.

For the situation at Hemerdon, there are some receptor locations for which the intervening topography results in obstacles of greater than 20 to 30m in height compared to the source-receiver line. For example, the terrain between the source location at Hemerdon mine and the receptor (dwelling) to the east of Dartmoor Zoo includes a hill that extends to approximately 46 to 49m above the source-receiver line (the effective obstacle height is approximately 49m for a source height of 2.0m above local ground level at Hemerdon mine – appropriate for a screen at ground level – and 46m for a source height of 8.0m – appropriate for some of the screens within the process building). In this situation, outline calculations using the Maekawa method indicate an effective barrier attenuation of approximately 8dB at 12.5Hz and 9dB at 16Hz (for a source height of 2m) and a little lower for a source height of 8m. For other receptor locations, such as Galva House, the intervening terrain results in an obstacle of approximately 20m above the source-receiver line, which is of the same order as the wavelengths under consideration. In this situation, the calculated effective barrier attenuation reduces to approximately 5dB. For lesser obstacles and where there is a direct line of sight between source and receiver, the calculated attenuation rapidly approaches towards zero.

It should be noted that the above barrier effect calculations are simplified because:

- the Maekawa calculation method does not take into account phase changes upon diffraction at the 'barrier'. Other methods that can account for such phase changes are available, but would introduce a level of complication that would require a substantial academic study to understand and is unwarranted for the situation under consideration; and
- perhaps of more importance, the calculations assume neutral atmospheric / meteorological conditions. The influence of meteorological conditions is considered in further detail below.

Sound Propagation – Meteorological Effects

The two main meteorological effects that influence the propagation of sound are refraction due to wind speed and temperature gradients in the atmosphere and wind or temperature generated turbulence.

Atmospheric turbulence arises when moving air passes over obstacles or when small parcels of air become hotter or colder than their surroundings, leading to turbulent convection. These moving parcels of air are unstable, and break down into smaller parcels or eddies, which then break down into even smaller eddies. The dimensions of these eddies are similar to the wavelengths of sound in the audible spectrum[28], which leads to the diffraction of sound waves passing through the turbulent air. This in turn can result in the destruction of the phase relationships between different sound paths (which might occur, for example, between the direct and ground reflected sound paths – in the

[28] Embleton, T F W. *Review of Outdoor Sound Propagation - The Sound Field, Micrometeorology and Topography*. Proc. I.O.A. Vol11 Part 5 1989. Also presented in Acoustics Bulletin, July/August 1991.

case of ground effects – or the direct and refracted sound paths in the case of barrier attenuation). It is generally not possible to analyse these turbulence effects, and some authors (e.g. Daigle[29]) have claimed that attenuation due to atmospheric turbulence can be neglected in practice. Given that the potential diffraction of sound waves occurs when the dimensions of the eddies are similar to the wavelength of the sound, one would expect that at the low frequencies of interest at Hemerdon (wavelengths of 27m at 12.5Hz and 21m at 16Hz), diffraction effects would only occur at the higher altitudes where the dimensions of the eddies are higher (see Figure AL-11). On the basis that the effects of atmospheric turbulence are too complicated for a theoretical analysis and the effects are believed too small (and smaller still at the low frequencies of concern at Hemerdon), atmospheric turbulence is not considered further in the noise model.

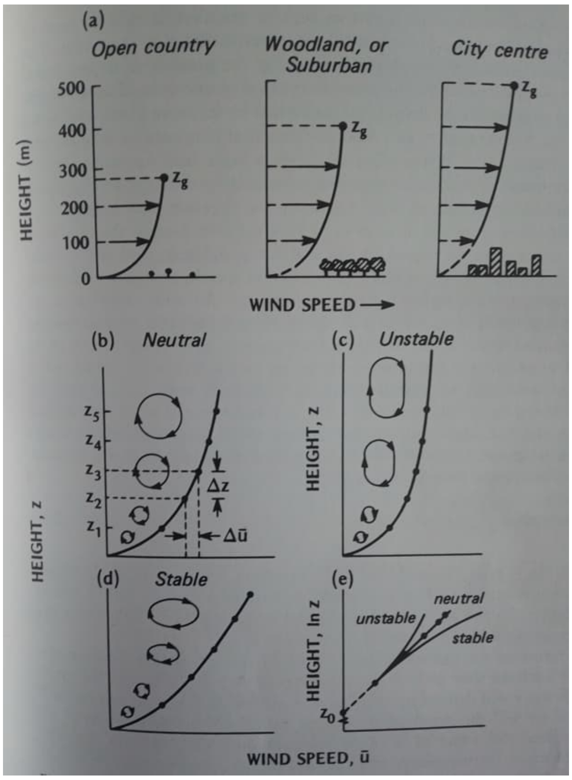

Figure AL-11: Wind speed profile near the ground: (a) effect of terrain roughness; (b) to (e) effect of atmospheric stability and eddy size / structure. In (e) the profiles of (b) to (d) are replotted on a natural logarithmic height scale. Figure taken from Oke[30] and based on data from Davenport[31] (a) and Thom[32] (b to e).

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[29] Daigle, G A. *Degradation of Various Types of Shadow Regions Due to Atmospheric Turbulence*. Proc. Internoise 83 pp259-262
[30] Oke, T R. *Boundary Layer Climates - 2nd Edition*. Routledge. 1987
[31] Davenport, A G. *The Relationship of Wind Structure to Wind Loading*. Proc Conf. Wind Effects on Structures, Symposium 16 Vol 1 pp53-102. HMSO (London) (1965)
[32] Thom, A S. *Momentum, Mass and Heat Exchange of Plant Communities*. In Monteith, J L (editor): *Vegetation and the Atmosphere – Volume 4: Principles* pp57-109. Academic Press (London) 1975.

Although the effects of atmospheric turbulence can usefully be neglected, the larger effects of refraction due to wind speed and temperature gradients needs to be considered.

Temperature gradients in the atmosphere arise from the process of convection, where parcels of air rise and fall according to the amount of thermal energy that the parcels contain relative to the surrounding air. This process is fuelled by a number of processes, including solar radiation, evaporation of surface water and saturation with water vapour (see Ref. 30). The temperature gradient in the atmosphere can be positive or negative, with negative gradients or temperature lapses (temperature decreasing with altitude) occurring on warm sunny days and positive temperature gradients or temperature inversions (temperature increasing with altitude) occurring on clear cloudless nights. It can be shown[33] that a temperature lapse in the atmosphere results in the upwards refraction of sound and that a temperature inversion results in downwards refraction (Figure AL-12 below).

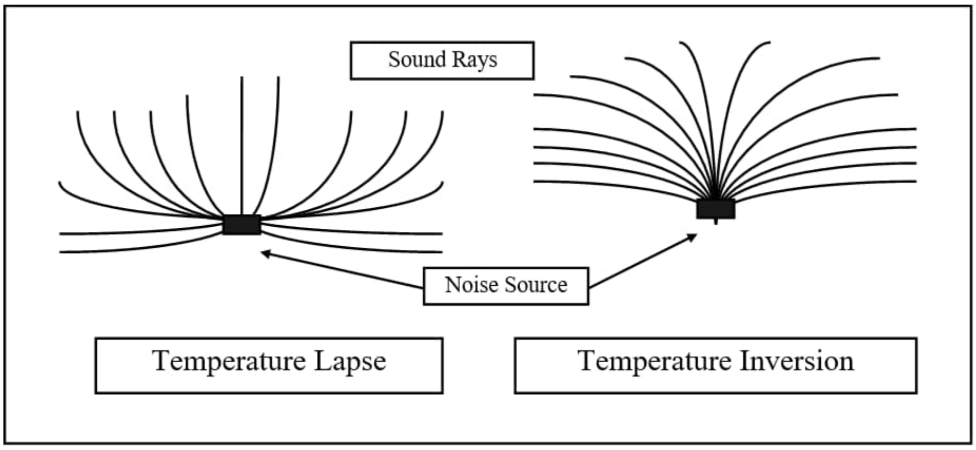


Figure AL-12: Effect of temperature gradients on sound propagation

Wind speed gradients in the atmosphere arise from frictional drag imposed on the air flow by the underlying surface. This frictional drag retards the motion of air close to the ground, which produces a sharp decrease in mean horizontal wind speed near the ground surface. The depth of this frictional layer depends on the roughness of the surface, and is typically of the order of 200 to 400 metres (see Ref. 30). It can again be shown (see Ref. 33) that wind speed gradients in the atmosphere lead to the refraction of sound, with the refraction being skywards upwind of the source and groundwards downwind of the source (Figure AL-13, below).

[33] Crocker, M J and Price, A J: *Noise and Noise Control* Vol. 1. CRC Press. 1975

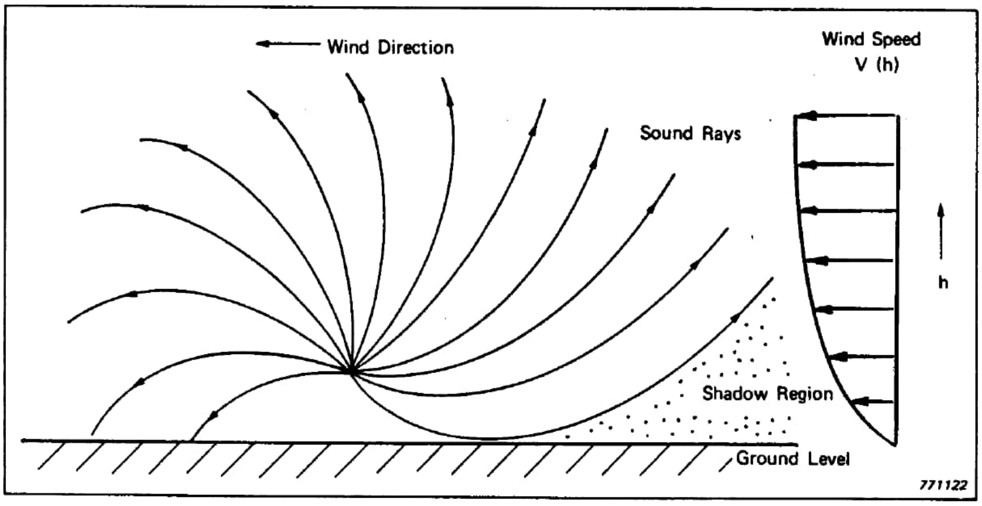


Figure AL-13: Effect of wind speed gradients on sound propagation

Wind and temperature gradients thus give rise to curved sound paths. These curved sound paths will, in turn, affect the propagation of sound in three ways;

- via modification of ground effects due to changes in the interaction of the direct and ground reflected sound paths caused by a change in the angle of reflection at the ground surface;
- via modification of barrier / screening effects due to the possibility of curved sound paths passing over the top of any barrier; and
- via possible focussing or 'lensing' effects resulting in higher sound levels downwind (or under a temperature inversion) and the creation of 'shadow zones' upwind or under temperature lapse conditions.

The interaction of direct and ground-reflected sound paths in the presence of wind or temperature gradients is shown in Figure AL-14 below. The situation in the absence of wind or temperature gradients is also shown for comparison.

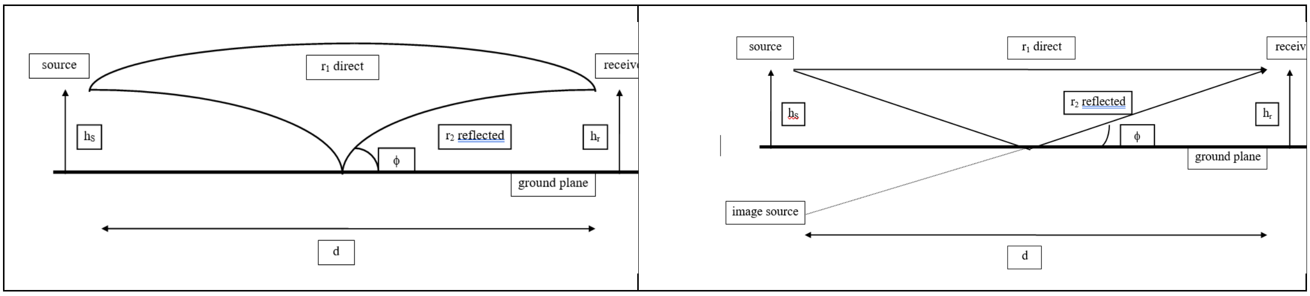


Figure AL-14: Interaction of direct and ground-reflected sound paths in the presence of (left) and absence of (right) wind or temperature gradients

In the situation with wind or temperature gradients the angle of incidence, ϕ, becomes greater, which changes the interference pattern between the direct and reflected sound paths at the receiver, resulting in a reduction of ground effects (both attenuation and amplification). As such, the effects of wind and temperature gradients result in ground attenuation effects being irrelevant at the low frequencies under consideration.

With regard to the effect of wind and temperature gradients on the sound attenuation that can be provided by sound barriers, Bies and Hansen (see Ref. 27) have detailed an approximate method, based on the work of Tonin[34], that takes into account the wind speed and temperature gradients in the atmosphere. In this model, the effect of the wind speed / temperature gradient, taken to be a downward refraction from source to receiver (i.e. downwind or under temperature inversion conditions), is assumed to be to increase the effective height of the noise source to a position on the tangent to the actual curved sound path extrapolated from the top of the barrier (see Figure AL-15, below).

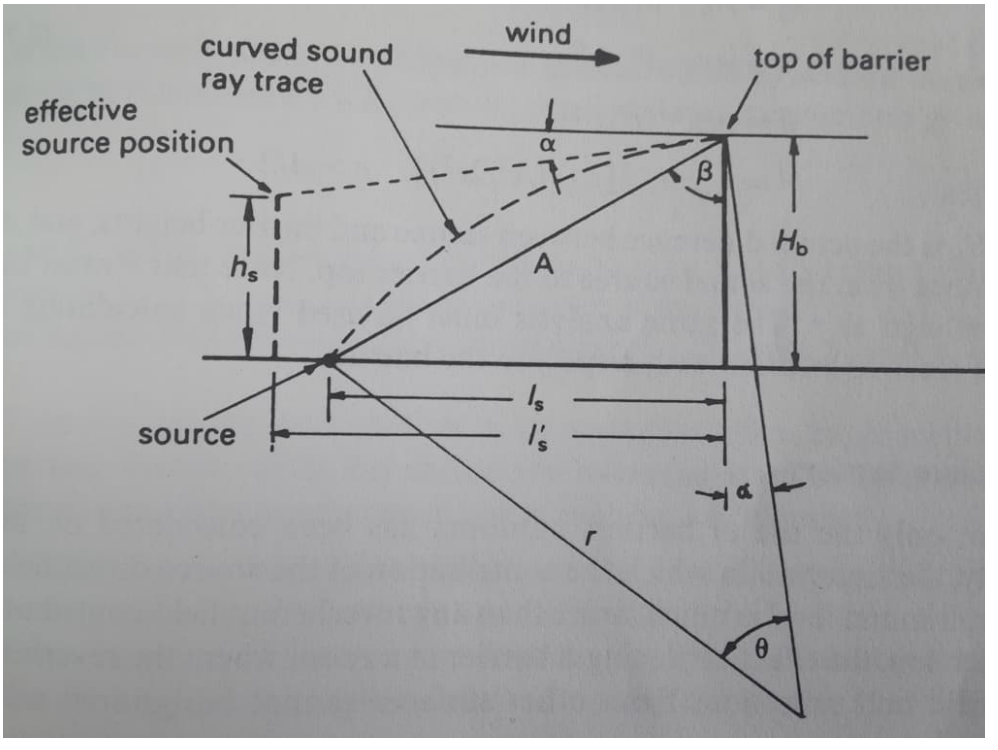


Figure AL-15: Geometry for locating the effective source position, assuming a positive vertical sonic gradient (from ref. 27)

The radius of curvature of the curved sound path is then calculated from the known information about the wind speed and temperature gradients, and the new effective source height determined through simple geometry. Of course, this procedure is only of use if the temperature and wind speed gradients are known; Bies and Hanson provide a method for calculating the curvature of the sound path based on wind speed and temperature measurements undertaken at two heights. The geometry shown in Figure AL-15, which demonstrates the calculation of an effective source position on one side of the barrier also needs to be applied to calculate an effective receiver position on the other side of the barrier.

Using the geometry shown in Figure AL-15:

The radius of curvature, r, of the curved sound ray is given by:

[34] Tonin, R: *Estimating Noise Levels from Petrochemical Complexes, Mines and Industrial Complexes*. Acoustics Australia 13 pp59-67. 1985

$r = c_0 / G_s$

where c_0 is the ambient speed of sound at a height of 1m above ground level and G_s is the total sonic gradient due to wind and temperature, given by:

$G_s = 0.015\ U + 10.29\ T_g\ (10\ T_g + T_0 + 273)^{-0.5}$

where U is the wind speed at 10m height, T_0 is the ambient temperature at 1m height, and T_g is the temperature gradient (in ^{o}C per m altitude, positive upwards). If r is positive, then the sound rays are curved downwards resulting in less attenuation.

