Independent Noise Working Group

Wind Turbine Amplitude Modulation &

Planning Control Study

Work Package 5 - Towards a draft AM condition

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Abbreviations

AM	Amplitude Modulation
EAM	Excessive (Enhanced) Amplitude Modulation
FFT (fFT)	Fast Fourier Transform
IoA	Institute of Acoustics
IoA GPG	Institute of Acoustics Good Practice Guide
NAM	Normal Amplitude Modulation
OAM	Other Amplitude Modulation
RUK	RenewableUK, the wind industry trade association
SCADA	Supervisory Control and Data Acquisition

1 Executive Summary

1.1 Excess (or enhanced) amplitude modulation noise (EAM) is defined in this work package as the audible level of amplitude modulation (AM) noise received in the far field. There are a number of existing methods for identifying and assessing excess (or enhanced) amplitude modulation (EAM), though few have been formally adopted. It is widely acknowledged that ETSU-R-97, the decibel procedure adopted in the UK, does not account for the noise characteristic of EAM and as such an additional means of control is needed for this widely occurring aspect of wind farm noise.

1.2 Four main methods for assessing or limiting EAM have been critically examined in this work package. These methods are representative of the range of assessment / control methods currently proposed for EAM.[1] Each method was tested with real world data from six different sites ranging from smaller single turbines to large wind farm developments. The methods tested were the Renewable UK template planning condition, a methodology proposed by RES for the Den Brook case, the original Den Brook EAM condition and the Japanese DAM methodology. In addition BS4142:2014 and BS4142:1997 were tested with data from two of the six sites.

1.3 Each method was assessed against necessary and desirable criteria for the protection of amenity as normally defined for planning controls. This included evaluation of whether the method worked with real life data, the practicality of implementing each method, whether the methods produced false positives or false negatives and most importantly whether the method was effective and thus was capable of being used to prevent periods of significant adverse impact.

1.4 The Renewable UK (RUK) proposed method aims to assess EAM using FFT analysis to calculate average AM values that can be converted to a penalty and applied to an ETSU-R-97 noise limit. The method is essentially designed to be run as an automated process. This method was found to be significantly flawed in a number of respects including imprecise condition wording, inability to filter extraneous noise and false negatives. The values of AM that are derived by the RUK method do not correspond to typical AM peak to trough levels and do not appear to relate to subjective impact. Most importantly this method failed to enable enforcement against adverse impact in any real case of identified EAM. Thus, application of a simple decibel penalty applied to existing ETSU-R-97 limits using this method was found not to provide a means of enforcement against impact in the most serious and significant of cases. It is concluded that the RUK method is unfit for purpose.

1.5 The RES method uses FFT to derive an AM value and then looks for periods where this value exceeds 2.5. This method acts on a trigger value (2.5) and as a precursor to the original Den Brook EAM assessment method. Other stages follow in the methodology but only this initial trigger stage has been tested in this work package. The RES method is essentially designed to be run as an automated process. The RES method, like the RUK method, was found to be flawed in a number of respects including imprecise condition wording, inability to filter extraneous noise, false positives and false negatives. The values of AM that are derived by the RES method do not appear to relate to subjective impact.

[1] This was correct at the time of writing (January 2015).

The redeeming feature of the RES method is the means of control, use of a trigger value rather than any independent assessment of EAM acceptability. Whilst the RES method misses significant periods of EAM a slightly modified version of the RES algorithm allowed some improvement to the identification of EAM. This modified approach could be used as an assisting tool for identifying EAM, using a trigger value, but due to the flaws listed above it is not recommended as a standalone assessment method.

1.6 The DAM method simply provides a means to rate EAM, using an AM index, and offers no guidance on how it might be used in part of a condition or what is an acceptable or unacceptable DAM value. Though influenced by extraneous noise, the DAM method worked well to identify periods of EAM and periods of borderline AM. In some cases it did not well reflect the peak to trough level of modulation, particularly where there was erratic AM, but in most cases the DAM AM index well reflected the typical peak to trough modulation. The DAM method for deriving an AM value is considered successful if used as a trigger value and could be used to determine a typical peak to trough value when EAM is not erratic or heavily influenced by extraneous noise.

1.7 The Den Brook method was found to work well with the data from all six sites tested and successfully identified EAM without being influenced by extraneous noise. Much of the success depends on the interpretation and implementation of the Den Brook method and this has been discussed in greater detail in the body of this work package. Of note, it is implicit that the Den Brook method should not be used as a simple trigger value and that an assessment of frequency and duration must be made by the assessor as to the extent of impact. This is consistent with other UK planning noise controls. If the Den Brook condition were to be treated as a simple metric or trigger value a higher peak to trough value in the region of 6dB would need to be used. However, it is not recommended that this condition is used as a simple trigger value.

1.8 The 2014 version of BS4142 was also used to assess impact at two of the six sites. BS4142 has previously been dismissed, both in ETSU-R-97 and by others, as an appropriate means of control for wind farm noise. The issues raised to support these arguments have been examined below and found inapplicable to the new version of the standard. BS4142:2014 was found to work very well for assessment and control of cumulative wind farm noise and character impact.

1.9 The ability of noise conditions to build in an assessment of frequency and duration with the control of unwanted sound was discussed at an early stage in the formulation of the work package scope. The difficulty of rating EAM for frequency and duration in the absence of research looking at long term impact of EAM and subjective response was raised as a legitimate issue. It is concluded that assessment of the extent of impact should remain the responsibility of those assessing and enforcing impact. This is consistent with the approach of the majority of noise conditions applied across the UK where a short time metric is applied but enforcement normally requires prolonged or high exceedance.

1.10 This work package shows that existing methods of controlling and assessing AM can be successfully modified and implemented to provide a prescriptive and unified assessment process for EAM. Where wind farm noise level and wind farm noise character require simultaneous assessment the use of BS4142:2014 is recommended. The rated wind farm

noise level should not exceed +10dB above the background sound level. Where wind farm noise EAM requires assessment in isolation, procedures based on the principles of the Den Brook condition should be used. This may be complemented by a simplified RES method, used to help identify periods of EAM where many weeks of data have been obtained, and by the DAM method where the extent of modulation is debated. A DAM rating of 3.5 or above / an AM index of 5 or above should be considered EAM. Use of ETSU-R-97 could be continued where the noise from a wind farm is steady, benign and anonymous, typically where the LAeq is not more than 2dB above the LA90, but with the caveat of widespread criticisms of the method and the allowance of excess noise particularly at night time. Whilst a review of the ETSU-R-97 methodology and recommended noise limits is long overdue, it is beyond the scope of this work package.

2 Scope and background

2.1 This work package deals only with audible excess amplitude modulation (EAM). Whilst EAM is primarily described by a peak to trough variation there are many other associated character features that undoubtedly contribute to the adverse perception of wind farm noise and EAM. This includes frequency content (particularly low frequency modulation), rhythmic aspects of the noise (beating), the erratic or steady nature of peak occurrences, predictability of the noise, interactive effects of multiple turbines generating AM or EAM, tonality, impulsivity, changes in spectral content from moment to moment, the rate of fall in decibel level, average or peak decibel level and other non acoustical factors.

2.2 Time and resource constraints necessarily limit this work package to assessment of audible EAM focusing on and with reference to peak to trough level. This is particularly the case as procedures described by others focus primarily on this factor; however, it is noted that this introduces a risk of uncertainty and understating of impact through excluding the multiplicity of impact factors beyond modulation depth. Cumulative character features will undoubtedly heighten perceived impact and consideration should be given as to whether multiple character features require multiple, additive penalties or rating. Consideration of such factors is beyond the scope of this project.

2.3 In this work package AM is used to refer generically to amplitude modulation caused by wind turbines. AM can include reference to EAM. Specifically, EAM is used to refer to the level of amplitude modulation that is experienced in the far field in an unreasonable and unacceptable manner and that was not considered in ETSU-R-97.[2]

2.4 Other research projects, see for example Renewable UK *Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect*, have sought to redefine AM or EAM as 'normal' (NAM) and 'other' (OAM).[3] NAM is taken as the inherent feature of all wind turbine noise commonly referred to as blade swish. OAM is essentially everything other than NAM and includes characteristics such as greater depth of modulation, different directivity patterns and different noise character. Whilst these definitions might initially be considered in keeping with the definition of EAM there are some primary conflicts that arise from further refinement of the NAM and OAM definitions.

2.5 NAM, as defined by Renewable UK research, is detectable close to the turbines and not expected at distances further than 400m - 500m. The frequency range is typically between 400Hz - 1000Hz. It should be negligible at large distances from the turbine(s). The modulation depth of NAM does not typically exceed 5dB(A). NAM is commonly defined as the AM originally envisaged by ETSU-R-97. However, the above definition of NAM (not further than 400m-500m and between 400Hz-100Hz) is different to that of AM given in ETSU-R-97. ETSU-R-97 described AM as only occurring close to the turbine, most apparent less than 50m from the base of a supporting tower. Modulation at this distance was in the order of 2-3dB and centred around the 800Hz - 1000Hz frequency region. Thus the

[2] Great Britain. Department of Trade and Industry (DTI) (1997). *ETSU-R-97 The Assessment and Rating of Noise from Wind Farms*.
[3] Renewable UK (2009). Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect. London: Renewable UK.

definition of NAM already departs significantly from that of AM described in ETSU-R-97 and allows more mid frequency impact and at further distances.

2.6 OAM is described in Renewable UK research as having lower frequency content, increased modulation depth and can occur at significant distances from the wind turbine(s). With reference to the above, OAM must by definition (of being everything other than NAM) occur at distances in excess of 400m - 500m, have greater modulation depth of up to 6-10dB(A) and have a spectral content that includes frequencies below 400Hz. In the Renewable UK report it is noted that reported incidence of OAM is limited and that where it does occur it is an intermittent and atypical feature. Conversely the occurrence of EAM at distances in excess of 400m - 500m and with lower frequency content is common both in the UK and internationally as confirmed in other work packages of this project, see for example WP2.1, WP2.2, WP3.1 and WP9. At those sites where EAM has been measured over a sustained period it is found frequently and can last for long periods.

2.7 NAM is primarily explained as trailing edge noise, which has a known cause. OAM is explained as other noise generation mechanisms not explained by trailing edge noise. The cause of OAM is attributed by Renewable UK as primarily due to blade stall. However, for this cause to be consistent with observation of EAM in the field, blade stall would have to occur frequently, for long periods and at a number of different wind farm / wind turbine locations (potentially all wind turbines). It does not follow that blade stall is the sole plausible explanation and definition of OAM. The definition and causes of AM are further discussed in WP1.

2.8 There is evidence of a lower frequency noise problem from wind turbines, for example extending down to around 30Hz.[4] This work package is limited to analysis of A weighted noise data, which will significantly reduce the apparent impact of these lower frequencies, and EAM that arises primarily in the region of 80Hz - 630Hz. It is accepted that the methods and analyses used in this work package are unlikely to be appropriate for these lower frequency issues.

2.9 The time constants now commonly used to measure EAM typically relate to a 'fast' response, either 125ms or 100ms data. This is true of the majority of EAM analysis methods discussed below. It is noted that the use of faster time constants may be appropriate but has not been considered in this work package. The use of faster time constants may have several important consequences including showing a 'messier' noise trace rather than a single clear peak (and trough) and increasing the peak to trough difference. Further work interrogating the appropriateness of the currently accepted time constants, 125ms / 100ms, and whether a shorter time constant is warranted is recommended but is unfortunately beyond the scope of this work package.

2.10 In summary, this report deals only with audible AM. EAM is AM enhanced or in excess of that envisaged by ETSU-R-97 and which is causing justifiable complaints. OAM is considered one aspect or a subset of EAM. EAM typically has a modulation depth of 3-13dB but can occasionally be higher and can contain significant lower frequency content. It has specific

[4] Cooper, S.E. (2014) for Energy Pacific (Vic) Pty Ltd. The Results of an Acoustic Testing Program Cape Bridgewater Wind Farm. Available from: http://www.pacifichydro.com.au/english/our-communities/communities/cape-bridgewater-acoustic-study-report/

noise character often described as thumping, beating, whipping, lashing etc. EAM is a common occurrence at wind energy installations across the UK.

3 Introduction and methodology

3.1 Amplitude modulation (AM) is further defined in WP1. This work package deals only with audible AM and does not cover very low frequency noise content. Literature and evidence relating to the existence, measurement and impact of AM is detailed in WP2.2. The effect of AM on local communities is discussed in detail in WP3.1 and with specific reference to Cotton Farm Wind Farm in WP9. There is significant evidence supporting the need for a planning condition to control EAM and thus prevent adverse impact arising. This work package aims to:

→ Review current and typical methods for assessing and controlling EAM.
→ Use real world data to test and define a workable and effective control for EAM that can be adopted going forward.

3.2 The potential for adverse impacts from a proposed development may be controlled by way of a planning condition as a pro-active approach to development control. Planning conditions are applied to approvals where a development might otherwise have been refused. The planning condition makes a development permissible and thus by definition in the absence of these conditions the development is considered to have an unacceptable impact.

3.3 The evidence provided in WP1, WP2.1, WP2.2, WP3.1, WP3.2 and WP9 provide support that EAM is an adverse and unacceptable impact generated by wind turbine development. It is also the case, as supported by evidence, that all wind turbine noise signatures exhibit AM to some degree and this is reflected in the wide prevalence of AM complaints and measured noise data that corroborates these complaints.[5] It follows that a standard planning condition addressing EAM that can be applied to wind turbine development is needed.

3.4 To date there have been a minority of wind turbine planning applications approved with a condition to control for AM. The most controversial has proved to be the Den Brook AM condition.[6] The Den Brook condition has been unanimously rejected by the wind industry and by those working with the wind industry. It has been criticised for identifying false positives and for placing controls that are too restrictive on the wind industry. Despite lengthy discussion and empirical evidence showing that false positives are in fact not generated by the Den Brook condition, it still fails to gain acceptance at planning application or inquiry stage. Residents have been left wholly unprotected. Whilst, as shown below, the Den Brook condition provides a logical and successful approach to control of AM, unfortunately it seems that the condition, at least in isolation, will not be adopted by those who are ultimately responsible for deciding the fate of a wind energy application.

[5] Lee, S., & Lee, S. (2013). Numerical modeling of wind turbine aerodynamic noise in the time domain. *Journal of the Acoustical Society of America , 133* (2), EL94-100.
[6] See Appeal Ref: APP/Q1153/A/06/2017162, Land to the south east of North Tawton and the south west of Bow. Inspector Andrew Pykett.

3.5 AM control has been achieved in part by way of the Swinford AM condition.[7] The Swinford condition requires the mitigation of AM, where complaints are received and where AM is considered a contributor to the noise complaint; however, there is no guide as to what is or is not acceptable. Similarly, the condition gives no standard protocol for the measurement or characterisation of AM. Whilst the Swinford condition has been adopted in other planning decisions it is still widely neglected and as such planning controls for AM remain in the minority.

3.6 Some conditions, mainly scheme type conditions, to control EAM have been applied on the basis that an acceptable form of control will be developed by the time the scheme requires approval.

3.7 More recently a new AM control has been proposed and arises from the Renewable UK (RUK) research on AM published in December 2013.[3] This control appears to be favoured by the wind industry. On publication, the drafted AM condition was accompanied by a heavy caveat that it required testing. Testing independently[8] and within this work package with real world data has shown major problems with the condition highlighted in the testing summarised below and to be further detailed in WP7.

3.8 The RUK condition follows an emerging theme of AM measurement techniques using fast Fourier transform (FFT) analysis and focuses on the energy occurring at blade passing frequency. This approach has been further refined and detailed by RES in their most recent submission to the ongoing case at Den Brook and by the IoA AMWG in their April 2015 discussion document; essentially they all rely on the same method / principles. [9,10]

3.9 Whilst there is a difference in assessment outcome the methodology used to derive an AM value is very similar between the RES and RUK methods. The RES condition, if fulfilled, reverts the user to the original Den Brook condition discussed above and is arguably superfluous. The Renewable UK condition proposes a simple character penalty of up to 5dB that can be added on to the noise level of a wind turbine / wind farm much like the existing ETSU-R-97 tonal condition and penalty. Consequently it does not relate directly to noise character impact but to overall noise levels.

3.10 In summary, there are four main existing AM conditions that can either be applied separately, as a stand alone control, or used in conjunction with the ETSU-R-97 noise limits. International research has also provided a plethora of AM measurement and quantification techniques and whilst these help to inform appropriate methods for assessing AM the majority do not define a level of acceptability. These techniques are discussed further below.

3.11 In assessing the relative merits of AM control it is helpful to consider and evaluate methods used to control other noise sources. Industrial noise is typically assessed and controlled with reference to the British Standard BS4142. This has recently been revised and the

[7] See Appeal Ref: APP/F2415/A/09/2096369, Land to the north-east of Swinford. Inspector John Woolcock
[8] Large, S. & Stigwood, M. (2014) The noise characteristics of 'compliant' wind farms that adversely affect its neighbours. *Internoise 2014* Melbourne, Australia.
[9] See West Devon Borough Council, planning application ref: 00261/2014.
[10] See: http://www.ioa.org.uk/sites/default/files/AMWG%20Discussion%20Document.pdf

current document is BS4142:2014 'Methods for rating and assessing industrial and commercial sound'.[11] The revised standard places greater emphasis on noise character and context of the noise in the wider environment. This arguably has greater relevance to wind turbine noise than the previous version of the standard. It is noted that the scope of the standard warns against its use where the source falls within the scope of other guidance. Whilst ETSU-R-97 is guidance for assessing wind farm noise, it does not include any assessment of noise character, with the exception of tonality. The noise limits of ETSU-R-97 are aimed primarily at steady, continuous, anonymous noise.[12] As such the assessment approach of BS4142:2014 may now be considered valid where wind farm far field noise contains AM; this has been discussed further below.

3.12 Other noise controls set absolute or threshold noise limits, much like the absolute limit for wind farm noise prescribed in ETSU-R-97. These types of control can become problematic where the noise is not benign or anonymous. Noise sources that have specific noise character often need additional measures to account both for the decibel level and character of the noise. Clay target shooting generates impulsive noise that attracts attention both due to its level and due to impulsive, intermittent character. Clay target shooting guidance sets a level relative to the maximum noise events measured during a defined period.[13] Lower limits are prescribed where the impact is more frequent and acceptability is related to background sound. Thus, there is an element of frequency and duration of impact in context with the character of the area that is accounted for within the clay target shooting guideline levels.

3.13 Controls on music noise can be found in the Code of Practice on Environmental Noise Control at Concerts and the Institute of Acoustics Good Practice Guide on the Control of Noise from Pubs and Clubs.[14,15] Music noise can be particularly intrusive due to the character of the noise, such as frequency content, rhythm, beating, changes in rhythm and time, but also due to the message imparted either by the lyrics, genre or by those playing the music. For concerts a threshold noise level is set, which reduces as the number of events increases. Thus, as residents are exposed to longer periods of noise impact the acceptable decibel level of impact is reduced to account for the reduced respite. Similarly, noise from pubs and clubs that occurs regularly is recommended to be inaudible internally at any time. Where impact occurs less frequently the protection of sleep is sought and inaudibility is only required between 23:00 and 07:00.

3.14 Guidance on noise associated with minerals extraction is particularly relevant to wind farm noise as both minerals extraction and wind energy generation have wider national benefits

[11] British Standards Institution (2014) *BS4142:2014: Methods for rating and assessing industrial and commercial sound*. London: BSI.
[12] This was largely appropriate in 1997 given the low level of knowledge regarding EAM at that time. ETSU-R-97 considered that WHO guideline levels were relevant but it is evident and widely accepted that these levels are relevant only to steady continuous general noise, as they are based on transportation noise sources, and not site specific noise.
[13] Chartered Institute of Environmental Health (CIEH) (2003). *Clay Target Shooting Guidance on the Control of Noise.*
[14] The Noise Council (1995). *Code of Practice on Environmental Noise at Concerts.* London: The Noise Council.
[15] Institute of Acoustics (2003). *Good Practice Guide on the Control of Noise from Pubs and Clubs.* St Albans: IoA.

and are often limited to locations where the resources are available.[16] This can naturally create land use conflicts. During daytime (07:00 - 19:00) and evening (19:00 - 22:00) noise levels should not exceed 10dB(A) above the background sound level and an absolute higher limit is set at 55dB LAeq. Between 22:00 and 07:00 noise limits should be set to reduce impact to a minimum but where this cannot be avoided the absolute higher limit is 42dB LAeq. It is clear that these levels apply to all areas of the country, both rural and urban, and hence limits will vary depending on the character of the area. It is further noted that additional limits may be needed to control for tonal noise or impulsive noise, i.e. additional limits for noise character.

3.15 In summary, there are a range of approaches already used to enforce adverse noise impact and particularly noise with character. These well established approach principles can be used to establish an appropriate method for assessing and defining AM impact limits.

3.16 In addition to finding a rating level or value of AM, sufficient consideration must also be made as to how this level or value is applied to a judgement of AM acceptability. The Den Brook approach takes a view that as soon as AM is judged unreasonable this element of the noise should be mitigated. It does not refer to the ETSU-R-97 limit. BS4142 applies a penalty to the overall noise level but this is assessed in context with the background sound environment occurring in the same (meteorological) conditions but in the absence of the intruding noise. The Renewable UK approach uses a value of AM to derive a penalty that is then applied to the ETSU-R-97 limit. An approach for AM assessment following the guidance for music noise would look at frequency, duration and time of occurrence of impact. This guidance approach implies that where AM impact occurs regularly it should be inaudible within the dwelling at any time. Other approaches use a sliding scale of acceptability depending on frequency and duration of impact, the more regular the impact the stricter the control. The minerals guidance suggests that impact should be minimised and assessed in relation to the background sound environment, particularly minimised at night time. It suggests that a separate control parameter independent of the preset noise limit might be appropriate where noise character is present. Applying such principles indicates there are therefore a number of ways in which an AM condition could be used to mitigate adverse impact.

3.17 Once an acceptable AM control method and means of application is decided, the AM condition must further satisfy key planning criteria. Government provides six objectives which any planning condition is required to meet.[17]

Conditions should only be imposed where they are:

1. *necessary*
2. *relevant to planning*
3. *relevant to the development to be permitted*

[16] Great Britain. Department for Communities and Local Government (2014). *Planning Practice Guidance: Guidance on the planning for mineral extraction in plan making and the application process.*[Online] Available from: http://planningguidance.planningportal.gov.uk/blog/guidance/minerals/. [Accessed 18/02/2015]

[17] Great Britain. Department for Communities and Local Government (2014). *Planning Practice Guidance: Use of Planning Conditions.* [Online] Available from: http://planningguidance.planningportal.gov.uk/blog/guidance/use-of-planning-conditions/application-of-the-six-tests-in-nppf-policy/ [Accessed: 10/12/2014]

4. *enforceable*
5. *precise*
6. *reasonable in all other respects*

3.18 The need and relevance of AM control is discussed above and supported by WP1, WP2.1, WP2.2, WP3.1 and WP9. The first three of the above listed objectives are therefore met.

3.19 Enforceability is key and will require firstly an effective method to identify AM and secondly an effective means of control. Any proposed condition or methodology recommended by this work package must effectively protect against unreasonable AM impact. This is particularly relevant as AM impact is additional to the overall decibel increase caused by the wind farm. It must be practicable to detect breaches and there must be a realistic prospect of measuring the noise. The condition should be enforceable within normal technical means, for example it should not need special ability to determine compliance or breach.

3.20 The condition must be precise, there must be an objective and measurable criterion and it must be clear as to how the condition can be met. The wording of any condition must be specific to prevent multiple interpretations and therefore conflicting conclusions on acceptability.

3.21 The condition must be reasonable and not unduly restrictive. It may be reasonable to require the turbine to be shut down temporarily to assess background sound levels but it is not reasonable to require the turbine to cease all operation in the event of complaints. There is also issue here for cumulative impact and multiple developments. It is reasonable to cease the operation of a turbine in the event of a complaint relating to that turbine but it is not reasonable or lawful to require another unrelated development to cease operation, for example to measure background sound, for the purposes of the complaint related turbine operation.

3.22 The means to assess compliance with the condition must be available to all parties. This includes accessibility to noise monitoring locations.

3.23 In meeting the above objectives it must be shown that the condition is effective. In this respect the condition must be shown to work and effectively prevent the impact that is judged unreasonable. To prove this any proposed condition must be rigorously tested. The testing should use real world data to ensure validity and be tested with a large sample of data. Samples should be taken from different sites where different situations arise such as background sound environment, number of turbines, size of turbines, noise character. This will test whether the condition is widely applicable and not designed only for one idealised manifestation of AM.

3.24 The data required to assess the condition should be open access without the need for protracted Freedom of Information requests. This will necessarily include the noise data and any other data used to test the condition. This may include wind speed data and the turbine SCADA data depending on the condition methodology.

3.25 Notwithstanding the objectives set by Government there are additional objectives that are desirable for the condition to meet.

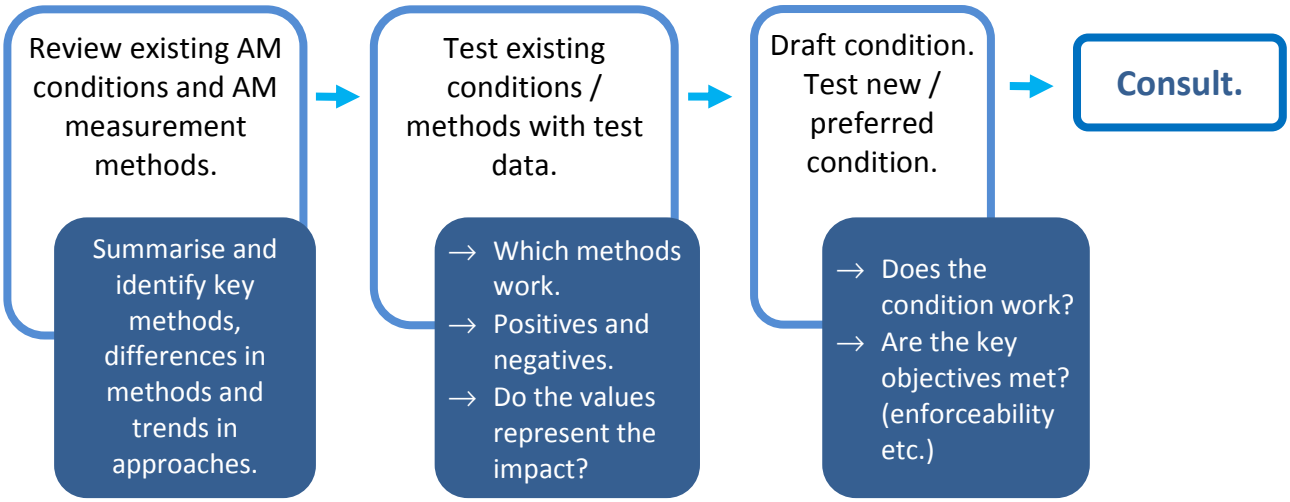
a. The condition must work with real world data. As described above this can vary from single turbines to multiple turbines. It might include cases where a clean AM peak to trough is visible in data and cases where the trace is influenced by multiple peaks and is less clearly defined. It must be able to deal with influences from other noise sources.
b. The condition must be comprehensible and practicable to implement. This is both in terms of accessing the location of compliance monitoring but also in the actual assessment of compliance. The condition should be aimed at those most likely to use it, local authority officers, and the tools and skills available to them. It should not require specialist expertise to interpret the data.
c. The condition should relate to the impact it is being designed to prevent. Any control should take account of the psychoacoustic response associated with the impact and reported complaints in existing cases.
d. The condition should be transparent. The methodology of the condition should be clear and detail any data manipulation or filtering steps. The ability to test data for compliance should be open access including any software required to analyse the data.
e. Others have proposed the preference for the condition to be workable with large amounts of data and therefore be largely automated.[18]
f. Most importantly it must be shown that the condition is effective, the control(s) must prevent periods of adverse AM.

3.26 There are numerous other factors that must be considered when deriving a condition, some of which are touched on above. This includes the method by which the condition controls AM and the way in which AM is defined and described. Controls can be objective or subjective, the implication is already that an objective control will be derived rather than a subjective assessment of whether AM exists and is acceptable. An objective method could be an AM value, a peak to trough level, a rating level, or some other value of AM determined by other data processing methodologies. The objective value that is determined could be a single value for each period examined, an average of values over an indeterminate time frame, a range of values describing how AM manifests over a period of time or a combination of these.

3.27 Once a decision is made as to how to derive the AM value it must be considered how this value controls noise impact. Is a penalty approach justified and can the noise limit simply be lowered to reflect greater impact of AM? The AM value could be applied directly as a rating either with an independent noise character scale or in relation to source noise (e.g. ETSU-R-97) and / or background sound (e.g. BS4142 assessment). The AM value could simply be a trigger value, once a certain value is reached it is no longer acceptable, but it might also consider context, frequency and duration of impact. Whichever is adopted the primary goal of preventing adverse impact must be achieved.

[18] This is only considered necessary if compliance is based on long term averaging. Long term averages are unlikely to be appropriate for short term effects and are unlikely to relate to impact.

3.28 The method used to derive a condition therefore requires several detailed steps. These are outlined in the flow diagram below, the first stage of this follows below.



3.29 As a final note it is worth considering the wider issue of AM control and complaints. WP3.1 concludes that a large proportion of wind farm neighbours do not realise that the noise problem they are suffering is attributable to AM. Often no action is taken against a wind farm generating AM until a resident complains to the Council. Research has long documented that the number of people who actually complain is limited and does not faithfully represent the number of those actually affected.[19] Any recommended condition or preferred methodology should ideally be readily understandable to the lay person, as noted above, but also the condition should be widely publicised. This could include reference to AM and AM control in guidance, readily understandable information for the lay person and ideally educational programmes for planning inspectors and local authorities.

[19] See for example: World Health Organisation (WHO) (2000) Noise and Health. Copenhagen: WHO & Health Protection Agency (HPA) (2010) Environmental Noise and Health in the UK. Didcot: HPA.

4 Review of existing AM assessment and quantification methods

4.1 Whilst in the UK there are only a few planning conditions that have been proposed for control of AM, internationally there are a range of procedures and methods for identifying and assessing AM. This section aims to provide a brief overview of the range of methods and procedures used but is by no means exhaustive.

4.2 **The Nordtest Method (NT ACOU 112) (2002).**[20] As well described by the scope of this method:

> *Noise with prominent impulses is more annoying than continuous types of noise (without impulses or tones) with the same equivalent sound pressure level. Therefore an adjustment Ki is added to the measured LAeq, if prominent impulses are present in the noise, to adjust for the extra annoyance due to the impulses.*

4.3 The adjustment is found by calculating the prominence P of a sound, which in turn relies on the onset rate (how quickly the sound rises in level) and the difference in level (how much the noise level changes by in dB). This method has recently been adopted by British Standard BS4142:2014 as an additional means for testing and rating noise character.

4.4 **The Den Brook Condition (2009).**[6] First drafted in 2009 this AM condition is commonly known as the Den Brook condition in reference to the wind farm appeal for which it was drafted. It was proposed at appeal and accepted by the Secretary of State. The history of this case is provided in more detail in WP4. The Den Brook condition was formulated by studying far field AM data and looking for key indicators that EAM was occurring. The condition sets a lower limit of 28dB LAeq,1min assuming that average noise levels below this level are unlikely to cause adverse noise impact. EAM is identified by looking for a difference in peak to trough level of more than 3dB(A). Importantly, this was never designed as a trigger value. Based on observations of field data it was concluded that if AM was regularly found in the region of 3dB(A), greater levels of modulation would also occur. Using the principles applied to other planning conditions, enforcement would not be expected to arise from isolated occurrences only at this value (3dB(A) peak to trough / 28dB LAeq). The assessor must use their expert judgement incorporating level of impact with frequency and duration of impact to decide where it is appropriate to take action.[21]

4.5 The condition also sets a lower requirement of impact occurring more than 5 times in a minute period (for example 5 peaks in a minute period) and that at least 6 minutes in an hour period should be affected before the condition is triggered. The condition provides a method for identifying EAM on the basis that EAM is unacceptable.

4.6 **Lee et al 2009.**[22] *An estimation method of the amplitude modulation in wind turbine noise for community response assessment.* Lee et al describes a method for estimating AM by looking at the spectogram of short time series of wind farm noise. For each frequency band

[20] Nordtest (2002). *Acoustics: Prominence of Impulsive Sounds and for Adjustment of LAeq.* Espoo: Nordtest.
[21] For example, this may be 50 examples of EAM with peak to trough level of 3-4dB(A). It may be only 10 examples of EAM with peak to trough level of 10dB(A).
[22] Lee, S. et al (2009). An estimation method of the amplitude modulation in wind turbine noise for community response assessment. Paper presented at the *Third International Meeting on Wind Turbine Noise*. Aalborg, Denmark.

a fast Fourier transform is applied to find two dominant peaks, one at the root-mean-square value and a second at blade pass frequency. The modulation depth can be calculated from the difference between the maximum and minimum value of the two peaks. This is applied to all frequency bands and a modulation factor, based on the modulation depth, is obtained. The study also found a high correlation between annoyance and increasing LAeq and annoyance and increasing modulation factor.

4.7 **Lenchine 2009.**[23] *Amplitude modulation in wind turbine noise.* Lenchine bases an assessment of amplitude modulation on fluctuation strength, building on work done by Fastl and Zwicker. The fluctuation strength is derived from measures of the modulation depth (difference between maximum and minimum values), the broad band A weighted or linear noise levels and the modulation frequency, typically around 1Hz to correspond with turbine blade pass frequency. Lenchine notes that a better correlation with subjective judgement of amplitude modulation is found using the non-weighted sound pressure level.

4.8 **New Zealand Standard - Acoustics - Wind farm noise (NZS 6808:2010) (2010).**[24] Special audible characteristics are identified in the New Zealand guidance and include tonality, impulsiveness and amplitude modulation. Where complaints of AM are received by a local authority a subjective assessment can be made and a 5dB penalty applied to the wind farm sound level if AM is considered present. AM can be confirmed where the A weighted peak to trough levels exceed 5dB on a regularly varying basis or if the measured third octave band peak to trough levels exceed 6dB on a regular basis in respect of the blade pass frequency.