The effective source position in the presence of downward refracting wind / temperature gradients is characterised by l'_s (the effective horizontal distance of the source from the barrier) and h_s (the increase in height of the effective source above the actual source), calculated from:

$l'_s = |r|\ \theta \cos \alpha$

$h_s = H_b - |r|\ \theta \sin \alpha$

$\alpha = 0.5\ (\pi - \theta) - \beta$

$\beta = \cos^{-1} (H_b / A)$

$\theta = \pm \cos^{-1} [1-(A^2 / 2r^2)],\ \ r > A/2$

H_b = actual difference between source and barrier heights

A = distance from actual source to the barrier top.

Applying this to the situation considered above (for the receptor locations at Galva House and the dwelling East of Dartmoor Zoo), a component wind speed of just 3.65m/s (equivalent to 8mph approx.) between the source and Galva House would result in an increase in the effective source position that would negate any attenuation due to barrier / topographical effects. For the dwelling east of Dartmoor Zoo, any barrier effects would be removed with a component wind speed of more than 7.6m/s.

In summary, it can be concluded that any attenuation resulting from barrier effects due to the intervening topography between source and receiver will be negligible in situations where the receiver is downwind of the source. The same will apply under conditions where there is a significant temperature inversion.

The analysis of possible focussing or 'lensing' effects and the creation of 'shadow zones' due to wind and temperature gradients is more difficult. The methods available to calculate such effects range from relatively simplified geometrical models through to extremely complicated methods requiring extensive computation effort, achievable only via the creation of computerised numerical models. However, all of the models require knowledge of, or estimation of, properties of the soil and ground cover that are not easy to obtain.

The calculation of the sonic gradient presented above for the estimation of the change in effective source height to be used in noise barrier calculations is specific to the geometry presented in Figure

AL-15. Bies and Hanson[35] have presented a more generalised model for the calculation of sonic gradients and radius of curvature for the sound paths, as follows:

Radius of curvature = c_0 [dc/dh]$^{-1}$

where c_0 is the speed of sound at sea level and 0ºC (331m/s) and [dc/dh] is the sound speed gradient at height h.

The sound speed gradient is given by:

[dc/dh] = [dc_{temp}/dh] + dU/dh

where dc_{temp}/dh is the sound speed gradient due to temperature effects and dU/dh is the wind speed gradient.

dct_{emp}/dh = 10 [dT/dh] [T_0 + 273]$^{-0.5}$

where T_0 is the temperature at 1m height (^{0}C) and dT/dh is the temperature gradient, which can be obtained from measurements at any 2 heights (the model assumes that the temperature gradient is linear).

dU/dh = ξ [U_{10m} / h]

where U_{10m} is the component wind speed at 10m height, and ξ is an empirically derived constant, depending on ground type, as follows:

Type of ground surface	ξ
Very smooth (mud flats, ice)	0.08
Snow over short grass	0.11
Swampy plain	0.12
Sea	0.12
Lawn grass, 1 cm high	0.13
Desert	0.14
Snow cover	0.16
Thin grass, 10 cm high	0.19
Air field	0.21
Thick grass, 10 cm high	0.24
Country side with hedges	0.29
Thin grass, 50 cm high	0.36
Beet field	0.42
Thick grass, 50 cm high	0.43
Grain field	0.52

Table AL-2: Values of the empirical constant ξ (from Bies and Hansen, ref 35).

Application of this model requires meteorological data which could be estimated from the data gathered by the on-site meteorological station at Hemerdon (the specific heights of the anemometer

[35] Bies, D A and Hansen C H: *Engineering Noise Control - Theory and Practice – 4th Edition*. Spon Press. 2009. (Note that this is different to ref. 13.)

and thermometer of the meteorological station at Hemerdon is different to the heights specified in the prediction model, so the model parameters would have to be estimated from the available data). Application of the model would also require a choice of assumption regarding the constant ξ. From the data presented in Table AL-2, this might be chosen to be somewhere in the range 0.2 to 0.3. The choice of parameters would, of course, introduce an element of uncertainty in any predictions.

Uncertainties regarding the influence of the type of ground cover is emphasised in an alternative model for predicting the wind speed profile as given by Oke (ref. 30). In this model, the mean wind speed U at height h is given by:

$U = [U_* / k] \, Log_e \, (h/h_0)$ where:

U_* is defined as a '*friction velocity*' (in m/s) which is dependent on soil conditions / ground cover

k is a constant (von Karman's constant, approximately equal to 0.40)

h_0 is defined as a '*roughness length*' (in m), which is also dependent on soil conditions / ground cover

The wind speed gradient is then calculated from the derivative of the above, and the radius of curvature calculated from that.

Tabulated values for h_0 are presented by Oke, as shown in the table below (the table refers to this parameter as z_0).

Surface	Remarks	z_0 Roughness length (m)
Water†	Still – open sea	$0{\cdot}1–10{\cdot}0 \times 10^{-5}$
Ice	Smooth	$0{\cdot}1 \times 10^{-4}$
Snow		$0{\cdot}5–10{\cdot}0 \times 10^{-4}$
Sand, desert		0·0003
Soils		0·001–0·01
Grass†	0·02–0·1 m	0·003–0·01
	0·25–1·0 m	0·04–0·10
Agricultural crops†		0·04–0·20
Orchards†		0·5–1·0
Forests†	Deciduous	1·0–6·0
	Coniferous	1·0–6·0

Table AL-3: Values of the empirical constant h_0 (z_0) (from Oke, ref 30).

A range of values for the constant U_* are given in a paper by Klug[36], which quoted values of U_* between 0.22m/s and 0.46m/s.

When considering the above, it should be noted that the range of values quoted, especially for the parameter h_0, can cover a wide range (more than an order of magnitude in the case of h_0). Calculations using these methods could therefore be subject to a wide range of uncertainty. For the purposes of predicting the impact of such effects at Hemerdon, it will be necessary to include this in the potential uncertainties, with the scale of the potential uncertainty based on worst case assumptions in the choice of the parameters detailed above.

As an aside, example calculation results presented by Klug are presented in Figure AL-16, which demonstrates the complex effects of sound focussing at locations along the propagation path.

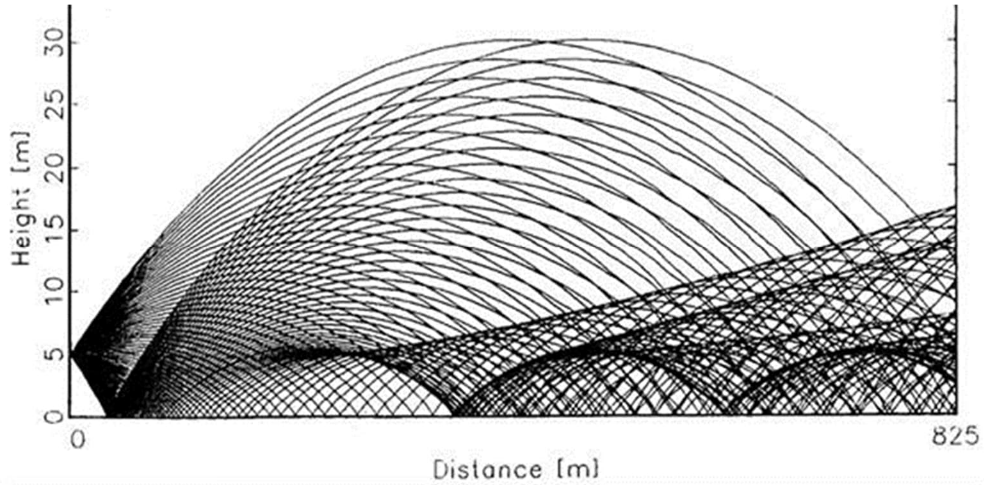


Figure AL-16: Example calculations showing the effects of sonic gradients (from ref. 36)

Predicting External Low Frequency Sound at the Receptor Locations

Following the outcomes of the review detailed above, the low frequency sound propagation model used to predict impacts from the operation of Tungsten West assumes:

- Source characterisation based on the ‘characteristic pressure’, $p_{sc}(t)$, taking into account the measurement data obtained from the on site mitigation trials.
- The effects of atmospheric absorption are negligible and are excluded for the sound prediction model.
- The effects of wind and temperature gradients result in negligible ground attenuation effects. Such effects are excluded from the prediction model.
- Similarly, any barrier or screening effects due to the intervening terrain will be negated by wind and temperature gradients and, as a worst case, are excluded from the model.
- Other meteorological effects such as sound focussing will occur under certain weather conditions, but when such conditions prevail, the effects could be significant. This is considered within the

[36] Klug, H: *Meteorological Effects on Long Range Outdoor Sound Propagation*, NASA report no 19910007383 (1991)

uncertainties in the prediction model. Quantification of these uncertainties requires further research. Calculations are undertaken for the situation with neutral meteorological conditions.

PART 2: THE LOW FREQUENCY SOUND PROPAGATION MODEL

The model and the modelling software has been developed by Eatec Dynamics. The software and the calculation algorithms used in the software are detailed below.

MAPPING LFN

The LFN mapping model is divided into 4 parts:

1. Characterising a source
2. Transmission into the environment
3. Combining sources
4. Assessing the effect at a receptor location

Characterising a source

For most sources of noise, the strength of the source is provided by the sound power and there are internationally recognised procedures for measurement. The method would be difficult to use for a screen and so a different strength term has been developed for this application.

Screen decks oscillate sinusoidally with a surface velocity of $v \times sin(2\pi f t)$ m/s where f is the screen running frequency in Hz. If the deck surface was solid, the pressure generated at the screen deck is given by the fundamental acoustic relationship:

$$p(t) = zv(t)$$

Where $p(t)$ is the air pressure as a function of time in Pa and z is the specific acoustic impedance of air in rayls. This has a value of 415 rayls at room temperature and 1 atmosphere of pressure.

A processing screen has a porous surface and there will be other leaks so that the generated pressure will be lower. This can be incorporated using the factor ρ (the acoustic efficiency) in the equation:

$$p(t) = \rho zv(t$$

The far-field pressure will depend on the total area of the vibrating surface (A m^2). For each doubling of distance away from the source, the pressure drops by 6 dB. To characterise a specific source, the pressure at a hypothetical distance of 1 m can be calculated by applying the factor $\frac{A}{4\pi \times 1}$. The characteristic pressure is then denoted as $p_{sc}(t)$

$$p_{sc}(t) = \frac{\rho A z v(t)}{4\pi}$$

To determine this value by experiment, the pressure close to the screen deck is measured. It is not practicable to have the microphone at the deck surface, so for all tests, a standard distance of 1 m above the centre of the deck was used. A simultaneous measurement of surface velocity was made using an accelerometer. This allows the acoustic efficiency term, ρ, to be calculated and using the deck area, the characteristic pressure can be determined. The characteristic pressure allows the ranking of different screens in terms of low frequency sound output.

This approach to assessing the strength of the source applies to changes in screen decks, underpan venting and active noise cancellation.

Source mitigation

If the source is mitigated in some way, for example by using an enclosure, the mitigation factor must first be evaluated by test or theory.

If the reduction obtained is R dB, then the characteristic pressure becomes:

$$p_{sc}(t) = \frac{\rho Azv(t)}{4\pi} \times 10^{\frac{-R}{20}}$$

Transmission into the environment

The mapping model of the surrounding environment extends far enough that the screen can be considered as a point source. The intensity of the pressure will reduce as the square of the distance between the source and the point of calculation so that the pressure reduces linearly with distance. In addition, the phase of the waveform relative to the source will change with distance from the source. This gives the pressure waveform at a receptor location, distance r from the source of $p_r(t,r)$ where:

$$p_r(t,r) = \frac{\rho Azv \times sin(2\pi ft - \alpha r)}{4\pi r}$$

A phase change of 2π will take one wavelength, λ. The speed of sound in air, c, relates the frequency to the wavelength as: $\lambda = \frac{c}{f}$, so when $r = \lambda$, $\alpha r = 2\pi$ giving $\alpha = \frac{2\pi f}{c}$.

The pressure waveform is thus:

$$p_r(t,r) = \frac{\rho Azv \times sin\left(2\pi ft - \frac{2\pi fr}{c}\right)}{4\pi r}$$

Combining sources

Individual pressure waveforms will combine in a linear manner at any receptor point. The parameters that characterise each source will vary and will have an additional variable which is the phase at time zero, ϕ. An expression for the total pressure at any point, at any time from n sources is given by $\widehat{p_r}(t,r)$:

$$\widehat{p_r}(t,r) = \sum_{i=1}^{n} \frac{\rho_i A_i z v_i \times sin\left(2\pi f_i t - \frac{2\pi f_i r}{c} + \phi_i\right)}{4\pi r}$$

Assessing the effect at a receptor location

The expression above gives a pressure waveform as could be measured by a microphone. The time history could be processed to give any of the standard outputs that an instrument could measure. A sufficient length of time would have to be analysed to give maximum levels and fluctuations, and if this is to be carried out for many mapping positions, there is a significant computational overhead. It is possible to obtain a more efficient result for the extreme values by noting that at some point in time, all pressure contributions will be in phase to give the maximum level and at another time, the combinations will be such that the pressure level is a minimum. Obtaining the maximum is straightforward:

$$(\widehat{p_r})_{max}(t,r) = \sum_{i=1}^{n} \frac{\rho_i A_i z v_i}{4\pi r}$$

Calculating the minimum absolute pressure is not so straightforward because the phase differences cannot be assumed in the calculation. For an approximation, if it is assumed that the phase is either zero or π, the summation of pressure values will have 2^{n-1} possible combinations and finding the minimum of these is computationally efficient.

For an exact result, the time series of the total absolute pressure must be evaluated for a sufficient time period to extract the minimum.

THE MODELLING SOFTWARE

Defining the sources

The individual screen sources are identified in an Excel spreadsheet with the format as described in the example below:

All screens running	Easting	Northing	Screen rpm	Stroke (mm)	Vibrating Area (m^2)	Phase (degrees)	Acoustic Efficiency	Active Noise Control (Pa)	Enclosure mitigation (dB)
140-SN-01 DMS Feed Preparation Screen	56899.9	58963.9	936.12	6.98	11.52	0	0.30	0	11
140-SN-06 Secondary DMS Screen	56912.2	58956.7	1000.8	3.96	8.64	0	0.30	0	11
140-SN-07 Scavenger DMS Screen	56914.9	58958.6	990.96	3.76	8.64	0	0.30	0	11
150-SN-01 Primary Mill Sizing Screen	56920.3	58955.8	948.54	6.57	9	0	0.30	0	11
110-SN-01 Secondary Crusher Scalping Screen	257124	59103.8	738	15	18	0	0.30	0	11
120-SN-11 Ore Sorter Sizing Screen	257058	58979.4	738	15	14	0	0.30	0	11
125-SN-01 Pebble Ore Sorter 1 Dewatering Scree	257041	59019.9	960	10	3.6	0	0.30	0	11
125-SN-02 Pebble Ore Sorter 2 Dewatering Scree	257037	59017.9	960	10	3.6	0	0.30	0	11
125-SN-03 Pebble Ore Sorter 3 Dewatering Scree	257034	59016.6	960	10	3.6	0	0.30	0	11
125-SN-04 Pebble Ore Sorter 4 Dewatering Scree	257029	59014.7	960	10	3.6	0	0.30	0	11
130-SN-12 Tertiary Crusher Sizing Screen	256958	58926.4	740	8.5	18	0	0.30	0	11
130-SN-13 Tertiary Crusher Deatering Screen	257014	58965.7	740	15	18	0	0.30	0	11

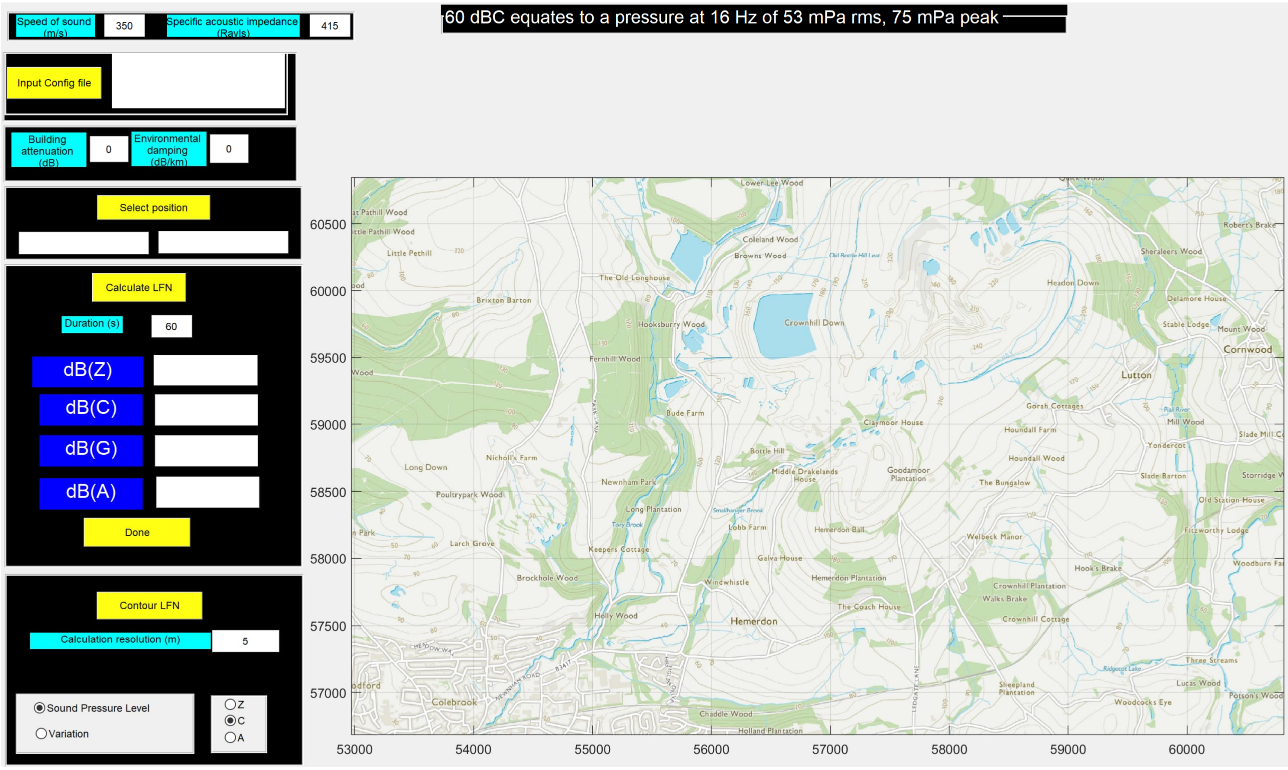
The first row is a title row and does not contain data used in the calculation.