4.9 **Di Napoli (2011).**[25] *Long distance amplitude modulation of wind turbine noise.* Based on noise measurements from long term noise monitoring near to a wind farm in Finnish Lapland, two different objective methods were used to assess amplitude modulation noise measured from wind turbines. This included the Nordtest method described above and fluctuation strength also detailed in Lenchine (2009) above. Downwind measurements were found to result in the highest rating values for amplitude modulation. A later assessment summarised in Di Napoli (2012) reports results only using the Nordtest method.

4.10 **Lundmark (2011).**[26] *Measurement of swish noise. A new method.* Lundmark identifies use of 125ms A weighted data analysed using fast Fourier transform. This allows indication of amplitude modulation frequency (blade pass frequency) and modulation strength. Lundmark notes the importance of measuring AM noise only when complaints arise and not, for example, on warm sunny days, which may be appropriate for other noise monitoring but not measurement of wind farm AM.

[23] Lenchine, V. (2009). Amplitude Modulation in wind turbine noise, in: *Proceedings of Acoustics 2009*, Adelaide, Australia, November 2009.
[24] New Zealand Wind Energy Association. (2010). *The New Zealand Wind Farm Noise Standard NZS 6808:2010.* Wellington.
[25] Di Napoli, C. (2011). Long Distance Amplitude Modulation of Wind Turbine Noise. *Fourth International Meeting on Wind Turbine Noise.* Rome, Italy.
[26] Lundmark, G. (2011). Measurement of Swish Noise. A new method. *Fourth International Meeting on Wind Turbine Noise.* Rome, Italy.

4.11 **McCabe (2011).**[27] *Detection and Quantification of Amplitude Modulation in Wind Turbine Noise.* A fast Fourier transform is again the focus of this method. AM is assessed using audio recordings filtered in to third octave bands. McCabe tests the method with data measured close to a wind farm and 450m from the wind farm. It is noted that modulation factor does not correlate with wind speed, particularly during daytime hours, which is converse to the relationship observed between noise level and wind speed. The modulation factor was found to correlate fairly well with wind shear.

4.12 **McLaughlin (2011).**[28] *Measurement of amplitude modulation frequency spectrum.* Notwithstanding that McLaughlin incorrectly considers AM as rare in the far field where many papers outlining similar methods for measurement of AM accept it is common and fundamental in wind farm noise annoyance, in other respects a similar approach to AM assessment is adopted. A fast Fourier transform is performed on data that has been down sampled and filtered. This is performed for each single octave band. McLaughlin presents some interesting results from a sample of wind turbine data that subjectively moves from 'swish' to 'thump' sound. Rather than differences in the harmonics of each single octave band distinct differences in modulation strength of the blade pass frequency are observed, for example as the sample moves to a 'thump' sound the modulation strength in the 250Hz and 500Hz single octave bands increases.

4.13 **Atzler et al (2011).**[29] *Evaluating the degree of annoyance caused by impulsive noise types.* Whilst not directly aimed at assessing wind farm noise this methodology has clear parallels, including for example with the Nordtest method, with other methodologies designed for assessing AM. Research undertaken on disturbing and impulsive noises created by vehicle engines results in an interesting and successful method for categorising and rating specific character features of engine noise. The overall noise level of the engine was measured and a fast Fourier transform used to obtain the spectral content for a given time period. This was then split in to temporal and spectral components to investigate impulsivity and spectral attributes respectively. With reference to the level, temporal structure (regularity), frequency contribution and impulsiveness, the noise from the engine was categorised as knocking, ticking, rattling or impulsive. A rating level for the noise was derived from a formula taking account of the noise level of the particular attribute, the difference between the attribute level and the overall noise and the impulsivity of the noise. The rating level was found to correlate well with subjective jury rating of the attributes. The type of approach, categorisation of noise attributes and rating of attributes in relation to noise level could be applied to wind turbine noise, AM and other character features such as tonality and impulsivity. The approach has parallels with a BS4142 assessment, discussed further below.

[27] McCabe, J.N. (2011). Detection and Quantification of Amplitude Modulation in Wind Turbine Noise. *Fourth International Meeting on Wind Turbine Noise.* Rome, Italy.
[28] McLaughlin, D. (2011). Measurement of amplitude modulation frequency spectrum. *Fourth International Meeting on Wind Turbine Noise.* Rome, Italy.
[29] Atzler, M. et al (2011). *Evaluating the degree of annoyance caused by impulsive noise types.* [Online] Available from: http://www.fev.com/fileadmin/user_upload/Media/TechnicalPublications/NVH/Evaluating_the_Degree_of_Annoyance_Caused_by_Impulsive_Noise_Types.pdf [Accessed: 18/02/2015]

4.14 **Draft New South Wales Planning Guidelines for Wind Farms (2011).**[30] Amplitude modulation is categorised along with tonality and low frequency noise as a 'special audible characteristic'. Excessive amplitude modulation is defined in the guidelines as a variation of 4dB(A) at the blade passing frequency. If excessive amplitude modulation is found then a 5dB(A) penalty is added to the predicted or measured wind farm noise level and this is compared against the noise limit to test compliance.

4.15 **Gabriel et al (2013).**[31] *Amplitude Modulation and Complaints about Wind Turbine Noise.* Gabriel uses two methods to investigate the intensity of AM. The modulation depth was obtained using a similar approach to methods outlined above involving fast Fourier transform. The audio sample was filtered and the modulation spectrum used to find the amplitude of the blade passing frequency. In addition the fluctuation strength, as discussed above and according to Zwicker, was used to gain a measure of AM.

4.16 **Cooper and Evans (2013).**[32] *Automated detection and analysis of amplitude modulation at a residence and wind turbine.* The aim of Cooper and Evans paper is to investigate assessment of AM in relation to the AM criteria outlined in the New Zealand Standard, also discussed above. To obtain the blade pass frequency (the modulation frequency) a fast Fourier transform with windows of 24 seconds, with window overlap, was used in each third octave band between 250Hz and 1000Hz (this range was found to be most reliable in giving the modulation frequency). The modulation frequency results were binned and a weighting applied to help refine modulation frequency and account for variations in the modulation frequency over time. To calculate the level of modulation, as required by the New Zealand Standard, an algorithm identifying maxima and minima with a sliding window but related to modulation frequency was used. The peak to trough difference was linearly averaged to calculate an average peak to trough difference for each 2 minute period analysed. Where excessive modulation is identified the 5dB penalty proposed by the New Zealand Standard would be enforced. As identified by Cooper and Evans, where noise levels are low this would have no effect on reducing impact or on compliance. It is noted that further refinements to the method and algorithm could be made to allow detection of AM at lower noise levels and lower modulation limit.

4.17 **Renewable UK (2013).**[3] *Template Planning Condition on Amplitude Modulation.* The Renewable UK template condition builds on work done previously, outlined above, using audio files and assessment using fast Fourier transform to find blade passing frequency. A series of averages is used to find a penalty that can be attributed to a turbine noise limit at a particular wind speed.

4.18 The assessment period is broken in to 10 second non overlapping intervals from a 10 minute period; ultimately an amplitude modulation value for each 10 minute period is to be derived. Each 10s time series is detrended, and the blade frequency found using a power spectral density function using a rectangular window. The energy found in a defined

[30] NSW Government Planning & Infrastructure. (2011). *NSW Planning Guidelines Wind Farms (Draft).* New South Wales: Department of Planning & Infrastructure.
[31] Gabriel, J., Vogl, S. & Neumann, T. (2013). Amplitude Modulation and Complaints about Wind Turbine Noise. *5th International Conference on Wind Turbine Noise.* Denver, U.S.A.
[32] Cooper, J. & Evans, T. (2013). Automated detection and analysis of amplitude modulation at a residence and wind turbine, in: *Proceedings of Acoustics 2013,* Victor Harbor, Australia, November 2013.

band around the blade passing frequency is calculated and ultimately this provides a value of AM for each 10 second period. The overall 10 minute AM value is the arithmetic mean of the 12 highest AM levels derived from the 10 second periods. Where doubt arises over extraneous noise sources the audio data is listened to for verification. The AM value for each 10 minute period is plotted against the appropriate wind speed. If no AM is measured in a 10 minute period a value of zero is used. A best fit line is drawn throughout the data to find an average AM level for each wind speed. A figure is provided to determine the applicable penalty for the average level of AM and this penalty, maximum 5dB, is applied to the noise limit.

4.19 A presentation to the IoA Wind Turbine Noise conference in Newport, 2014 (Levet & Craven, 2014) tested the RUK method for rating AM with other methods including the DAM method discussed further below.[33] Levet & Craven found that the AM values derived using the RUK method tended to underestimate AM peak to trough values and suggested including energy in the second harmonic (of blade pass frequency) particularly where the AM trace was not clean or sinusoidal.

4.20 **Renewable UK (RUK) (2013).**[3] *Development of an AM Dose-Response Relationship.* The RUK research includes at work package B(2) the findings of tests undertaken by the University of Salford on the development of a dose response relationship for AM. Listening tests were conducted using artificially generated stimuli. The findings of the listening tests indicated that LAeq was the most dominant indicator of annoyance. Whilst in some tests an increase in modulation depth was found to increase annoyance rating, this was not found to be significant and increases in annoyance rating due to modulation depth were minimal with relatively large confidence intervals.[34] Initial tests found that temporal parameters and modulation frequency had little or no impact on annoyance rating. The use of A weighted values were found to give consistent results and suggested that this is an appropriate weighting filter to apply for the stimuli in this case. The work concluded that annoyance depended crucially on LAeq and to a much lesser extent on modulation depth. The research therefore does not have any directly applicable dose-response relationships that can be applied for EAM assessment based on a measure of modulation depth.

4.21 **Fukushima et al (2013)**.[35] *Study on the amplitude modulation of wind turbine noise: Part 1 - Physical investigation.* A large study program of 34 wind farms across Japan was used to inform this study and further details are provided in Tachibana (2013).[36] The study by Fukushima et al focused on recordings from 18 wind farms and used the difference in the measured A weighted slow and fast noise level to find an amplitude modulation rating. The AM depth, DAM, is found by calculating the difference between the L5 and L95 of the difference between the fast and slow measured noise level. The DAM of 3 minute samples

[33] Levet, T & Craven, M (2014). Initial findings using RUK AM assessment methodology. *Wind Turbine Noise AM, and where to next for ETSU-R-97?* Newport, 2014.
[34] Indicating a wide variability in participant's rating of stimuli and less confidence that the increase in annoyance is due solely to modulation depth.
[35] Fukushima, A., Yamamoto, K., Uchida, H., Sueoka, S., Kobayashi, T., Tachibana, H. (2013). Study on the amplitude modulation of wind turbine noise: Part 1 - Physical investigation. *Internoise 2013.* Innsbruck, Austria, 15-18 September 2013.
[36] Tachibana, H., Yano, H., & Fukushima, A. (2013). Assessment of wind turbine noise in imission areas. *5th International Conference on Wind Turbine Noise.* Denver.

taken from 18 wind farms was obtained. A DAM of 2-2.4 was most commonly found. It was found that fluctuation sensation begins at AM of around 2dB.

4.22 **RES Den Brook (2014).**[9] *Written scheme relating to condition 21 Den Brook Wind Farm - implementation of condition 20 for the identification of greater than expected amplitude modulation.* Due to objections against the Den Brook AM condition, discussed above, the developer of the Den Brook Wind Farm (RES) devised a scheme, similar to the methodology outlined in the RUK condition, which is undertaken prior to the use of condition 20. The history of the Den Brook case is further discussed in WP4.

4.23 A convoluted series of analysis steps are required by the scheme before the original AM condition, condition 20, is checked for exceedance. The steps are similar to the RUK analysis of AM. Stages 1-3 of the scheme are prerequisites before data can be tested for AM. Stage 4 identifies the analysis of greater than expected amplitude modulation (GTE-AM). Firstly the 1 minute LAeq(s) taken from an hour period must be greater than 28dB LAeq to be included in assessment. The 1 minute periods are split in to separate, non overlapping, 10s periods and detrended by subtracting the mean value. The power spectral density function is obtained using a rectangular window. Assuming that the blade pass frequency found from this analysis is consistent with the wind farm SCADA data the energy in the band centred on the blade pass frequency is calculated and used in a given formula to find the level of AM. If this AM level is greater than 2.5dB the audio data is used to verify that the source of the noise is the wind farm / turbine. If at least six separate 10s periods give an AM level greater then 2.5dB then the entire hour of data is assessed using condition 20 (see the Den Brook condition above). If this assessment of the data, using the Den Brook condition (condition 20), identifies GTE-AM the data is filtered to focus on the blade pass frequency and condition 20 is repeated. This is to ensure that the variation in noise level is solely attributable to the blade passing frequency. If GTE-AM is still indicated following the above analysis then a scheme to mitigate GTE-AM must be submitted to the local authority.

4.24 Whilst the scheme has been approved and so is now formally attached to the planning approval of the Den Brook Wind Farm, the original condition 20 can still be implemented and enforced regardless of the scheme outcome. The aim of the scheme is to provide a pre-filter process of checking compliance, though in reality it attempts to provide a substitute for the assessment method in condition 20. In doing so it has adopted an FFT approach as an attempted substitute for the methodology discussed in paragraph 4.4 - 4.5 above, though it cannot replace the original condition. If a simple check using the condition 20 metric shows AM regardless of the scheme approach, it constitutes a breach and warrants enforcement.

4.25 **BS4142: 2014.**[37] BS4142 has been extensively and successfully used for a number of years and applied to a range of situations. The basic concept of BS4142 is that the source noise is compared to the background sound in the same conditions (meteorological conditions, operating conditions etc). The source noise is rated for any attention drawing characteristics and the difference between this rated source level and the background sound level indicates the acceptability of the noise source. The 1997 BS4142 had a simple

[37] British Standards Institution (2014) *BS4142: Methods for rating and assessing industrial and commercial sound*. London: BSI.

blanket 5dB penalty for noise character. The revised standard introduces separate, cumulatively additive penalties for impulsivity, tonality, 'other' characteristics where the source is neither tonal nor impulsive and a penalty for intermittency. In terms of AM assessment, the overall noise level of the wind farm or wind turbine, measured as an LAeq rather than an LA90, would be measured and rated for characteristics including AM, which may be impulsive and / or intermittent, and / or tonal. The background sound level in the same operating and meteorological conditions would then be deducted from the rated wind farm / turbine noise level to give an indication of acceptability.

4.26 **Adoption of AM conditions.** Planning controls for amplitude modulation have been adopted in some more recent planning approvals in the UK. In some cases the RUK condition has been adopted. In other cases a scheme, similar to the RES Den Brook scheme, has been attached to planning approval. In other cases AM controls have been adapted or simplified, for example the condition below applied to a single 500kW turbine by Newark and Sherwood District Council, which appears to be derived from the 3dB(A) modulation depth expressed in the Den Brook condition:

> *The peak to trough sound modulation produced by the wind turbine shall not exceed 2-3dB(A) above background levels when measured at noise sensitive properties.*[38]

4.27 **Summary.** There are several different methodologies for deriving an AM value but two main differences in how this relates to a control for AM. Firstly the AM value can be used to derive a penalty that ultimately influences the overall noise limit. Thus, AM is controlled by way of lowering the noise level or noise exposure level. Examples include the Renewable UK method. Secondly the AM value is used to judge whether or not AM is acceptable. A higher AM value indicates that AM is not acceptable and that the noise must be mitigated, the lower the value the more likely it will be considered reasonable. Thus the AM value is treated as a trigger point for mitigation measures. Examples include the Den Brook condition. BS4142 provides a hybrid methodology where a penalty is derived to acknowledge intrusive character features and applied to the overall noise level, but importantly this is then compared to the background sound level rather than a threshold noise limit. This latter method has the benefit of adding context to the assessment, both in terms of context of the noise within a specific environment and a human / subjective context.

4.28 A major trend in the methodologies used to identify and quantify AM is to find the blade passing frequency using a fast Fourier transform and then derive a value for AM relating to the power in that frequency band. Other methods include looking at the typical peak to trough level of the modulation. The methods discussed above have been categorised in to four main types of control parameter. The areas define how AM is assessed and include:

i. application of a penalty (usually maximum of 5dB) to the overall noise limit

[38] Application ref: 11/00275/FUL *Installation of a 500kw wind turbine with hub height of 75m, blade diameter of 54m blade to a maximum height of 102m to tip. transformer station building at turbine base and all ancillary works.* Newark and Sherwood District Council.

ii. identification of whether a trigger value is exceeded (though there is variation in how this can be applied)

iii. derivation of an AM value (this applies to methods where a process for deriving an AM value is simply proposed but no indication of how this might be applied).

iv. context / human judgement (this refers mainly to BS4142, but other conditions and methods including those not for solely addressing AM, are also included here as they involve a measure of judgement on aspects such as level of impact, frequency and duration etc.)

Penalty applied to overall noise limit	Trigger value	Derivation of AM value only	Context / human judgement
- Nordtest method - New Zealand Standard - Draft New South Wales Planning Guidelines - Cooper and Evans (2013) - Renewable UK (2013)	- Den Brook (2009) - Lee et al (2009)[39] - RES Den Brook (2014) - Clay target shooting guidance	- Lenchine (2009) - [Di Napoli (2011)] - Lundmark (2011) - McCabe (2011) - McLaughlin (2011) - Atzler et al (2011) - Gabriel et al (2013) - Cooper and Evans (2013) - Fukushima et al (2013)	- BS4142 (2014) - Den Brook (2009) - Minerals guidance (PPG) - Concert Code - Good Practice Guide for Pubs and Clubs

4.29 Four main methodologies have been chosen for detailed testing with AM data. At two of the sites examined below BS4142:2014 has also been tested. Methodologies that offer a full description of the derivation of an AM value and indicate how the methodology can be applied to assessment of AM have been preferred. At least one method from each of the categories identified above has been chosen to offer a broad approach to potential AM control. The methods, how they are applied to control AM and other key features are summarised in the table below.

[39] Whilst no trigger value is defined the AM value derived is compared to annoyance and hence could be used to indicate the onset of annoyance.

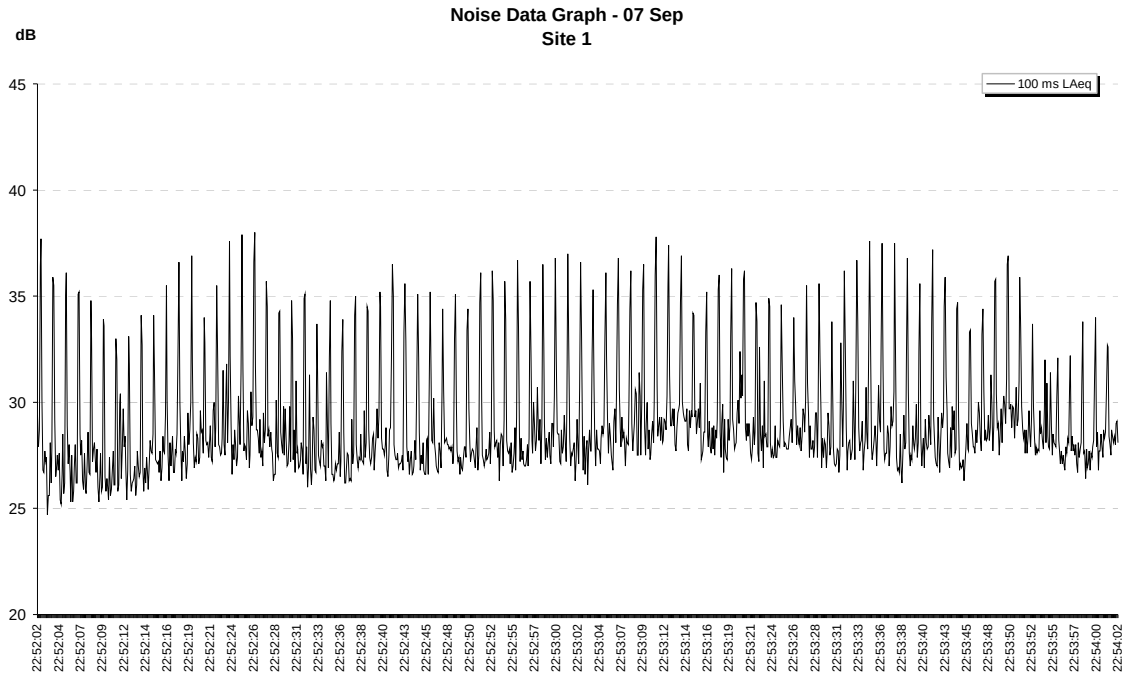
Method	AM value	Assessment period	AM control	Control for extraneous noise / 'false positives'
Renewable UK	Derived from FFT.	10s assessment periods used to get an average AM value for the 10 min period.	AM value averaged for each wind speed and converted to a penalty (max 5dB) to be applied to the noise limit.	1. Investigate SCADA data to confirm peak at BPF. 2. Listen to audio data.
RES (Den Brook)	Derived from FFT.	10s assessment periods.	Trigger value, if more than 6 periods in an hour have AM value greater than 2.5dB then mitigation needed.	1. Confirm BPF is consistent with SCADA data. 2. Audio inspection to confirm AM. 3. Assess following band pass filtering.
Fukushima et al	DAM rating derived from looking at L5-L95 of difference between Lfast and Lslow.	3 minute periods (180s and 200s periods used in this study to subdivide a 10min period).	N/A (AM sensible when DAM higher than 1.7dB(A)).	N/A
Den Brook	Regular peak to trough modulation of greater than 3dB and LAeq greater than 28dB.	1 minute periods.	Trigger value, if above this mitigation is needed. NB must be applied with judgement of frequency and duration and severity of impact.	1. Witness noise measurements. 2. Visual inspection of data. 3. Audio inspection of data.
BS4142:2014	Penalties attributed to overall noise level for noise character.	In the standard 1 hour during daytime and 15 minutes during night time. 10 minute periods are considered below.	Decibel penalty for character added to overall wind farm noise level and subtracted from the background sound level. Difference indicative of severity of the problem.	1. Witness noise measurements. 2. Visual inspection of data. 3. Audio inspection of data. 4. Include estimate of uncertainty.

5 Test data

5.1 A range of test data has been selected to provide a variety of turbine size and noise character.

5.2 **Site 1. Single 50kW turbine.** This size of turbine is at the bottom of the rated power range identified in the Institute of Acoustics Good Practice Guide to the Application of ETSU-R-97.[40] The turbine has caused complaints from nearby residents, who specifically complained of the noise character. The noise was not described as loud, but particularly annoying and intrusive because of the inability to acclimatise to the noise or for the noise to be masked or forgotten.

5.3 An example of the noise measured at site 1 is given below.



5.4 ETSU-R-97 noise limits are frequently applied to smaller wind turbines, despite there being a disproportionate ratio of noise impact and renewable energy in the planning balance compared to that of larger turbines for which ETSU-R-97 is designed. There are significant differences both in size and noise character between noise from smaller and larger turbines. With an increasing incidence of complaints from smaller wind turbines arguably a condition to control for noise character should be equally applicable to smaller turbines especially where ETSU-R-97 noise limit controls have been applied.

5.5 The data from site 1 provides extracts of wind turbine noise that are highly tonal and pulsate regularly. The level and character of the AM is fairly consistent but it is not AM as might be conventionally described or defined in relation to larger wind turbines. The modulation in this case is largely tonal rather than a broadband blade noise. However, it is

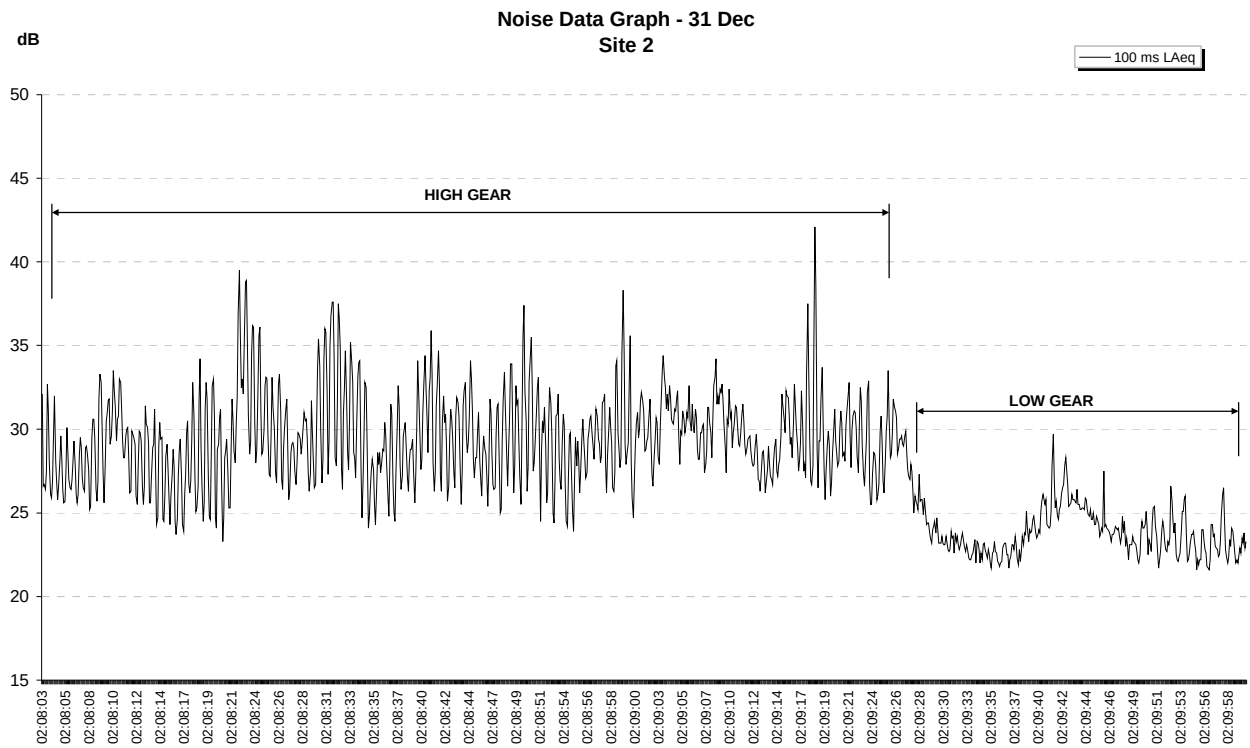
[40] Institute of Acoustics (IoA) (2013) A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise. St Albans: IoA.

an example where turbine noise has been complained of and established as intrusive but the measured decibel levels may be considered 'low'. This data will test the noise conditions for cases where intrusive AM occurs, albeit at low decibel levels, and also where there is an extraneous noise source that must not be included in the analysis of AM impact.

5.6 **Site 2. Single 275kW turbine.** This size of turbine falls within the scope of ETSU-R-97. The turbine model has two different gears and at a wind speed of approximately 6-7m/s the turbine regularly interchanges between the two gears (with no predictability as to when the change will occur). The data from site 2 provides extracts of wind turbine noise that has variable tonality and AM.

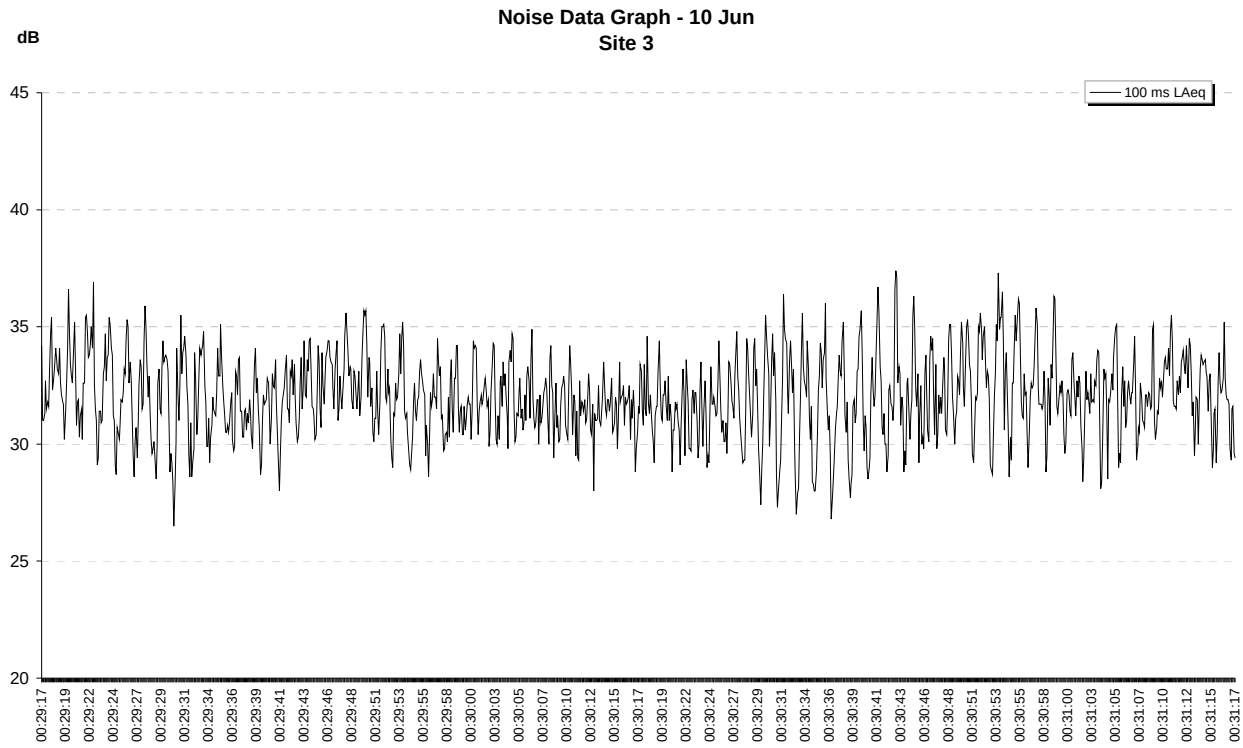
5.7 The AM varies in character, it is very erratic and can cease suddenly. As the turbine operates in two gears there are two sets of noise character that can be assessed, it also tests the condition for a turbine model that can vary in AM, tonality and blade pass frequency. The gears have different tonal and AM characteristics. The data in this case is also useful for testing extraneous noise sources and 'false positives' (finding AM where there is no AM). The data contains extraneous noise that visually looks very similar to AM but has different spectral character and so can be identified by third octave band analysis. The turbine has generated noise complaints from nearby neighbours and again, it is the character of the noise that is specifically referred to as intrusive.

5.8 An example of the noise measured at site 2 is given below.



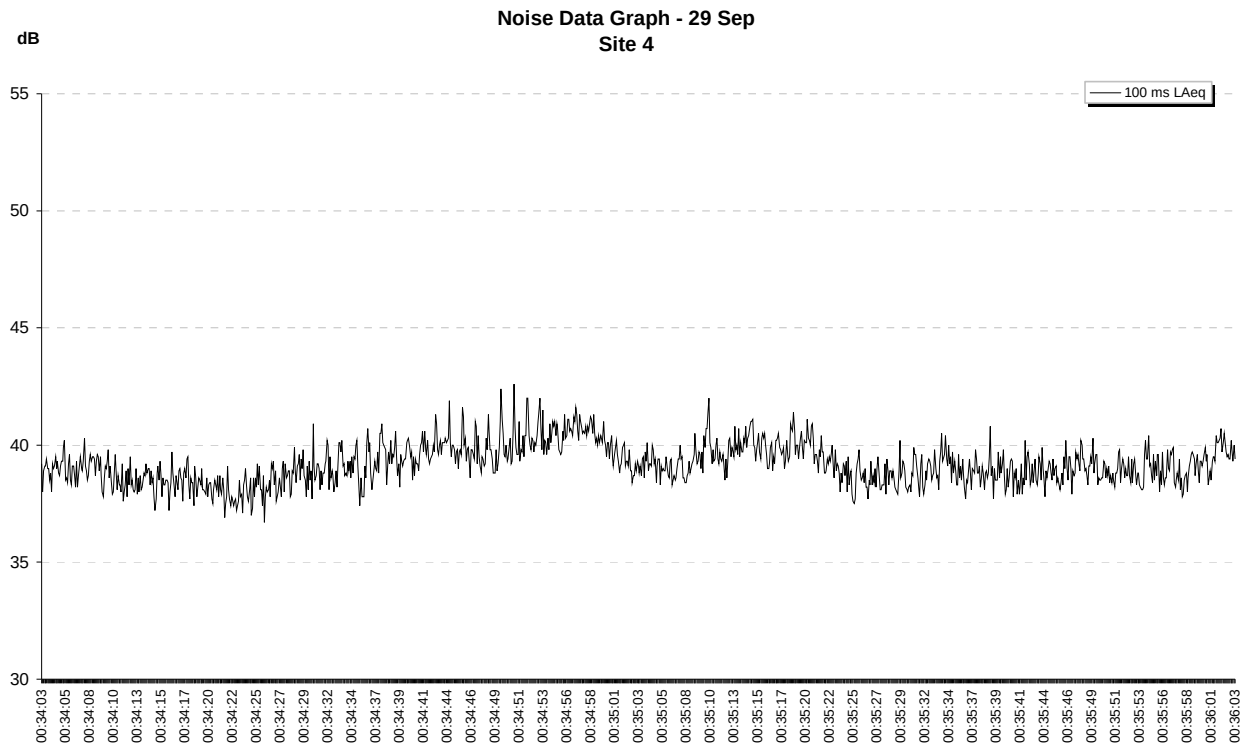
5.9 **Site 3. Two 2.05MW turbines.** These two turbines have been the cause of significant complaints across a community. The size and rated power is well within the range of turbines typically erected in accordance with ETSU-R-97. These turbines provide useful data for testing AM controls as they exhibit strong rhythmic properties and AM often falls in and out of synchronicity.

5.10 An example of the noise measured at site 3 is given below.



5.11 **Site 4. Eight 2MW turbines.** Despite complaints from this wind farm an additional seven turbines have been granted planning permission to extend the wind farm. The measurements used in this case do not represent the complainant's location, but are taken approximately 1.8km from the nearest turbine. Whilst the wind turbine noise was the dominant noise source in the area there was no significant modulation and as such this can be considered a good test case where an AM condition should not trigger.

5.12 An example of the noise measured at site 4 is given below.

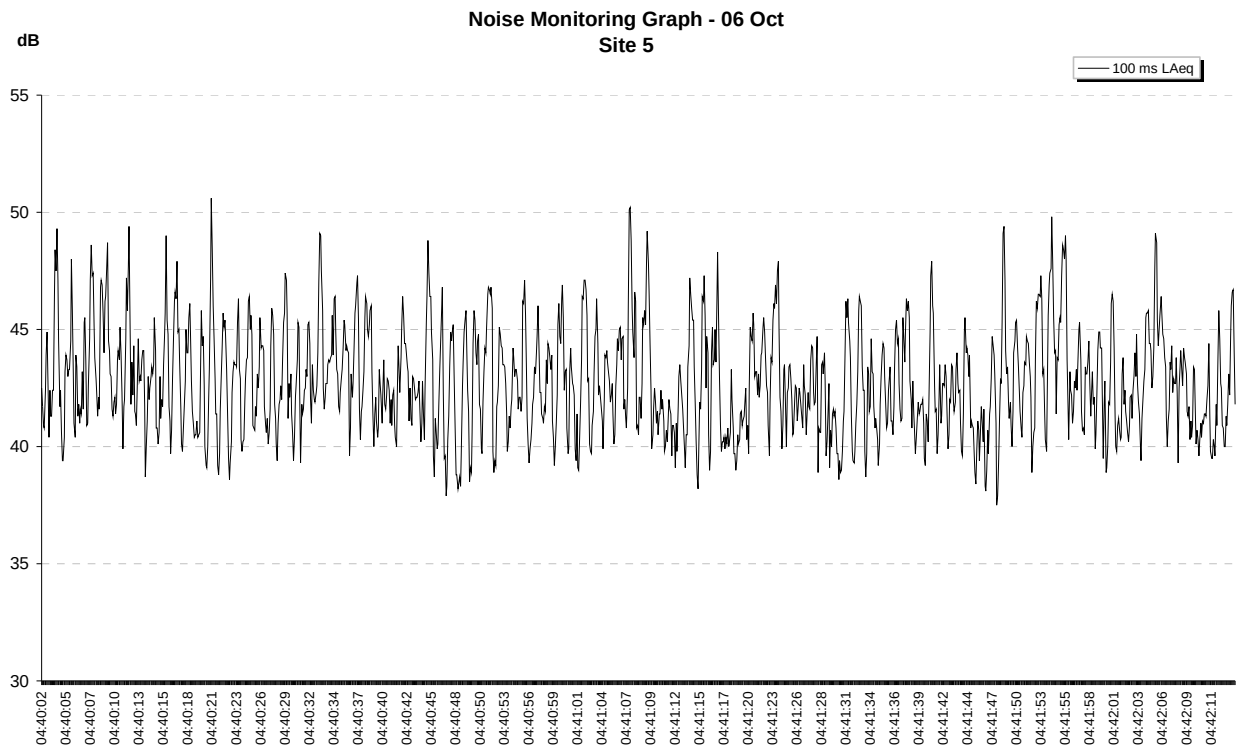


5.13 **Site 5. Eight 2.05MW turbines.** The site 5 data is taken from Cotton Farm Wind Farm. Concerns of adverse impact from AM were raised at the planning stage but a condition to control for AM was considered not necessary by both the applicant's noise consultant and the planning inspector.

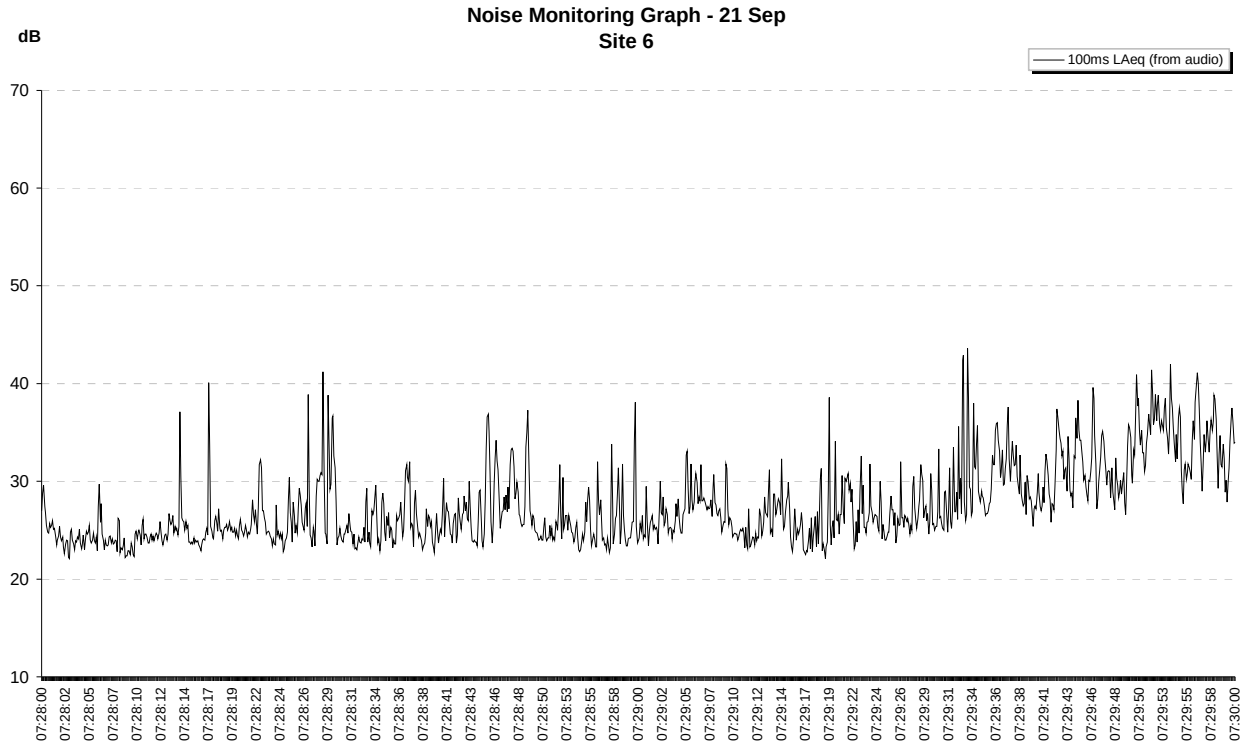
5.14 The residents' continued concerns post planning approval resulted in the funding of a permanent monitoring station to measure and record noise levels from the wind farm. Since the wind farm became operational in 2013 significant complaints have resulted from the nearby community. The experience of those neighbouring the Cotton Farm Wind Farm is detailed in WP6.2 and WP9.

5.15 Recently compliance testing has revealed that the wind farm is not compliant with the ETSU-R-97 noise limits. The wind farm also generates substantial EAM. The wealth of data provided by the long term monitoring station at Cotton Farm facilitates extensive testing of AM controls. It provides data where AM may be considered borderline, intrusive, examples of excessive AM and periods of on/off testing where background sound levels and wind farm noise and AM can be measured in the same conditions.

5.16 An example of the noise measured at site 5 is given below.



5.17 **Site 6 - no wind turbine noise source in area.** Site 6 has been chosen to test for false positives. Despite there being no source of wind turbine noise or AM to assess, this data has been used historically to demonstrate failure of the Den Brook method due to identification of false positives, i.e. identifying AM where there is none. The analysis of the data is detailed further below; however, it is noted that the preliminary and crucial step of the Den Brook condition, and indeed any noise condition, is to ensure that what you have measured and are assessing looks like AM and / or sounds like AM. Furthermore the Den Brook condition and the DAM rating method do not propose to be an automated condition. Therefore this data is primarily used to test the RES and RUK methods, which are aimed at automation and minimal human intervention. An example of the data from this site is given below.


Noise Monitoring Graph - 21 Sep
Site 6
dB
100ms LAeq (from audio)
70
60
50
40
30
20
10
07:28:00
07:28:02
07:28:05
07:28:07
07:28:10
07:28:12
07:28:14
07:28:17
07:28:19
07:28:22
07:28:24
07:28:26
07:28:29
07:28:31
07:28:34
07:28:36
07:28:38
07:28:41
07:28:43
07:28:46
07:28:48
07:28:50
07:28:53
07:28:55
07:28:58
07:29:00
07:29:02
07:29:05
07:29:07
07:29:10
07:29:12
07:29:14
07:29:17
07:29:19
07:29:22
07:29:24
07:29:26
07:29:29
07:29:31
07:29:34
07:29:36
07:29:38
07:29:41
07:29:43
07:29:46
07:29:48
07:29:50
07:29:53
07:29:55
07:29:58
07:30:00

6 Testing protocol

6.1 Each method has been tested using data measured from five different wind turbine / farm sites and one site where there was no wind farm noise. The audio has been listened to and a brief description of each 10 minute period has been provided. The methods have been assessed in 10 minute periods or chunked in 10 minute period assessments as far as possible to align assessment with conventional methods for analysing wind farm noise in the UK and hence to facilitate comparisons.

6.2 The Den Brook method simply involves a visual inspection of the data and identification of turbine noise regularly modulating by more than a 3dB(A) peak to trough and which has an average noise level greater than 28dB LAeq, 1minute. If noise measurements have not been attended, and in the absence of written notes confirming that all noise is attributable to the turbine(s), then the audio data is inspected for confirmation of AM.

6.3 The DAM rating method does not prescribe a detailed methodology but simply provides a method for deriving a value for the AM in a given period. It is assumed in this work package that the period being assessed would necessarily be checked either pre or post analysis to ensure that the noise measured is only attributable to wind farm noise and therefore that extraneous noise has been excluded. However, to facilitate the processing of the DAM value the method has been applied to all periods, including those affected by extraneous noise. DAM values influenced by extraneous noise should not necessarily be taken as a failure of the method. The DAM method was originally tested by the authors using 3 minute periods though they advise this is not a set period. This time period has however, been replicated where possible. To facilitate analysis with the data gathered in some cases other time periods have been used, typically periods of 180 seconds and 200 seconds have been used.

6.4 The Renewable UK method (RUK) involves derivation of a blade pass frequency from a peak in the modulation spectrum. This is calculated using fast Fourier transformation. Software has been written by RUK to facilitate this analysis; however, there are important differences between how this might be used and how the data has been assessed in this work package.

6.5 The RUK software begins by asking the user to input the blade pass frequency of the turbine(s). This assumes that the user has access to the SCADA data or has already performed a preliminary assessment to ascertain the estimated blade pass frequency. The user then enters this blade pass frequency at the first stage of the software's algorithm. The AM values for each 10s period, and therefore each 10 minute period, are derived based on this value. As much or as little data can be assessed using this estimated blade pass frequency as desired by the assessor. An entire day, night or week could be assessed assuming a single blade pass frequency. This is important as the blade pass frequency can vary and variation from the blade pass frequency that has been entered into the software will ultimately influence the value of AM. If the true blade pass frequency, i.e. that observed in the data, deviates from that assumed then a lower AM value will be derived. Where the blade pass frequency varies significantly from the entered blade pass frequency then it results in no AM being identified.

6.6 To counter this effect the analysis in this work package has used the blade pass frequency derived from each individual 10s period to calculate the AM value for the same 10s period. Thus, rather than assuming a blade pass frequency of 0.74Hz to calculate the AM value for each 10s period over the course of several hours, it allows for small changes in the blade pass frequency so that the blade pass frequency used to calculate the AM value for a series of 10s periods might be 0.74Hz for the first few periods and then 0.78Hz, 0.76Hz, back to 0.74Hz etc. This has been tested, with some examples given below, and consistently derives higher AM values than using the original RUK method. In many cases, where there is no significant extraneous noise, there is little difference between the two methods. Whichever method is used a check must still be made that the estimated blade pass frequency (derived from the modulation spectrum) is consistent with the actual blade pass frequency of the turbines.

6.7 The RES method does not detail how the assessment method might be implemented in software. It is assumed that the process would be similar to the RUK method above where a blade pass frequency value is entered prior to analysis. As noted above there are problems identified with this approach. For consistency, in this work package the same method of analysis for deriving the blade pass frequency and calculating an AM value has been used for the RES method as the RUK method. That is, each individual 10 second AM value is calculated using the corresponding estimated blade pass frequency (peak modulation frequency) derived using the RES methodology.[41] The AM value is calculated using the energy only in the first peak in the modulation spectrum. In some cases this work package has investigated inclusion of energy at harmonics of this peak to provide a better indication of whether AM is present in the data. This is discussed further below.

6.8 In this work package only the method for deriving the RES AM value has been tested, that is stage 4a in the planning condition submitted by RES. The RES methodology involves a list of convoluted steps both prior to and following on from derivation of the AM value. This includes checking complainant's noise logs, additional checks with the original Den Brook condition and re runs of the RES method following additional verification steps. The testing of the entirety of the RES method and associated protocol is beyond the scope of this work package.

6.9 **Important note on RES and RUK methods.** Both the RES and RUK methods require that the estimated blade pass frequency / peak modulation frequency derived from the data is checked against the turbine SCADA data. This is to ensure that the peak modulation frequency of the data is consistent with that of the rotational speed of the turbines (recorded by the SCADA data) and thus that the modulating noise is caused by the turbines. SCADA data is not open access and it is notoriously difficult to achieve SCADA data release from developers. As a result, the testing below has not been able to verify that the peak modulation frequency of the turbines (the estimated blade pass frequency) is consistent with the actual SCADA data. Consistency checks have been made in the analysis below; however, this assumes that blade pass frequency, as would be given by the SCADA data, is the most consistent peak modulation frequency that occurs where there is clear, uncorrupted AM in the data.

[41] There are subtle differences in how the RES and RUK method derive the peak modulation frequency and calculate the AM value.

6.10 Whilst the consistency check is an important step for both the RES and RUK methods, it is unknown how well this can work with the SCADA data. This is an important issue. Where there are multiple turbines SCADA data will often provide multiple and different rotational speeds for the turbines. Which speed should be used to check consistency? There may be further difficulties in using this data, for example if the peak modulation frequency is different to the rotational speed of the turbines but the data clearly shows wind turbine AM. The RUK and RES conditions cannot therefore be fully tested in the absence of data where there is simultaneous SCADA data and noise data. This is a limitation of the testing done in this work package.

6.11 False positives, i.e. identifying AM where there is none, is a concern that has been raised in relation to some AM assessment methods. Similarly, the assessment of false negatives, i.e. not identifying AM where there is AM, and inclusion of extraneous noise in the overall AM value are important tests of each method. The data used for assessing the different AM methodologies includes periods that facilitate this analysis.

7 Results from existing AM controls and methods

7.1 **Site 1 - 7th September 22:20 - 23:30.** Due to the smaller sample period for this site all graphs have been included below. As wind farm noise is typically analysed in 10 minute periods the measured data is presented first as a 10 minute period graph and then split in to three 3 minute period graphs for closer inspection. To facilitate analysis of the DAM rating method periods of 180s (3 minutes) have been used in this case. Thus, analysis of the DAM rating excludes the final 1 minute of each 10 minute period.

7.2 The first 10 minute graph is produced in larger scale and labelled to describe what is shown on each graph. This is given as figure 1 below. A summary table of the results is also given below, see table 1. The Den Brook assessment is provided only in the tables, not graphically, as the assessment can be made by a simple visual inspection of the graph and further confirmation with the audio data where necessary. Also provided in the summary table is a brief description of the audio for each 10 minute period.

Table 1: Summary of results - Site 1 - 07 Sep

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value?	RES Den Brook triggered?	Japanese rating	
					DAM	AM index
2220	Farming machinery audible - turbine hum audible in last minute of recording, sounds like just turned on.	No. Nothing that looks / sounds like AM.	No. Corruption and inconsistent BPF.	No. Identified in last minute.	3.8 3.2 3.2	5.3 4.4 4.4
2230	Turbine hum audible (at a lower frequency), some talking, turbine operational by end of period.	Yes. (≈ 7dB). Clear examples.	No. Corruption and inconsistent BPF.	No.	6.4 15.4 10.2	9.3 20.1 14.5
2240	Clear periods of turbine noise and lack of extraneous noise.	Yes. (≈ 7-10dB) Many clear examples	A = 3.7	Yes. Lots of periods >2.5.	7.0 4.6 7.5	10.2 6.6 10.9
2250	Clear periods of turbine noise and constant noise throughout.	Yes. (≈ 7-11dB) Many clear examples	A = 4.2	Yes. Lots of periods >2.5.	8.2 7.1 4.8	11.9 10.3 6.9
2300	Turbine noise still clear but some other extraneous noises now present.	Yes. (≈ 3-4dB) Not so many clear examples.	No. Corruption and inconsistent BPF.	No.	3.6 3.5 4.1	5.0 4.9 5.8
2310	Turbine still going but more extraneous noises present.	Yes. (≈ 3-4dB) Not many clear examples.	No. Corruption, and inconsistent BPF.	No.	4.5 5.5 6.2	6.5 8.0 9.0
2320	Turbine still going but more extraneous noises present.	Yes. (≈ 3-4dB) Not many clear examples.	No. Corruption and inconsistent BPF.	No. (only one 10s period)	6.0 7.7 4.4	8.7 11.2 6.3
2330	Turbine noise still there, some (turbine) thumping noise and some wildlife noise.	Yes. (≈ 4-5dB) Not many clear examples.	No. Corruption and inconsistent BPF.	Yes.	7.7 7.7 7.4	11.2 11.2 10.8

Figure 1: Site 1 - 07 Sep - 22:20. Example graph with labels.

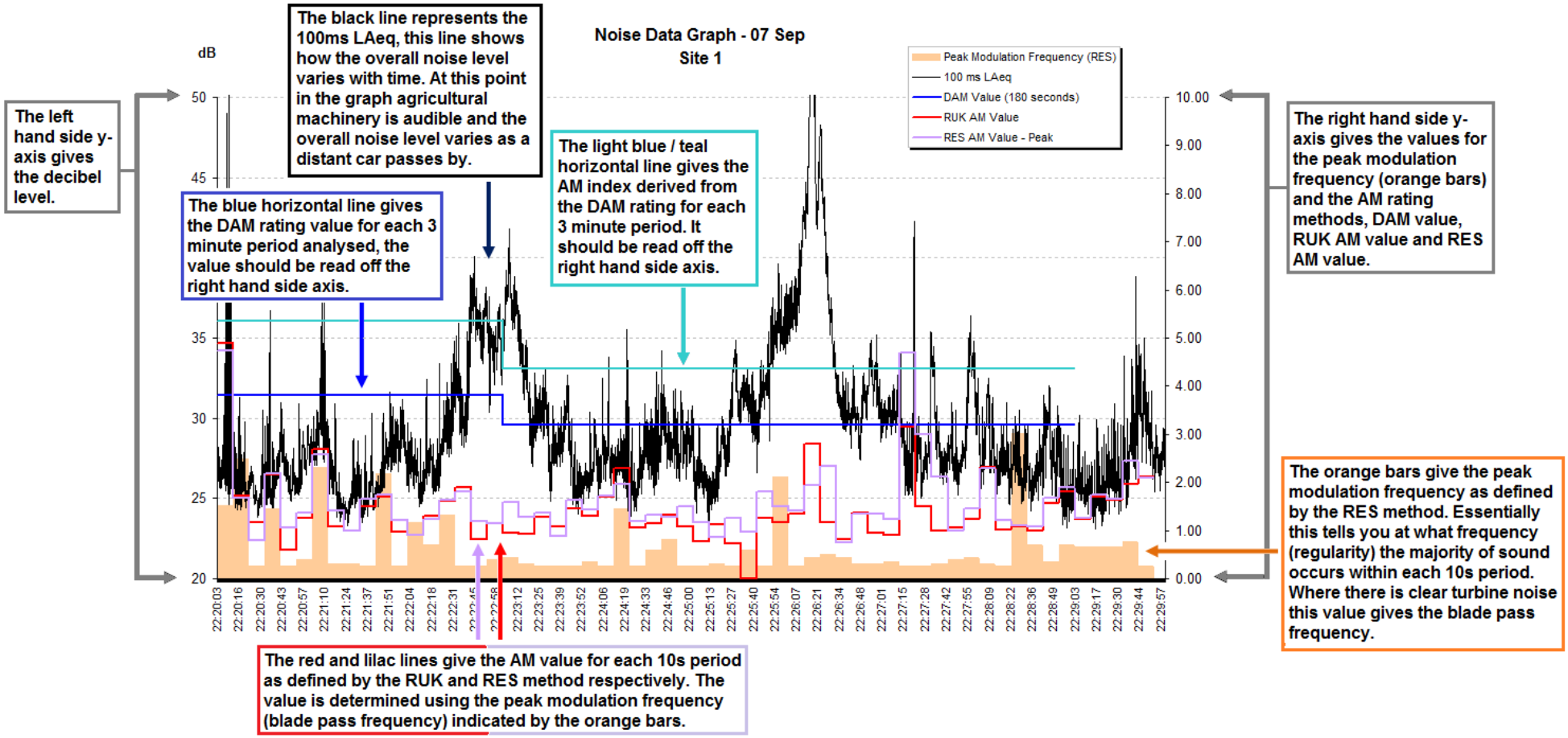


Figure 2: Site 1 - 07 Sep - 2220 (10 minutes)

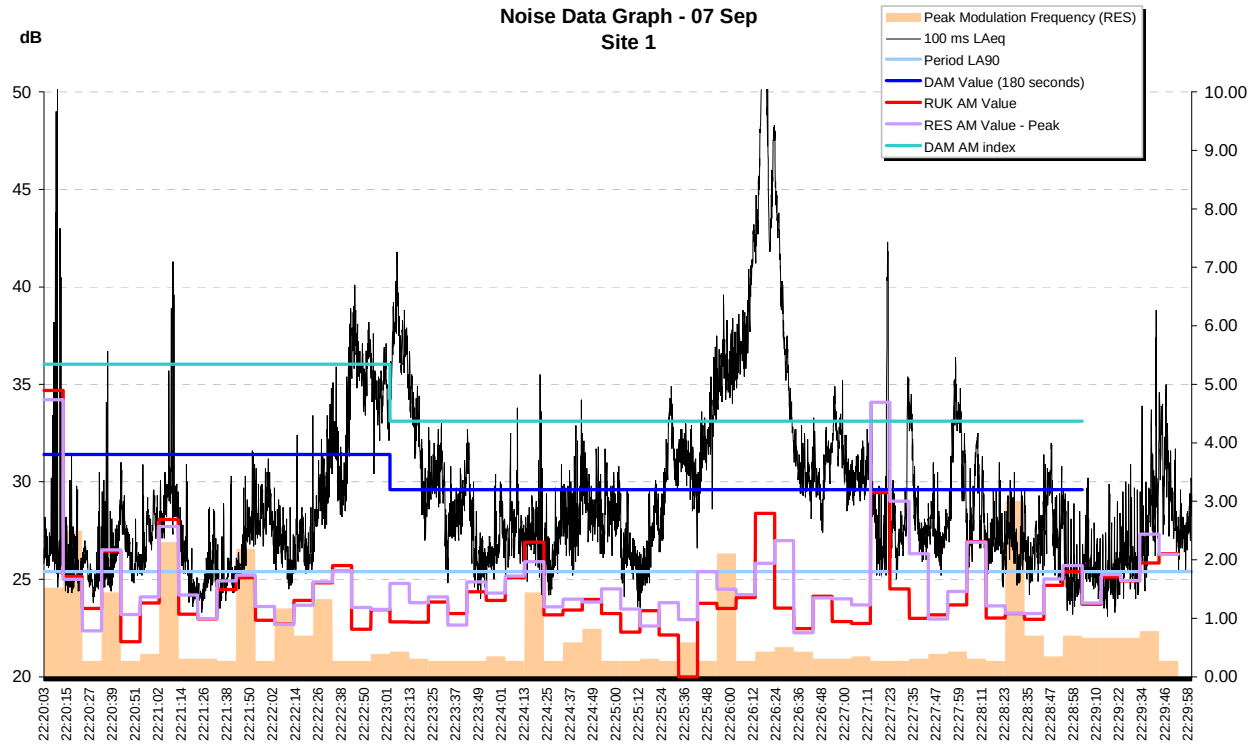


Figure 3: Site 1 - 07 Sep - 2220

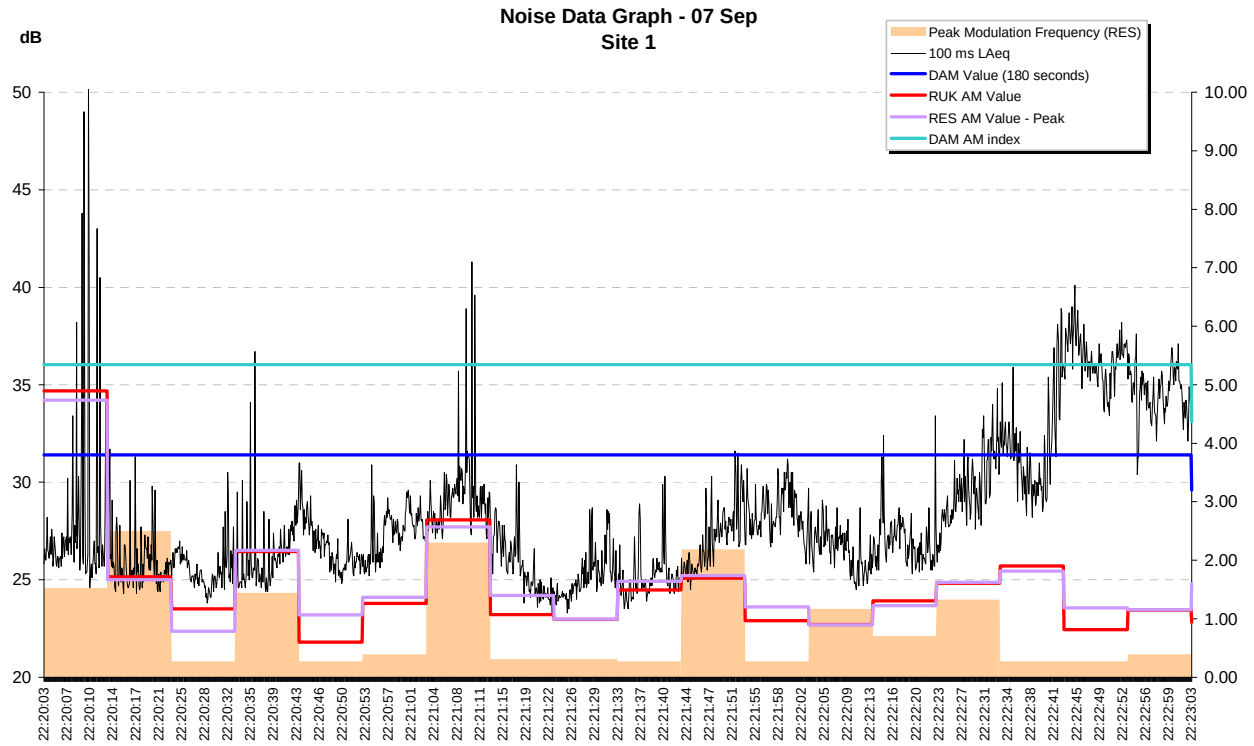


Figure 4: Site 1 - 07 Sep - 2223

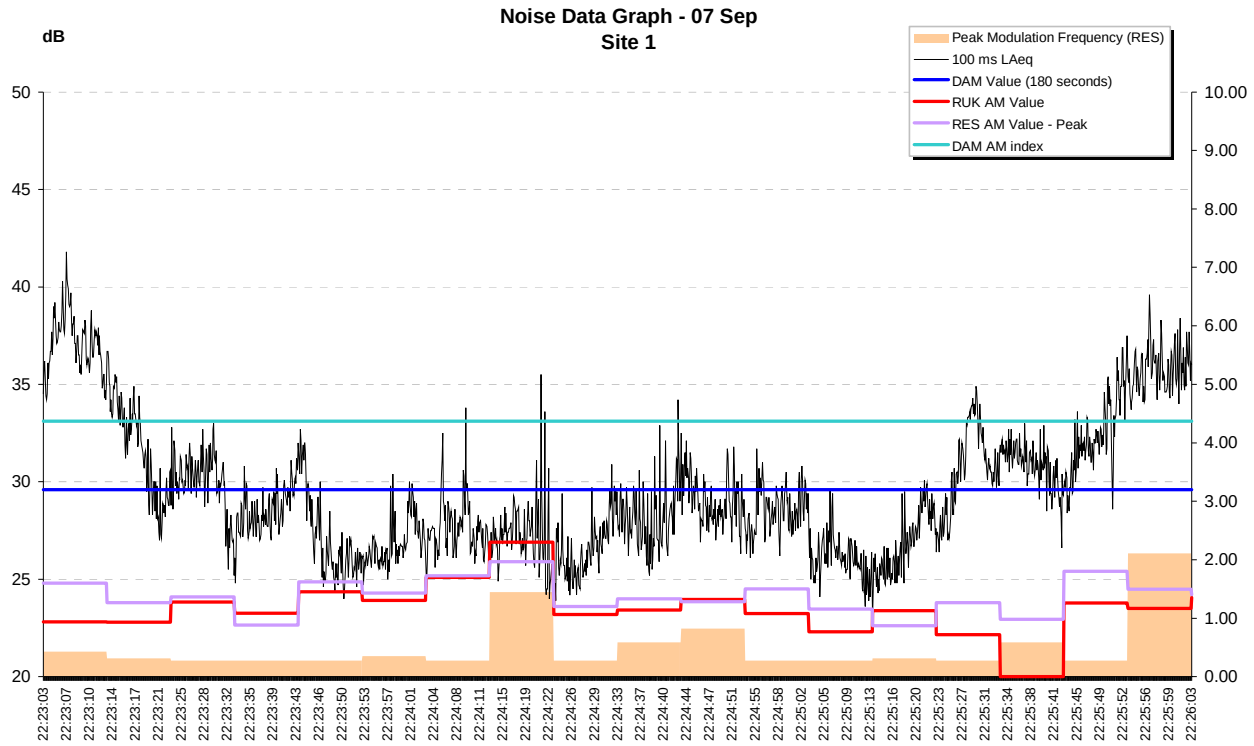


Figure 5: Site 1 - 07 Sep - 2226

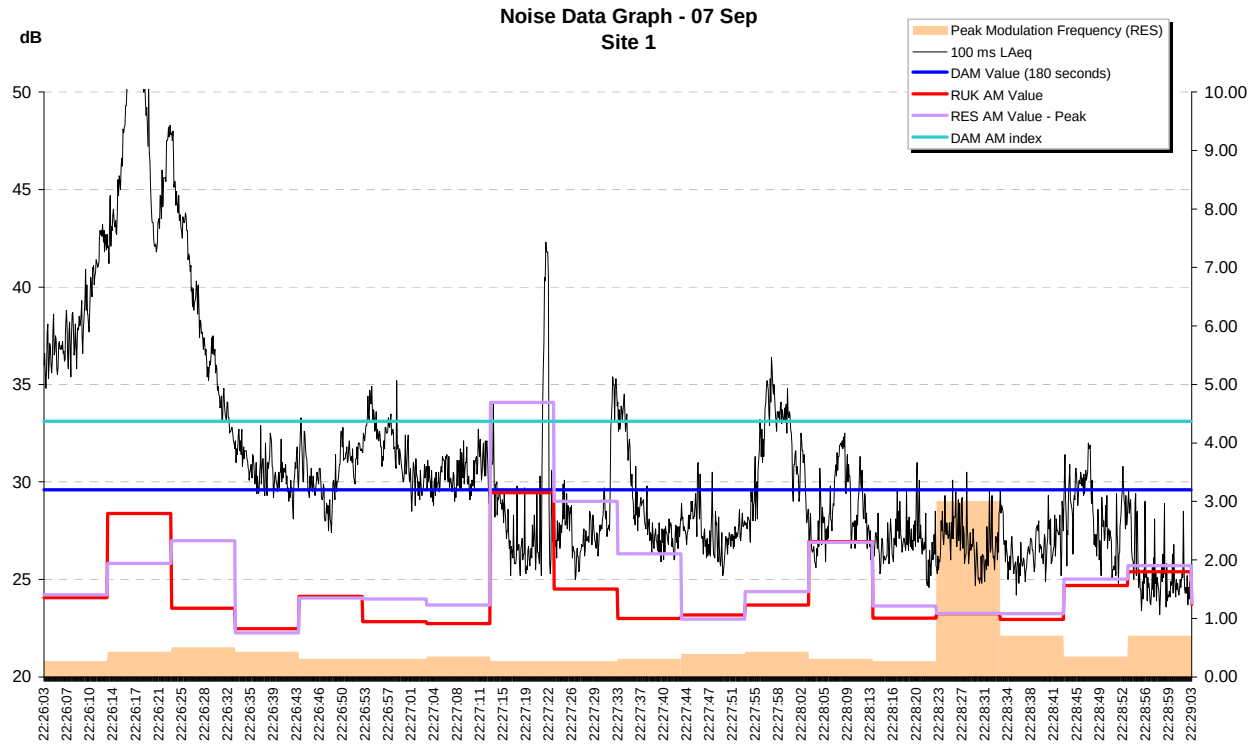


Figure 6: Site 1 - 07 Sep - 2229

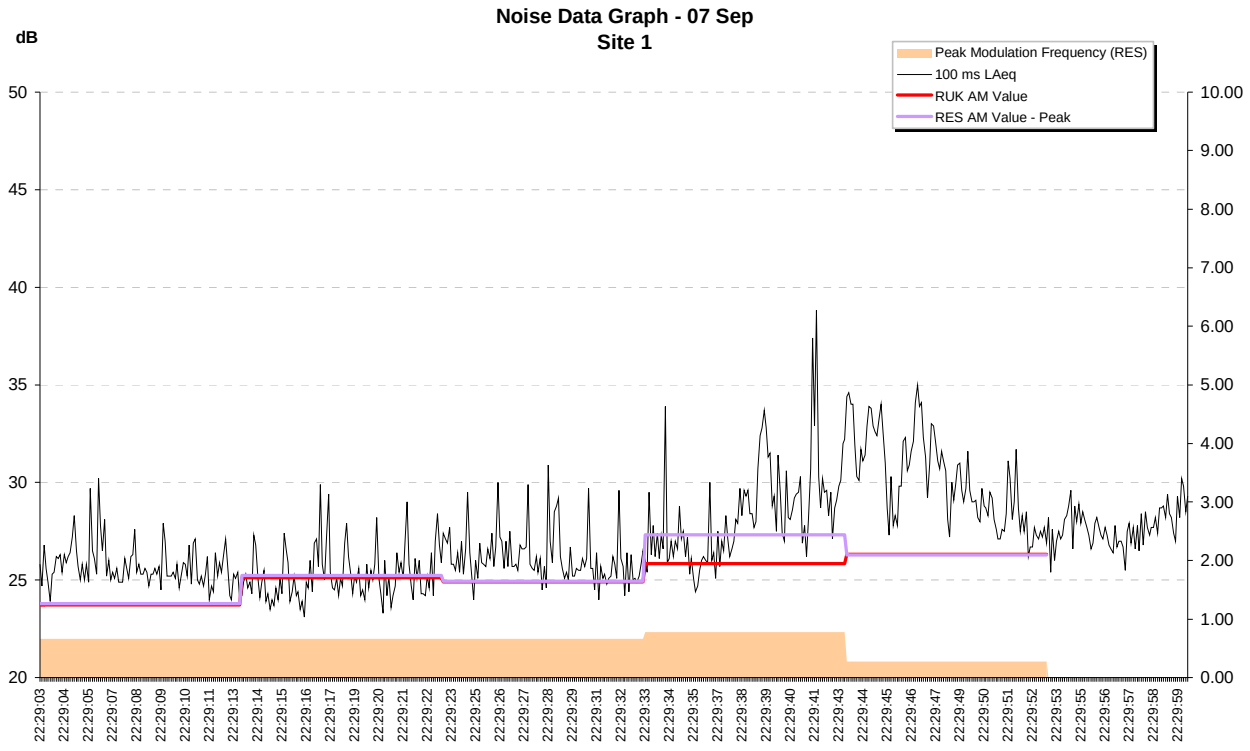


Figure 7: Site 1 - 07 Sep - 2230 (10 minutes)