The subsequent rows give the operating parameters for each screen.

Column 1	Identifier for the screen.
Easting	Easting coordinate for the screen centre.
Northing	Northing coordinate for the screen centre.
Screen rpm	Running speed of the screen.
Stroke	Peak to peak displacement of the screen in mm.
Vibrating area	Area of the vibrating deck in m^2.
Phase	Phase of the screen at time zero in degrees.
Acoustic Efficiency	Measure of the radiation efficiency of the screen (between 0 and 1).
Active Noise Control	Peak pressure developed by the ANC loudspeaker in Pa.
Enclosure mitigation	Mitigation provided by the enclosure in dB

Running the application

Starting the application gives the following screen:



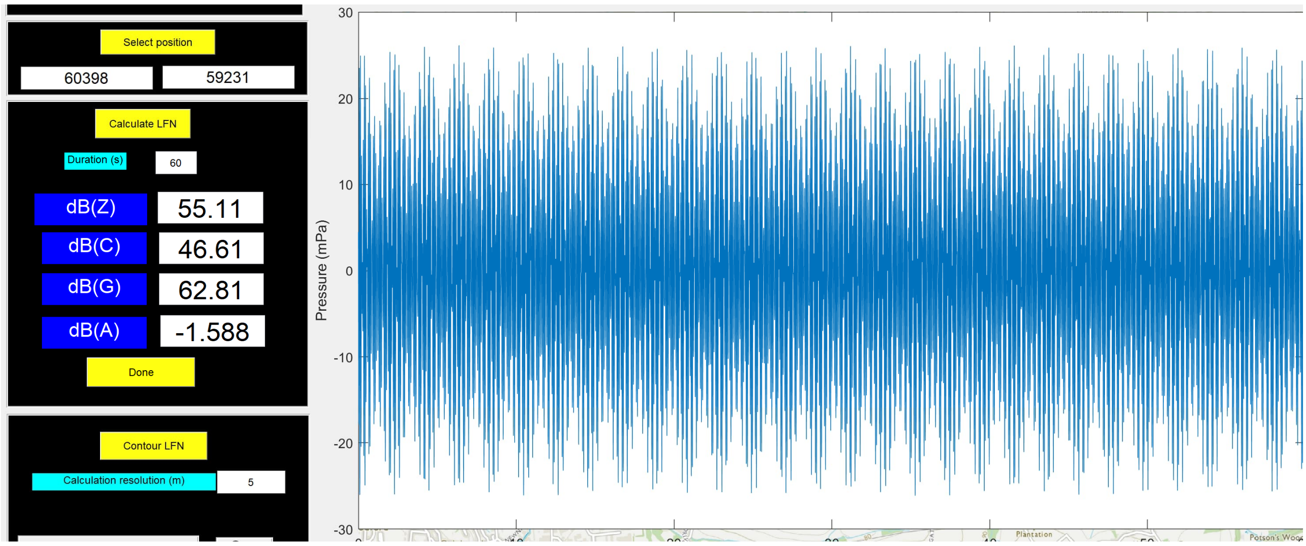
Certain parameters can be varied for the calculation:

Speed of sound	Default 350 m/s.
Specific acoustic impedance	Default 415 Rayls.
Building attenuation	Loss caused by the building walls; default 0 dB.
Environmental damping	Loss in the environment; default 0 dB/km.
Duration	Length of time for calculated waveforms; default 60 s.
Calculation resolution	Pressure values calculated at this resolution; default 5 m.

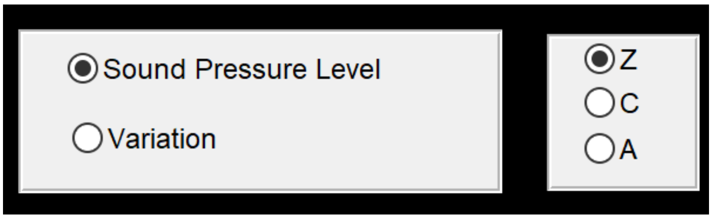
The configuration to be analysed is selected by pressing the *Input Config file* button and navigating to the required file. There are then two options: calculating the waveform at a specified location or plotting SPL contours across the map.

Calculating waveforms and contours

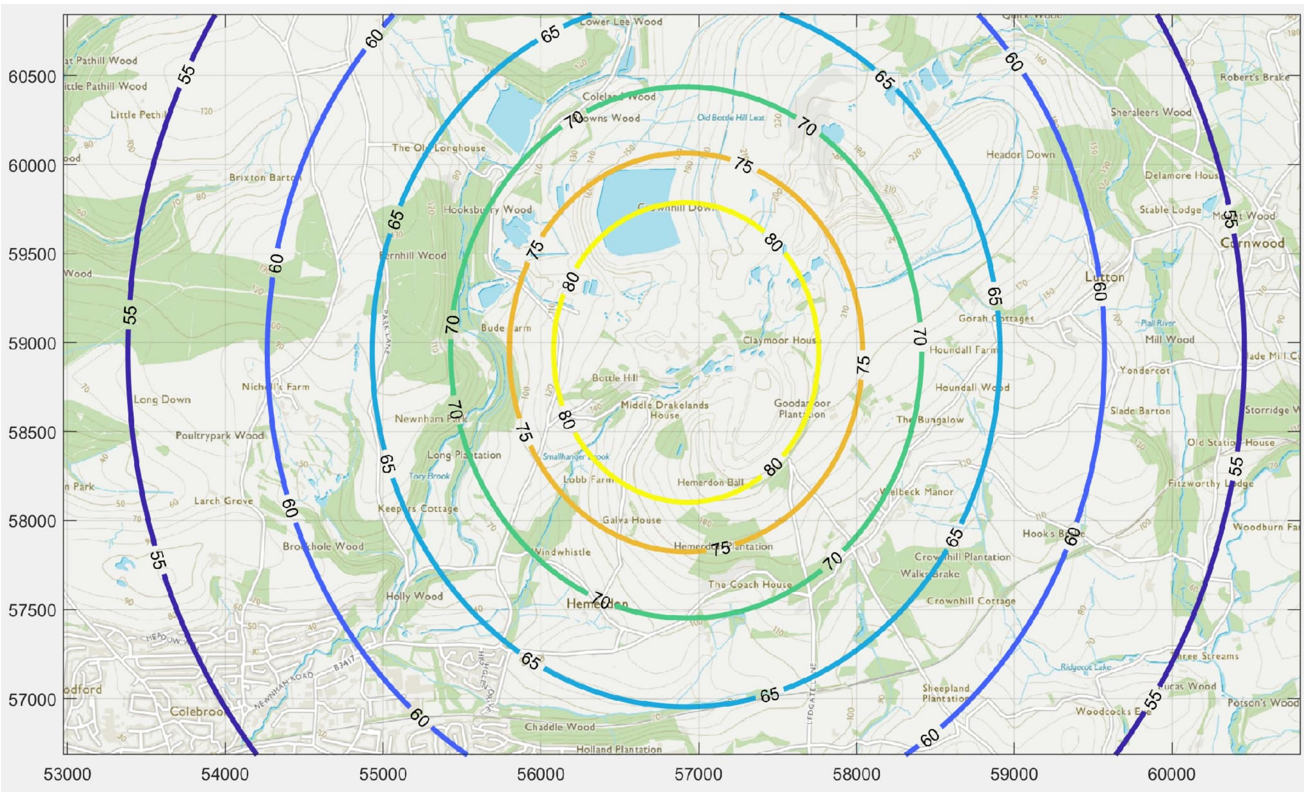
Waveforms for any receptor location can be calculated by entering values for the Easting and Northing for the position of interest in the boxes below *Select position* and pressing *Calculate LFN*. The pressure time history is displayed for the duration specified. The dB(Z), dB(C), dB(G), and dB(A) values are also given.



Contours can be calculated by first selecting the type of contour required:



Sound Pressure Level is the magnitude of the pressure and Variation is the difference between the highest and lowest levels over time. An example Sound Pressure Level Contour is shown below:



Appendix M

DESCRIPTION OF SCREENS

TECHNICAL NOTE

Attention: ESG Manager, General Manager

CC: Technical Services Manager

From: Phil Hingston

Date: 10th August 2023

Re: Description of Screening Units

Introduction

This document sets out to provide an overview of the screening units that will be operated under the new Tungsten West (TW) operational plan.

The screen descriptions will be listed in order of process flow.

Screening Units

115-SN-02 Secondary Crusher Sizing Screen

Phase 1

Description

Screen is positioned in a close circuit configuration with the secondary crusher to produce <80mm product ahead of ore sorting.

Dimensions

10° inclined 2.0m x 6.0m deck with an 80mm aperture and throughputs of 829 and 896tph for years 1 and 2 respectively.

Operation

Primary jaw crushed material (nominally <150mm) will feed onto the screening deck with the undersize passing to coarse ore stockpile via conveyor. The oversize falls off the end of the screen directly into the cone crusher with the crushed material returned to the screen.

The bulk of the screening separation will be at the feed end of the deck, in the first quarter to a third of the deck where the finest material will be screened. The final three-quarters to two-thirds of the deck will be coarse material that is greater than 80mm or near size particles that need to bounce into the correct orientation to pass through the deck. This area of the screen would have considerable voidage between the particles as they are coarse and with the Hemerdon ore its impossible for the particles once crushed to lock together to form a slab covering the entire screening deck. This is due to the edges of the particles being rough from to the crushing process and will always leave voids between them.

Phase 2

As above but duplicated with expected throughputs of 641tph per deck.

125-SN-11 Ore Sorter Sizing Screen

Description

Separating the secondary crushed product into the ore sorter feed products (-80+30mm, -30+10mm and -10mm).

Dimensions

5° inclined 2.4m x 5.5m deck with a top deck aperture of 30mm and a lower deck aperture of 10mm. Throughputs of 351 tph for Phase 1 and 500tph for Phase 2.

Operation

The ore will be fed to the screen via a conveyor where the +30mm material will be retained on the top deck and the -30+10mm material retained on the bottom deck. The -10mm will be washed through the bottom deck and pumped to the tertiary crusher dewatering screen.

Due to the size of the aperture, there would be minimal risk of any water pooling creating a "chute" like situation. Both decks would see the majority of the screening being conducted at the feed end of the screen, with the near and oversize working their way down the final two-thirds / three-quarters of the deck with considerable voidage between the particles.

125-SN-01/06 Ore Sorter Dewatering Screens

Phase 1

Description

These screens remove the final inherent moisture on the surface of the rocks from the ore sorter feed streams.

Dimensions

Horizontal 1.2m x 3.0m deck with a 4mm aperture with Pebble feed rates of 46.5tph (year 1) and 47.5tph (year 2), and Cobble feed rates of 72tph (year 1) and 90tph (year 2).

Operation

These screens will be fed via individual conveyors drawing from the respective cobble and pebble feed bins, with the rate controlled by a weightometer. As the screens are purely for dewatering and there are limited fines and no additional water, there will be always gaps between particles whilst on the screen decks.

Phase 2

As above with 2 additional screens, 1 each for cobble and pebble, with tonnages of 45tph for Pebble and 85tph for Cobble per unit.

130-SN-12 Tertiary Crusher Dewatering Screen

Description

This screen removes the -0.8mm fines feed component of the feed material and pumps the fines to the pre-existing fines tank. Oversize feeds the closed-circuit tertiary crushing circuit.

Dimensions

Horizontal 3.0m x 6.0m deck with a 0.8mm aperture with throughputs of 137tph for year 1, 134tph for year 2 and 183tph for year 3>.

Operation

The -10mm bypass material from the ore sorter sizing screen will be joined by the ore sorter accepts (concentrate). The very fine material, predominately the clays and sand will be washed through with the majority of the water at the front of the screen where a risk of pooling could be expected. At the discharge end of the screen there will be a wide range of material from 80mm to 0.8mm with minimal water and no risk of the deck acting like a chute.

130-SN-13 Tertiary Crusher Sizing Screen

Description

This screen is positioned in the tertiary crusher closed circuit producing an 8mm DMS feedstock.

Dimensions

10° inclined 3.0m x 6.0m deck with an 8mm aperture with Pebble feed rates of 209tph (year 1), 279tph (year 2) and 444tph (year 3>).

Operation

The screen is fed by a combination of the tertiary dewatering screen oversize and the tertiary crusher discharge. The tertiary crushers crush down the +8mm from the tertiary crusher sizing screen. The bulk of the separation will be at the front of the screen where the finer material will be removed quickly from the deck, with the near size material working its way down the screen before reaching the correct orientation to pass through the apertures. As the material moves down the deck and more -8mm material is removed the amount of voidage in the bed increases.

140-SN-01: Dense Media Preparation Screen

Description

The DMS preparation (prep) screen is a pre-existing screen inherited from the Wolf Minerals Ltd (Wolf) operation. The screen removes any fines that have been generated by the tertiary crusher ahead of mixing with the media for dense media separation.

Dimensions

Horizontal 2.46 x 4.876m deck with an 0.8mm aperture with feed rates of 103.5tph (year 1), 112.2tph (year 2) and 160.0tph (year 3>)

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Operation

The screen will be modified from Wolf operation where the central divider will be removed as only one Primary DMS will be used in Phase 2 and this is surplus to requirements. Under Wolf this screen was designed to take c. 400tph split into 2 x 200tph lots for each Primary DMS module. The proposed peak tonnage under TW is 160tph, some 40% of the original design tonnage, significantly reducing the loading on the screen and allowing for a wider spread of material, decreasing the bed depth and increasing the voiding.

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140-SN-02/03 Primary Dense Media Sinks Screens

Description

These screens are also inherited from Wolf and will only be used in Phase 2. These screens are used to recover the dense media from the sinks / concentrate from the dense media cyclones. Due to the new operating parameters, only one of the two screens will be operating at any one time.

Dimensions

Horizontal 2.4 x 4.8m deck a 0.8mm aperture with feed rates of 12.1tph (year 3>).

Operation

The cyclone discharges the concentrate from the underflow of the cyclone with some of the dense media slurry. This material flows down a set of static screens (with no moving parts) to recover as much of the media at the correct density as possible. The vibrating screen then washes the remainder of the media from the particles. As the tonnages are so low for this size of screen, there is copious amount of voidage and no risk of pooling of any water.

140-SN-04/05 Primary Dense Media Floats Screens

Description

These screens will be replaced with new Vibramech screens and will only be used in Phase 2. As with 14-SN-02/03, these screens are used to recover the dense media albeit from the floats / tailings from the dense media cyclones. Due to the new operating parameters, only one of the two screens will be operating at any one time.

Dimensions

Banana shaped with 3.6m x 7.3m deck with an 0.8mm aperture with feed rates of 117.2tph (year 3>).

Operation

The cyclone discharges the tailings / floats from the overflow of the cyclone with some of the dense media slurry. This material flows down a set of static screens (with no moving parts) to recover as much of the media at the correct density as possible. The vibrating screen then washes the remainder of the media from the particles.

As there are limited fines in this material and the wash bars deliberately cause turbulence to turn the particles to assist with the media recovery, there is a considerable amount of voidage on that deck.

140-SN-06 Secondary Dense Media Floats and Sinks Screen

Description

These screens are also inherited from Wolf and will be used in both Phase 1 and Phase 2 albeit with different duties. Under Phase 1 the secondary DMS circuit will act in a primary DMS capacity, before reverting to a secondary duty in Phase 2. As with 140-SN-02/03/04/05 these are designed to recover the dense media back into circuit. This screen is equipped with a divider, with one third allocated to the sinks and the two thirds for the floats.

Dimensions

Horizontal 1.8m x 4.8m deck a 0.8mm aperture with floats rates of 81.2tph in year 1 and 81.0tph in year 2 over the two thirds of the deck. The equivalent sinks tonnages on the one third side of the screen are 9.1tph and 9.9tph respectively for years 1 and 2. The tonnages under phase 2 are 1.0tph of sinks and 11.1tph of floats.