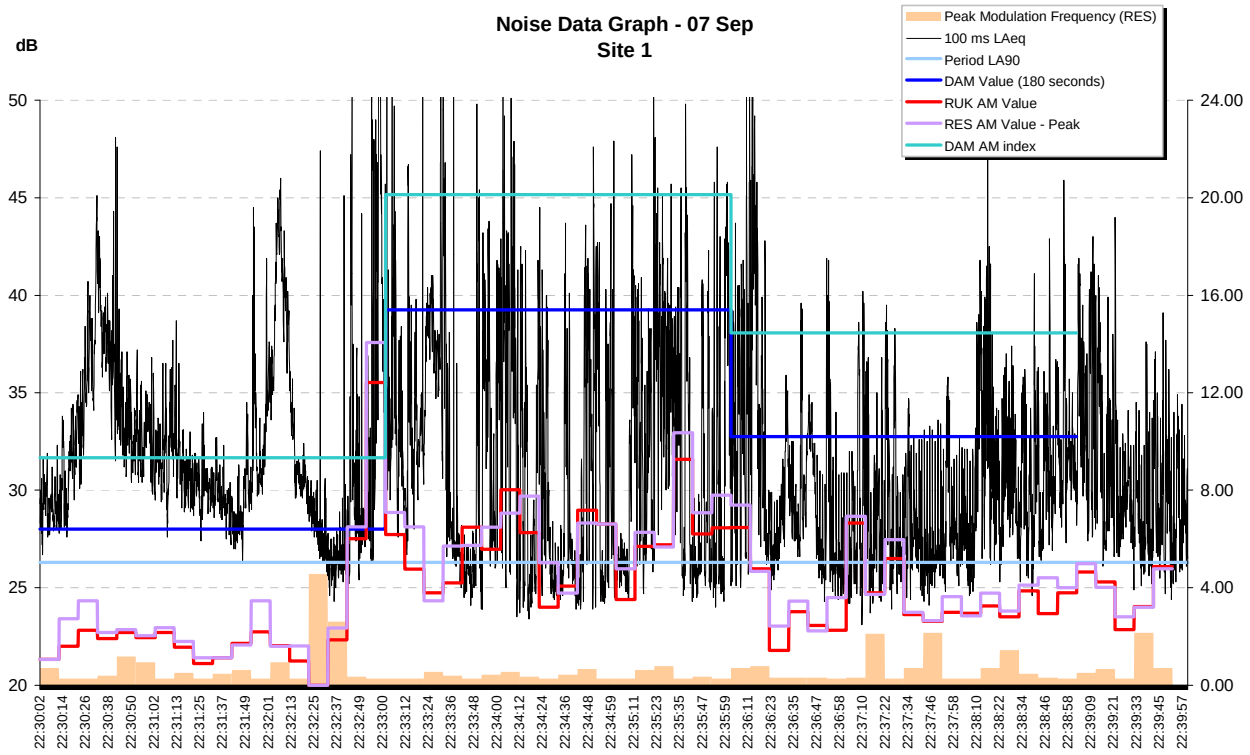


Figure 8: Site 1 - 07 Sep - 2230

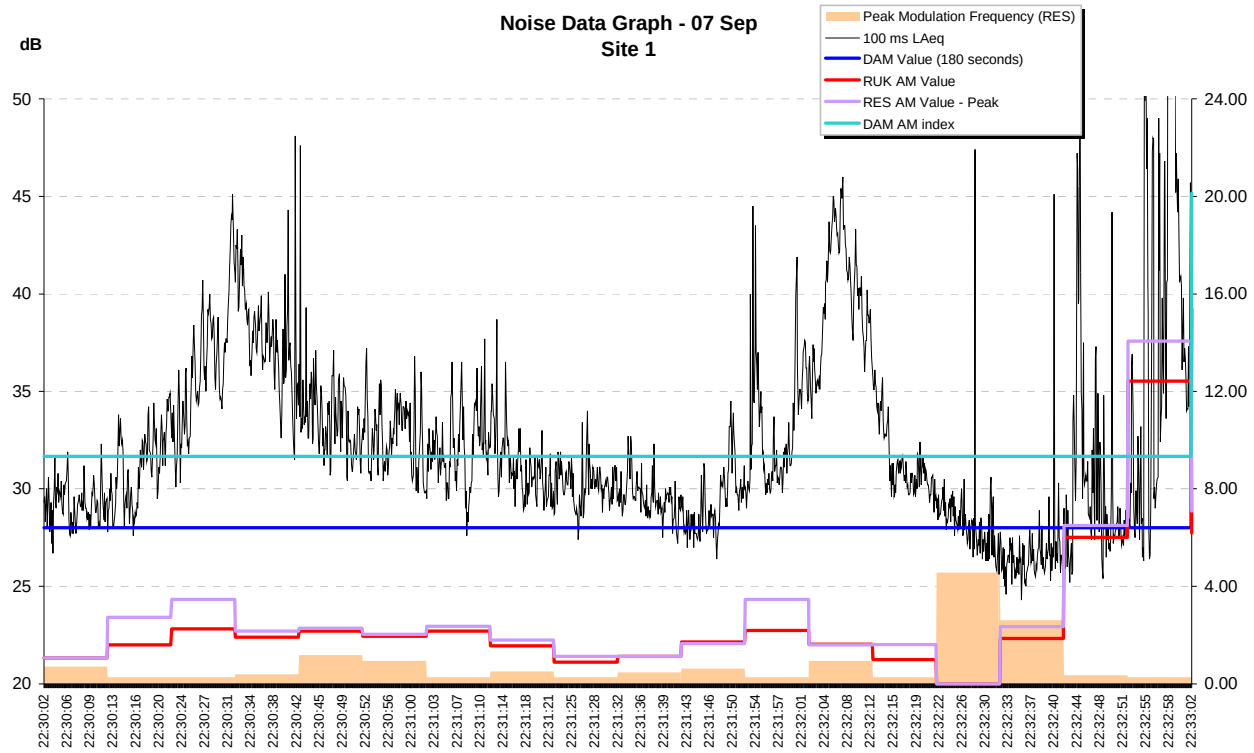


Figure 9: Site 1 - 07 Sep - 2233

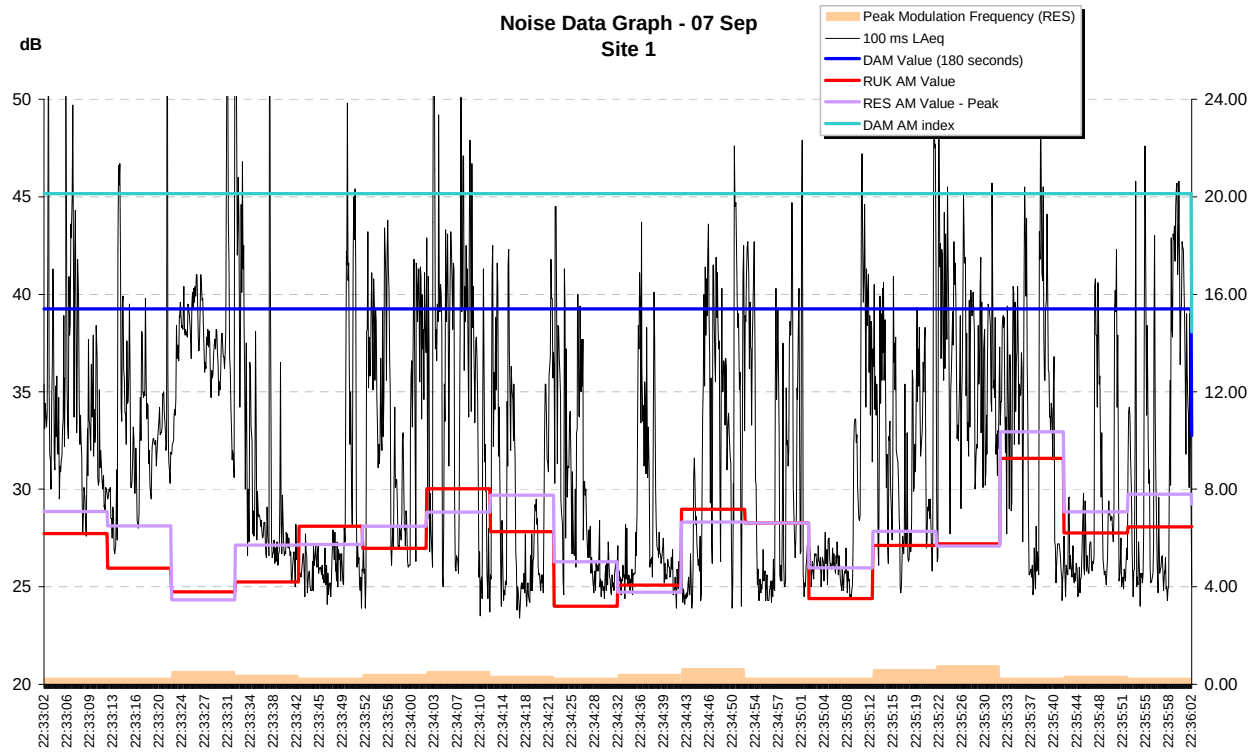


Figure 10: Site 1 - 07 Sep - 2236

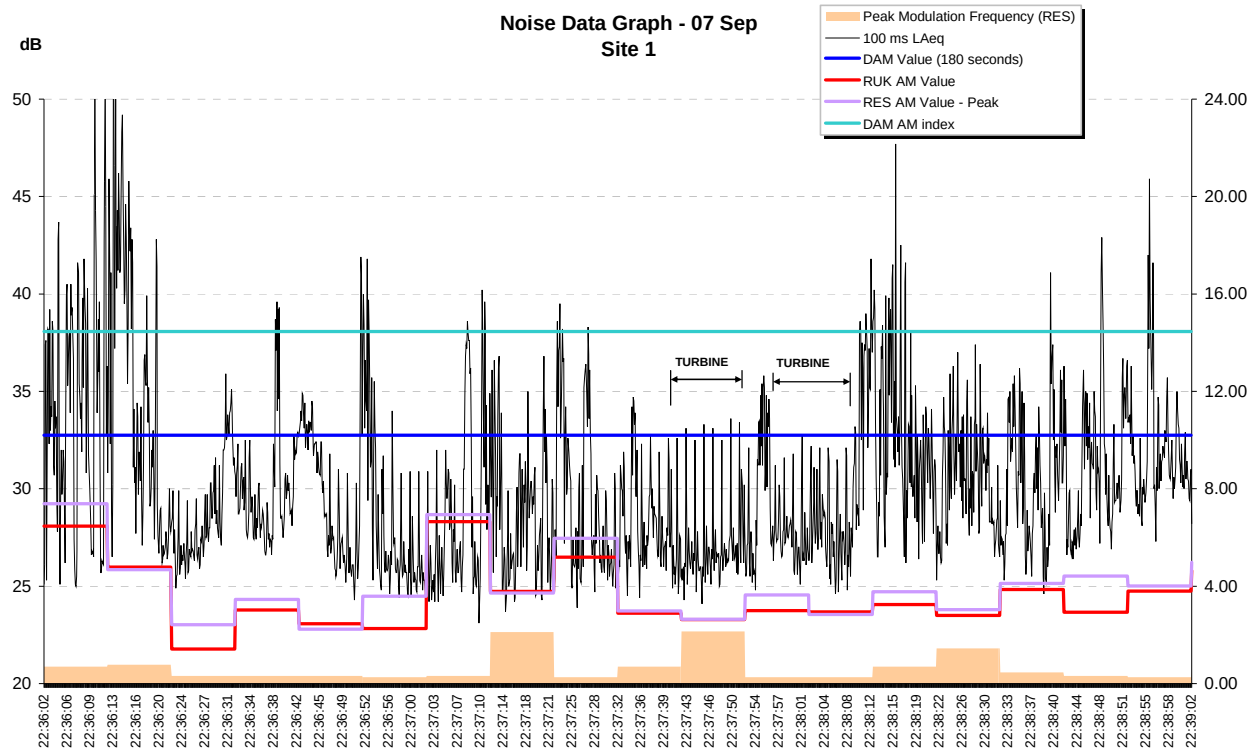


Figure 11: Site 1 - 07 Sep - 2239

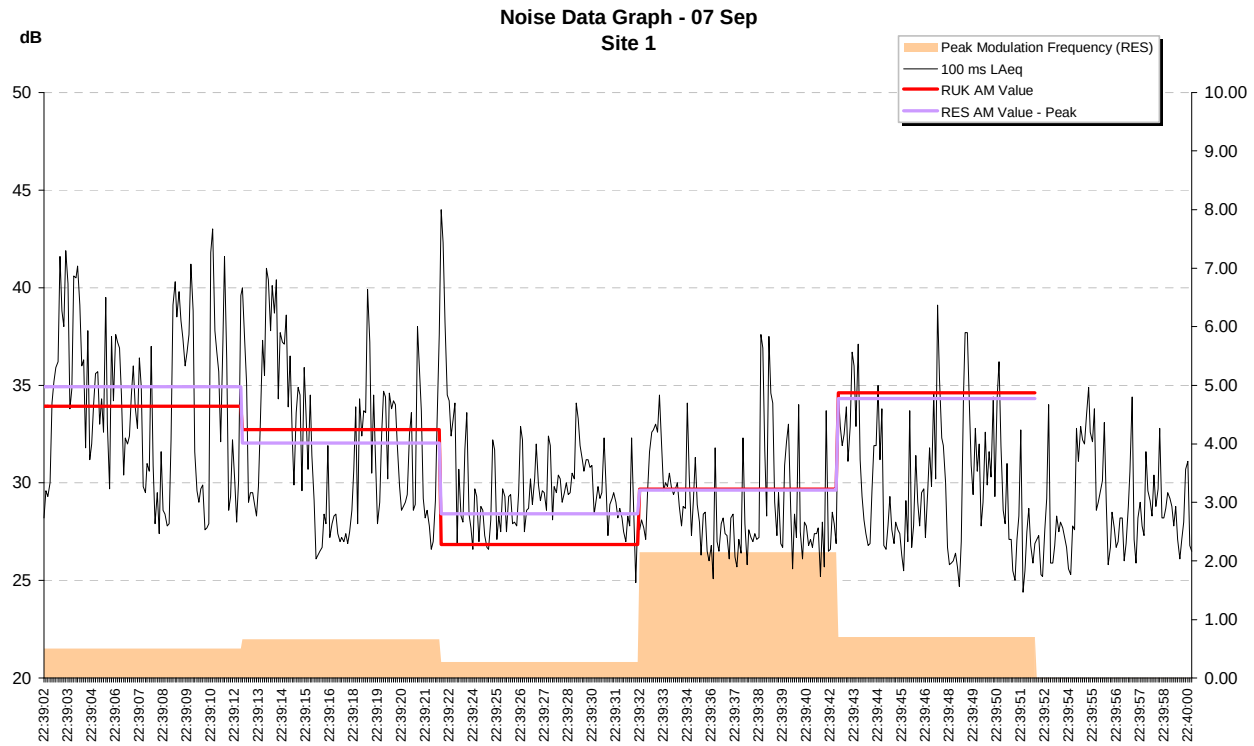


Figure 12: Site 1 - 07 Sep - 2240 (10 minutes)

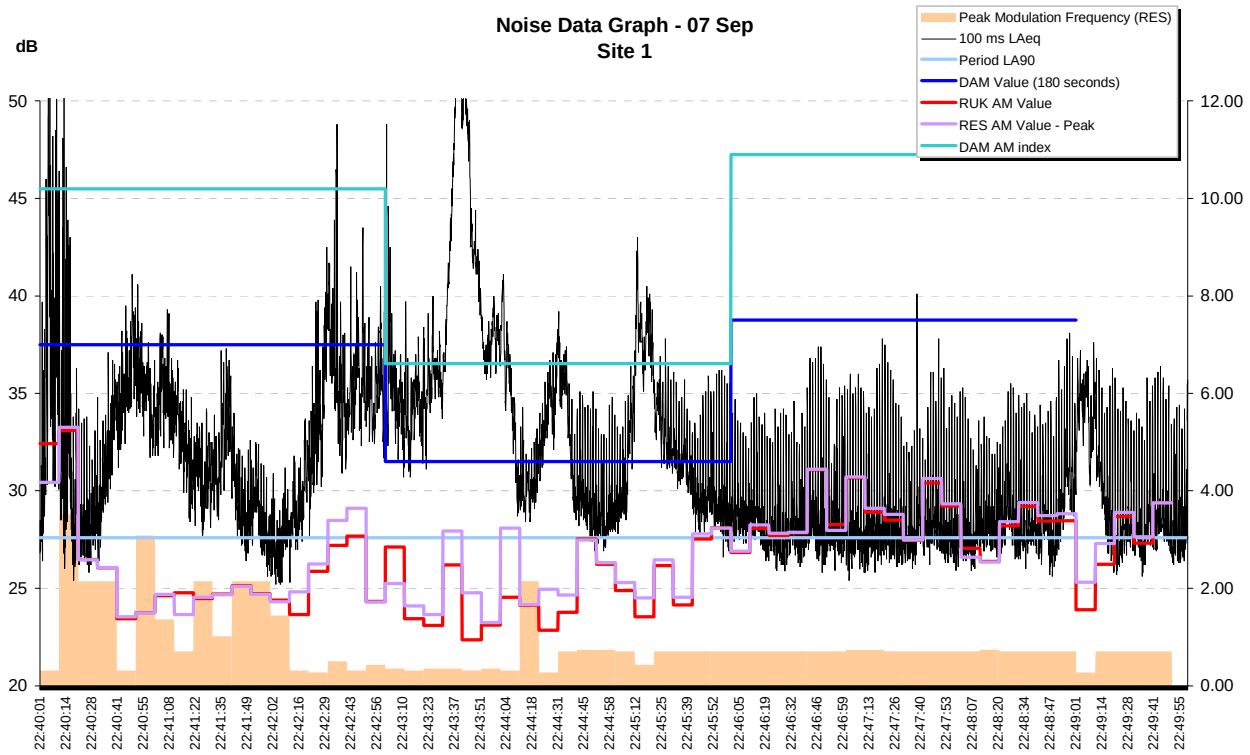


Figure 13: Site 1 - 07 Sep - 2240

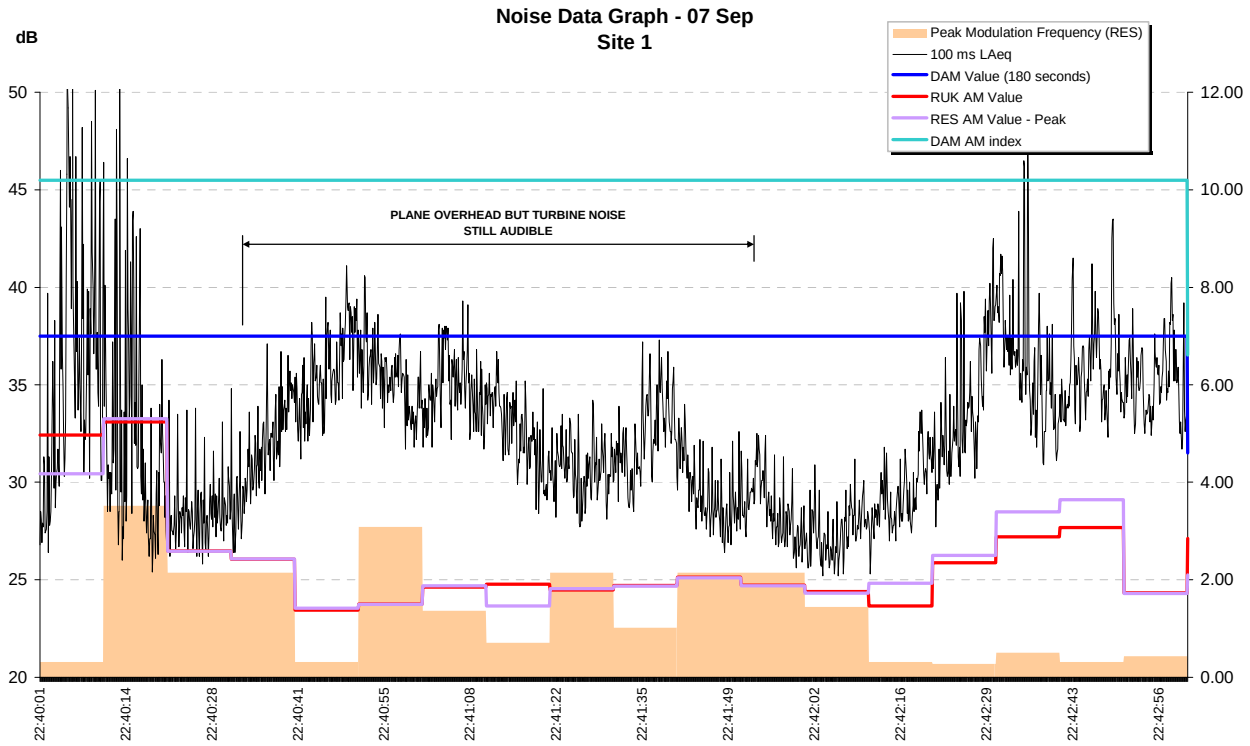


Figure 14: Site 1 - 07 Sep - 2243

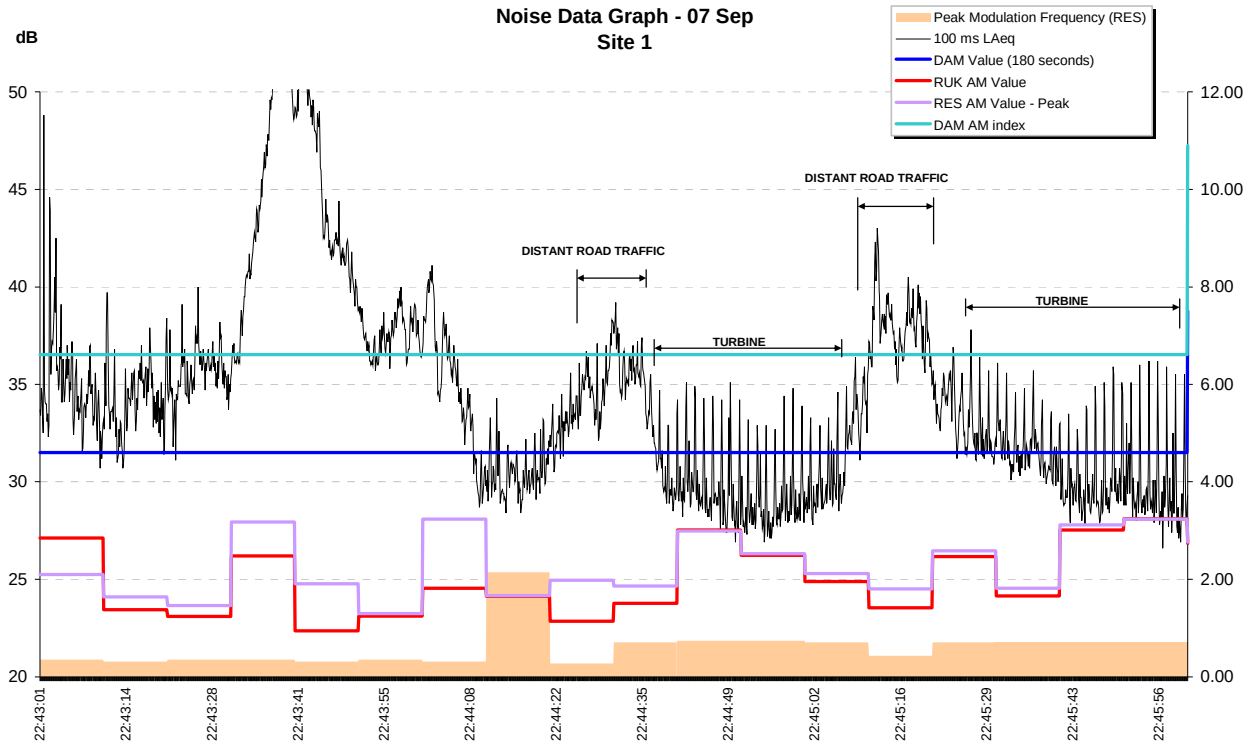


Figure 15: Site 1 - 07 Sep - 2246

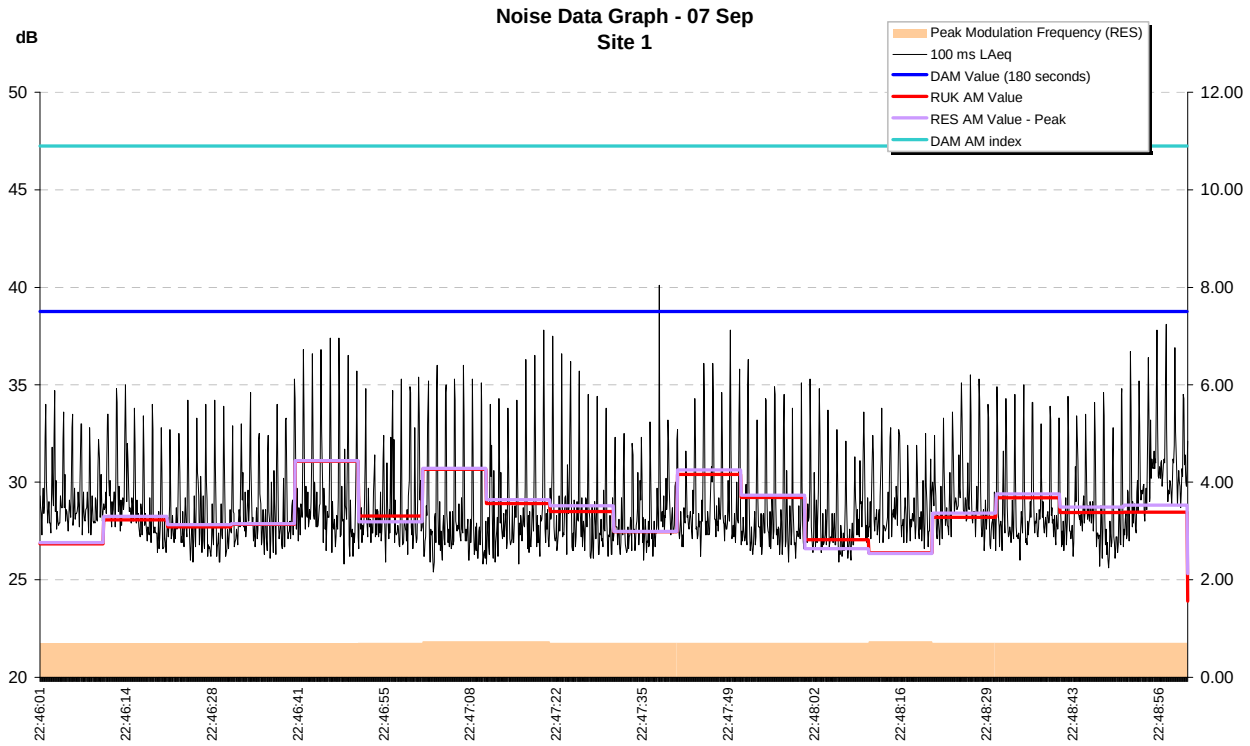


Figure 16: Site 1 - 07 Sep - 2249

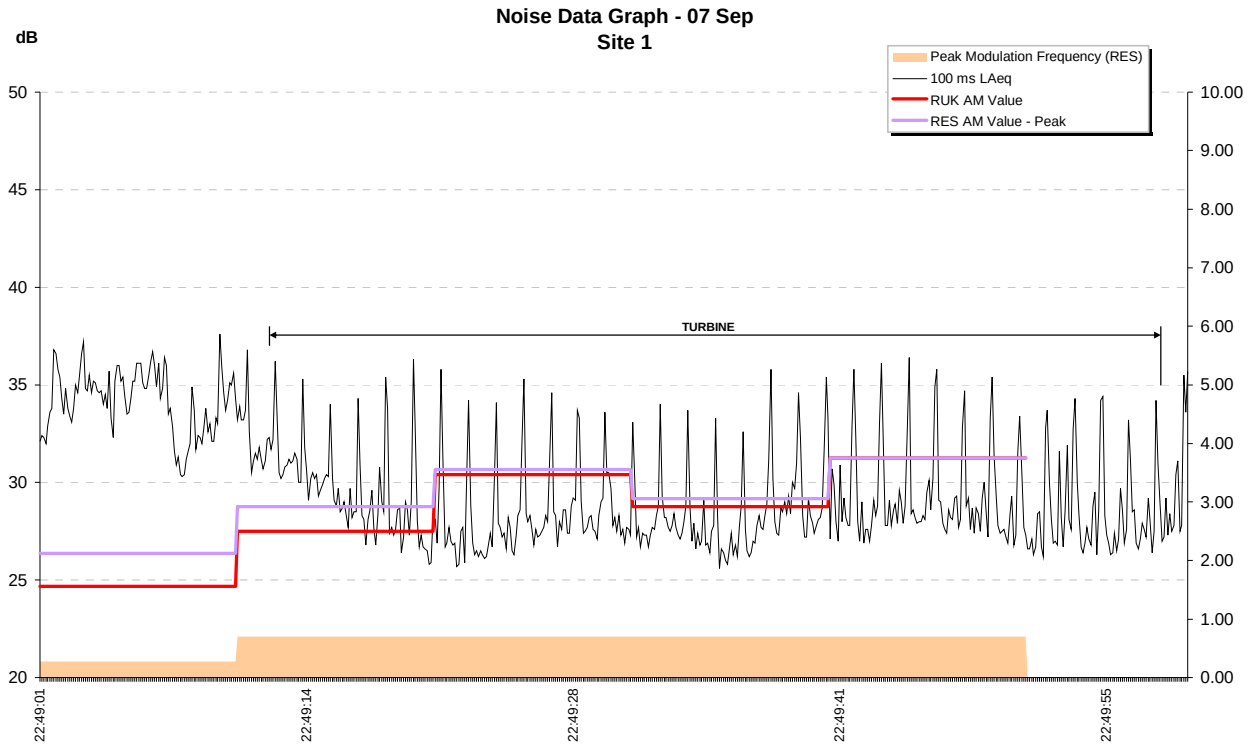


Figure 17: Site 1 - 07 Sep - 2250 (10 minutes)

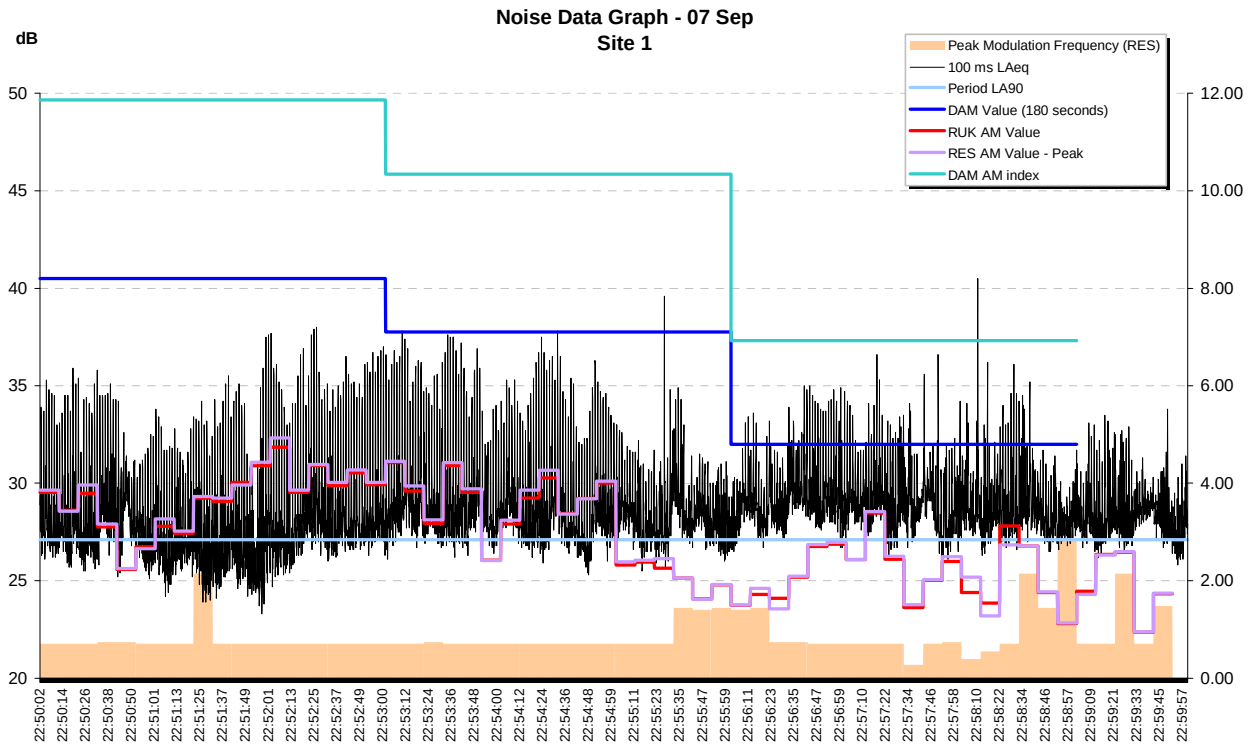


Figure 18: Site 1 - 07 Sep - 2250

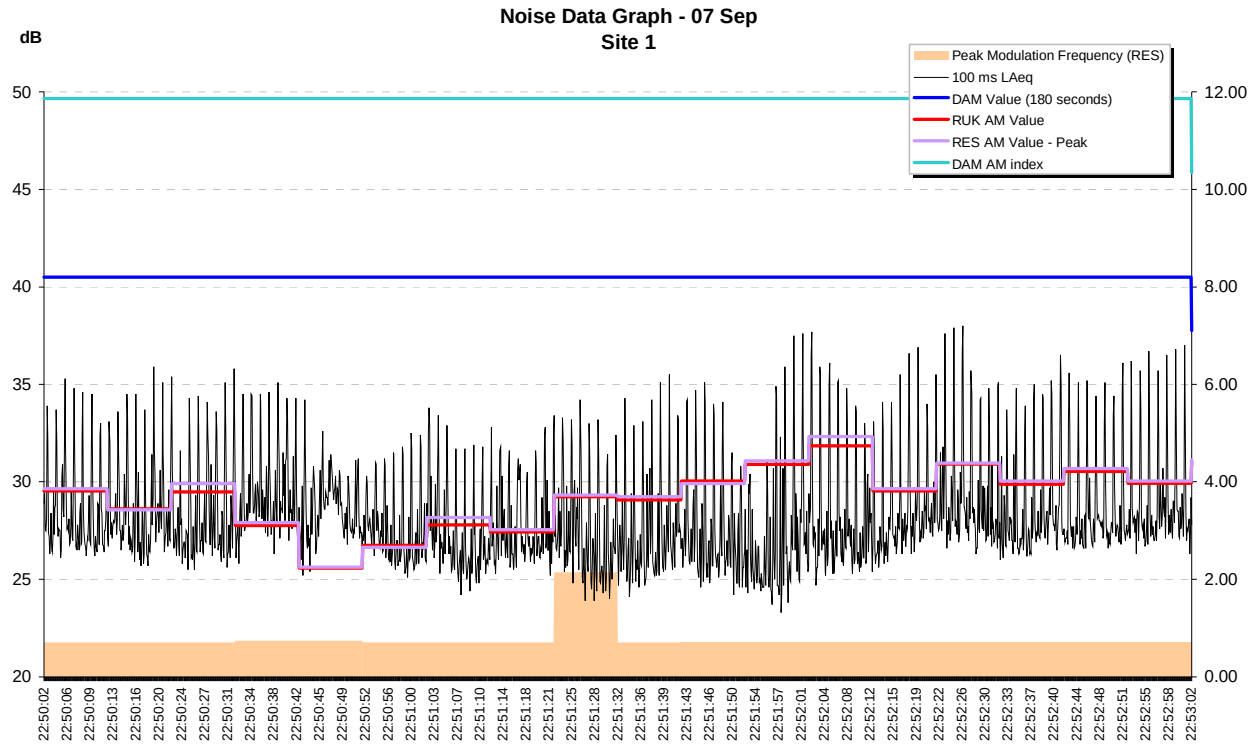


Figure 19: Site 1 - 07 Sep - 2253

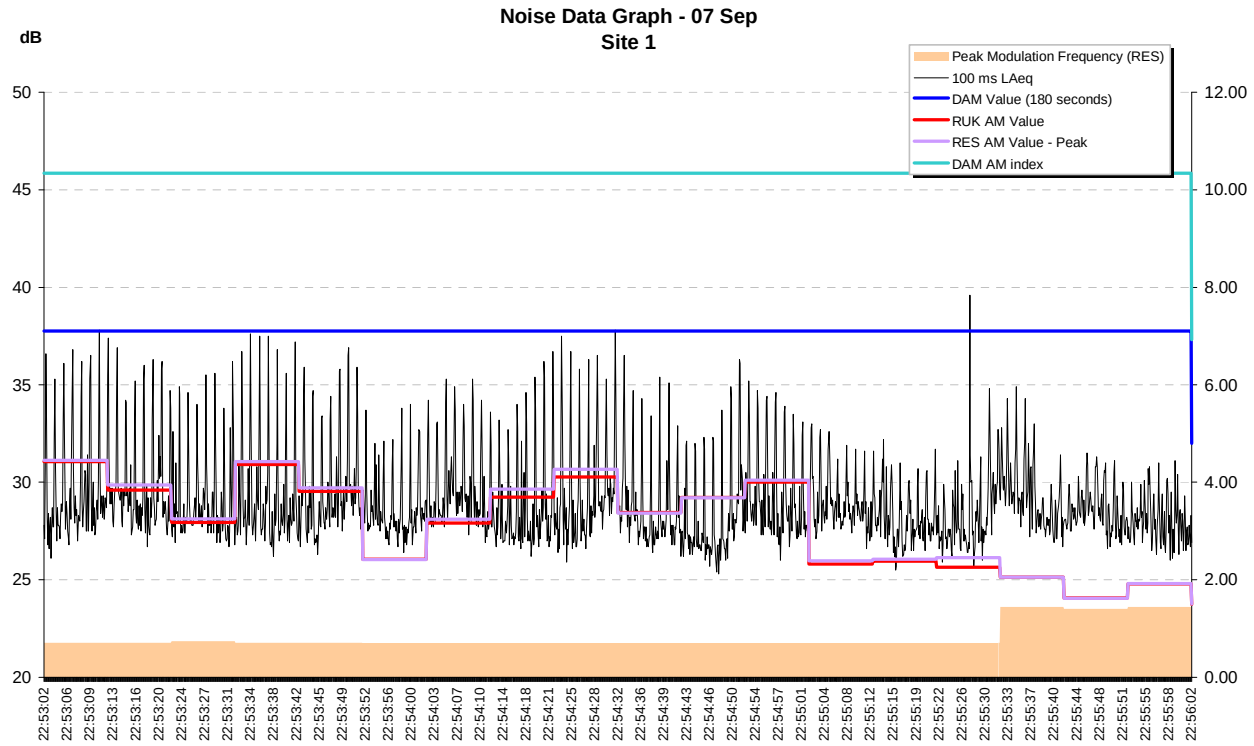


Figure 20: Site 1 - 07 Sep - 2256

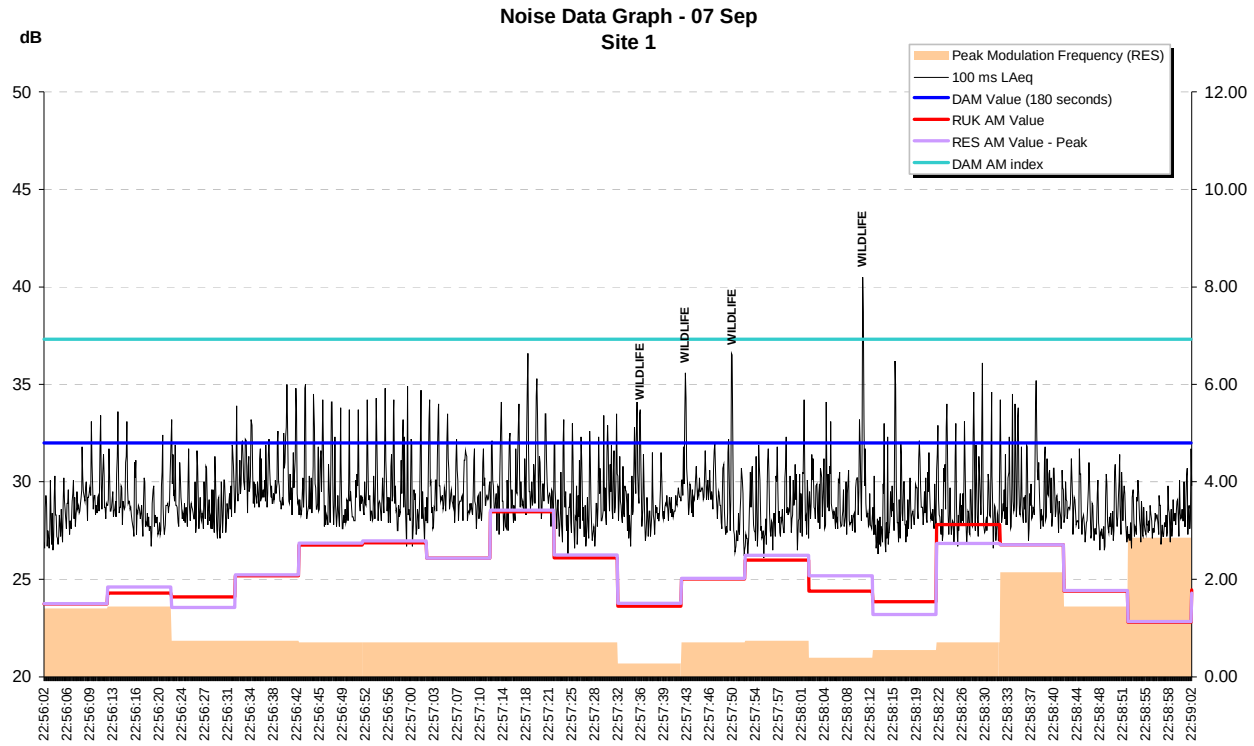


Figure 21: Site 1 - 07 Sep - 2259

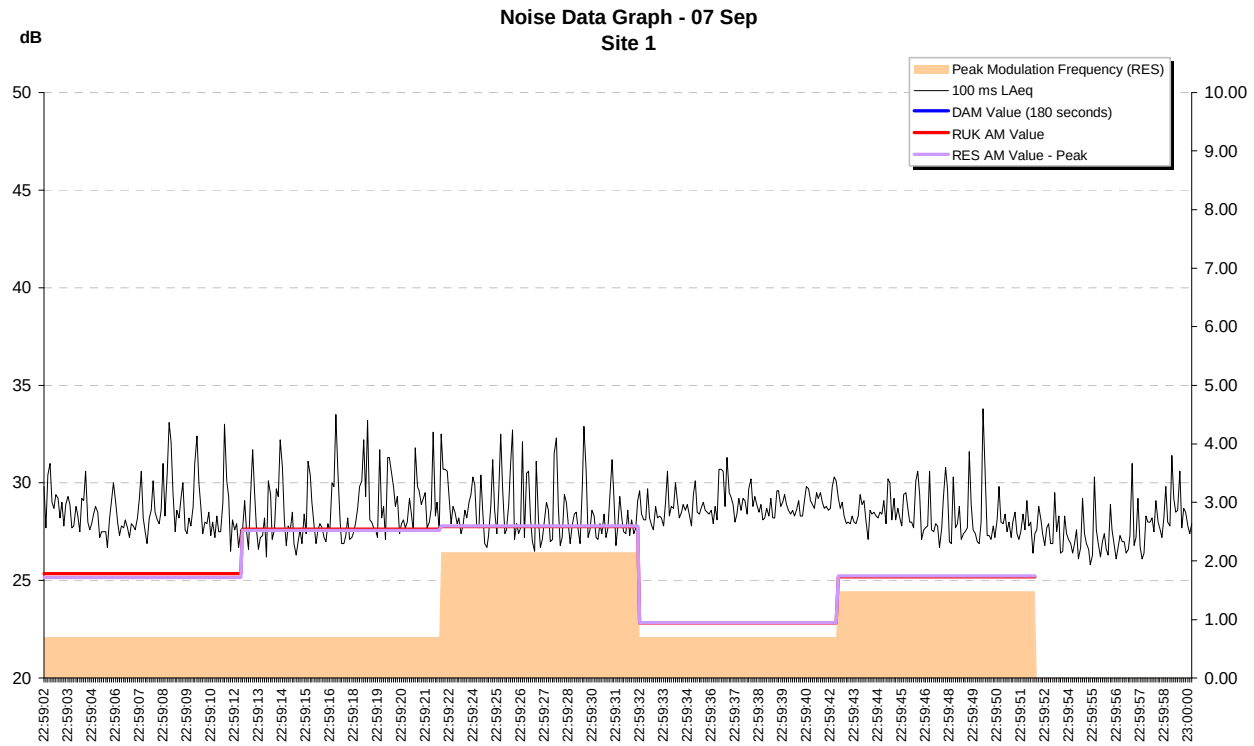


Figure 22: Site 1 - 07 Sep - 2300 (10 minutes)

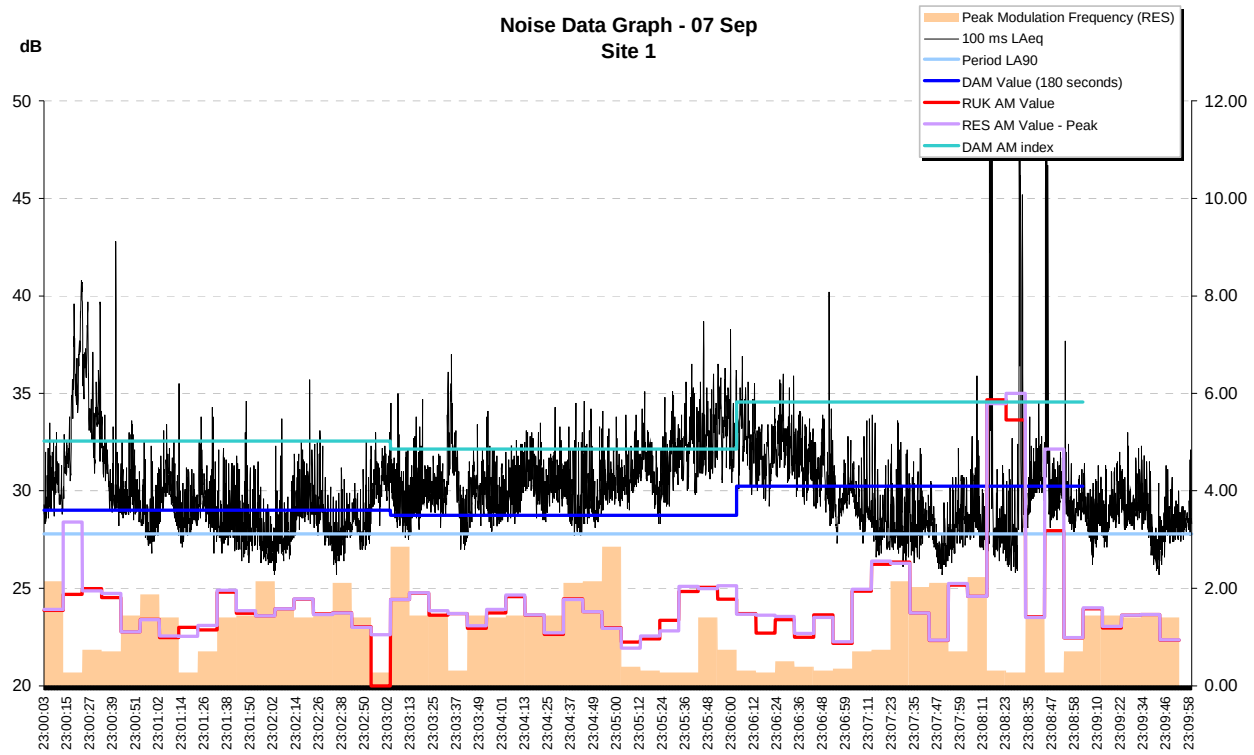


Figure 23: Site 1 - 07 Sep - 2300

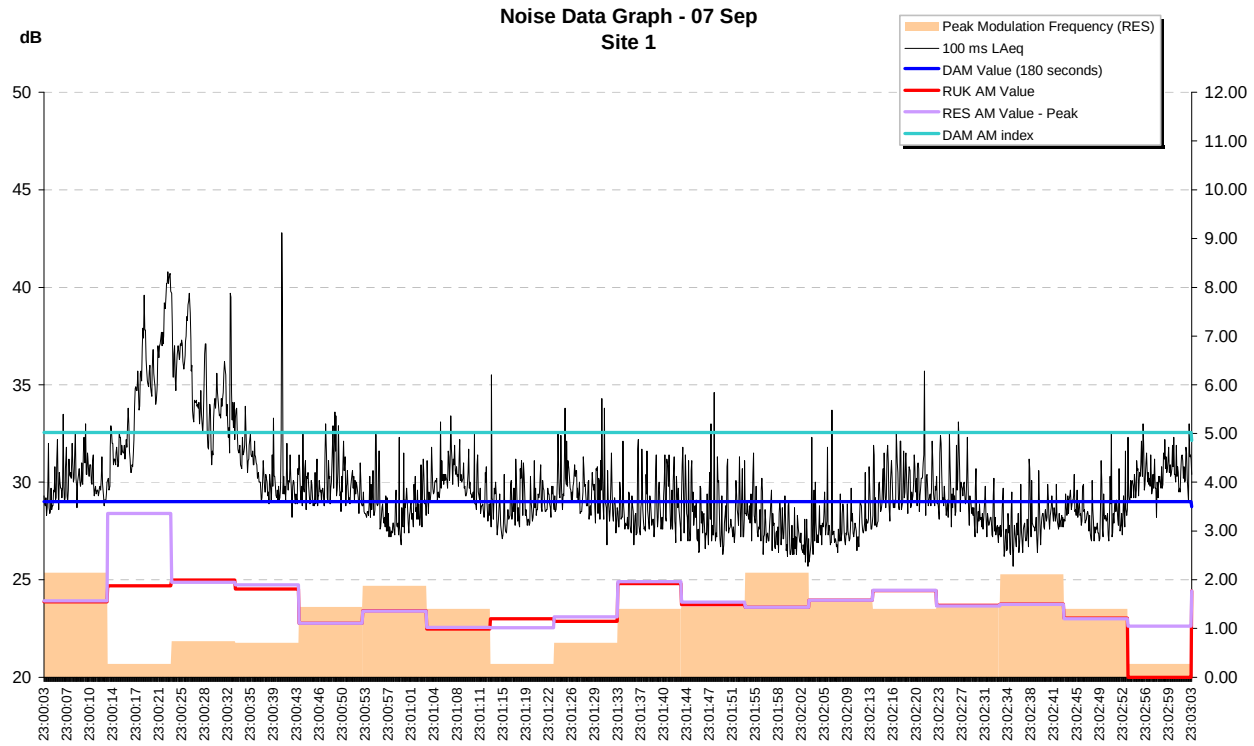


Figure 24: Site 1 - 07 Sep - 2303

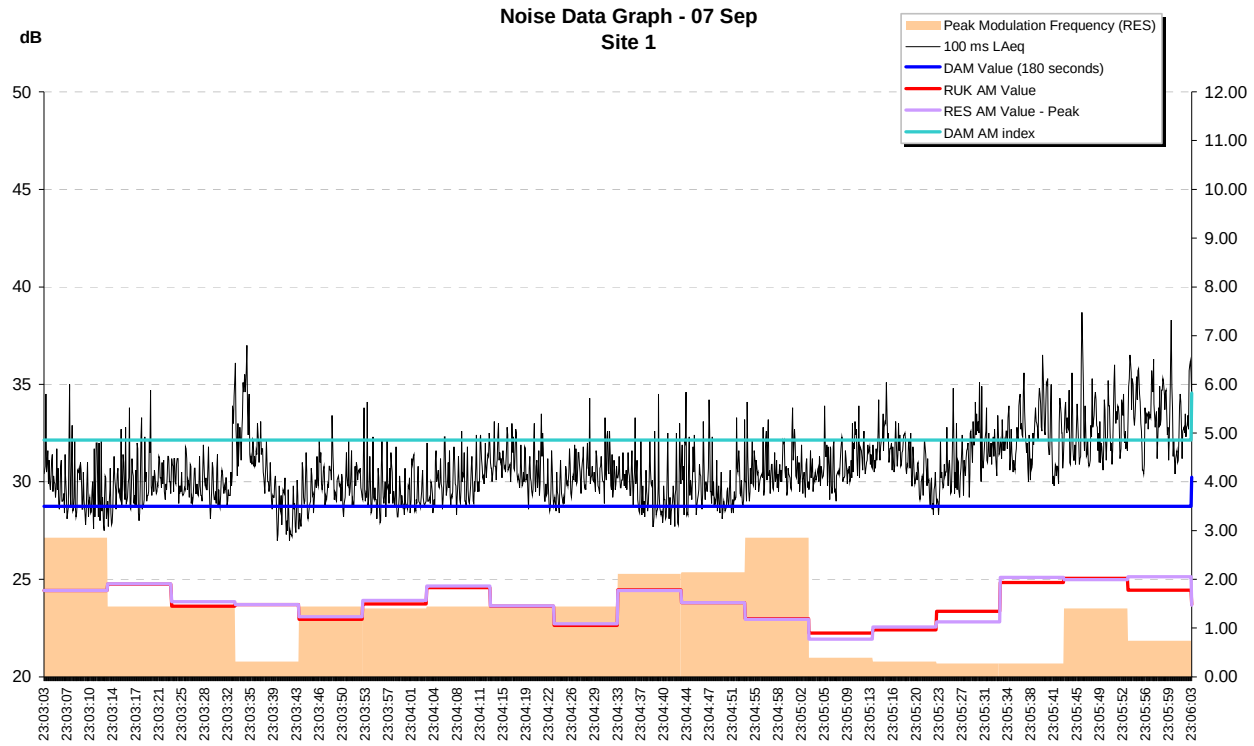


Figure 25: Site 1 - 07 Sep - 2306

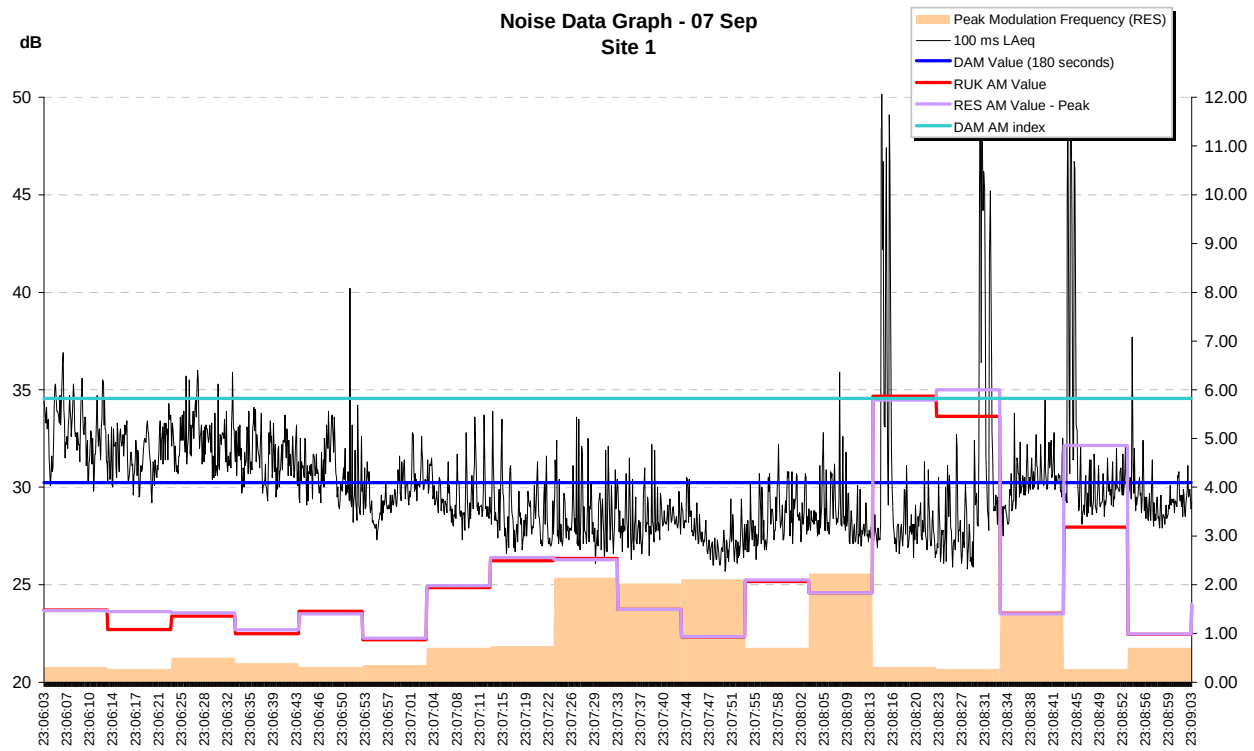


Figure 26: Site 1 - 07 Sep - 2309

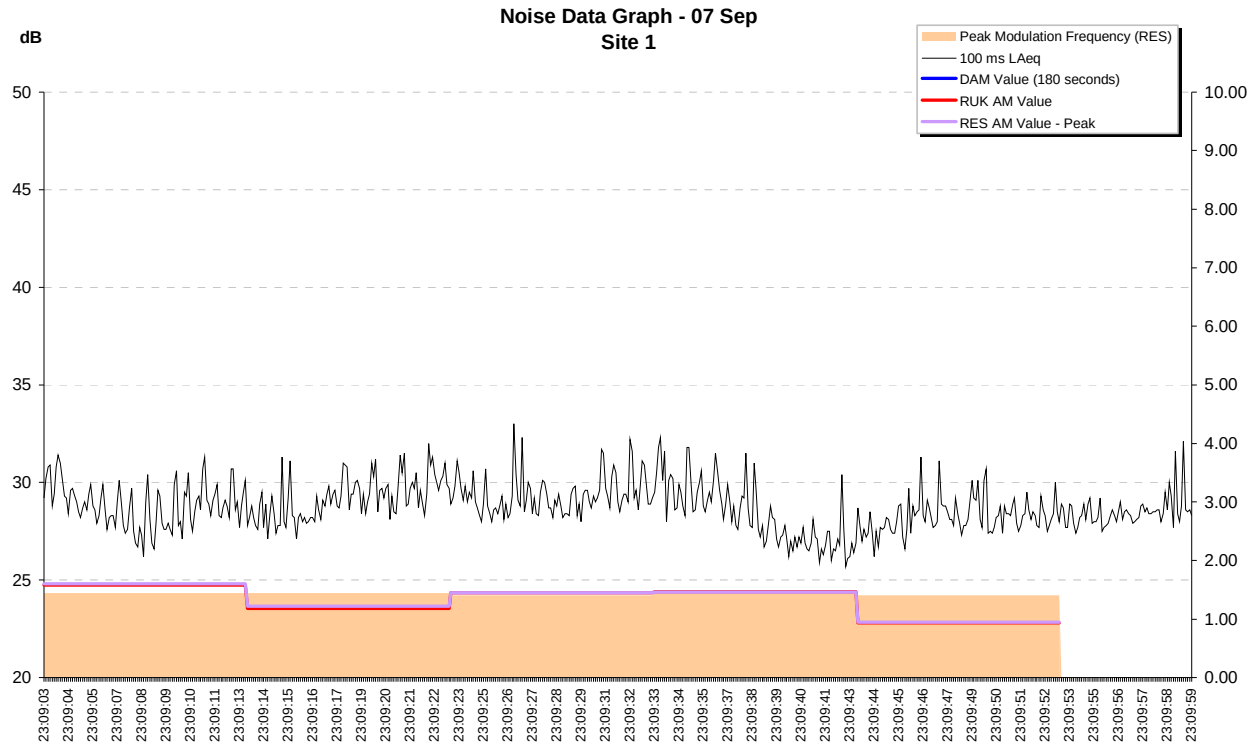


Figure 27: Site 1 - 07 Sep - 2310 (10 minutes)