Operation

The cyclone products will both drop onto the one divided screen for media recovery. The initial part of the screen will use wedge wire screen panels to maximise the recovery of the media at the correct density. The final two thirds will use spray bars to wash the particles to recover the media.

During Phase 1 the loading of the floats side of the screen will be higher than during Phase 2 and the previous Wolf operation. However, as the floats and sinks have common underpans for the correct and dilute medium, the voidage on the sinks side of the screen, of which there will be abundance due to the low concentrate masses, will allow considerable venting.

140-SN-07 Scavenger Dense Media Floats and Sinks Screen

Description

These screens are also inherited from Wolf and will be used in both Phase 1 and Phase 2 albeit with different duties. Under Phase 1 the scavenger DMS circuit will act in a secondary DMS capacity, before reverting to a scavenger duty in Phase 2. As with the other dense media screens these are designed to recover the dense media back into circuit. This screen is equipped with a divider, with one third allocated to the sinks and the two thirds for the floats.

Dimensions

Horizontal 1.8m x 4.8m deck with an 0.8mm aperture with floats rates of 8.50tph in year 1 and 9.23tph in year 2 over the two thirds of the deck. The equivalent sinks tonnages on the one third side of the screen are 0.60tph and 0.67tph respectively for years 1 and 2. The tonnages under Phase 2 are 0.03tph of sinks and 1.67tph of floats.

Operation

The cyclone products will both drop onto the one divided screen for media recovery. The initial part of the screen will use wedge wire screen panels to maximise the recovery of the media at the correct density. The final two thirds will use spray bars to wash the particles to recover the media.

The tonnages are so low on this screen under either duty that the material on the deck will be very sparse and the deck coverage will be very low.

150-SN-01 Primary Mill Sizing Screen

Description

This screen is another being reinstated from the Wolf operation and will be used in both Phase 1 and Phase 2. In both phases, this screen will be fed with the secondary DMS sinks and the primary mill discharge.

Dimensions

Horizontal 1.8m x 5.0m deck with a 0.8mm aperture bottom deck and a 4.0mm top deck. Throughput rates are nominally 20.6tph (year 1), 22.3 tph (year 2), 31.2tph (year 3>).

Operation

The feed to the screen will be pumped into the screen feed box before flowing onto the top deck of the screen. The fine material along with the majority of the water will flow through the top deck to the bottom deck where the -0.8mm material will be screen out and pumped to the fines circuit. As with all screens the bulk of the fine material, and the water will wash through in the first third of the screen before the remainder of the deck will be sizing near size particles.

TW are going to operate this screen differently to the Wolf operation, where the top deck is going to feed the scavenger DMS circuit instead of the middle deck. It should be noted that the screen in Phase 2 will receive approximately 60% of the original Wolf design tonnage, significantly reducing the load on this screen.

Supporting Media

Figure 1 and Figure 2 show two examples of screens operating under the Wolf Minerals operation. Whilst these photos will not directly demonstrate what the TW operations will look like, it provides a good example of how the dewatering screens and DMS screens will look like in operations.

Figure 1 shows the old Wolf product screen, where this separated 0.8mm fines from a material of a 4mm top size. This clearly shows the water pooling at the back of the screen, but once this material has passed through the deck, the material moving forward is clean and demonstrates good voidage between the particles.

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Figure 1: Example Wet Screen with 0.8mm Deck

Figure 2 shows the secondary dense media screen during the Wolf operation. The screen clearly demonstrates that the sinks side of the screen will have vast amounts of voidage, which would be expected during the TW operations.

Figure 2: Example of Secondary DMS Screen

Appendix N

RESEARCH ON LFN AMPLIFICATION IN BUILDINGS

SOUND TRANSMISSION INTO BUILDINGS AND BUILDING EFFECTS

INTRODUCTION

It is noted that previous investigations into low frequency sound from the Hemerdon mine (whilst operating under the control of a previous operator, Wolf Minerals) revealed that low frequency sound levels within the residential properties at which measurements were undertaken were "a few dB" higher within some rooms compared to other rooms within the same building[37].

The investigations undertaken by the Environment Agency (see Ref 37) noted that:

- At "Receptor 1", a large window was found to have a resonance at 16 to 20Hz, which *"could accentuate a 16Hz tone"*. It was also noted that *"the room dimensions were erratic and would not support standing waves"*.
- At "Receptor 2": "*It is not known whether there is any particular physical property of the house (e.g. natural resonance) which may amplify or exacerbate sound pressure levels in the 50Hz one third octave band. Comparison with sound pressure levels measured externally may provide useful information."* For the same receptor there is a comparison of the increase in measured levels (internally) in the 16Hz third octave band and 31.5Hz third octave band when the Wolf Minerals plant started operating compared to the period when it was not operating.
- For the same receptor location ("Receptor 2") it is stated that: *"It is not known if levels measured in the 50Hz one third octave band at the residential property are due to some natural resonance at that frequency at the property."*

There is a hint in these comments that amplification effects within the building were suspected, although there is no direct evidence to indicate whether this was the case.

The potential for such effects has therefore been investigated, as detailed below.

REVIEW OF PUBLISHED TECHNICAL LITERATURE ON LOW FREQUENCY NOISE TRANSMISSION INTO BUILDINGS

There is little literature on the subject of low frequency (below about 63Hz) sound transmission into buildings, whether it be based on theory or measurement. Much of the literature that does exist relates either to air overpressures from blasting; or building response in terms of induced vibration as a result of excitation by low frequency sound (again, much of it relating to blasting); or building response in terms of re-generated sound due to radiation from building elements subject to groundborne vibration (primarily from trains). There is much published research relating to low frequency sound from wind turbines, but this rarely considers the effect of building structures on the propagation path.

Selecting information from the published technical literature that will be directly relevant to the situation at Hemerdon therefore requires some caution. Data relating to blasting / air overpressures may not be appropriate because the impulsive nature of blasting sources might not be of sufficient

[37] Environment Agency report ref. Wolf-20170922-LFN: *Low Frequency Noise Assessment – Drakelands Mine* (Dec 2017). We have only seen a redacted version of this report which obscures details of specific receptor locations and individuals to ensure compliance with the relevant data protection legislation.

duration to set up resonances in the building elements. Data relating to the vibration response of building elements, and the subsequent re-radiation of sound from the vibration building elements, might be unreliable for two reasons. Firstly, the available literature is usually based on sources such as blasting and underground rail which are not necessarily representative of the situation at Tungsten West. Secondly, there is the convoluted calculation path; one would have to consider the energy transfer from the incident sound wave exciting the building elements and then the energy transfer as the vibrating building elements re-radiate the sound. The two steps in the calculation would involve two sets of uncertainty, and the uncertainty associated with these calculations can be high. Furthermore, the fundamental laws of physics (conservation of energy) dictate that the sound energy re-radiated by a vibrating building element cannot be greater than the incident sound energy that excites that building element in the first place.

The natural response to this situation is to revert back to fundamental acoustic theory. However, this introduces problems in terms of complexity and validation of the calculation method, given the paucity of real world measurement data at such low frequencies. For example, when calculating the modal response of a room with assumed rigid boundaries, at very low frequencies the transmission through the room boundaries will act as effective damping to the room response, which would make such a theoretical approach impossible without information relating to the damping of the building structure. Furthermore, at the long wavelengths associated with low frequency sound, the dimensions of the room or even the whole of the building structure may be smaller than the wavelength, in which case the structure might appear effectively invisible to the impinging sound wave. For the situation at Hemerdon, where the screens will operate at 12.5 Hz or 16 Hz, the wavelengths of the resulting sound will be approximately 27m at 12.5 Hz and 21m at 16 Hz.

In practice, therefore, it is necessary to take a holistic approach, taking into account both fundamental acoustic theory and published empirical / measurement data, but noting the limitations (and advantages) of both. In particular, when interpreting published empirical / measurement data, consideration needs to be given to how data presented as energy averaged values (e.g. simple numerical corrections in terms of dB reduction) might be applied to a wave based prediction model that is capable of predicting beating effects (e.g. taking into account both the amplitude and phase of the incident sound wave).

Four approaches have therefore been considered:

- Measurement data on outside to inside low frequency sound transmission
- Approach based on groundborne vibration data
- Room modes
- Wave based approach

Published Data on Outside to Inside Low Frequency Sound Transmission

Hubbard *(Noise Induced House Vibrations and Human Perception)*[38] presents a study showing measured *reductions* in low frequency sound between outside and inside as a function of frequency,

[38] Hubbard, H H: *Noise Induced House Vibrations and Human Perception*. Noise Control Engineering Journal, 19 pp49-55 (1982)

as shown in Figure AN-1. The noise source was military aircraft, so it can be assumed that the most significant sound path would be via the roof structure, although at low frequencies entry via the whole building envelope including walls and windows would also be significant. In Figure AN-1, the hatched area of the graph encompasses results presented by other authors (see references in footnotes to this document).

Hubbard notes, however, that there are limited data points for frequencies below 50Hz and that, at this frequency range, the wavelengths are comparable to or greater than the room dimensions and that there will not be a diffuse sound field within the room. Hubbard also notes that the inside distribution of sound pressures can be non-uniform because of standing wave patterns, structure-borne sound and cavity resonances due to room, closet and hallway configurations. The paper concludes that it is difficult to characterise the low frequency noise environment inside of a house structure based on a knowledge of the outside noise environment.

Another point to note is that the data presented by Hubbard is sourced primarily from case studies[39] with (military) aircraft as the noise source. Although aircraft noise contains a large low frequency component, entry into the building envelope is likely to be weighted to transmission through the roof structure, although there will also be significant transmission through walls and windows. For the situation at Hemerdon, entry into the receptor buildings is likely to be via all surfaces, but possibly weighted towards the walls and windows rather than the roof (this will be dependent on the situation for each receptor location). If there is additional attenuation associated with propagation through the (presumably unoccupied) roof space, and measurements were undertaken within the occupied spaces of the building, then the reductions presented by Hubbard may be an overestimate. However, in all cases the measurement data shows a reduction in low frequency noise levels from outside to inside.

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[39] The case studies considered by Hubbard are taken from the following published sources: Carden H D and Mayes W H: *Measured Vibration Response Characteristics of Four Residential Structures Excited by Mechanical and Acoustical Loadings*. NASA TN D-5776 (1970); Mayes W H; Findley D S; and Carden H D: *House Vibrations Significant for Indoor Subjective Response*. NASA SP-189 (1969); Young J R: *Attenuation of Aircraft Noise by Wood-Sided and Brick-Veneered Frame Houses*. NASA CR-1637 (1970); Tempest W: *Infrasound and Low Frequency Vibration*. Academic Press, London (1976); and Bishop D E: *Reduction of Aircraft Noise Measured in Several Schools, Motels, and Residential Homes*. Journal of the Acoustical Society of America Vol 39 No 5, pp 907-913 (1966)

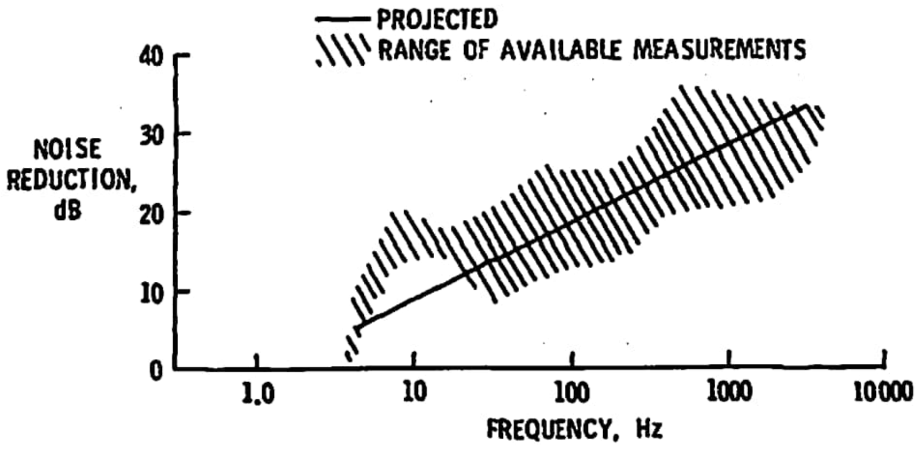

Figure AN-1: House noise reduction as a function of frequency for the windows closed situation (from Hubbard)

Doi et al[40] present results of trial measurements to quantify the transmission of low frequency noise into a test building. Results presented in terms of the indoor minus outdoor sound pressure levels are shown in Figure AN-2 below. The data in this figure are based on room averaged sound pressure levels within the building versus sound pressure levels measured immediately outside the building. The sound source was specially designed for the trials and comprised a vibrating board acting like a speaker diaphragm (similar to the situation with the screens at Hemerdon mine).

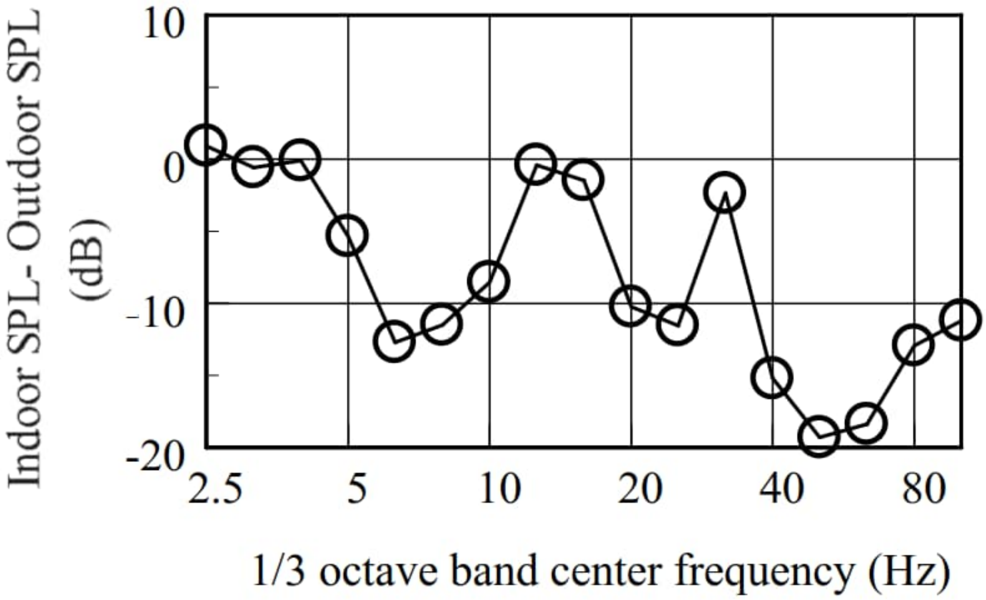

Figure AN-2: Transmission of low frequency noise into a test building (from Doi et al)

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[40] Doi, T; Iwanaga, K; and Naka, Y: *Experimental Approach on Transmission of Low Frequency Sound into A Building*. Proc. Internoise 2014

Doi et al conducted a number of additional exercises, both experimental and theoretical, to explain the results presented above. In summary, they concluded that (with some unknowns):

- The results at very low frequencies (below about 4 Hz) are due to the air-tightness of the room. The building is effectively invisible to the low frequency sound, and there is no difference between indoor and outdoor noise levels.
- Beyond about 4Hz, the difference between indoor and outdoor noise levels appears to follow a mass law for the building envelope.
- At around 12.5Hz there is a resonance due to the natural frequencies of windows and doors being in this region (confirmed by on site measurements). Again, the building appears to be effectively invisible to the low frequency sound and there is negligible difference between the outdoor and indoor noise measurements.
- At frequencies above about 20Hz, the results in terms of indoor minus outdoor sound pressure levels are influenced more by the effect of sound pressure levels outside the building increasing due to the presence of the building itself (i.e. the reflection / façade effect of the building). This is shown in Figure AN-3, below. When this is taken into account, the actual sound reduction provided by the building envelope would appear to be negligible.

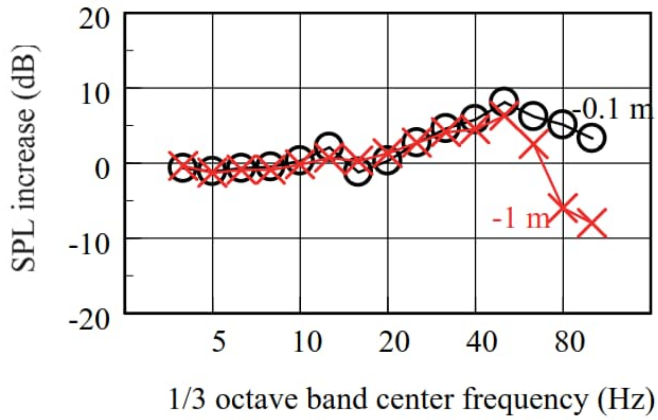

Figure 12 – Measured results on SPL increase due to the presence of a building (in front of the building, 0.1 m and 1 m away from the glass panes)

Figure AN-3: Façade effect due to presence of building (from Doi et al)

In summary, the research detailed above finds that the sound reduction afforded by the building envelope at the low frequencies under consideration (12.5Hz and 16Hz) is small or even negligible. However, no instances of amplification within the building have been found.