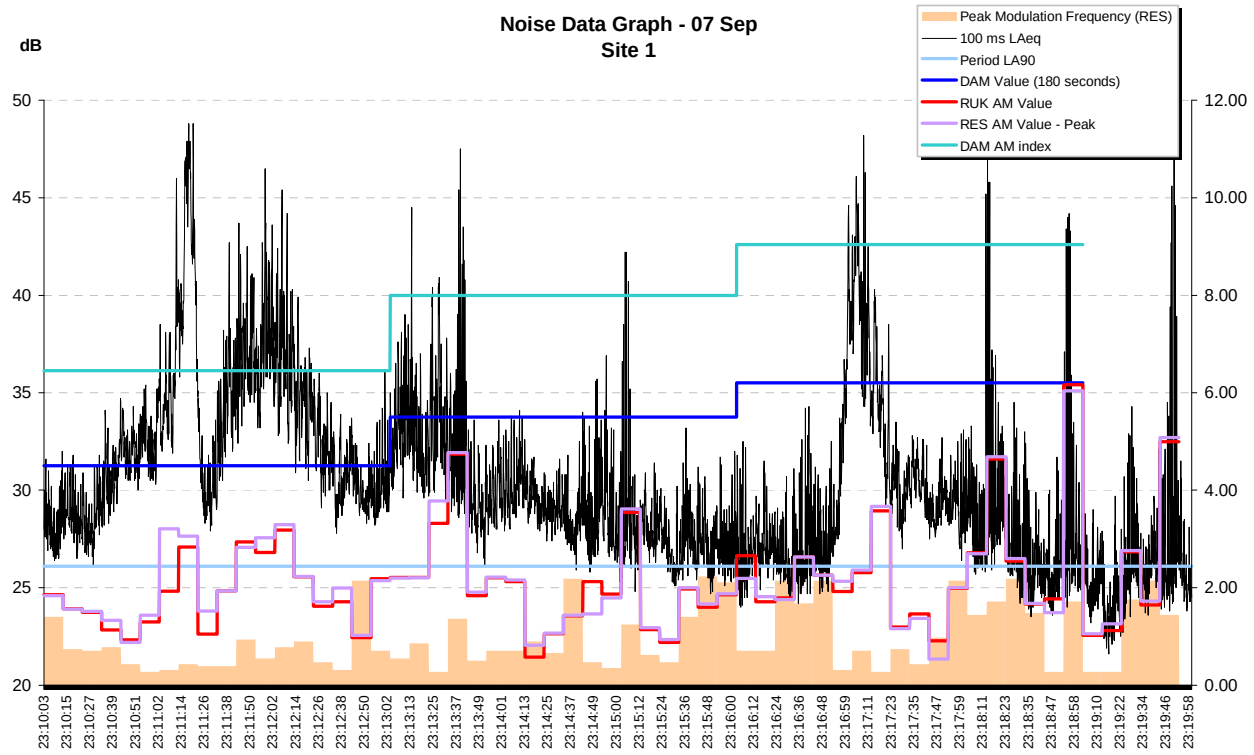


Figure 28: Site 1 - 07 Sep - 2310

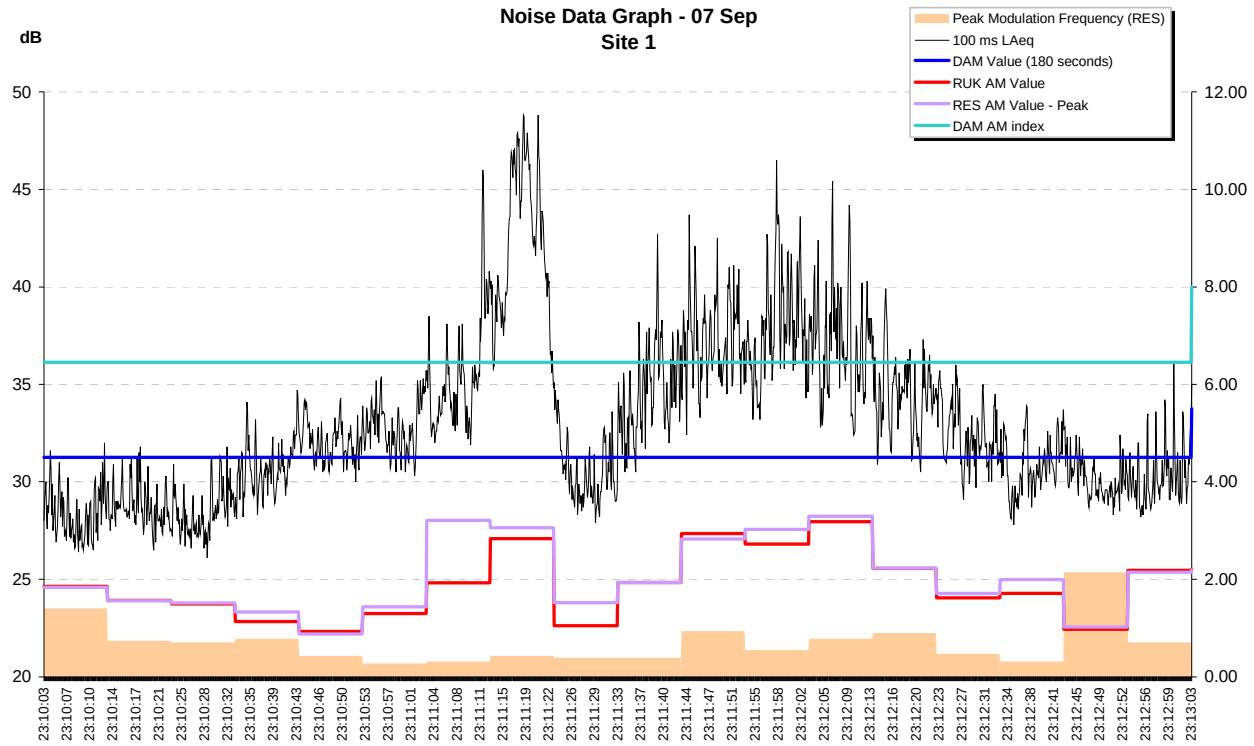


Figure 29: Site 1 - 07 Sep - 2313

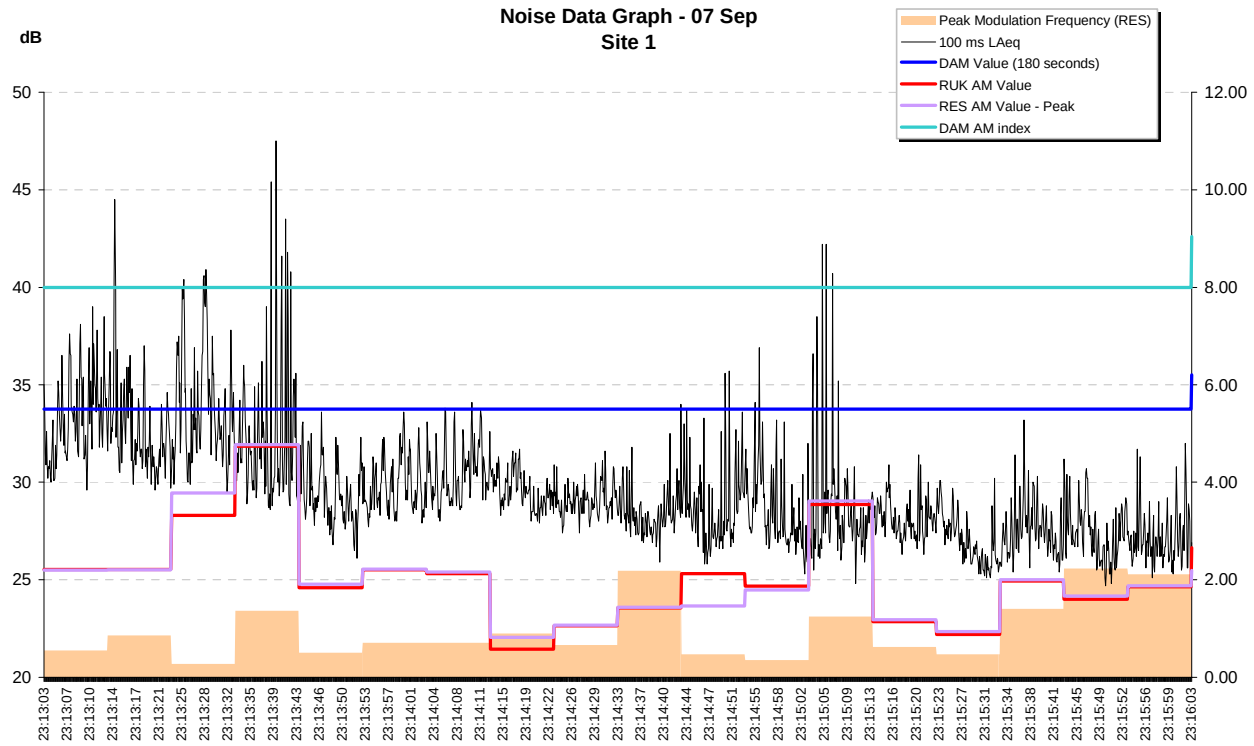


Figure 30: Site 1 - 07 Sep - 2316

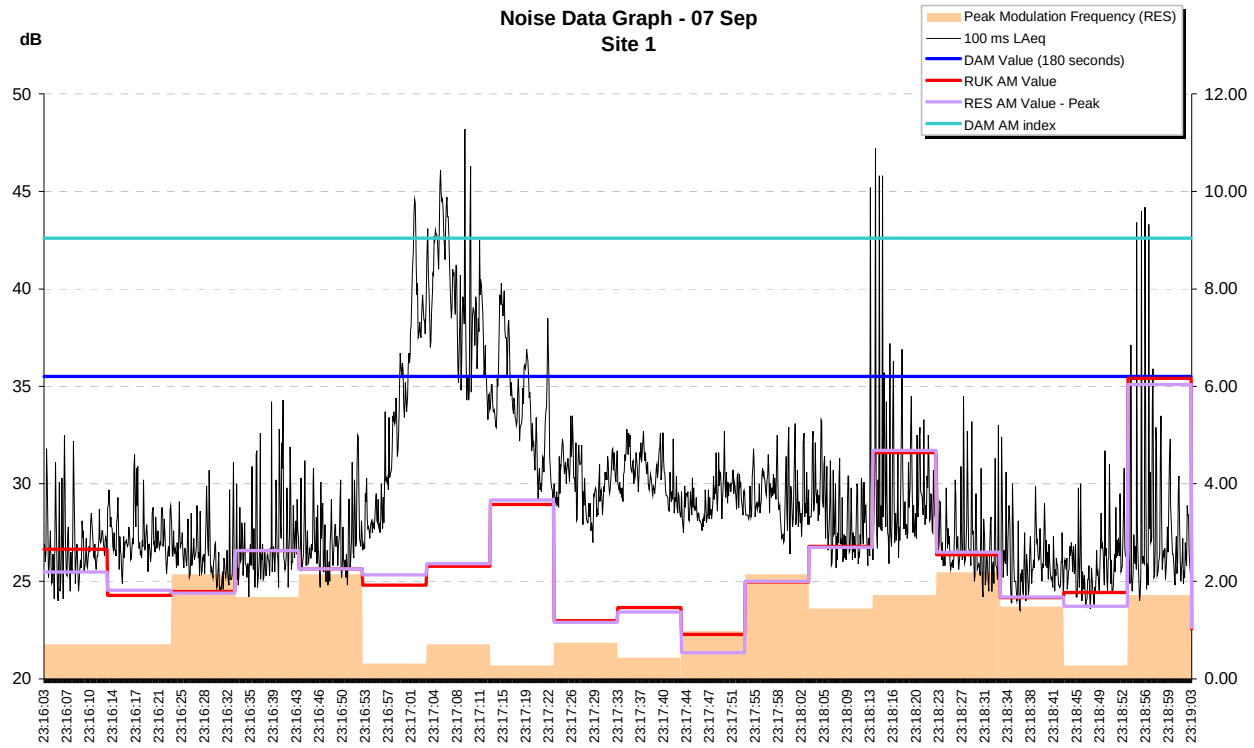


Figure 31: Site 1 - 07 Sep - 2319

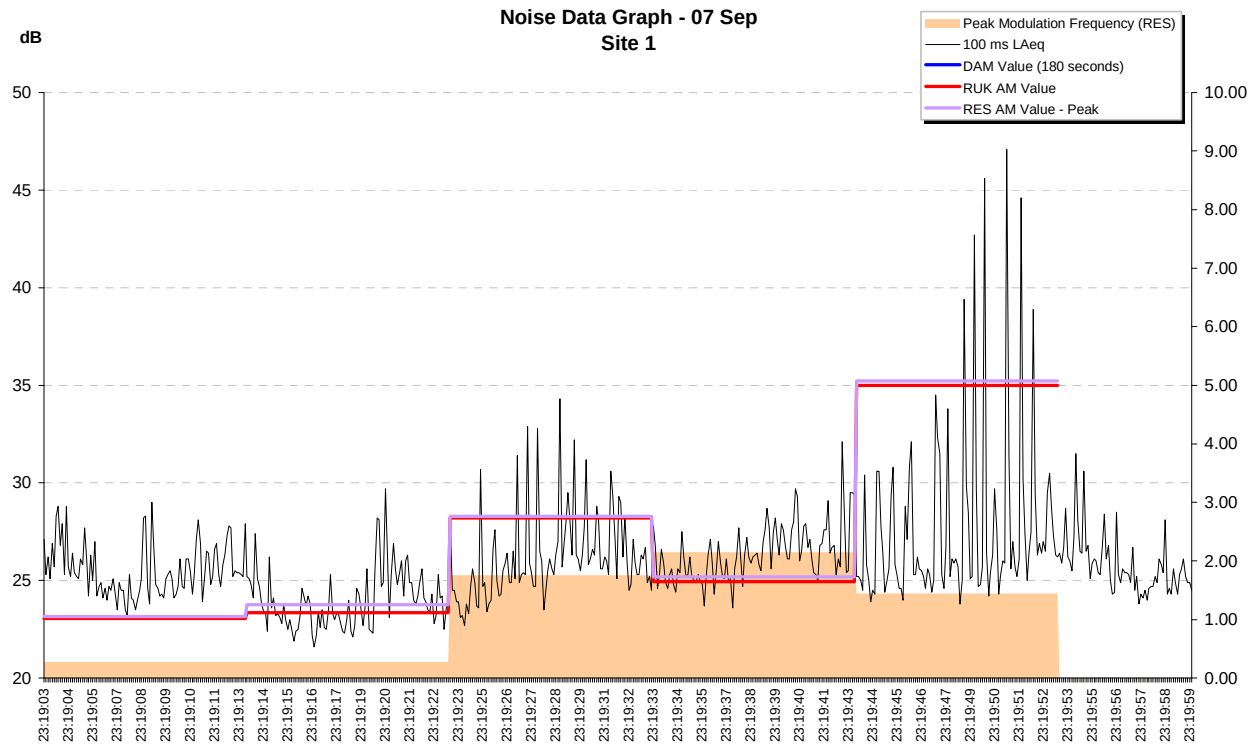


Figure 32: Site 1 - 07 Sep - 2320 (10 minutes)

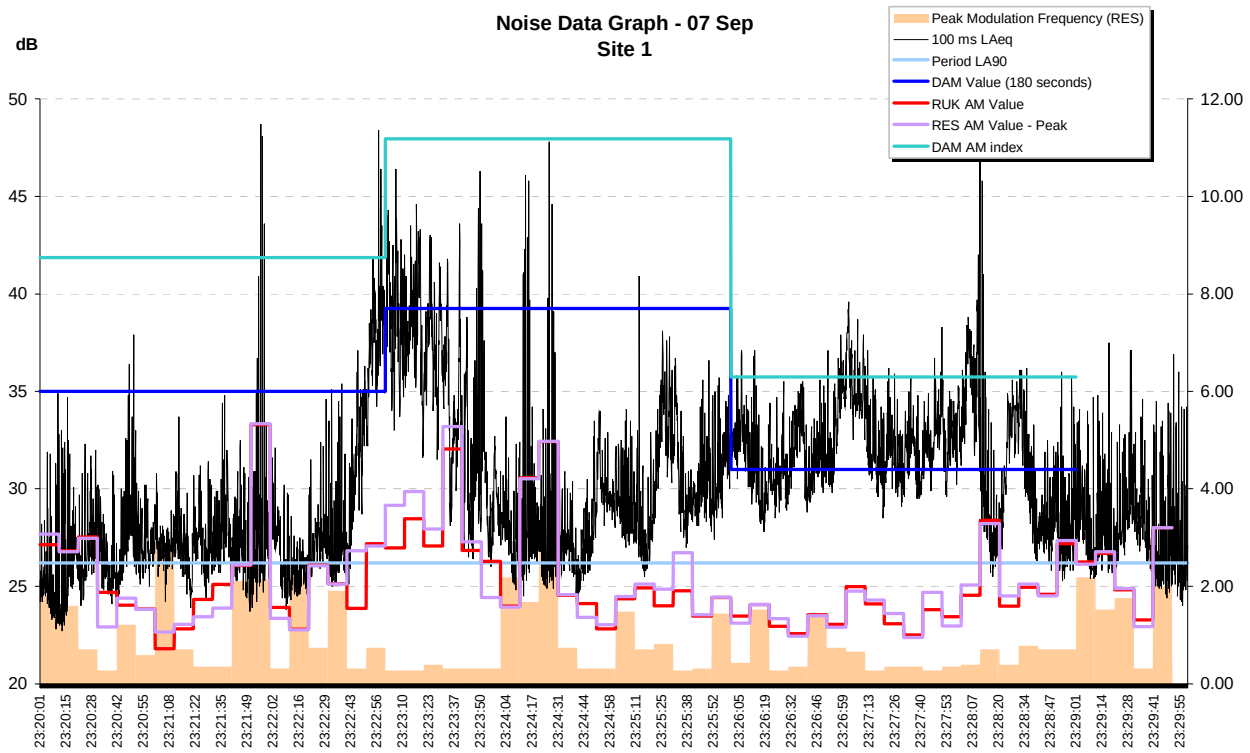


Figure 33: Site 1 - 07 Sep - 2320

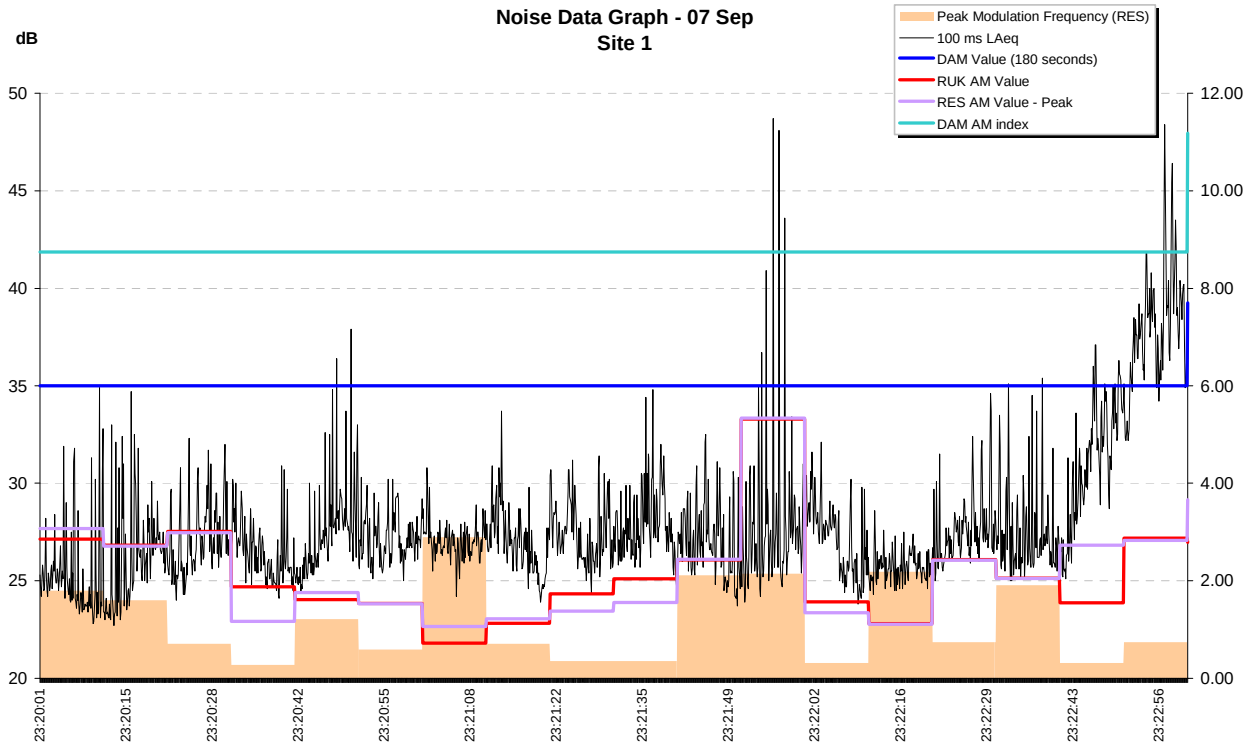


Figure 34: Site 1 - 07 Sep - 2323

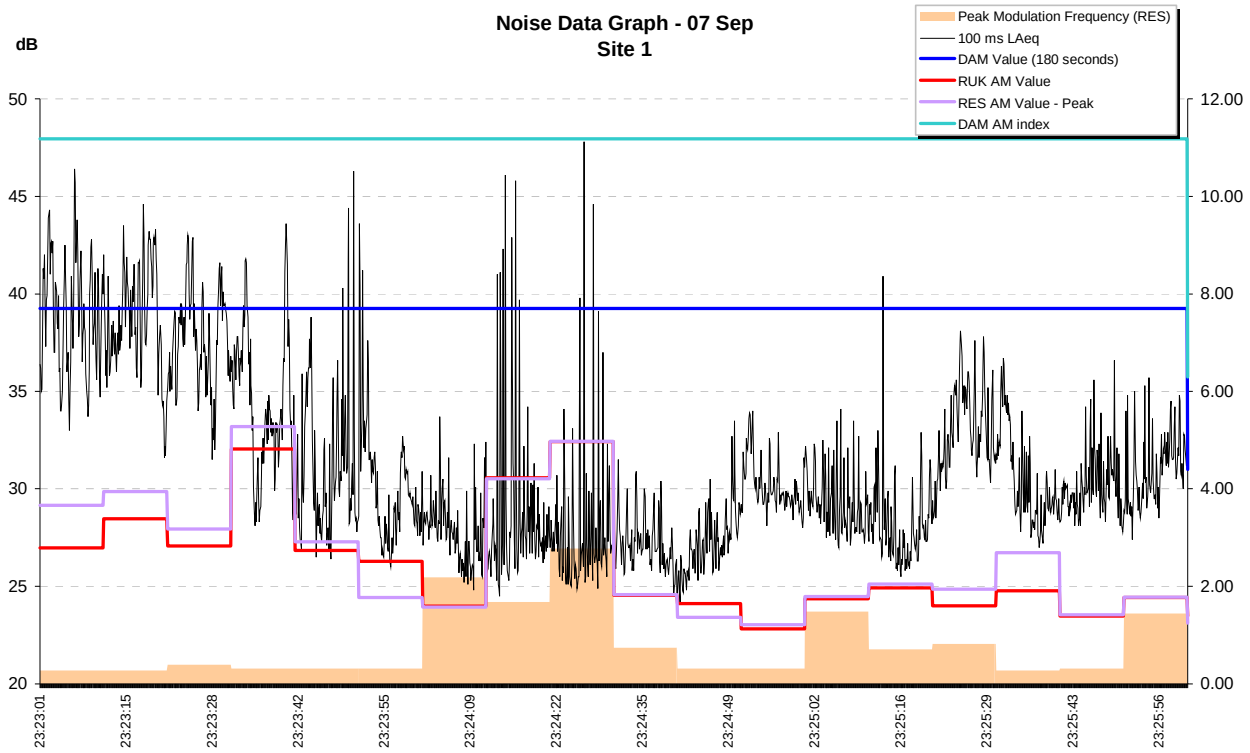


Figure 35: Site 1 - 07 Sep - 2326

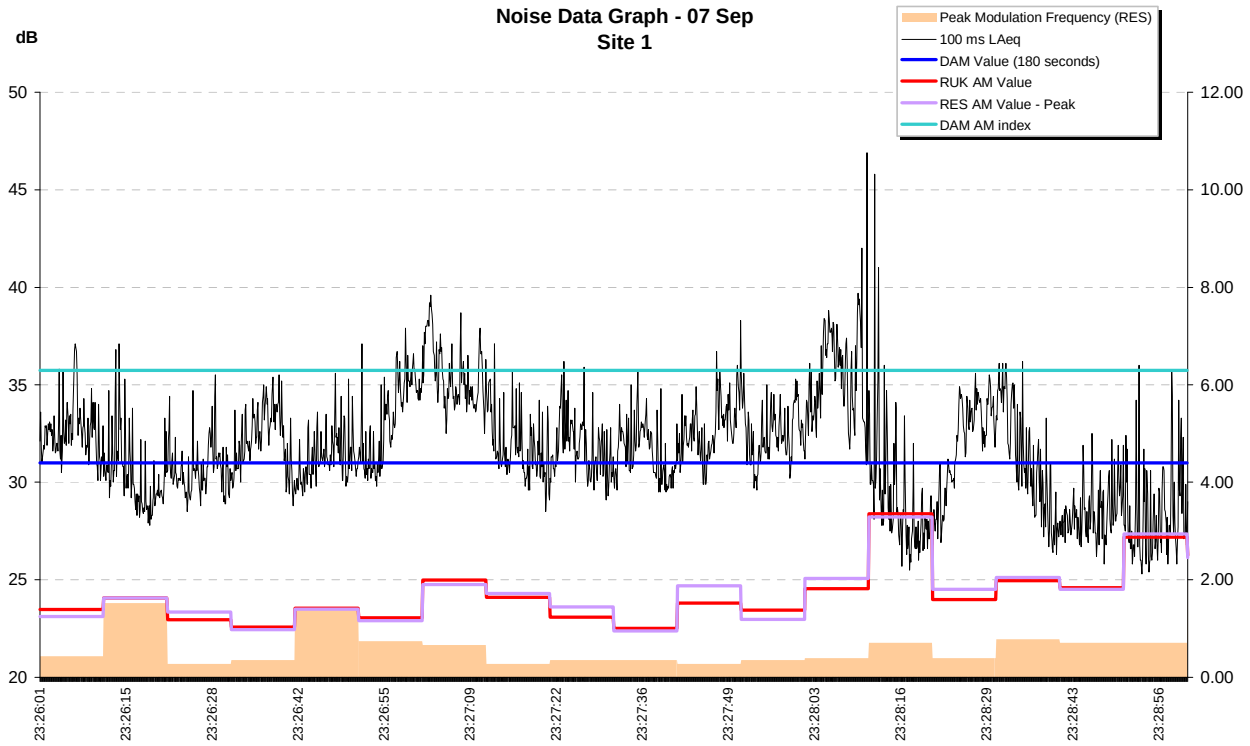


Figure 36: Site 1 - 07 Sep - 2329

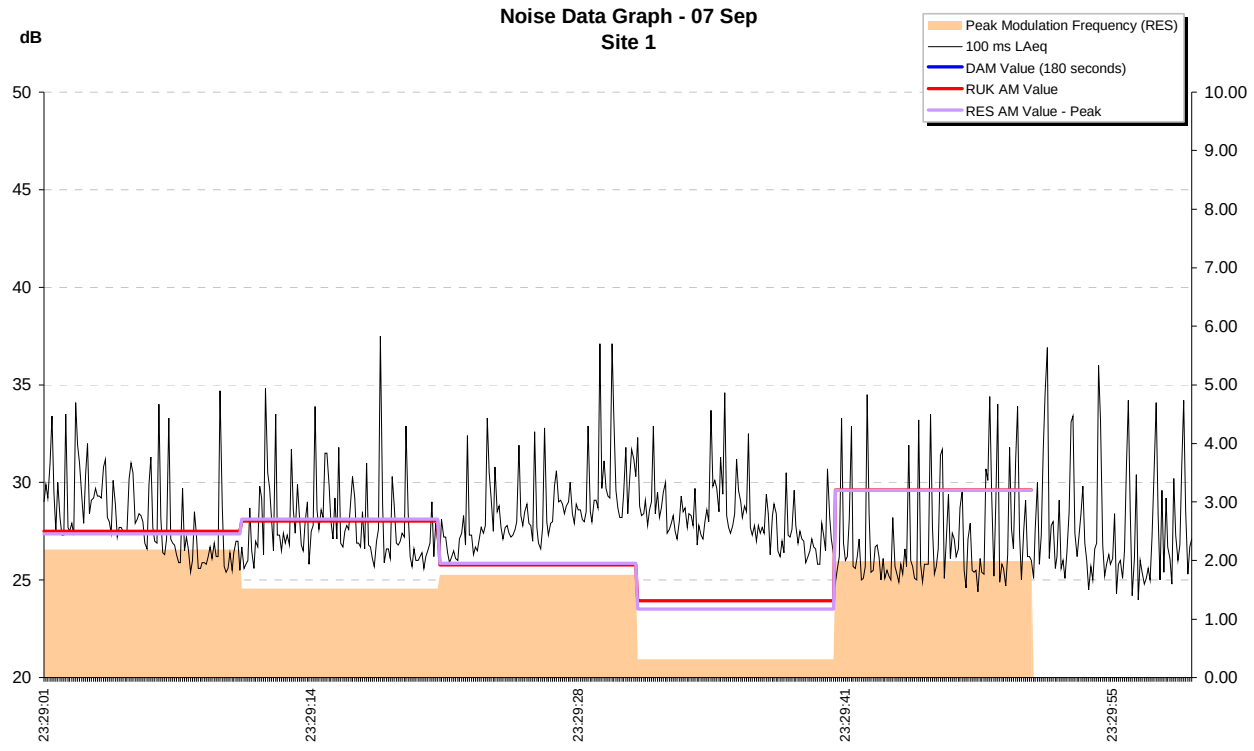


Figure 37: Site 1 - 07 Sep - 2330 (10 minutes)

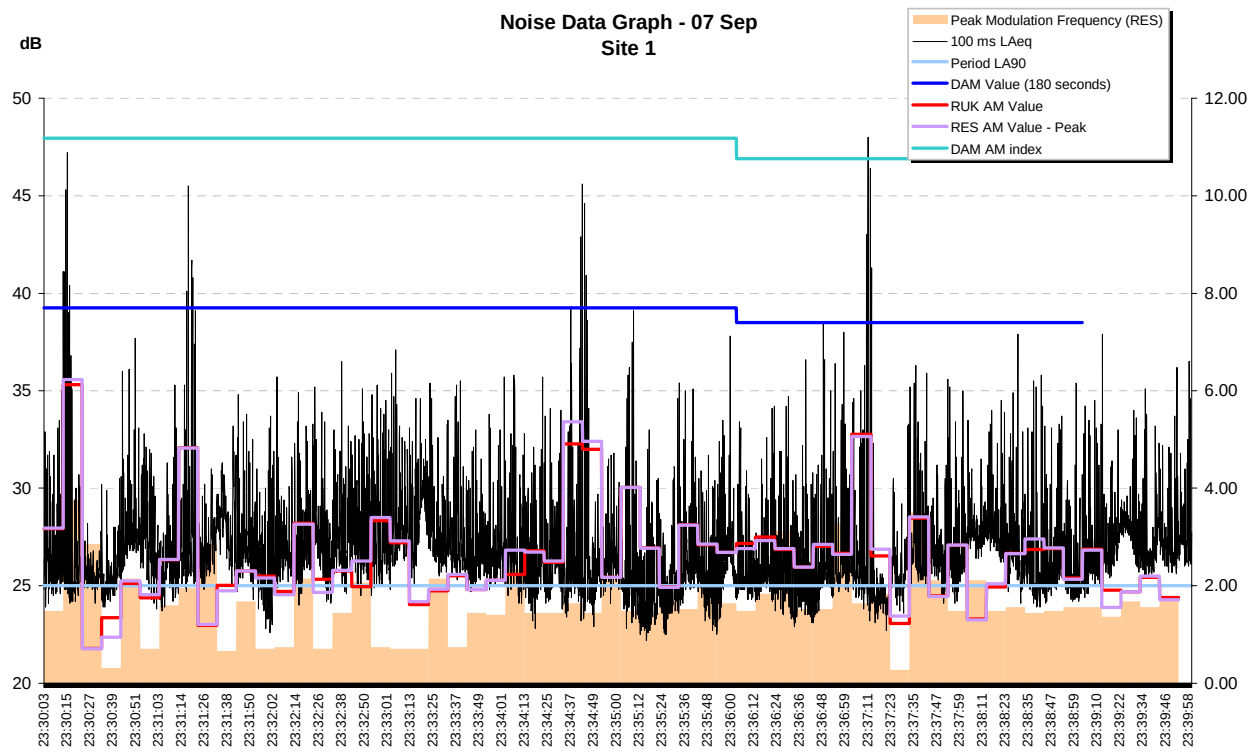


Figure 38: Site 1 - 07 Sep - 2330

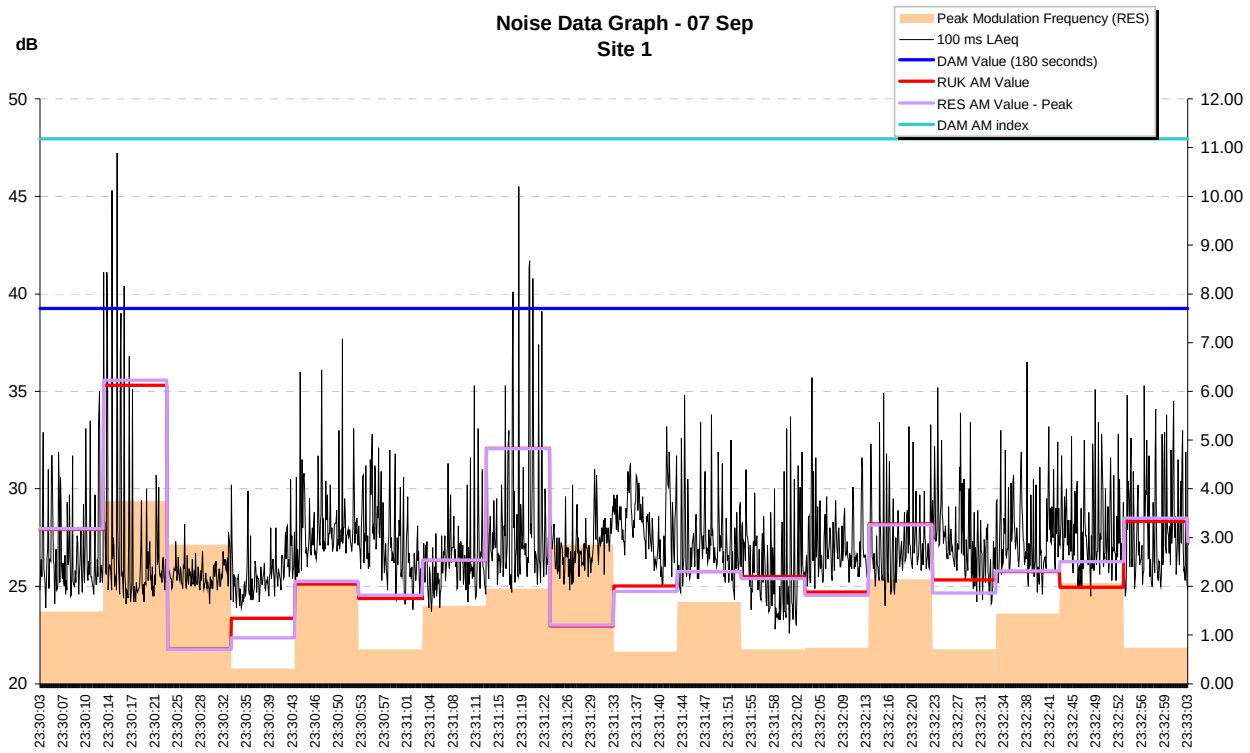


Figure 39: Site 1 - 07 Sep - 2333

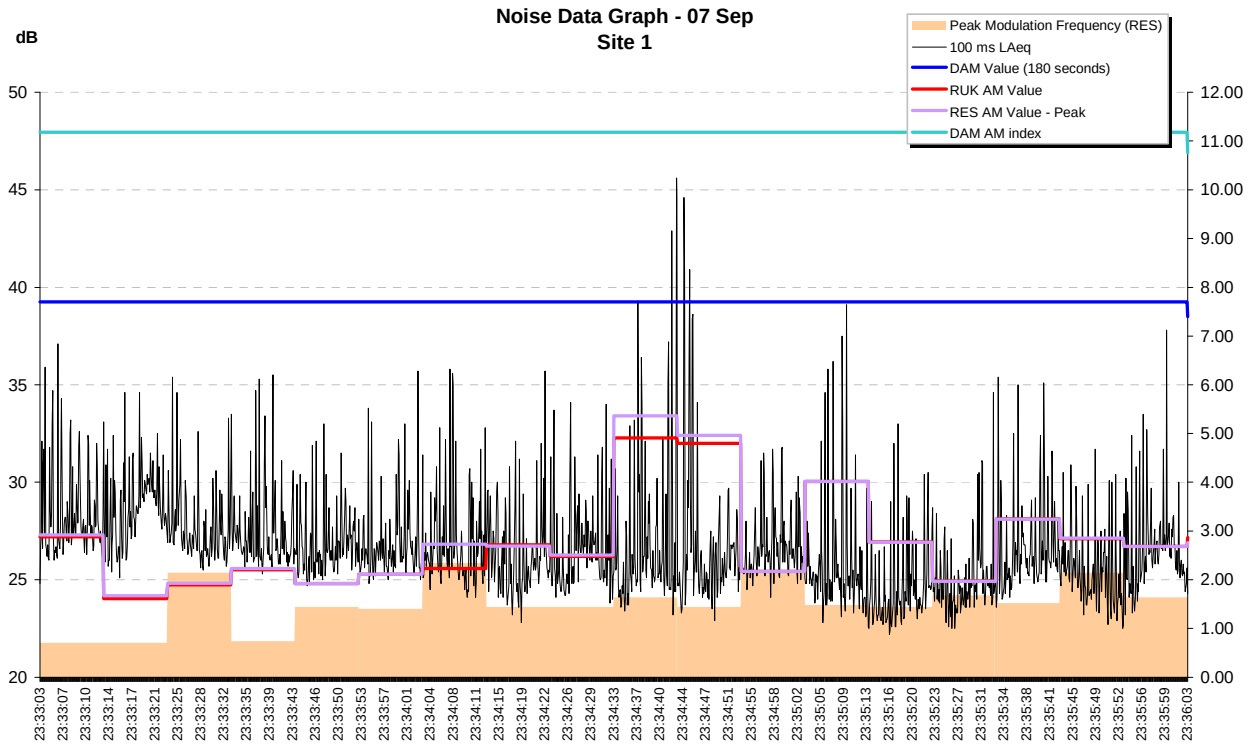


Figure 40: Site 1 - 07 Sep - 2336

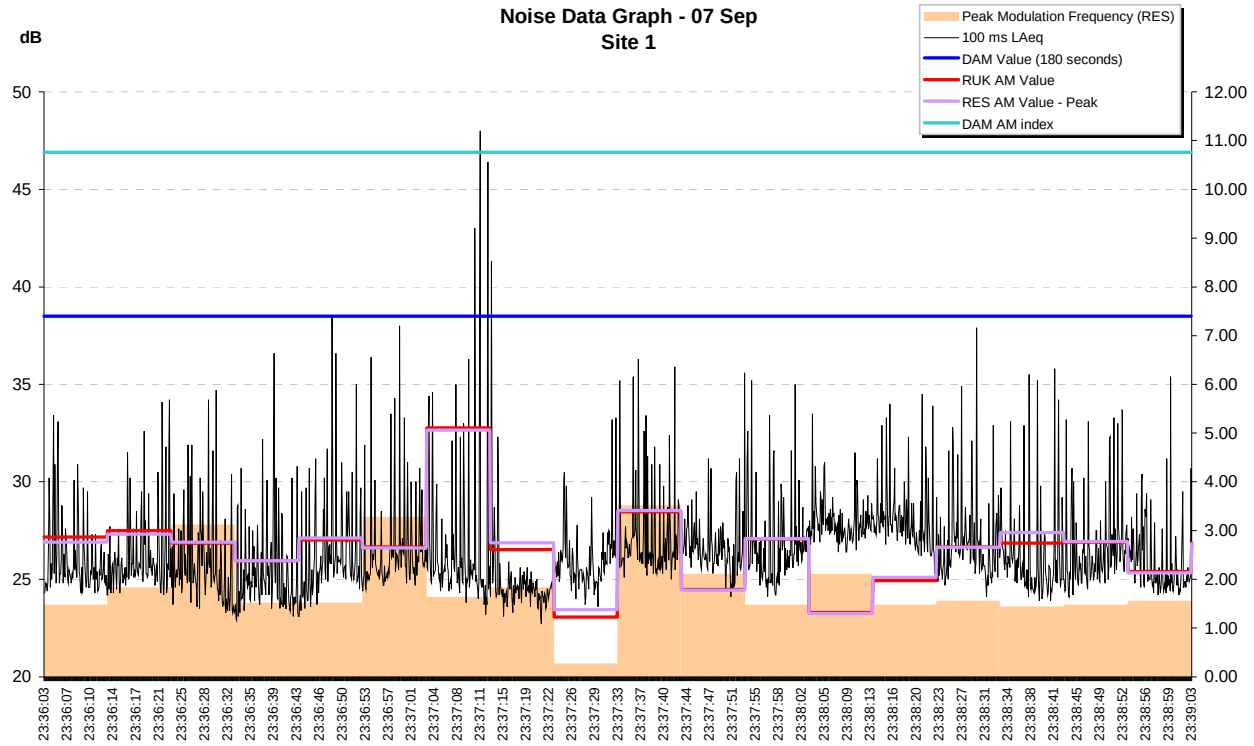
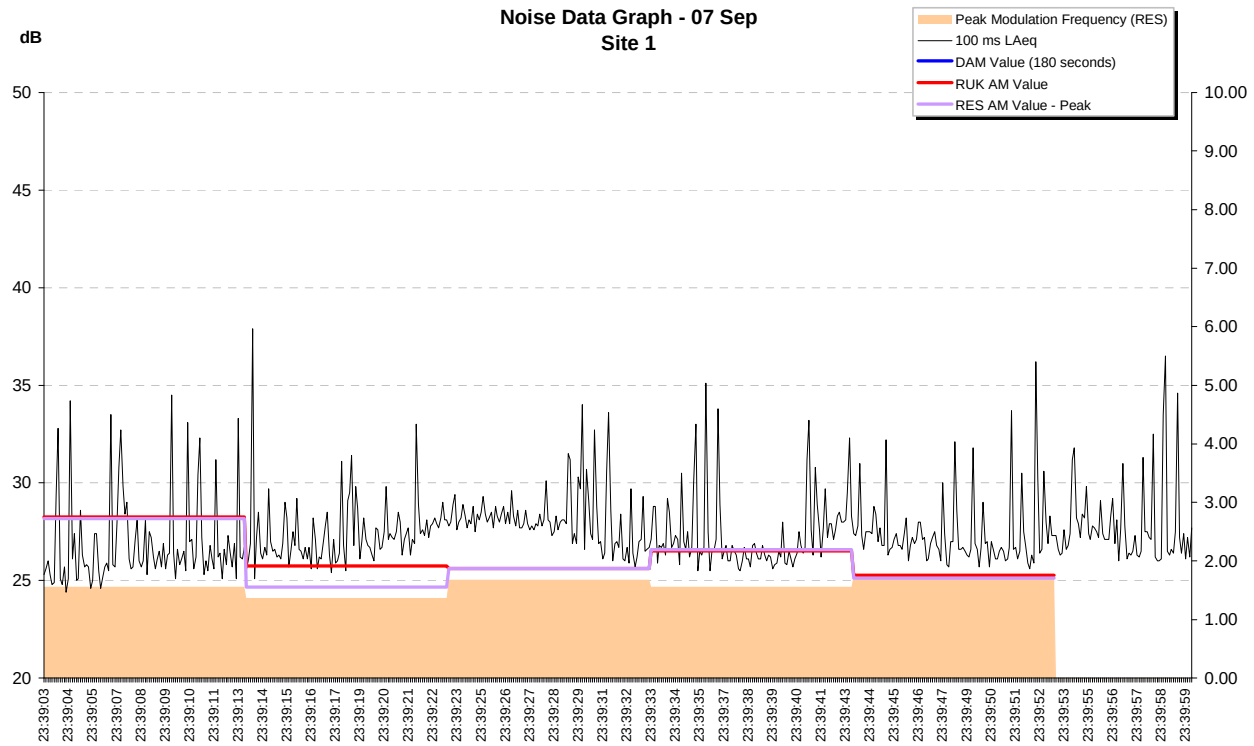


Figure 41: Site 1 - 07 Sep - 2339



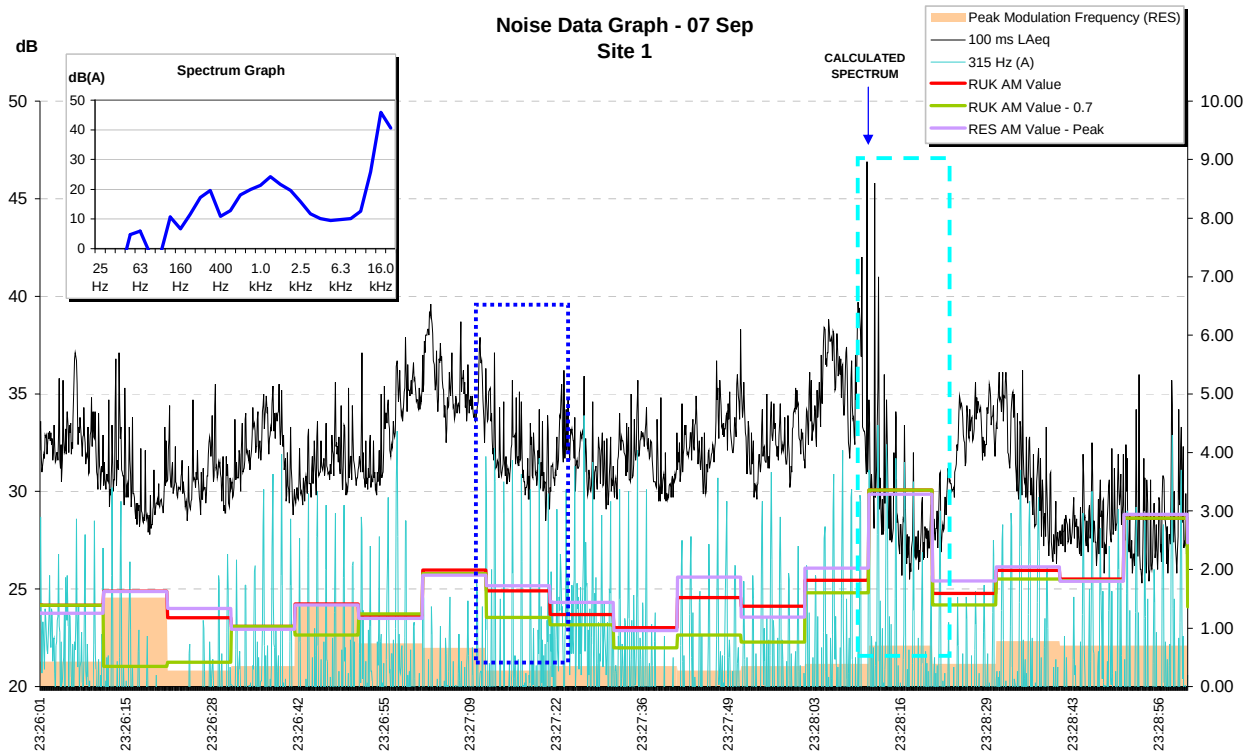
7.3 **Preliminary discussion - Site 1.** A number of interesting results can be observed from site 1. Firstly, the presence of extraneous noise can be seen to influence all four methods tested. This influences the Den Brook method and the RES Den Brook method least as only a threshold exceedance / trigger value is needed to activate the condition. Thus, as long as there are a minimum of 6 occurrences of AM with a peak to trough of sufficient magnitude, and with a 1 minute LAeq greater than 28dB(A), then EAM is indicated by the condition.

7.4 The Den Brook method is only influenced by extraneous noise where the extraneous noise masks the visual appearance of AM on the graphs despite it being audible within the audio data.

7.5 The DAM method should arguably not be criticised for failure to exclude extraneous data, as it is only a tool for assessing the level of AM where there is a clear example of AM. It is not a planning condition with a prescribed methodology for use. There are examples in the above graphs where the DAM method does and does not appear to be adversely influenced by extraneous noise. What is of note is that when there are clear periods of AM uninfluenced by extraneous noise the DAM rating and AM index are both very similar to the typical peak to trough level observed in the data. However, where there is extraneous noise the DAM rating and AM index can be significantly influenced.

7.6 The site 1 data highlights some problems with reliance of the RES and RUK methods on consistent peak modulation frequency and blade pass frequency (SCADA data). Even where there are clear periods of uninfluenced turbine AM the blade pass frequency can be highly variable, see for example figure 17 above, which shows a 10 minute period at 2250. Both methods, but particularly the RUK method, would exclude many periods where there is clear turbine noise from assessment. The presence of extraneous noise either results in exclusion prior to any assessment or the presence of some extraneous noise corrupts the derivation of the peak modulation frequency thus making it inconsistent with the actual blade pass frequency and then excluding it from assessment. Another example of this is shown in figure 42 below. This is the same figure as figure 35 above, but with the 315Hz A weighted 1/3rd octave band energy also plotted on to the graph. This 1/3rd octave band is dominated by turbine noise and so can be considered a good indicator of turbine AM.

Figure 42: Site 1 - 07 Sep - 2326 (315Hz 1/3rd octave band added to graph)



7.7 Firstly, the fluctuation and variation in the peak modulation frequency (orange bars) can be observed despite the continued operation of the turbine. Secondly, the period highlighted by the light blue dashed lines appears to be influenced by extraneous noise occurring at the same time as the turbine noise. The presence of extraneous noise is confirmed by audio data and from spectral analysis (see the inset spectrum graph, which shows high frequency noise energy at around 16 kHz). Comparing the period highlighted by light blue dashed lines with the earlier period highlighted by dark blue dotted lines there is a difference in RUK AM rating of 1.8 (3.4-1.6). This is despite the noise level generated by the turbine (reference the A weighted 315Hz third octave band noise trace) remaining similar in both periods. This indicates that the RUK method cannot exclude extraneous noise that coincides temporally with wind turbine AM.

7.8 The same problem arises if using the RUK method as originally written, assuming a constant blade pass frequency for the whole period to calculate the AM value rather than the blade pass frequency (peak modulation frequency) for each individual 10s period. This is also shown in figure 42 above. The RUK AM value for each 10s period calculated assuming a constant blade pass frequency of 0.7Hz is plotted in green. This is the blade pass frequency of the turbine as evident from periods where there is clear turbine noise and little other extraneous noise. Comparing the period highlighted by light blue dashed lines with the earlier period highlighted by dark blue dotted lines there is a difference in RUK AM rating of 2.2 (3.4-1.2). Thus, the data indicates that the RUK AM values can be skewed by extraneous noise.

7.9 **Site 2 - 31st December 01:40 - 02:50.** Site 2 is a single turbine that has two operating gears, distinct AM, and tonal features associated with the two separate modes. The lower gear generates a tonal drone and is often accompanied by a low level blade swish. The higher gear operation creates a tonal whine at around 1kHz and is accompanied by blade noise similar to a harsh scraping sound. The operational modes and associated sounds are referred to in the results table below.

7.10 For the purpose of assessment using the RES and Renewable UK (RUK) method on this occasion (31 Dec) it is assumed that the blade pass frequency is that when operating in the higher gear, thus periods of lower gear operation are treated as inconsistent with the blade pass frequency of the turbine.

7.11 As with site 1 the data is presented graphically in 10 minute periods, for consistency with wind farm guidance, and then split in to three 3 minute period graphs. To facilitate analysis of the DAM rating periods of 180s (3 minutes) have been used in this case. Thus, analysis of the DAM rating excludes the final 1 minute of each 10 minute period. As above the Den Brook assessment is provided only in the tables, not graphically, as the assessment can be made by a simple visual inspection of the graph and further confirmation with the audio data where necessary. Also provided in the summary table is a brief description of the audio for each 10 minute period. A summary table of the results is given in table 2 below. For brevity only the first 10 minute period has been provided graphically below.

Table 2: Summary of results - Site 2 - 31 Dec

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating	
					DAM	AM index
0140	Turbine drone audible at the beginning though not much swish until higher mode operation with high level swish. No extraneous noise.	Borderline, ≈28dB LAeq. (≈ 8-15dB). Low gear operation <28dB LAeq,≈3dB P-T	A =4.8.	Yes. Lots of periods >2.5.	5.1 6.5 2.6	7.4 9.5 3.4
0150	Some distant plane noise at the start of the period. Drone and low level blade swish audible throughout and minimal corruption from extraneous noise.	No. Low gear operation <28dB LAeq and ≈3dB P-T	No. All operation in lower gear (inconsistent BPF).	No. Consistent BPF for lower gear but <2.5.	3.2 2.4 2.5	4.4 3.0 3.2
0200	All noise in period is attributable to the turbine. High level swish. Odd occasions of wind gust and higher gear operation at end of period.	Yes. (≈ 7-11dB) Many clear examples.	A = 5.4	Yes. Lots of periods >2.5.	2.1 2.4 6.9	2.5 3.0 10.1

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating	
					DAM	AM index
0210	Turbine drone dominant throughout and some low level blade swish. Some noise from wind in trees.	No. Low gear operation <28dB LAeq and ≈3dB P-T	No. All operation in lower gear (inconsistent BPF).	No.	2.1 2.1 2.0	2.5 2.5 2.4
0220	Drone and low level swish at start of period, clear uncontaminated turbine noise trace (high level swish) with some wind at the end of the period.	Yes. (≈ 5-10dB) Only just above 28dB LAeq.	A = 4.5	Yes. Lots of periods >2.5.	1.9 5.5 2.8	2.2 8.0 3.7
0230	Drone and low level blade swish until last minute of the period.	Yes. (≈ 6dB) Only in last minute.	No. Operation mainly in lower gear (inconsistent BPF).	No.	2.2 2.1 2.0	2.7 2.5 2.4
0240	High mode operation at start of period with tonal resonances. Not so much swish in second half of period, some drone and wildlife noise.	Yes. (≈ 4-8dB) Many clear examples.	A = 3.0	Yes. Fewer periods >2.5.	4.1 1.6 1.5	5.8 1.7 1.5
0250	Drone and wind in the trees audible at start of period. High mode operation and windier with lots of tonality and resonance. Predominantly turbine noise and minimal extraneous noise.	Yes. (≈ 7-12dB) Many clear examples.	A = 4.3	Yes. Lots of periods >2.5.	3.8 4.3 4.3	5.3 6.1 6.1

Figure 43: Site 2 - 31 Dec - 0140 (10 minutes)

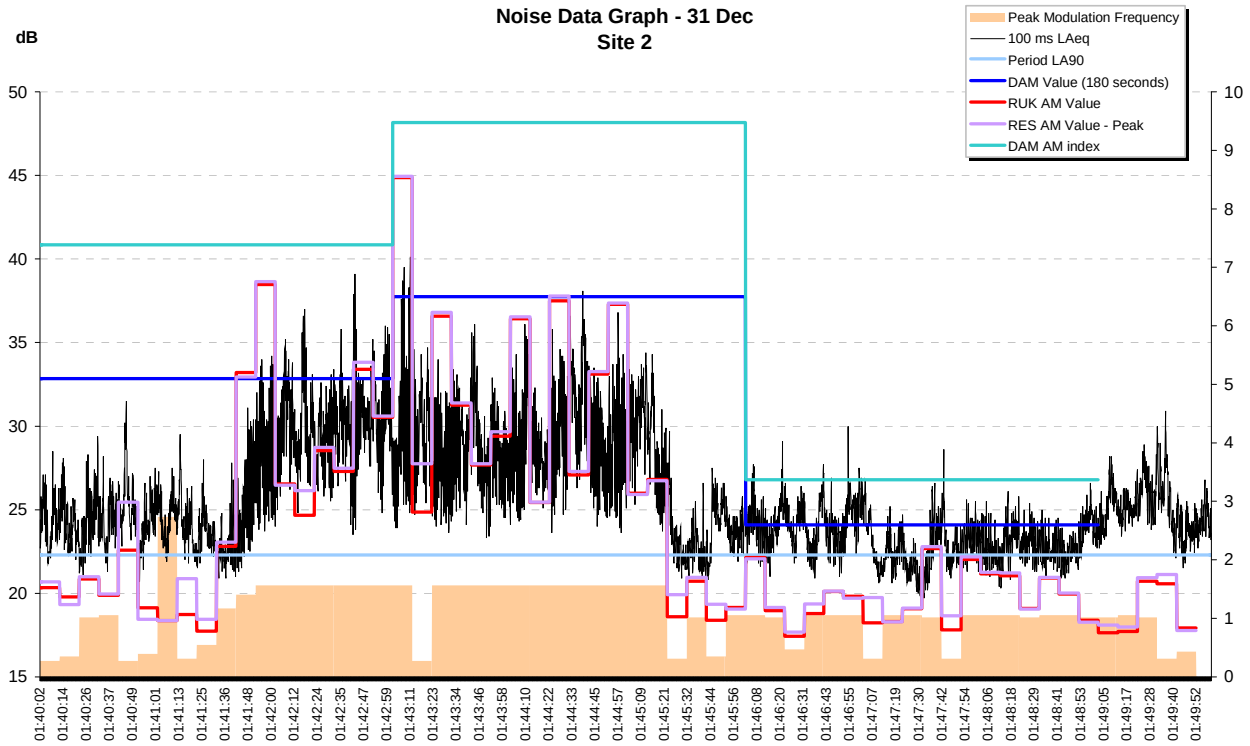


Figure 44: Site 2 - 31 Dec - 0140

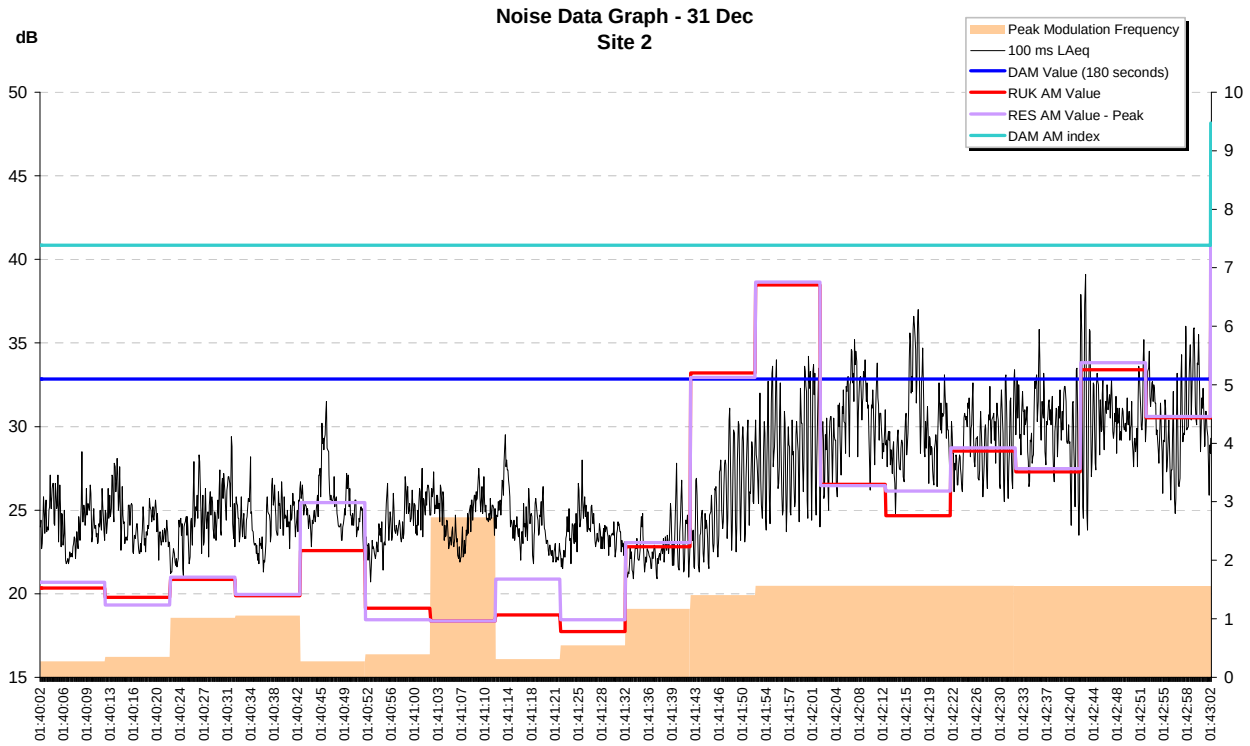


Figure 45: Site 2 - 31 Dec - 0143

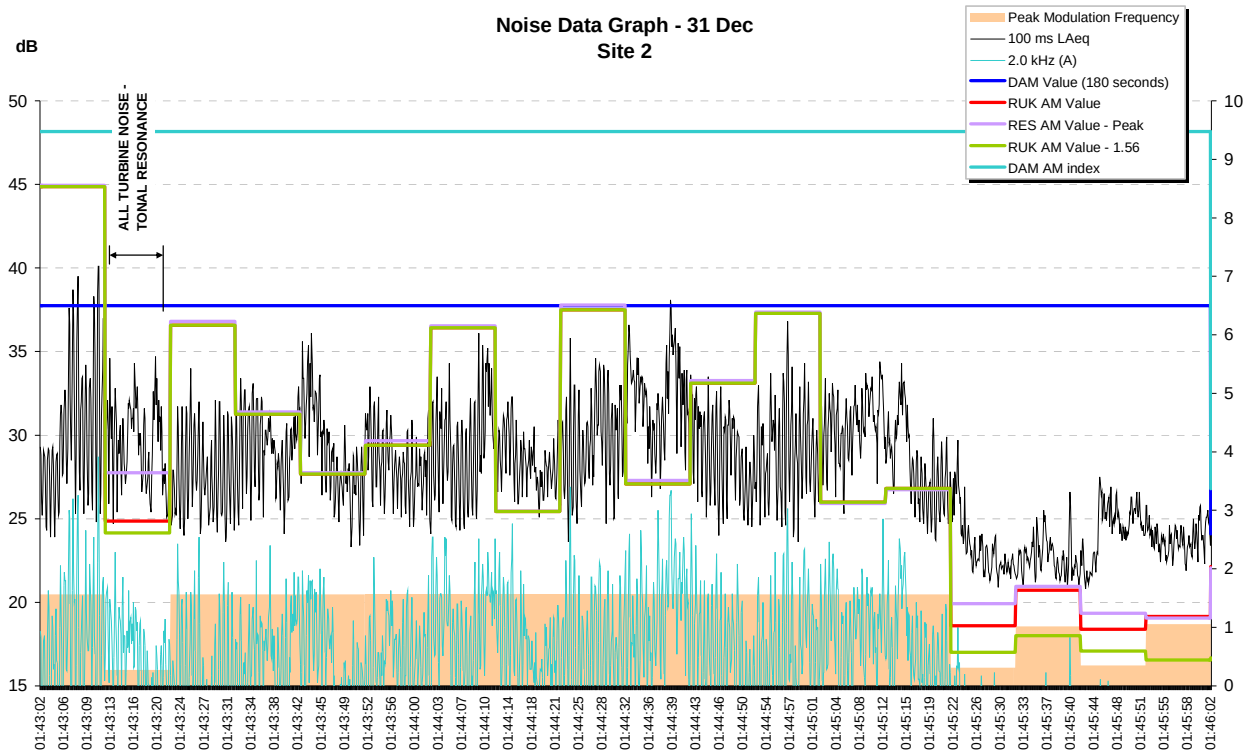


Figure 46: Site 2 - 31 Dec - 0146

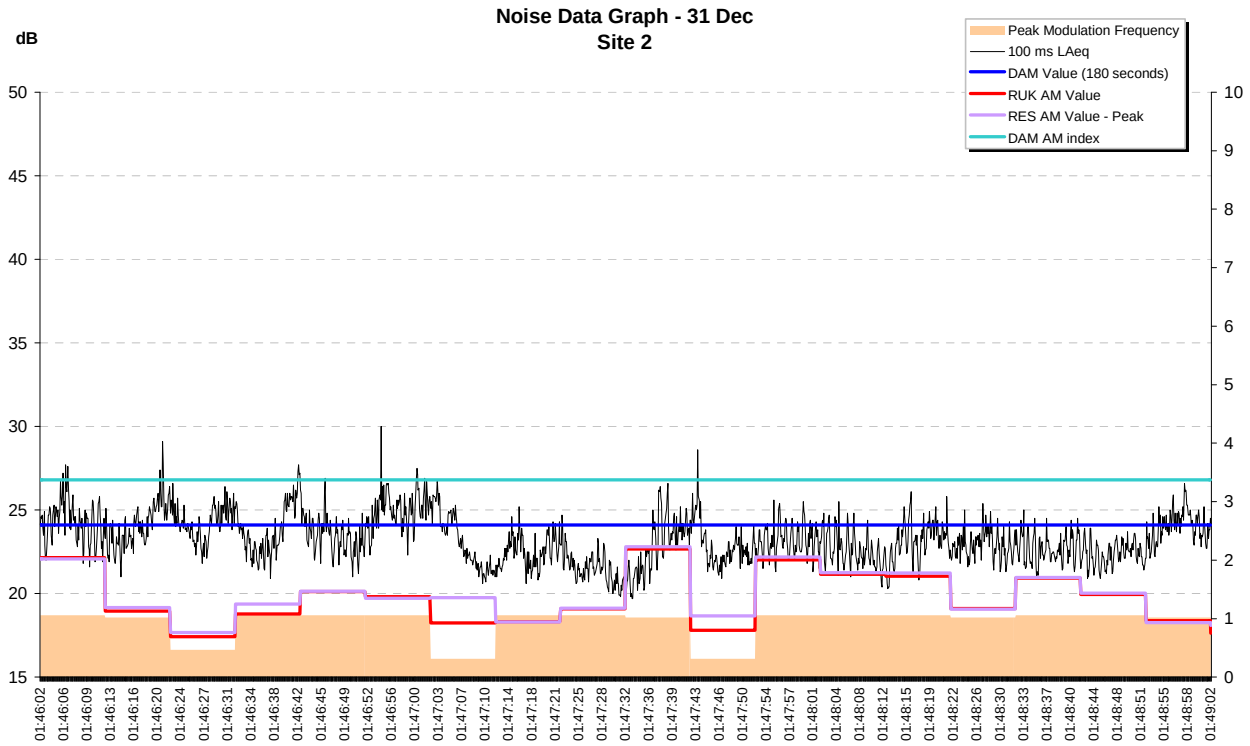
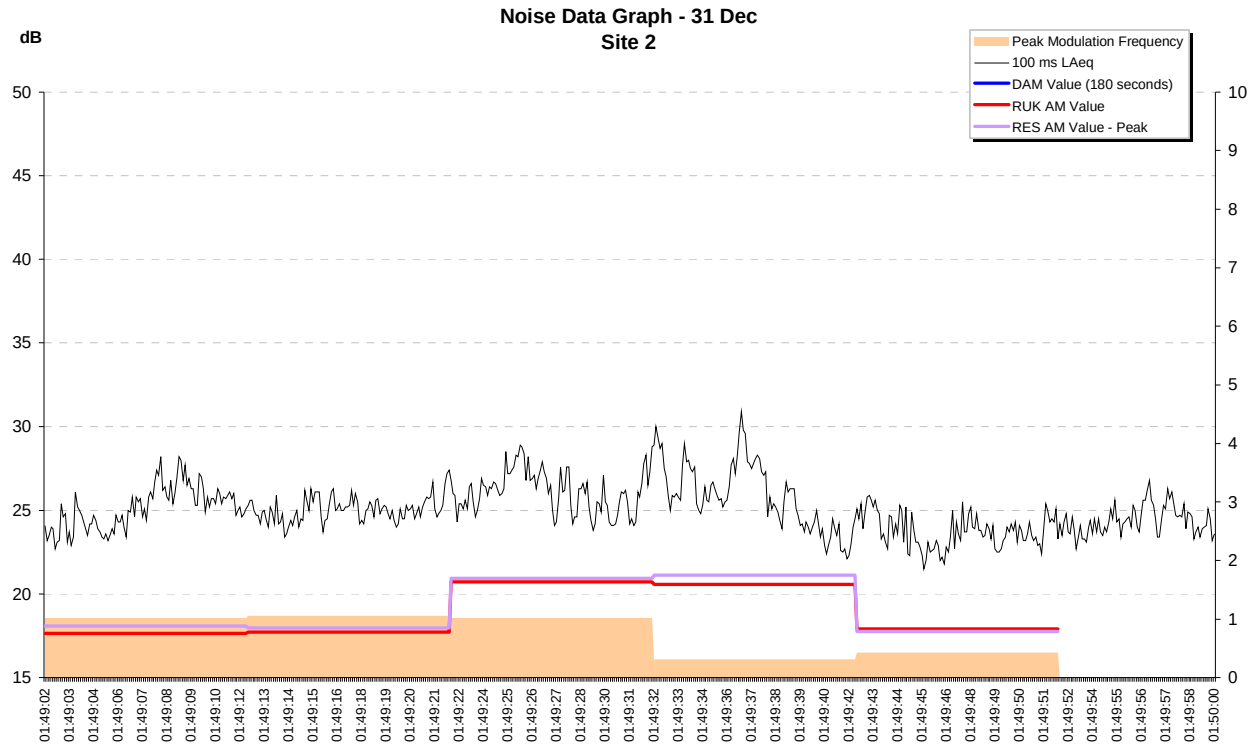
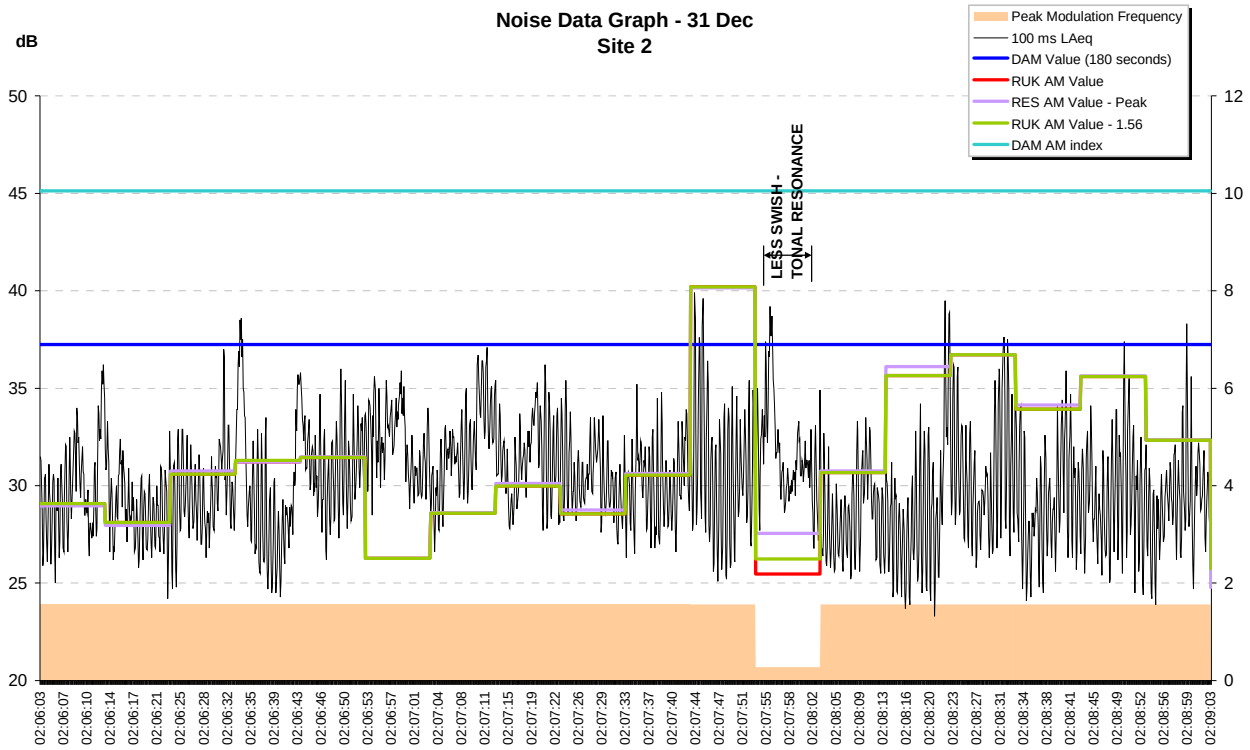


Figure 47: Site 2 - 31 Dec - 0149



7.12 **Preliminary discussion - Site 2 - 31 December.** The initial analysis of site 2 on 31 December shows that all four methods tested are fairly consistent with each other in terms of identifying AM and distinguishing between higher gear mode operation and the lower gear mode. The DAM method is influenced by some plane noise at approximately 01:50 but this is minimal and it is otherwise consistent with the other methods. The DAM rating tends to underestimate typical peak to trough level and fall at the lower range of the modulation peak to trough level estimated by visual inspection. However, conversion of the DAM rating to the AM index results in the typical peak to trough level being well characterised and the AM index reflects the range of EAM peak to trough within the 10 minute period. Derivation of the peak modulation frequency using the RES and RUK methods is more reliable with the data at site 2, compared to site 1, though it does fail in a couple of examples when there is significant tonal dominance in the data. This is evident in figure 45 above and in the example shown in figure 48 below.

Figure 48: Site 2 - 31 Dec - 0206 (example of tonality corrupting identification of BPF)



7.13 It is noted that the dip in peak modulation frequency would not be evident if entering a consistent blade pass frequency as intended by the RUK method. However, there would still be inconsistency between the blade pass frequency as given by the turbine and the peak modulation frequency identified by the FFT analysis. Thus, it is likely that the period would be excluded from analysis. In any event, running the RUK method assuming a constant blade pass frequency of 1.56Hz results in a very low value of AM for periods with strong tonality. The AM value for the labelled period in figure 45 above, at 01:43, is 2.6. The following 10s period, also dominated by turbine noise, results in an AM value of 6.2. The labelled period in figure 48 above results in an AM value, assuming a constant blade pass frequency of 1.56Hz, of 2.5. The following 10s period, which contains similarly modulating turbine noise has an AM value of 4.3. Thus, the RUK method fails where there are other character features such as tonality.