Approach Based on Groundborne Vibration Data

Lightweight building elements such as suspended floors are known to exhibit amplification effects when subject to groundborne or structure-borne vibration generated by, for example, underground railways or adjacent surface railways. A summary of the most recent research is presented by Villot et al[41]. There are, though, a couple of important points to note about this research when considering its relevance to the situation at Hemerdon mine:

Firstly, the energy transfer mechanisms involved in the transmission of groundborne vibration into buildings are very different to acoustic excitation due to low frequency sound. With groundborne vibration, the energy transfer is via a direct coupling of the building structure and the ground. Any attenuation or amplification effects within the building occur due to impedance changes between the various materials and elements (ground, foundations, walls and floors) along the transmission path. Although this may result in localised increases and decreases in vibration level (velocity or acceleration) within different building elements there can be no net increase in vibration energy as this would contravene the laws of physics (conservation of energy). In the case of excitation of building elements by low frequency sound, the situation is different. Both the impinging sound wave that might cause building elements to vibrate and the subsequently re-radiated sound wave will be travelling through air with the same acoustic impedance. There can therefore be no localised amplification (in terms of sound level, or pressure) due to impedance changes, just as there can be no net increase in sound energy.

Secondly, although the research on building response to groundborne vibration has shown that amplification effects can occur within lightweight building elements such as windows and suspended floors, the same research shows that there is an attenuation as vibration propagates from the ground and into the building foundations. The amplification and attenuation effects effectively cancel each other out[42] and, in accordance with the laws of physics, there can be no net increase in vibration energy due to the presence of the building.

In summary, an approach based on groundborne vibration data is found to be inappropriate for estimating the building response to low frequency sound. However, data relating to the response of buildings to groundborne vibration does indicate that amplification effects (in terms of sound energy) due to the presence of the building will not occur.

Room Modes

Room modes occur when the dimensions of a room (between opposite facing walls or between floor and ceiling) coincide with the wavelength (or multiples of the wavelength) of the sound. This can result in multiple sound reflections and an amplification due to constructive interference between the direct and reflected sound waves. Where the room dimensions are different to the wavelength of the sound, partially destructive interference will occur.

Although it is simple to calculate the modal response of a simple box room with rigid boundaries, at very low or infrasonic frequencies the transmission through boundaries will act as effective damping on the response. The situation gets even more complicated if you have buildings with stud walls

[41] Villot, M; Guigou,C; Jean, P and Picard, N. (2012). *Procedures to Predict Exposure in Buildings and Estimate Annoyance.* A report from the RIVAS (Railway Induced Vibration Abatement Solutions) collaborative project.

[42] The Association of Noise Consultants Guidelines: *Measurement and Assessment of Groundborne Noise and Vibration* (3rd Edition, 2020) advise that, as a first approximation, the amplification and attenuation effects can be assumed to cancel out, although more complex analyses are possible.

inside, or where the rooms are of an irregular shape or where closet or hallway situations result in an imperfect 'box' room. This would make an analytical approach untenable, unless one were to create a FE model of each building, based on a knowledge of all room layouts and dimensions and measured data on the damping properties of the building envelope.

In the case of the situation at Hemerdon, the relevant wavelengths are approximately 27m at 12.5 Hz and 21m at 16 Hz. Modes at 12.5 Hz and 16 Hz can therefore only occur within a very large room and would likely be irrelevant for most receptor locations.

In summary, an analysis of potential low frequency sound amplification within the receptor locations due to room modes is not feasible, and it is, in any case, not likely to be an issue for most receptor locations.

A Wave Based Approach

The need to be able to quantify the observed beating effects due to the operation of multiple screens means that use of a wave based prediction model is desirable for assessing the situation at Hemerdon. It has been noted elsewhere that prediction models such as ISO 9613 are therefore not suitable because, amongst other issues, the method is based on the application of numerical correction factors to account for the various phenomena associated with outside sound propagation, which will not allow for wave based calculations to predict beating effects. For the same reason, using published measurement data on outside to inside low frequency sound transmission or basing assumptions on groundborne vibration data to estimate the building response would not allow for the prediction of beating effects, as it would rely on the application of numerical correction factors.

A wave based approach has been presented by Dowding[43] to assess the structural response of buildings to (impulsive) low frequency noise and air blasts from mining operations.

Dowding notes in the chapter section titled "Structural Response to Air Blasts" that *"Structures do not respond to ultralong wavelengths because the (blast wave) envelopes both the front and back faces of the structure at the same time, and cancellation occurs"*. Reference is made to a study by Wiggins[44] to justify this. In this context, a wave will envelope both the front and rear faces if the room / house dimensions are less than one half wavelength. For c=340 m/s, this would be equivalent to approximately 10.6m at 16Hz and 13.6m at 12.5Hz (so true for small to medium sized houses, but not necessarily true for large houses).

Dowding also notes that discussions by Wiggins and also Clarkson and Mayes[45] demonstrate that no simple, reliable, theoretical way exists to determine internal pressures. The method used by Dowding, noting that it simplifies a complex situation, is to consider the pressure waves at the front face of the house and at the rear face of the house, and superpose them as follows:

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[43] Dowding, C H: *Construction Vibrations – 2nd Edition* (originally published by Prentice Hall in 2000 but updated by the author in 2006)
[44] Wiggins, J H: *Effects of Sonic Boom*, J H Wiggins Company, Palos Verdes Estates, CA
[45] Clarkson, B L and Mayes, W H: *Sonic Boom Induced Building Structure Responses including Damage*. Journal of the Acoustical Society of America Vol 5 No 2 (1972)

- Start with the (free-field) pressure waveform calculated or measured at the front face of the building
- Superpose an equal but negative (free-field) pressure waveform as calculated or measured for the rear face of the building, displaced in time by an amount equivalent to the time taken for the wave to traverse across the building structure.
- The result is assumed to be the net pressure within the building.

Dowding has used this method primarily to calculate vibration of the structure rather than internal sound pressure levels, although the method would seem to be equally appropriate for the calculation of sound pressure.

Dowding notes that the method tends to overpredict, because it does not take into account material damping of the building envelope. However, note that because the method is based on the superposition of sound waves, the maximum *variation* in sound pressure level will never exceed 6dB. This is consistent with the findings of the measurement surveys detailed above which found a variation of “a few dB” in sound pressure levels measured at various locations within the receptor locations studied around Hemerdon mine. However, note that this relates to a variation in sound pressure levels and does not necessarily represent an increase in internal sound pressures compared to those immediately outside the building.

It should also be noted that the method presented by Dowding was derived for blast induced low frequency noise; i.e. single event and one source. In this situation, any variation within the building would be experienced as a spatial variation rather than a temporal variation. For the situation at Hemerdon, there will be multiple sources (screens) in operation and the wave based approach adopted in the prediction model involves the superposition of calculated pressure waveforms from each of the screens, as calculated for each receptor location. The model will therefore be capable of predicting the variation in sound pressure within the buildings, which will be more readily experienced as a temporal variation or ‘beating’ effect. It is therefore concluded that the wave based modelling approach, including superposition of the calculated pressure waveforms from each of the screens, be adopted to account for such effects.

Summary

In summary,

- Published research on outside to inside low frequency sound transmission into buildings finds that the sound reduction afforded by the building envelope at the low frequencies under consideration (12.5 Hz and 16 Hz) is small or even negligible. However, no instances of amplification within the building have been shown.
- Consideration of available research on vibration transmission into and through buildings also indicates that effects will be small or negligible. The laws of physics (conservation of energy) determine that no amplification in sound *energy* can occur.
- Notwithstanding this, measurement surveys undertaken at receptor locations at and around Hemerdon mine have shown a variation of “a few dB” in sound pressure levels measured at various locations within individual receptor buildings. However, these results do not demonstrate any amplification effects within the building, and the research detailed above suggests that amplification effects will not occur. Resonance effects (e.g. from windows) can occur, but will only serve to negate any sound attenuation that might otherwise have been provided by the building façade / envelope. It is likely that observed variation in sound pressure levels within receptor

locations is based on such localised effects but does not demonstrate amplification within the building.

- For the purposes of the low frequency sound prediction model, a worst case assumption would be that the building structure is effectively ‘invisible’ to low frequency sound.

Appendix O

DECK VENTING AND ACTIVE NOISE CONTROL TRIAL

Low Frequency Noise mitigation tests on screen 150-SN-01

Report: EDR1147/4

Date: 26th August 2020

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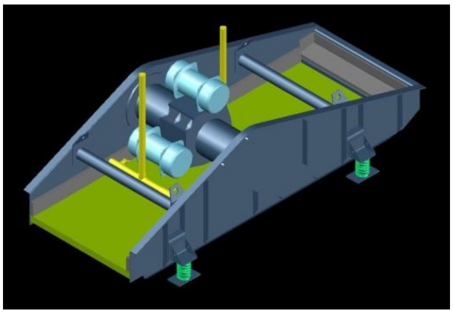
1 Introduction

To ensure that Low Frequency Noise (LFN) does not create an environmental nuisance, the sound pressure levels generated by the vibrating screens must be controlled and mitigated where necessary. Previous experience has shown that some screens were capable of producing sound levels that could be detected in neighbouring communities and so changes are necessary. Two mitigation methods have been proposed: reducing the efficiency of the noise generation mechanism and noise cancelling. Screen 150-SN-01 was made operational to carry out tests to investigate both of these methods.

2 Generating LFN

Some disturbance is required to initiate a sound. Excluding explosive sources, this usually involves a vibrating surface that interacts with the air around it. The larger the vibration, the louder the sound and the frequency of vibration matches that of the sound. It can be shown that the pressure generated is directly proportional to the surface velocity and the constant of proportionality is known as the acoustic impedance. Most machinery has vibrating surfaces, but generally at frequencies in the audible range with any surface velocities below 20 Hz being negligible. This is not the case for processing screens which are designed to run at low frequencies with a high surface vibration. In pure pressure terms, they produce far more LFN than audible noise. As well as surface velocity, the strength of a sound source depends on the total area of the vibrating surface and the source strength can be calculated as a sound power. Processing screens have large vibrating areas so the sound power is high.



3 Reducing the efficiency of noise generation

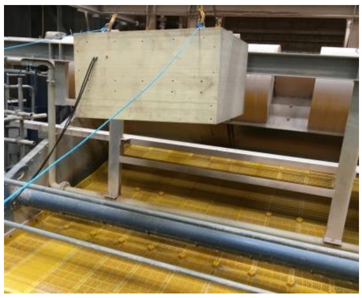
A screen deck generates pressures of opposite phase above and below the deck surface. Above the deck, the sound is free to propagate into the environment; below the deck, the air pressure is confined by the underpan. This is the principle of a conventional loudspeaker and is efficient at generating sound providing the air masses are well separated. Having a porous deck allows for partial cancellation of the pressure and the overall transmitted sound will be lower. This was evident when the plant was run previously where the screen with the largest area had large open holes in the deck giving lower air pressures than a smaller screen where the deck was covered with product and no openings. The experiments that have been carried out will establish how much open area in the deck is required to achieve acceptable output of LFN. This will then enable the appropriate screen to be selected. A final check on the chosen screen will be undertaken to confirm the behaviour.

Another air path can be exploited by maximising the gap between the screen and underpan. Tests have already shown that this has a mitigating effect although it will not be sufficient alone to give the required reductions.

4 Cancelling the noise at source

The principle of noise cancellation is well developed for comfort in a noisy environment. Noise cancelling headphones are in frequent use in air travel. In practice, the control algorithms are more complex for cancelling broadband sounds in the audible range than for a single low frequency. However, the sound power required for the infrasound generated by a processing screen is considerably larger.

A trial of active noise cancelling was undertaken during the time that Wolf Minerals was operating. A large loudspeaker was suspended above the Scrubber screen and driven at a frequency close to the running speed of the screen to cause beating. Measurements were made outside the building about 60 m away with the loudspeaker off and on. The loudspeaker generated 15.6 dB lower air pressure than the screen giving a reduction at the measurement point of 6.4 dB.



5 Strength of the source

For most sources of noise, the strength of the source is provided by the sound power and there are internationally recognised procedures for measurement. The method would be difficult to use for a screen and so a different strength term has been developed for this application.

Screen decks oscillate sinusoidally with a surface rms velocity of v m/s. If the deck surface was solid, the pressure generated is given by the fundamental acoustic relationship

$$p = zv$$

Where p is the rms air pressure in Pa and z is the specific acoustic impedance of air in rayls. This has a value of 415 rayls at room temperature and 1 atmosphere of pressure.

In practice, a processing screen has a porous surface and there will be other leaks so that the generated pressure will be lower. This can be incorporated using the factor ρ (the acoustic efficiency) in the equation:

$$p = \rho zv$$

The far-field pressure will depend on the total area of the vibrating surface (A m^2). For each doubling of distance away from the source, the pressure drops by 6 dB. To characterise a specific source, the pressure at a hypothetical distance of 1 m can be calculated by applying the factor $A/_{4\pi}$. The characteristic pressure will be denoted as p_{sc}

$$p_{sc} = \frac{\rho Azv}{4\pi}$$

To determine this value by experiment, the pressure close to the screen deck will be measured. It is not practicable to have the microphone at the deck surface, so for all tests, a standard distance of 1 m above the centre of the deck will be used. A simultaneous measurement of surface velocity will be made using an accelerometer. This allows the acoustic efficiency term ρ to be calculated and using the deck area, the characteristic pressure can be determined. The characteristic pressure allows the ranking of different screens in terms of infrasound output. It does not, however, lead to a limit value that would ensure that the criteria at the sensitive receptors would be met. For this reason, tests at the Hemerdon site also include simultaneous measurements at a distance of 56 m from the screen and at 3 locations in the community that have experienced infrasound problems previously. This will establish the relationship between characteristic pressure and far field levels so that a limit can be associated with the characteristic pressure. With this limit, a screen can be tested in the factory to determine suitability before being installed on site.

For final verification, the effects of a new screen would also be measured at the community receptors.

This approach to assessing the strength of the source applies to changes in screen decks, underpan venting and active noise cancellation.

6 Tests performed

The tests carried out were intended to quantify the sound output from various deck media, underpan venting, deck venting and active noise control. Table 6.1 summarises the parameters for each test.

Test	Test date	Test completion time	Deck medium/surface	% open area	Side venting	Speaker
2a	04/08/2020	10:58	0.63x12	9.56	Open	OFF
2a	04/08/2020	11:07	0.63x12	9.56	Open	ON 30A
1	04/08/2020	17:36	0.8x12	12.9	Open	OFF
1	04/08/2020	17:45	0.8x13	12.9	Open	ON 30A
1	04/08/2020	18:33	0.8x14	12.9	Closed	OFF
1	04/08/2020	18:42	0.8x15	12.9	Closed	ON 30A
2b	05/08/2020	13:23	0.63x5.5	18.6	Closed	OFF
2b	05/08/2020	13:34	0.63x5.5	18.6	Closed	ON 30A
3	06/08/2020	06:53	9x9	38.9	Closed	OFF
3	06/08/2020	07:02	9x9	38.9	Closed	ON 30A
4	06/08/2020	12:08	10.7x10.7	48.1	Closed	OFF
4	06/08/2020	12:18	10.7x10.7	48.1	Closed	ON 30A
5	06/08/2020	16:35	38.6x38.6	44.7	Closed	OFF
5	06/08/2020	16:45	38.6x38.6	44.7	Closed	ON 30A
6	07/08/2020	11:14	90x90	38.7	Closed	OFF
6	07/08/2020	11:24	90x90	38.7	Closed	ON 30A
7	07/08/2020	15:39	Plywood 100%	0	Closed	OFF
7	07/08/2020	16:03	Plywood 100%	0	Closed	ON 30A
8	08/08/2020	07:32	Plywood+2 chimneys	6.67	Closed	OFF
8	08/08/2020	07:47	Plywood+2 chimneys	6.67	Closed	ON 30A
8	08/08/2020	07:54	Plywood+2 chimneys	6.67	Closed	ON 20A
8	08/08/2020	08:07	Plywood+2 chimneys	6.67	Closed	ON 20A
9	08/08/2020	09:10	Plywood+2 de-watering panels		Closed	OFF
9	08/08/2020	09:22	Plywood+2 de-watering panels		Closed	ON 30A
11a	08/08/2020	10:22	Plywood+2 chimneys+1 open panel	10	Closed	OFF
11a	08/08/2020	10:35	Plywood+2 chimneys+1 open panel	10	Closed	ON 30A
11b	08/08/2020	11:09	Plywood+1 chimney	3.33	Closed	OFF
11b	08/08/2020	11:18	Plywood+1 chimney	3.33	Closed	ON 30A
11c	08/08/2020	11:45	Plywood+1 open panel	3.33	Closed	OFF
11c	08/08/2020	11:55	Plywood+1 open panel	3.33	Closed	ON 30A
10	08/08/2020	12:29	Plywood 100%	0	Open	OFF
10	08/08/2020	12:39	Plywood 100%	0	Open	ON 30A

12	08/08/2020	13:37	No deck	100	Open	OFF
12	08/08/2020	13:47	No deck	100	Open	ON 30A
13	24/8/2020	10:38	Plywood 100%	0	Open	OFF
13a	24/8/2020	11:03	Plywood + 0.63x12 18 elements open	2.2	Open	OFF
13b	24/8/2020	11:24	Plywood + 0.63x12 36 elements open	4.4	Open	OFF
13c	24/8/2020	11:46	Plywood + 0.63x12 54 elements open	6.6	Open	OFF
14c	24/8/2020	12:35	Plywood + 0.63x12 51 elements open + 3 removed elements	6.6	Open	OFF

Table 6.1 Tests performed

7 Screen sound pressure levels

Figure 7.1 shows the sound pressure levels from each test when the noise cancelling loudspeaker was switched off. The following observations can be made:

- For all deck media without the plywood, the sound pressure levels were close to that from the test with no deck medium.
- Tests 7, 10 and 13 were carried out with a 100% plywood deck. In Test 7, the gap between the screen and underpan was closed with a wood barrier whereas for Tests 10 and 13, the gap was open. The results for Tests 10 and 13 should have been identical and it is unclear why there was a difference.
- Creating holes in the plywood deck gave a significant reduction in the sound pressure level.

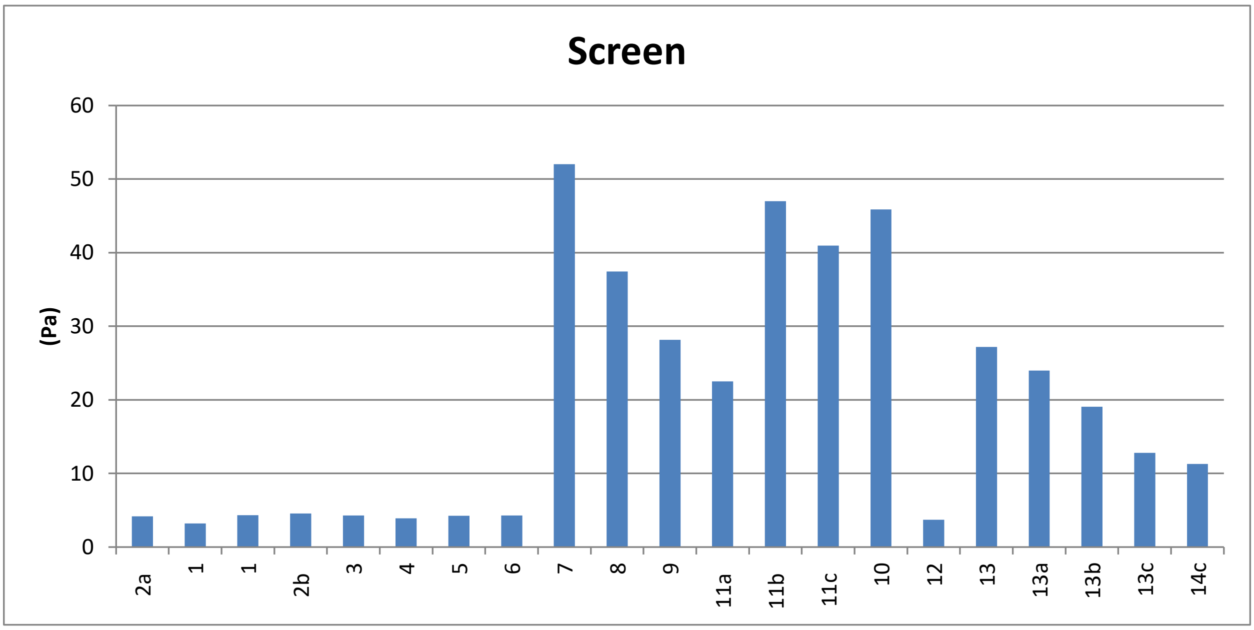


Figure 7.1 Screen sound pressure levels

8 Acoustic efficiency

The rms velocity of the screen deck was 229 mm/s for the tests carried out on 4th August and 210 mm/s for the tests on 19th August. Using the sound pressure levels from the screen microphone 1 metre above the deck, the acoustic efficiency for each test configuration can be determined and is shown in Figure 8.1.

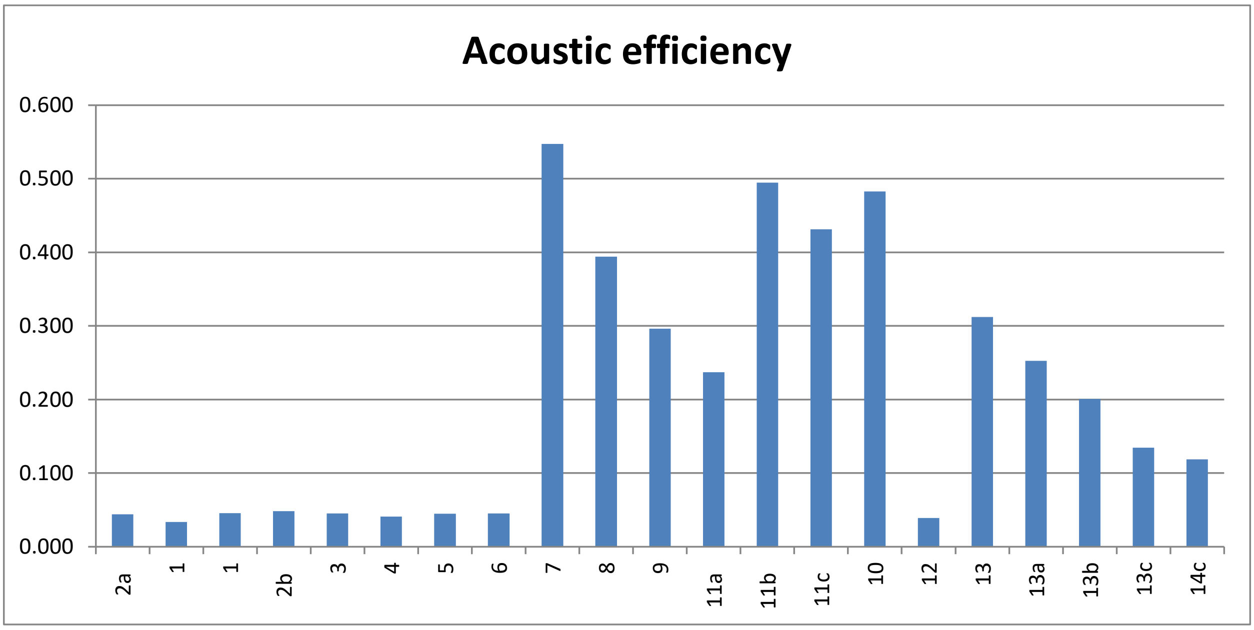


Figure 8.1 Acoustic efficiency for each test configuration

9 Outside sound pressure levels

It would be expected that, providing the upper surface of the deck was the only source of sound pressure, the pattern in the measurements taken 56 m from the screen on the ground outside the building would be the same as that from the microphone 1 m above the deck. This did not appear to be the case (Figure 9.2) and strongly suggested that a second source was making a contribution. An inspection revealed that the outlet to the underpan was open (Figure 9.1) and a considerable dynamic air pressure could be felt when the screen was operating. The magnitude of this air pressure would depend on the opacity of the deck and would affect the measurements taken outside. This secondary source makes the interpretation of the outside results difficult.

Figure 9.1 Open outlet to the underpan

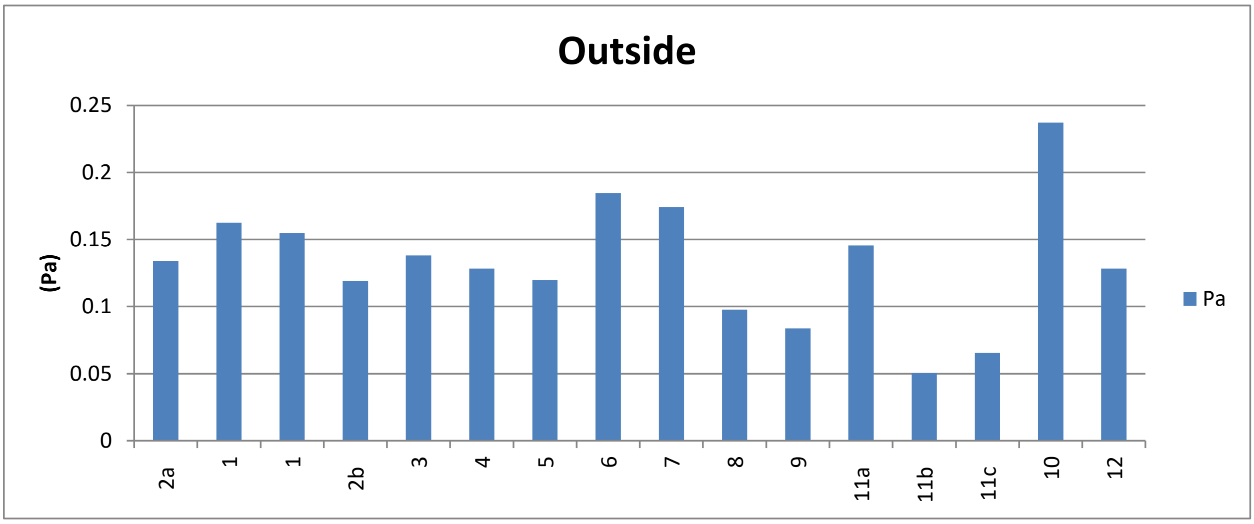


Figure 9.2 Sound pressure levels measured outside

The hypothesis that a secondary source affects the outside measurements is further reinforced by comparing the measured values with those expected at a distance of 56 m. Assuming the pressure level to drop according to the square of the distance, the theoretical pressures can be compared with those measured (Figure 9.3). Clearly, there is a greatly reduced measured level when the plywood was on the deck which would cause the underpan air pressures to increase.

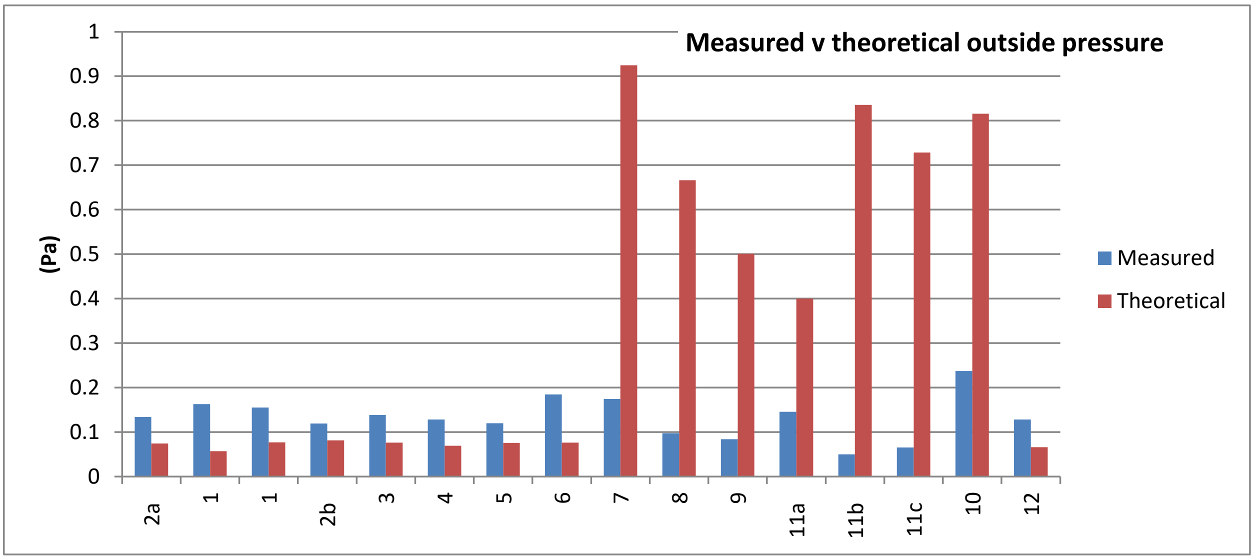


Figure 9.3 Outside sound pressure levels compared with predictions

10 Sound pressure levels at Sparkwell

One of the far-field monitors was located in the grounds of Dartmoor Zoo in Sparkwell as shown in Figure 10.1.

Figure 10.1 Location of the Sparkwell monitor in Dartmoor Zoo

The sound pressure levels for the different tests measured at this far-field location are shown in Figure 10.1.

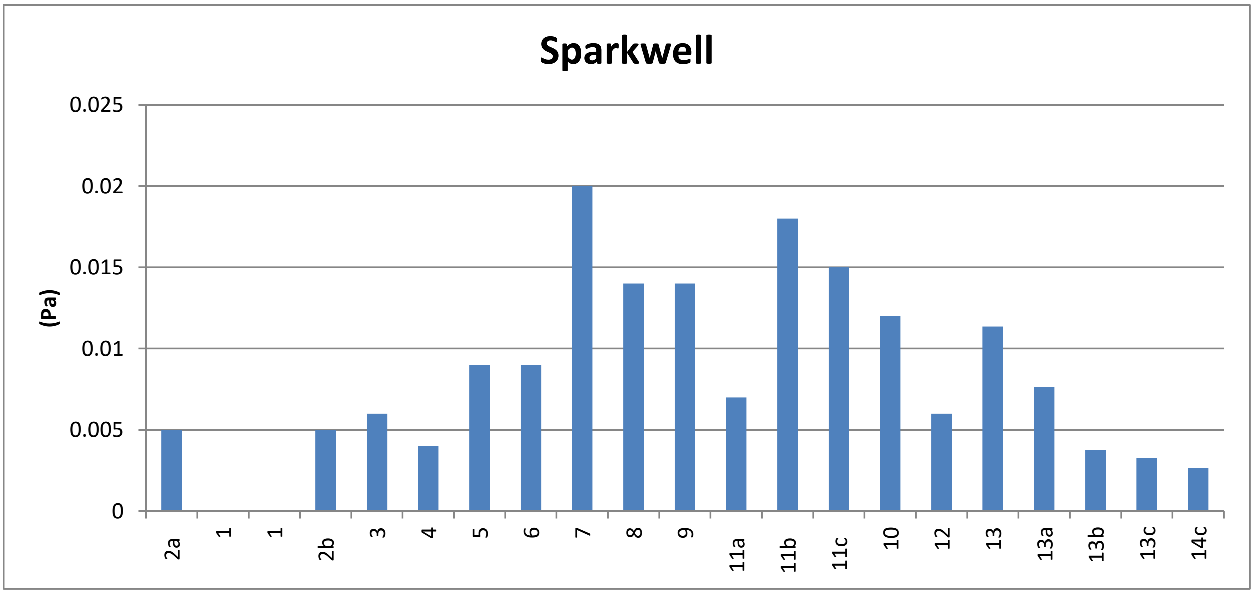


Figure 10.2 Sound pressure levels measured at Sparkwell

11 Effect of screen media opacity

It was expected that the sound pressure level generated by the screen deck would depend on the opacity in an approximately linear way. This proved to be generally true when plywood covered the majority of the deck surface, but it was not the case with the polyurethane media. Figures 11.1 and 11.2 show the sound pressure levels above the screen and at Sparkwell as a function of deck open area. When the holes were in an effective plywood deck, a clear drop in sound pressure level can be seen with increasing open area. Without the plywood, the dependence on open area was very weak. The most likely explanation for this behaviour is that the polyurethane media is flexible and deforms under inertia and air pressure loading. If this is the case, the surface velocity will be greatly reduced, and since the sound pressure level is linearly dependent on that velocity, it also will be reduced. This hypothesis will be checked by experiment.

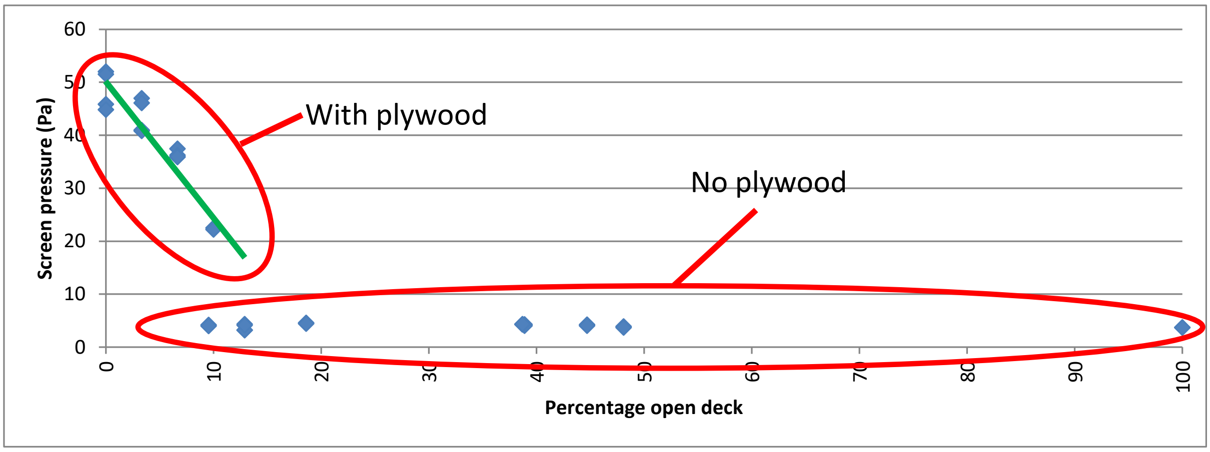


Figure 11.1 Sound pressure levels above the screen as a function of open area

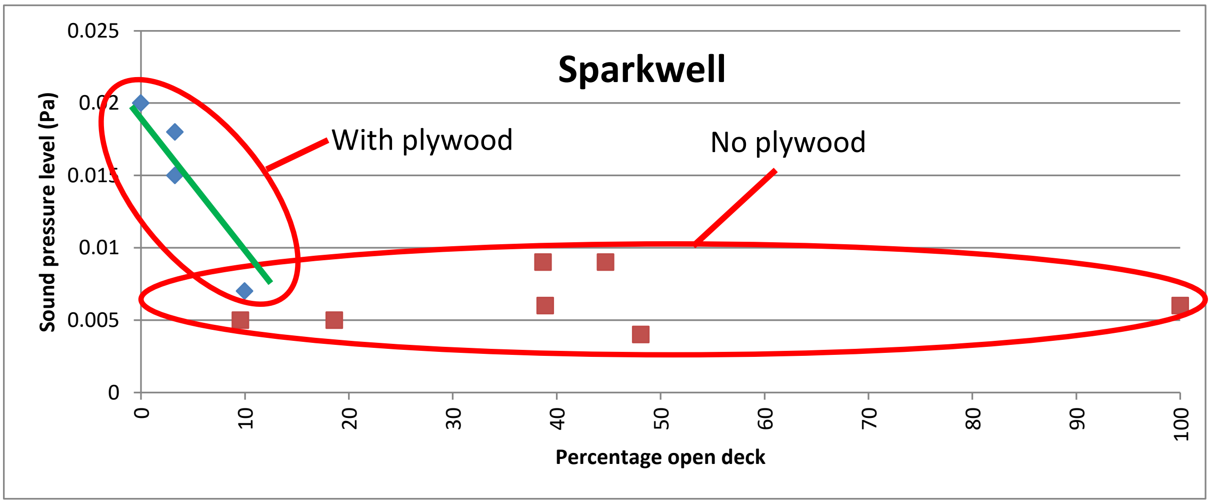
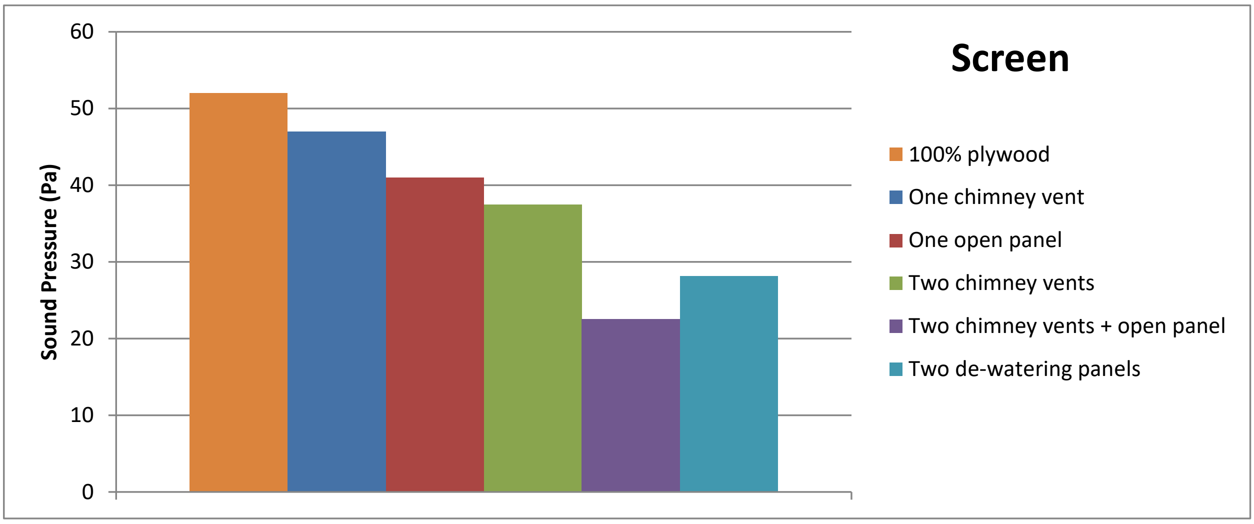


Figure 11.2 Sound pressure levels at Sparkwell as a function of open area

12 Effect of open areas in the plywood deck

While the relationship between sound pressure levels and open deck area did not seem strong with the polyurethane media, it was much clearer with the open areas in the plywood deck. The charts in Figure 12.1 show the levels from different open areas in the deck, both at the screen and at the Sparkwell location.



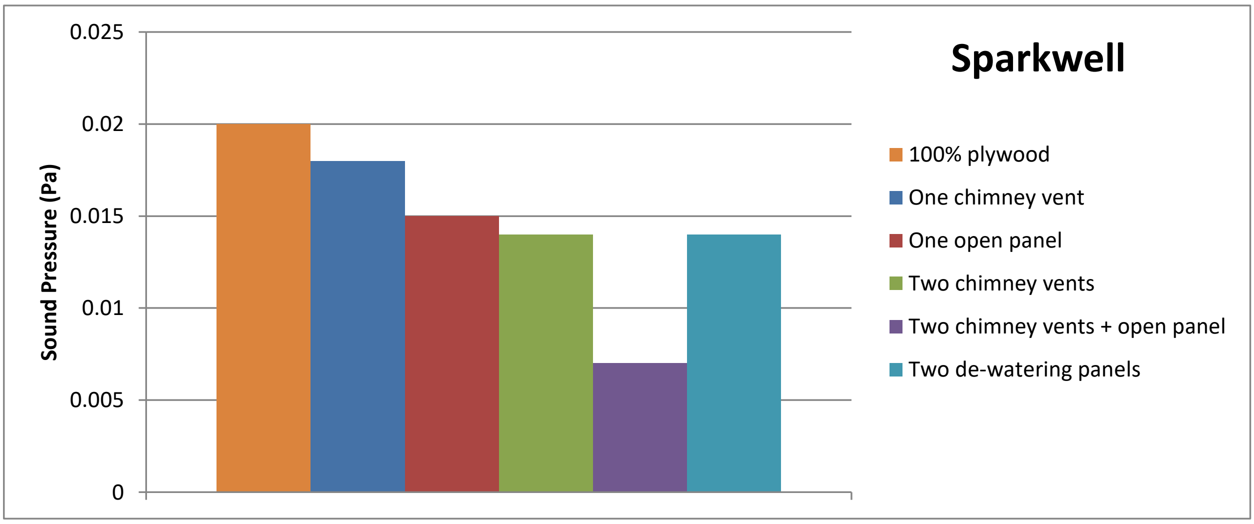


Figure 12.1 Sound pressure levels with vent size in the plywood deck.

13 Effect of side venting

The gap between the screen and the underpan provides an air path for pressure cancelling. The extent to which this could affect the far-field sound pressure levels was tested using the deck covered with plywood and no deck venting. Measurements were made with the gap closed as much as possible with a plywood barrier and then repeated with the barrier removed. The drop in dynamic pressure at the screen was small, but significant. The effect at the far-field monitor at Sparkwell was greater as shown in Figure 13.1.

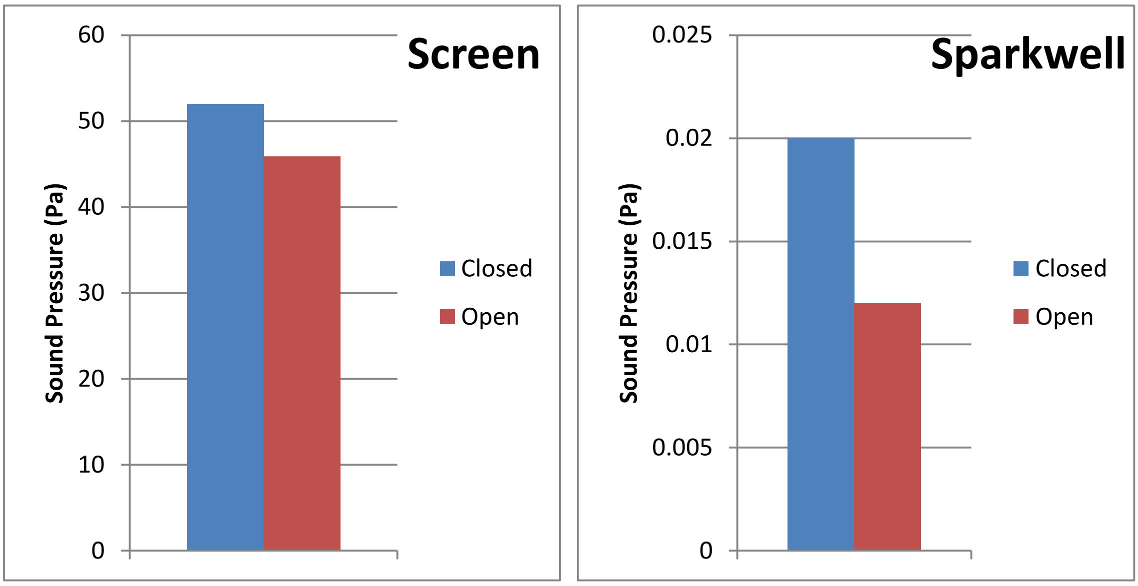


Figure 13.1 Sound pressure levels with closed and open side venting

14 Distributed deck venting

Results from the testing in early August 2020 showed that open vents in an otherwise acoustically opaque deck were effective at reducing the transmitted sound pressure levels. For a working solution, it would be better to have a greater number of smaller area vents. To check that this solution would also be effective, a further set of tests was carried out in late August 2020 with different distributions of vents.

The 0.63 x 12 media was first covered with plywood, fixed with screws to the deck mats. Holes were cut in the plywood to reveal 3 elements for each hole. An element represents 0.12% of the deck area, so each hole was 0.36%. Five tests were carried out with no holes, 6, 12 and 18 holes distributed as shown in Figure 14.1. The fifth test was with the 18 holes and with the central hole (green outlined in red) cut through the underlying 3 elements of the screen mat. The tests were designated Ph 0 to Ph 5 according to Table 14.1.

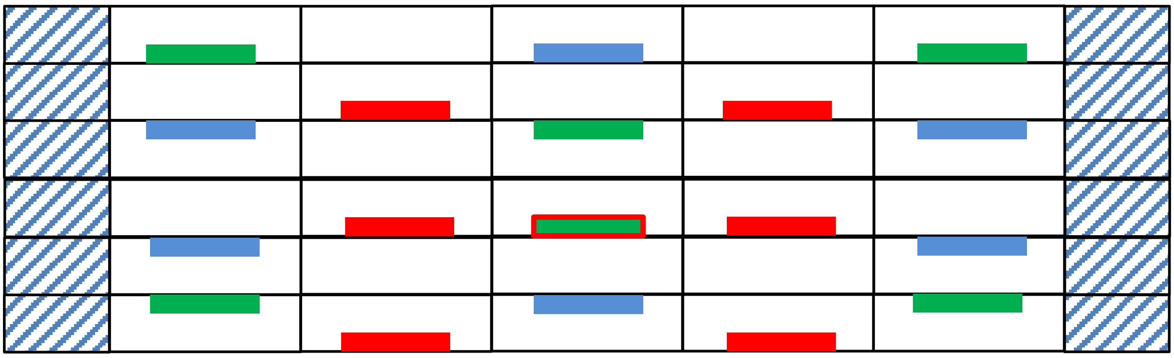


Figure 14.1 Distributed vent locations

Test	Vents	Vented area
Ph 0	None	0%
Ph 1	Green	2.2%
Ph 2	Green + blue	4.4%
Ph 3	Green + blue + red	6.6%
Ph 4	Green + blue + red (one vent with cut mat)	6.6%

Table 14.1 Vent areas

The sound pressure levels above the screen and at Sparkwell are shown in Figure 14.2. For all of these tests, the gap between the screen and the underpan was open and this would have reduced the pressure levels accordingly. However, the tests with 100% plywood gave 27.2 Pa at 1 m above the screen deck where on a previous test in the same condition it was 45.9 Pa. The reason was not identified, but it might have been caused by some of the plywood not being fully secured. There was an observation of panels “flapping” during the measurements.

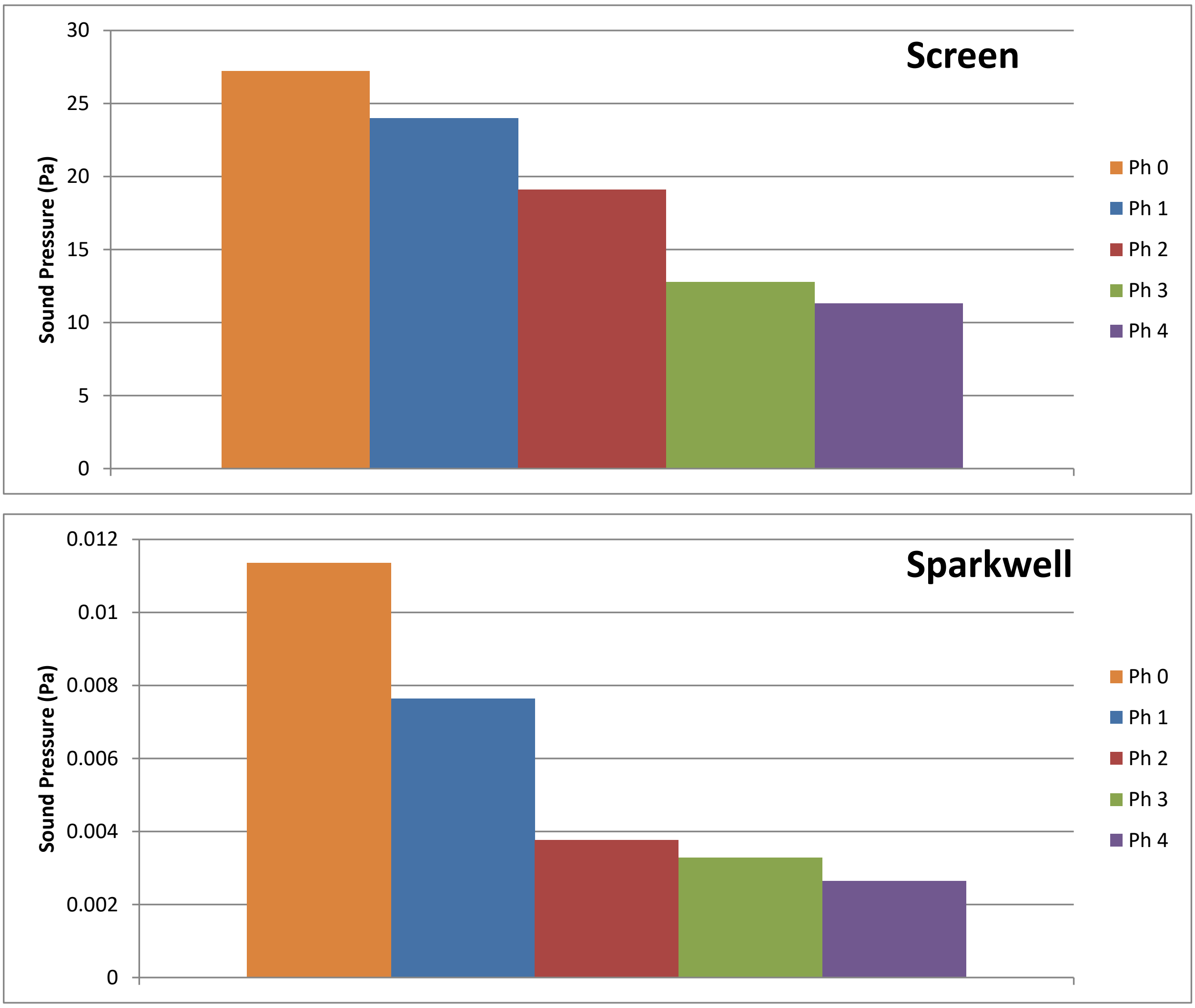


Figure 14.2 Sound pressure levels from distributed venting tests

15 Active sound control

With active sound control, the objective is to generate a dynamic air pressure to cancel that coming from the screen deck. To do this, a large loudspeaker must be synchronised with the screen motion to ensure that the correct phasing is maintained. A loudspeaker was constructed for trial purposes and assessed in two separate tests. In the first, the drive signal came from a signal generator at a frequency close, but not identical, to the running speed of the screen. This meant that at times, the pressure interference caused a maximum value and at others a minimum value. The results show how much reduction would be possible with the correct frequency control.

In the second test, the loudspeaker was controlled from a signal generated by an accelerometer fixed to the screen. This ensured that a fixed phase was possible between the two sound pressures. This phase was varied to find the optimum for pressure cancellation.

15.1 Controlling with a signal generator

With control from a signal generator, the amplitude of the pressure will rise and fall with successive cycles of constructive and destructive interference. This is illustrated in Figure 15.1.1 with a measurement made above the screen, in this case with the 0.63 x 5.5 deck medium. The results clearly show that, with correct control, a substantial reduction in dynamic air pressure is possible. The prototype loudspeaker could only be run at low power and the diaphragm was not optimised. The next version should be able to generate about 10 times the pressure amplitude.

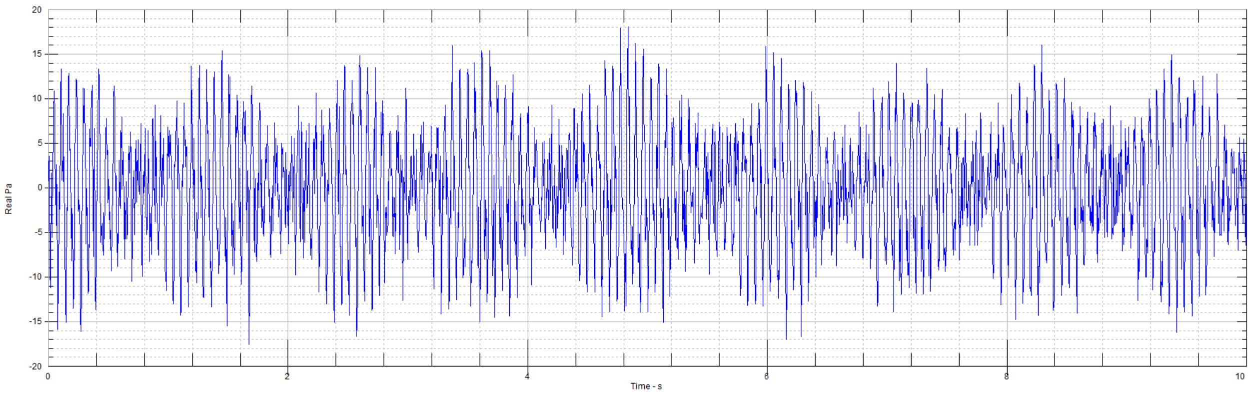


Figure 15.1.1 Screen air pressure with loudspeaker under signal generator control

Figure 15.1.2 shows the absolute level of pressure cancelling that is possible with the loudspeaker system in its current configuration. The values in the chart represent the pressure reduction that would be obtained between the system off and system on. Test 8 was carried out with the amplifier power set to 30 A, as for other tests, then for 20 and 10 A to demonstrate that an increased power would have a beneficial effect.

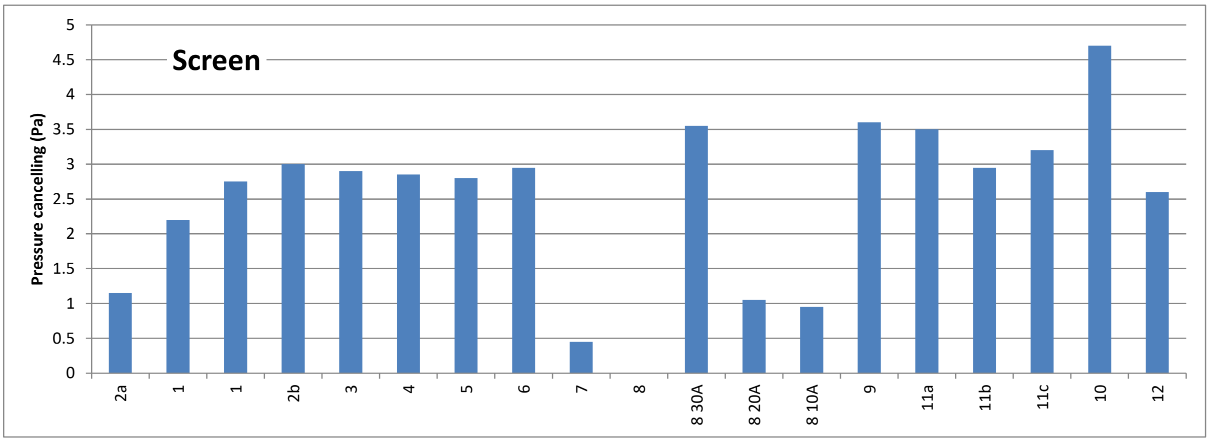


Figure 15.1.2 Pressure reduction from active sound pressure control

15.2 Controlling from the screen motion

For this test, the motion of the loudspeaker diaphragm and the screen deck were locked together in frequency, and the phase between them was varied using a feature of the DSP in the drive amplifier. The screen was fitted with the plywood deck with 18 holes and the cut mat section (configuration for Ph 5).

The power level was set to 23.7 A for this trial and the phase delay varied from 0 to 70 ms in 5 ms increments. A further test at 30 A was carried out at the optimum phase delay of 35 ms. The results are shown in Figure 15.2.1.

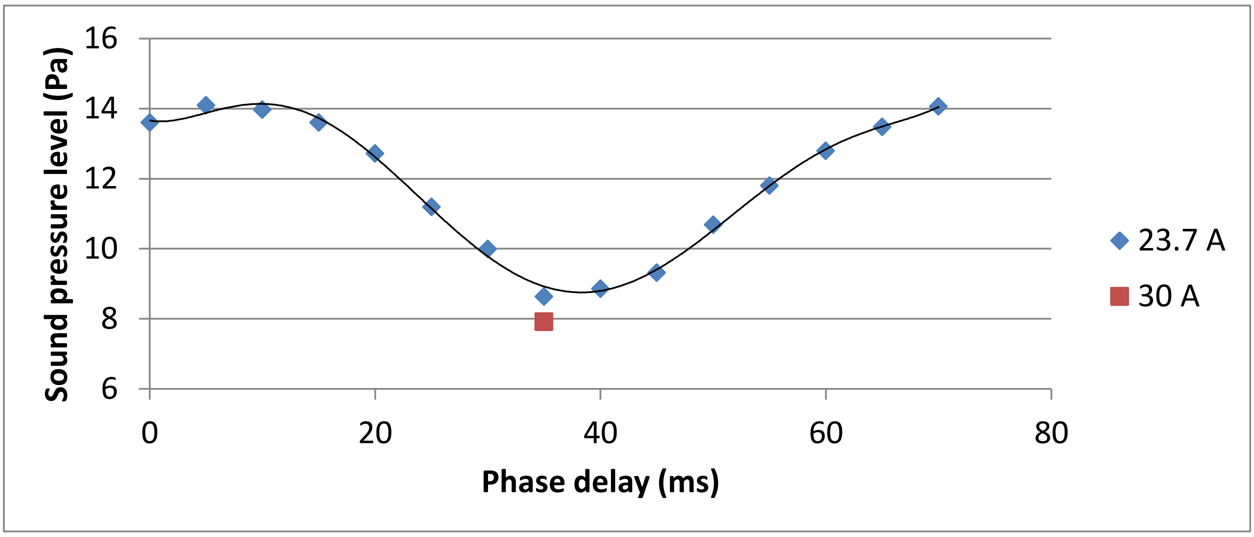


Figure 15.2.1 Variation of sound pressure levels above the screen with loudspeaker phase delay

The remote monitor at Sparkwell detected the tests with the phase variation. Figure 15.2.2 shows the hour period from 13:00 to 14:00 on 24th August when the tests were carried out. The axes of the chart give the minutes from 13:00 on one horizontal axis and the frequency on the other horizontal axis. The vertical axis is pressure. Ridges running parallel to the time axis show variations in level at a given frequency. Ridges running parallel to the frequency axis show transient events. The ridge line at 15.6 Hz, the running speed of the screen, varies in amplitude with changes in phase settings in the tests. For clarity, the times when the phase setting was 0, 35 ms, and the last, higher power test, are marked on the plot. This clearly shows that the sound reduction introduced by the loudspeaker has a beneficial effect in the far-field.

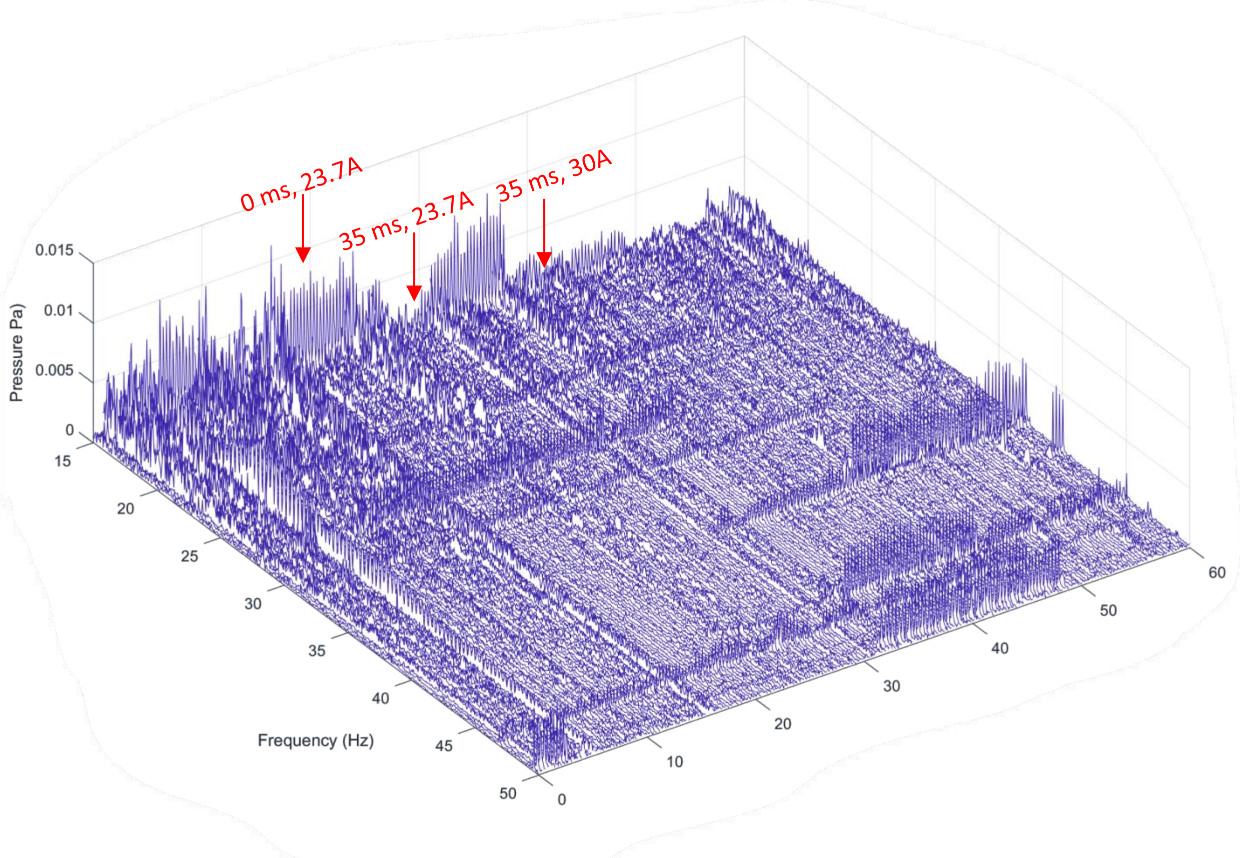


Figure 15.2.2 Sound pressure levels at Sparkwell during phase variation tests

16 Conclusions and recommendations

The objectives of the tests were to determine the most effective ways of reducing the acoustic efficiency of the screens. The tests on different screen media showed that changing mesh size alone would not be sufficient to reduce the sound pressure level. Open areas in the screen deck gave a significant reduction and these could be a small number of large holes or a larger number of smaller holes. Typically, it would appear that between 6 and 10% of the deck should be vented to achieve a worthwhile reduction. A new design of screen mat is being developed which has a hole of about 10% in area. This will be trialled with product flowing over the screen to assess the sound reduction.

The noise cancelling loudspeaker has been shown to give worthwhile far-field sound reductions. Further work is required to replace the existing 100 kg steel diaphragm with an 8 kg honeycomb version. The control system has been shown to work and now needs a robust industrial equivalent to be developed.

The following actions are required to further this work:

- Carry out noise measurements on a heavily loaded screen to compare with an empty screen to show that the product loading significantly increases the acoustic efficiency.
- Develop a deck mat with venting that could allow the screen to have at least 6% open area and the potential to increase this value.
- Test an existing screen with product loading before and after the fitting of the new vented panels. Ideally, this should be carried out with measurements above the screen and measurements in the far-field (> 1 km).
- Upgrade the loudspeaker to incorporate the light-weight diaphragm and optimise the control system for maximum sound power.

Appendix P

UNCERTAINTY CONSIDERATIONS

APPENDIX R: UNCERTAINTY CONTROL MEASURES

Uncertainty Control Measures	Applicable?	Adopted?/Comments
Measurement		
Only use appropriate monitoring equipment capable of measuring over the intended frequency range and check (and record) calibration level before and after measurements	✓	Yes. Calibrations undertaken and within acceptable levels
Take measurements using the appropriate time and frequency weighting	✓	Yes
Make detailed notes, including details of the equipment, weather, survey positions (including approximate distances), contributing noise sources, presence of screening etc.	✓	Yes – detailed site notes available and relevant information included in the NIA
Take photographs, and record survey locations using GPS if possible	✓	Yes
Take measurements at different distances to establish propagation	✓	Yes – achieved during the LFN trial
Take measurements at different heights where relevant	×	N/A for LFN
Don't just measure at the "noisiest" parts of site, but establish how "quiet" it is, too, where relevant to the assessment	×	N/A for LFN
Measure under different operating conditions relevant to your assessment / adopt worst case if known	✓	Yes – achieved by using different ply coverings during the LFN trial
Measure more than one cycle/ event (ideally at least three)	×	N/A
Determine state of repair of any associated source, where relevant	✓	Yes – screen commissioned by supplier prior to LFN trial
Use a windshield	✓	Yes – wind shield used throughout at all locations.

Avoid wet conditions (particularly in terms of rain on the windshield/mic and on neighbouring surfaces)	×	N/A for LFN
Avoid electrical and electromagnetic interference (such as from power cables and radio transmitters)	✓	Yes
Avoid extreme temperatures – traffic conditions can be different in freezing conditions, whilst meters can overheat and fail in a case when in direct sunlight during the summer.	✓	Yes
Make measurements during different weather conditions	✓	Yes
Where on one source is dominant, as a minimum, measure during conditions favourable to propagation	✓	Yes – measurements obtained over a range of conditions
Avoid tree/leaf (movement) sound where possible – ideally take measurements the same distance from sources of such sound as any receptors of interest	×	N/A for LFN
Avoid dawn chorus sound where possible – ideally take measurements the same distance from trees and bushes as any receptors of interest	×	N/A for LFN
Measure outside the receptor in question where possible	✓	Yes – measurements undertaken at various receptor locations
Where it is not possible to install a meter outside the receptor in question, install a meter elsewhere and undertake additional attended measurements.	×	N/A – measurements obtained at receptor locations
Avoid atypical traffic conditions (such as during school holidays and road works – road traffic incidents can significantly affect flows, but which can't be predicted and their occurrence can't always be established after the survey – check the data for anomalies)	×	N/A for LFN
Avoid presence of you and/or the microphone resulting in atypical conditions (e.g. people stopping to talk, workers on site adjusting their way of working, etc.)	✓	Yes
Include measurements which allow a robust acoustic efficiency value to be derived	✓	Yes, although a cautious approach has been taken

Evaluate any difference in noise level which might results between using manufacturer noise levels versus measured noise levels	✓	Yes. The assessment is based on manufacturer source data for some screens. For some screens, a comparison of measured versus manufacturer data has been undertaken and measured levels are lower.
Data handling		
Download data immediately after survey and process promptly whilst details are fresh in your head	✓	Yes
Use digital transfer methods wherever possible, double check data read-off manually	✓	Yes
Look at the time-history (in as fine a resolution as possible) for any unexpected events – preferably with active spectral data	✓	Yes
Prediction		
Use measurement data at different distances/locations to verify propagation	✓	Yes, although it has identified the need to undertake more research on LFN and wind effects
Use measurements at different heights to verify screening effects, where relevant	×	N/A for LFN
Use propagation calculation procedure relevant to source and distance	✓	Yes
Use detailed traffic flow data applicable to the assessment methodology	×	N/A for LFN
Use detailed sound source data (including octave-bands levels), accounting for size, height and directivity, where known	✓	Yes
Use detailed topographical data and base mapping	✓	Yes, although topographical information is excluded from the noise model as it has little effect on LFN levels
Identify different ground types	×	N/A for LFN
Apply an order of reflections of at least one	×	N/A for LFN

Use 3D view feature of the modelling software to check the accuracy of the model	×	N/A for LFN
Produce contour plots as a further means of identifying any abnormalities or errors in the model	✓	Yes
Where mitigation is included in the noise model, ensure it is tested with proven results available.	✓	Yes, although assessment uses a cautious approach to quantifying the reduction from inherent mitigation
LFN Uncertainty		
Assess any amplification effects of LFN in buildings	✓	Yes – no amplification has been assumed within the a, cautiously, no attenuation from the building structure.
Quantifying and assessing the effects of beating caused by more than one screen operating	✓	Yes – a +5dB correction can be applied for beating

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