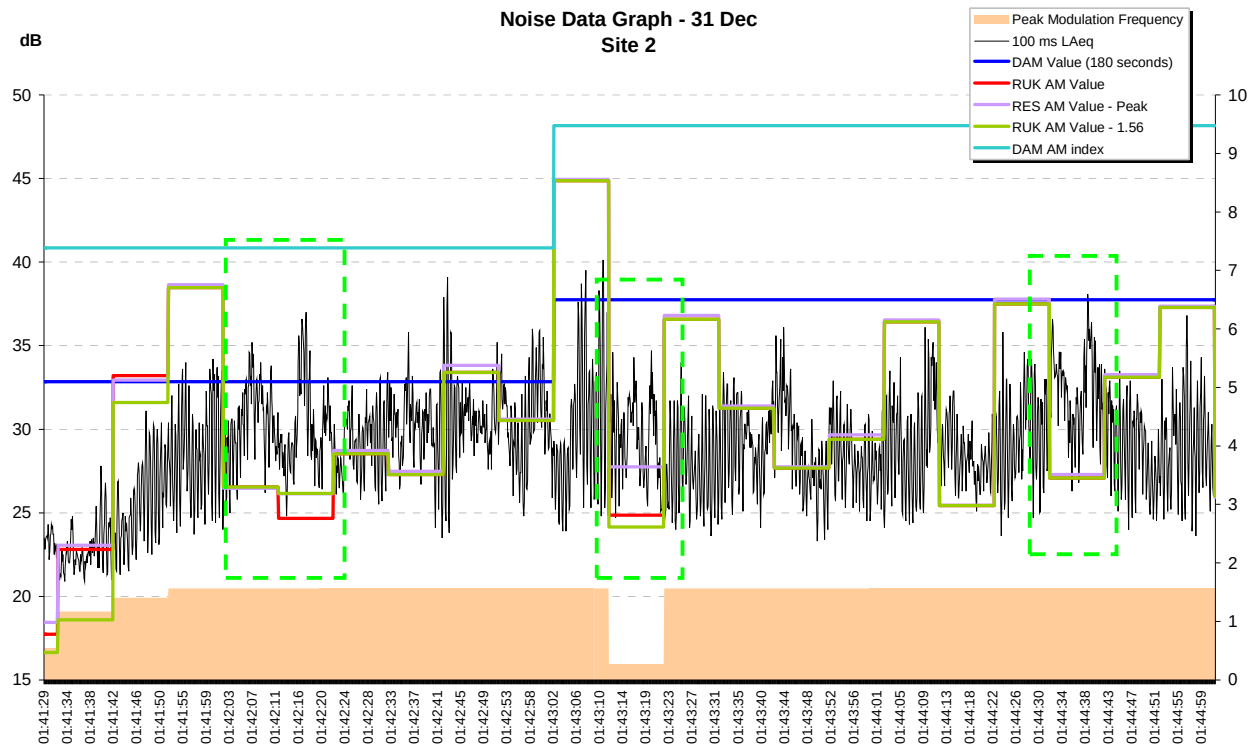
7.14 Assuming a constant blade pass frequency of 1.56Hz all periods in the lower gear mode, with a blade pass frequency of approximately 1.05Hz, would be missed by the RES and RUK methods. This is because the use of a blade pass frequency of 1.56Hz results in AM values derived from the RES and RUK methods significantly lower than if derived using the actual blade pass frequency of 1.05Hz. This suggests that the RES and RUK methods will fail where turbines have distinct and fast changing operational modes.

7.15 The site 2 data demonstrates the benefit of the modified methods used in this work package, which use the blade pass frequency as derived for each 10s period to calculate the AM value. The modified method allows for variations in the blade pass frequency without reducing the calculated AM value. Without this modification the RES and RUK methods cannot be used for turbines where the blade pass frequency is easily and commonly variable.

7.16 Individual AM values rated by RUK method for each 10 second period can also be highly variable. See for example figure 49 below. The three highlighted periods, enclosed by light green dashed lines, show periods where there is still significant turbine noise and blade swish audible within the data but the tonality dominates the A weighted noise trace, thus disrupting the visual manifestation of the modulation in the time series. The RES and RUK AM values for these periods are significantly lower than neighbouring periods. The RUK AM value falls to around 2.8 during these periods, compared to RUK AM values where there is clear modulation more typically derived in the region of 6. Whilst this does not have a significant impact on the RES method, which simply aims to identify AM, it does imply that the RUK AM value derived for the 10 minute period could be easily influenced by other character features.

7.17 The data from this site also shows that the RUK AM values do not well reflect the peak to trough value of AM. The 10 minute period from which figure 49 is taken has an AM (10 minute) value of A = 4.8. This is despite peak to trough levels of up to 15dB, many 10 second RUK AM values in the region of 6 and a 10 second RUK AM value of 8.6.

Figure 49: Site 2 - 31 Dec - 0141 (example of tonality corrupting AM value)



7.18 The RES Den Brook method for identifying AM is fairly consistent with the original Den Brook method with positive identification of AM for the data from site 2 on 31 December.

7.19 **Site 2 - 11th January 20:20 - 23:50.** A second and longer period of wind turbine data was included for site 2 to test further the methods for identifying and assessing AM. This second period was also included due to the presence of extraneous noise, noise from ducks, which looks similar to AM on the A weighted noise trace and could be falsely included in an assessment of AM. Noise attributable to ducks can be clearly distinguished from wind turbine noise by reference to the spectral content of the noise, namely in this case the dominance of the A weighted 2kHz 1/3rd octave band relative to the overall A weighted 100ms LAeq noise level.

7.20 For brevity only the last two ten minute periods analysed on this occasion have been provided below. The two ten minute periods show an example of the turbine operating in the higher gear and an example of very tonal turbine noise whilst the turbine is operating in the lower gear.

7.21 In addition to the standard parameters plotted on to the graphs an indication is provided as to which 10s periods have been included in the derivation of the overall AM ("A") value for each 10 minute period, see "Included in A" on the graphs, as required by the Renewable UK (RUK) AM condition. This equates to the 12 highest AM values during the 10 minute period that have a peak modulation frequency consistent with that of the blade pass frequency of the turbine(s). In the absence of formal definition, consistent with the blade pass frequency is taken in this case as +/- 10%. Unless otherwise stated the AM values have been calculated based on the blade pass frequency for each 10s period and not a blanket blade pass frequency.

7.22 The blade pass frequency of the turbine in the higher mode is 1.56Hz and in the lower mode 1.05Hz. This is identifiable from clear periods of AM with no corrupting extraneous noise. The Renewable UK results in square brackets below indicate the A value derived assuming a constant blade pass frequency of 1.56Hz, the higher gear blade pass frequency. This references the original RUK method, which requires a constant blade pass frequency to be used rather than the slightly modified method, used in this work package. The A value derived uniformly across this work package and given in all of the tables and analyses below uses the peak modulation frequency from each individual 10s period. It does include a consistency check with the blade pass frequency that is not afforded by the assumption of a constant blade pass frequency.

7.23 In this table an indication of whether the DAM rating is likely to have been influenced by extraneous noise is also given and denoted by a ' after the DAM value. This is provided to facilitate comparison of values that are and are not influenced by extraneous noise and to provide an indication of the typical range of DAM values that are derived from EAM data.

Table 3: Summary of results - Site 2 - 11 Jan

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating[42]	
					DAM	AM index
2020	Some distant road traffic noise at start, turbine drone clear and blade swish (some thumpy blade noise).	Yes. (≈5dB). Just above 28dB LAeq.	A =2.7. Lower gear. [A = 1.0]	Yes. Only a couple of periods >2.5.	3.4 3.9 3.4	4.7 5.5 4.7
2030	Turbine drone dominant, some extraneous noise (road traffic noise). Increases in wind enhance tonality.	Yes. (≈4-5dB). Just above 28dB LAeq.	A =2.1. Lower gear. [A = 1.1]	Yes. Only a couple of periods >2.5.	3.1 3.4 3.6	4.2 4.7 5.0
2040	Drone and blade noise dominant, some extraneous road traffic and rail noise.	Yes. (≈5dB). At 28dB LAeq.	A =2.4. Lower gear. [A = 1.0]	Yes. Only a couple of periods >2.5.	3.4' 3.0' 3.8	4.7' 4.0 5.3
2050	Drone and blade noise dominant, some occasional distant wildlife noise.	Yes. (≈4-7dB). Just above / at 28dB LAeq.	A =2.5. Lower gear. [A = 1.2]	Yes. A few periods >2.5.	3.7 4.1 3.9	5.2 5.8 5.5
2100	Drone and swish dominant, some extraneous noise (dog barking, wildlife and train noise) particularly towards the end of the period.	Yes / borderline. (≈3-4dB). Just at 28dB LAeq.	A =2.6. Lower gear. [A = 1.8]	Yes. A few periods >2.5.	4.4' 4.0 4.4'	6.3' 5.7 6.3'
2110	Lots of extraneous noise at start of period (dog and road traffic noise). Turbine drone audible, not so much blade noise. Turbine dominant in high gear towards end of period.	Yes. (≈5-7dB). Clearly above 28dB LAeq.	A =3.5. Higher gear. [A = 3.5]	Yes. Lots of periods >2.5.	4.1 5.3 3.5	5.8 7.7 4.9
2120	Lower gear drone and blade noise dominant, though less blade noise than previously.	Borderline / no. (≈3dB). At 28dB LAeq.	A =1.9. Lower gear. [A = 1.1]	Yes. Only one period >2.5.	3.9 3.5 3.3	5.5 4.9 4.5
2130	Drone and blade noise dominant, very little extraneous noise until end of period.	Yes. (≈4-5dB). Above 28dB LAeq.	A =2.4. Lower gear. [A = 1.2]	Yes. A few periods >2.5.	3.3 4.1 3.4	4.5 5.8 4.7

[42] ' Denotes the presence of potentially corrupting extraneous noise.

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating[42]	
					DAM	AM index
2140	Extraneous noise at start of period, then turbine drone and blade noise dominant.	Borderline / no. (≈2-3dB). At 28-30dB LAeq.	A =2.3. Lower gear. [A = 1.3]	Yes. Only one period >2.5.	3.0' 3.5' 4.6'	4.0' 4.9' 6.6
2150	Drone and blade noise in lower gear at start, lots of wildlife noise but very tonal modulating noise from turbine towards end of period.	Yes. (≈6-10dB). Clear periods.	A =2.7. Lower gear. [A = 2.3]	Yes. Only a couple of periods >2.5.	3.4 11.0' 5.4	4.7 15.4' 7.8
2200	Turbine drone and blade noise at start, noise from ducks towards end of period.	Yes. (≈6dB). Clear periods.	A =3.5. Lower gear. [A = 1.6]	Yes. Lots of periods >2.5.	5.2 5.5' 6.5'	7.5 8.0' 9.5'
2210	Turbine soon dominant in higher gear, lots of extraneous noise from ducks.	Yes. (≈8dB). Clear periods.	A =5.3. Higher gear. [A = 5.3]	Yes. Lots of periods >2.5.	6.5' 5.7 5.7	9.5' 8.3 8.3
2220	Turbine drone and blade noise in lower gear, variation in strength of tonality. Operation in higher gear mode but lots of extraneous noise from ducks.	Yes. (≈5-6dB). Clear periods.	A =3.6. Higher gear. [A = 4.1]	Yes. A few periods >2.5.	8.6' 6.1 4.4	12.4' 8.9 6.3
2230	Turbine in lower gear, lots of drone and blade noise but also lots of corrupting extraneous duck noise.	Yes. (≈5dB). Not as much. Above 28dB LAeq.	A =3.1. Lower gear. [A = 7.8]	Yes. A few periods >2.5.	5.5 10.6' 18.7'	8.0 14.9' 22.9'
2240	Turbine in lower gear, drone but less blade noise. Lots of duck and wildlife noise.	Yes. (≈5dB). Audible but lots of contamination.	A =3.0. Lower gear. Limited useable data. [A = 4.4]	Yes. A few periods >2.5.	7.7' 8.0' 12.2'	11.2' 11.6' 16.8'
2250	Turbine drone and swish but lots of duck noise also. Higher gear towards end of period also corrupted by duck noise.	Yes. (≈7dB). Clear periods.	A =3.5. Higher gear. [A = 3.9]	Yes. Lots of periods >2.5.	9.0' 5.1 5.9	12.9' 7.4 8.6
2300	Turbine in lower gear for most of period, drone and blade noise. Less duck noise but some wildlife noise.	Yes. (≈5-8dB). Above 28dB LAeq.	A =3.1. Lower gear. [A = 1.4]	Yes. Lots of periods >2.5.	4.5 4.8 4.2	6.5 6.9 6.0

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating[42]	
					DAM	AM index
2310	Turbine in lower gear at start, clear drone and blade swish. Higher gear towards end of period, thumpy blade noise but also lots of duck noise.	Yes. (≈8-11dB). Clear periods.	A =5.1. Higher gear. [A = 5.2]	Yes. Lots of periods >2.5.	4.8 7.4' 4.7	6.9 10.8' 6.8
2320	Turbine in lower gear at start, drone and blade noise with minimal extraneous noise. Second half of period lots of duck noise when turbine in higher gear.	Yes. (≈5dB). Clear periods.	A =3.2. Higher gear. [A = 3.8]	Yes. Lots of periods >2.5.	4.7 9.4' 8.0'	6.8 13.4' 11.6'
2330	In high gear at start then soon in lower gear, some duck noise, turbine very tonal and some blade thump.	Yes. (≈5-6dB). Clear periods.	A =3.4. Lower gear. [A = 4.1]	Yes. Lots of periods >2.5.	5.8 6.7' 5.3	8.4 9.8' 7.7
2340	Turbine soon in higher gear, lots of whine and blade noise but also lots of duck noise. Return to lower gear and lots of very tonal modulating noise.	Yes. (≈5-8dB). Clear periods.	A =6.7. Higher gear. [A = 6.5]	Yes. Lots of periods >2.5.	9.7' 6.8' 8.7'	13.8' 9.9' 12.5'
2350	Turbine in lower gear, very tonal and lots of blade noise. Some extraneous noise at end of period.	Yes. (≈6-8dB). Clear periods. At 29dB LAeq.	A =3.9. Lower gear. [A = 1.9]	Yes. Lots of periods >2.5.	6.0 6.2 4.7'	8.7 9.0 6.8'

Figure 50: Site 2 - 11 Jan - 2340 (10 minutes)

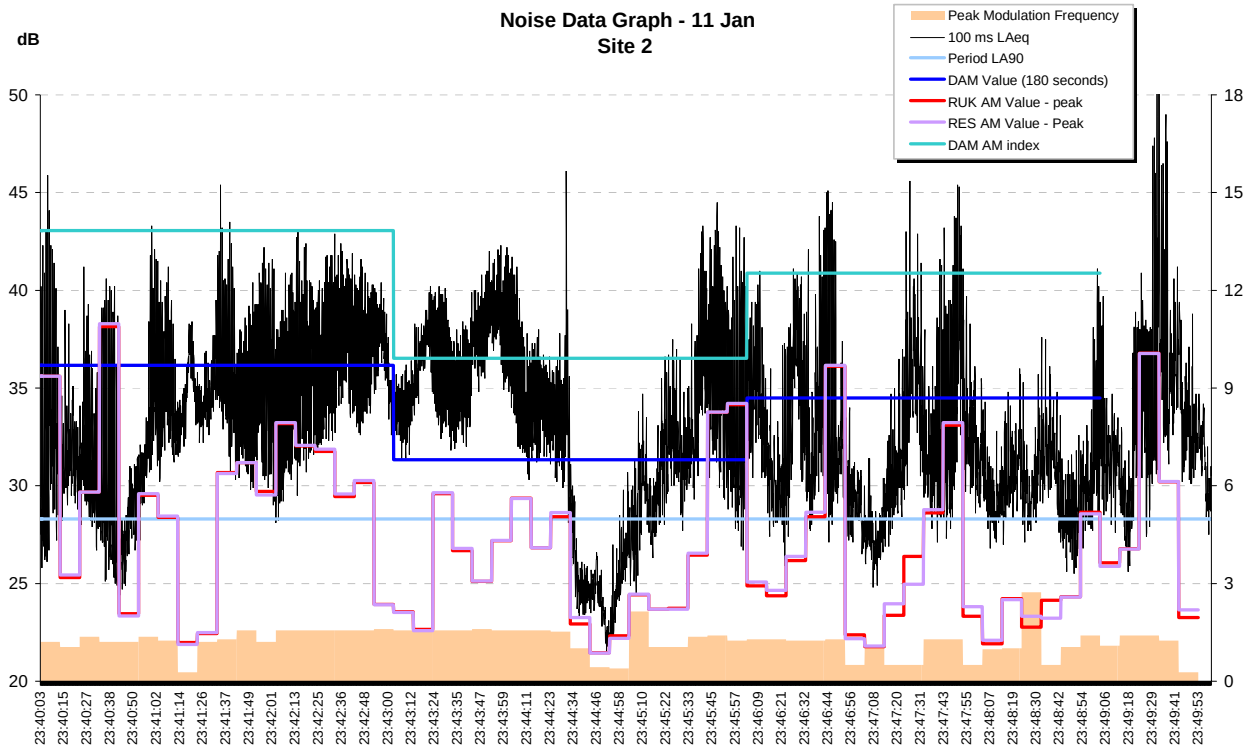


Figure 51: Site 2 - 11 Jan - 2340

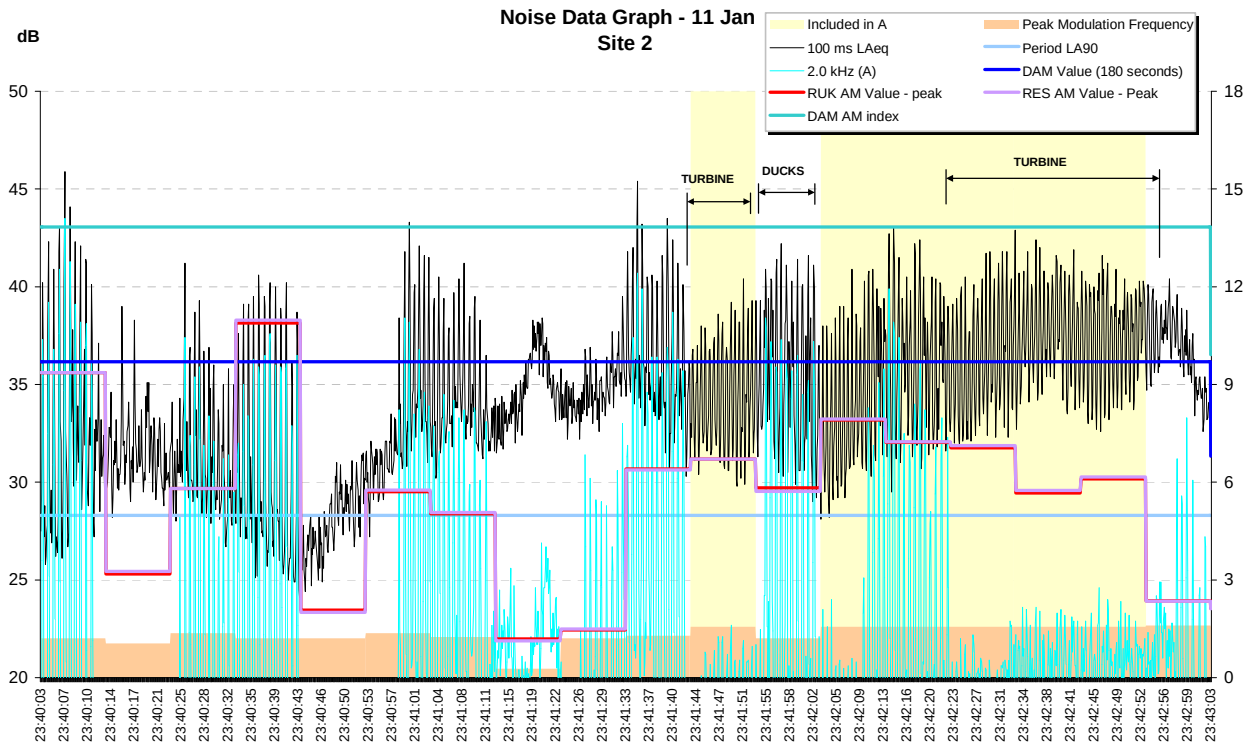


Figure 52: Site 2 - 11 Jan - 2343

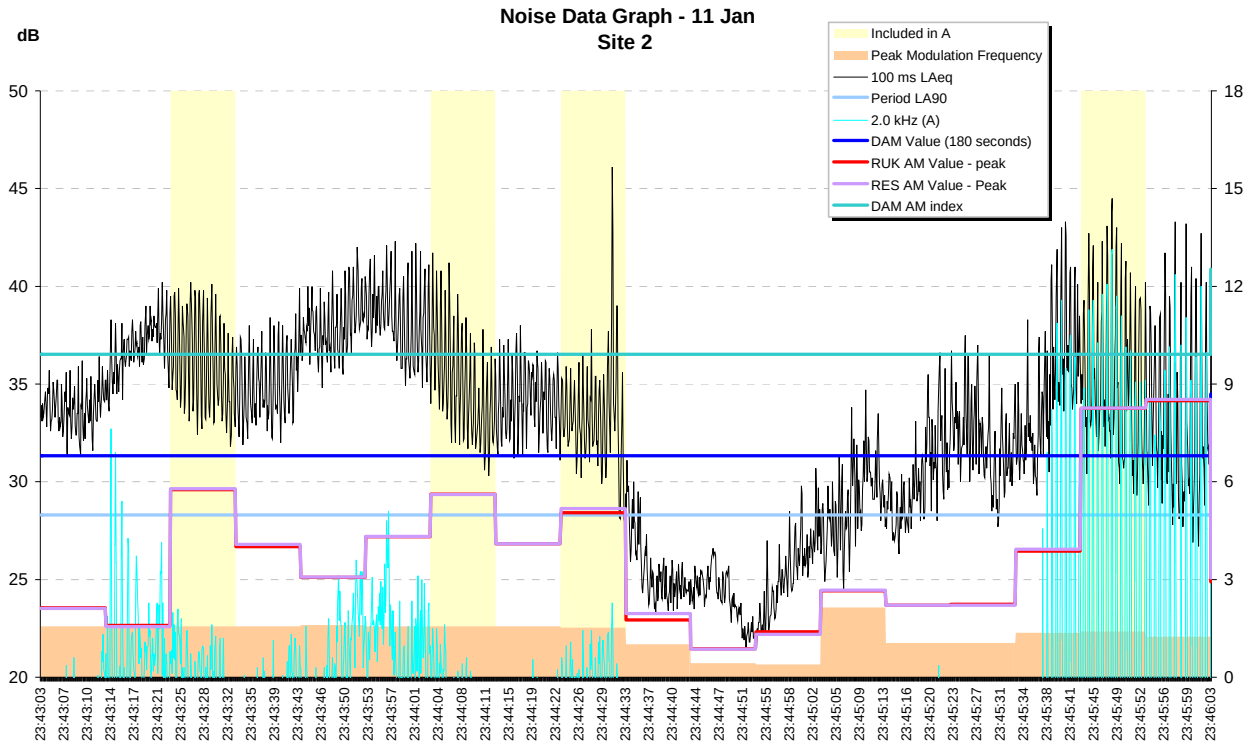


Figure 53: Site 2 - 11 Jan - 2346

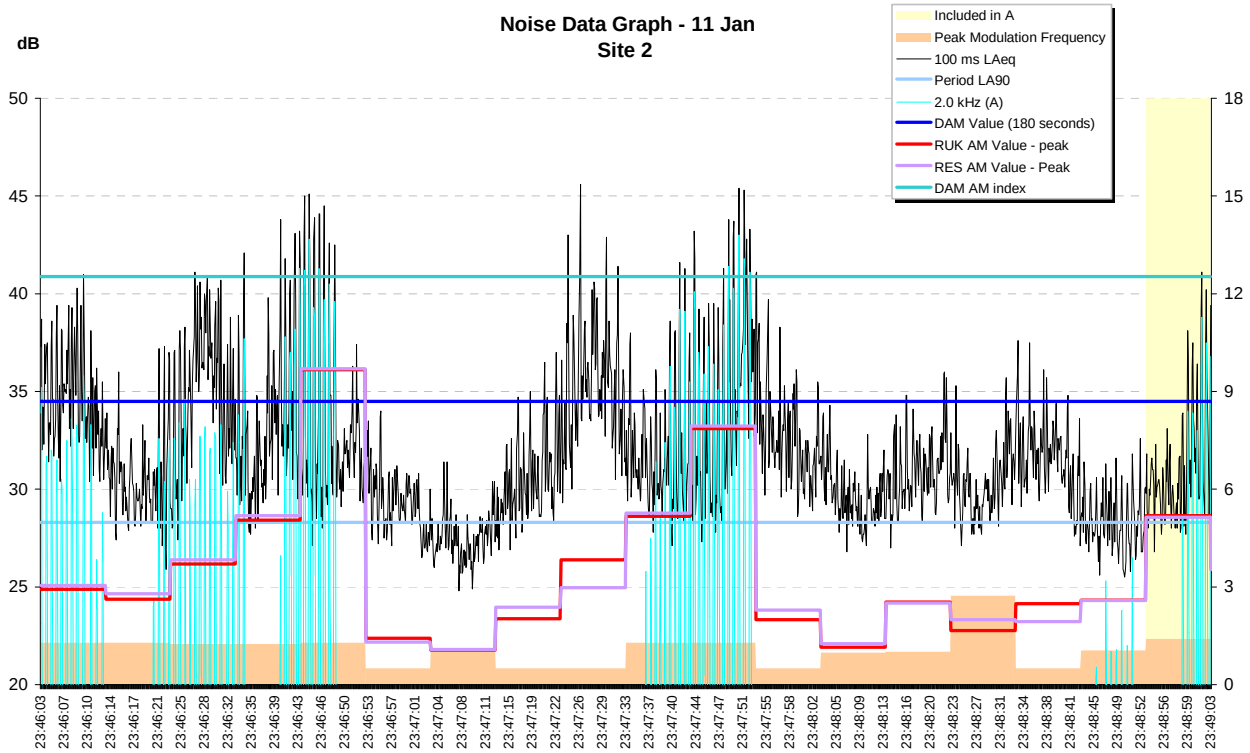


Figure 54: Site 2 - 11 Jan - 2349

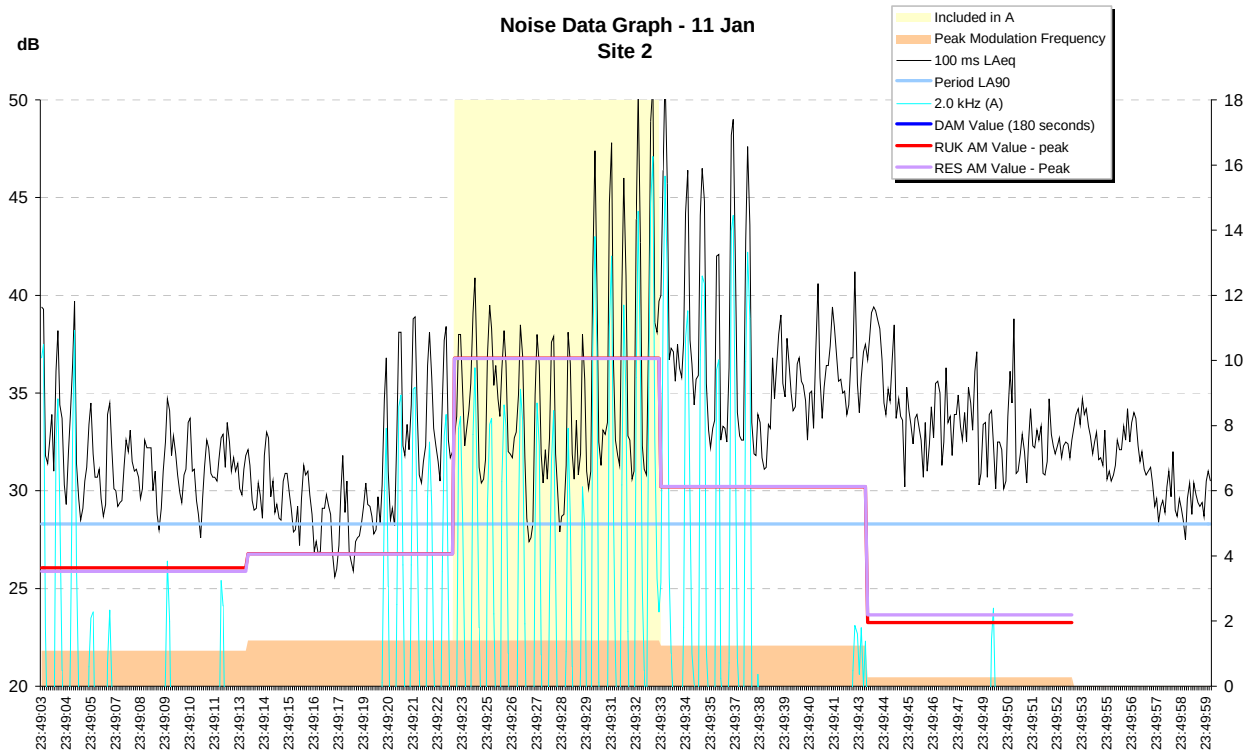


Figure 55: Site 2 - 11 Jan - 2350 (10 minutes)

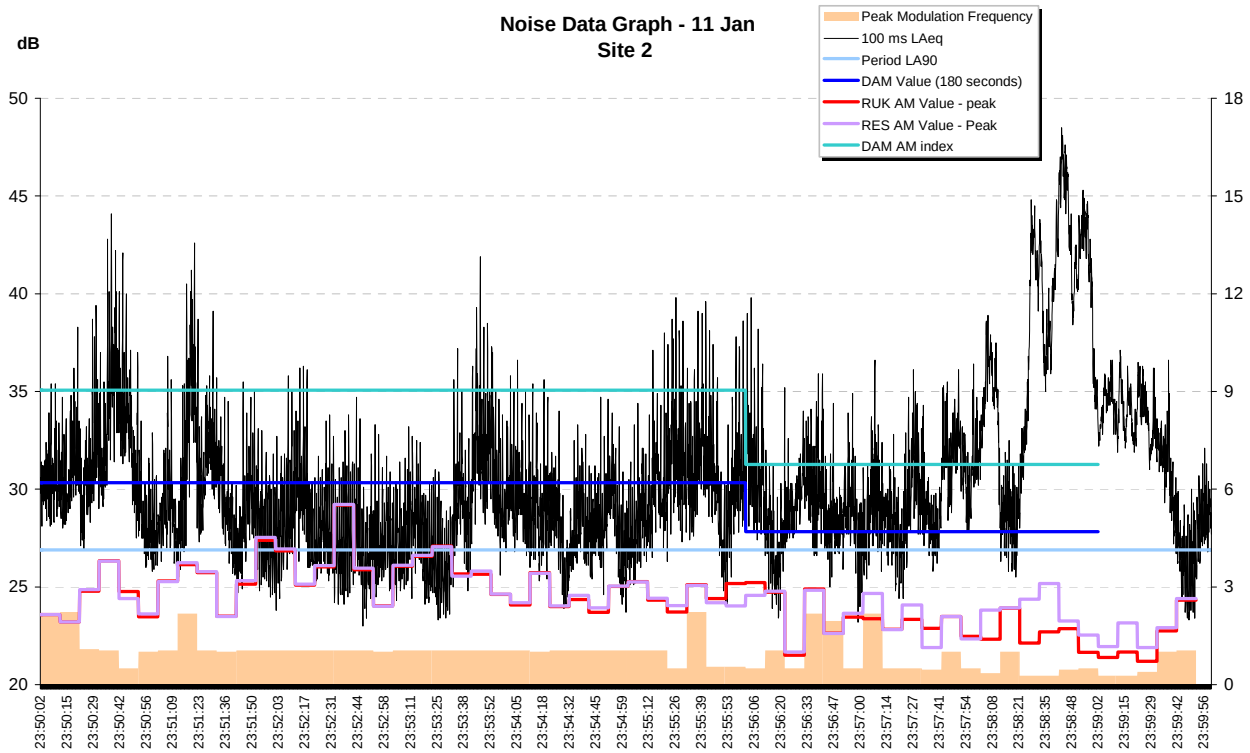


Figure 56: Site 2 - 11 Jan - 2350

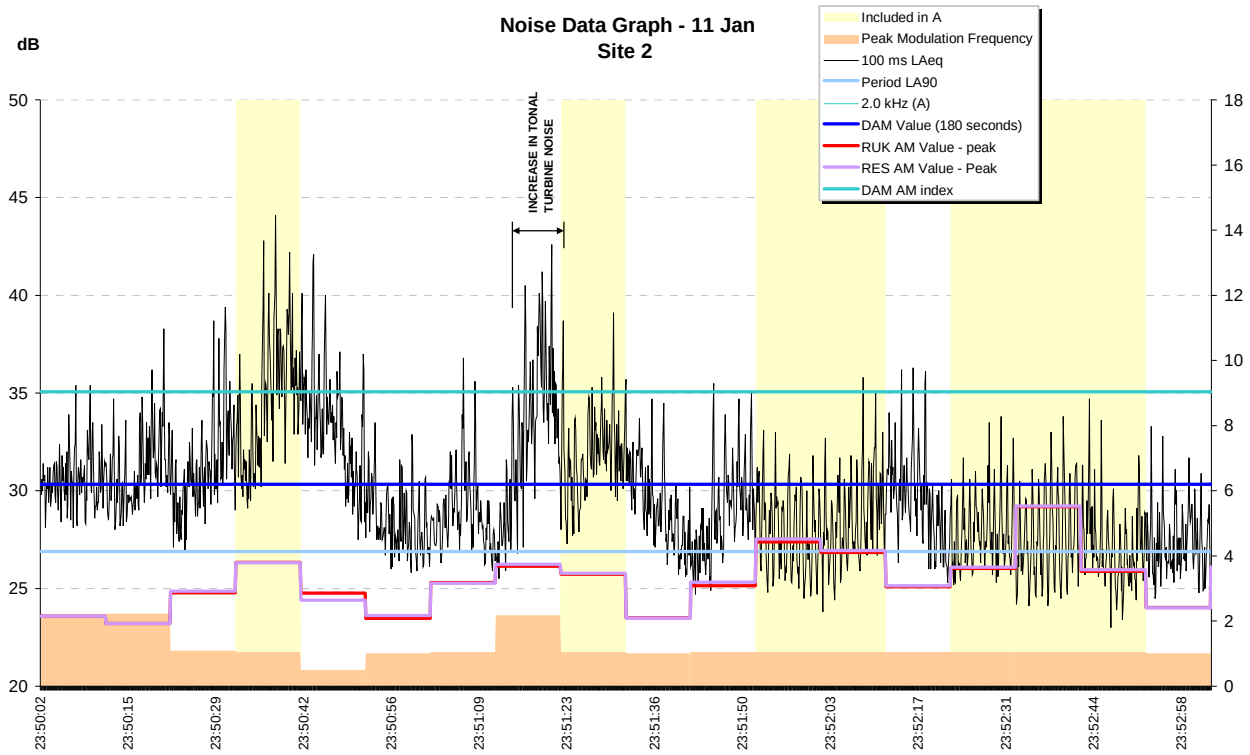


Figure 57: Site 2 - 11 Jan - 2353

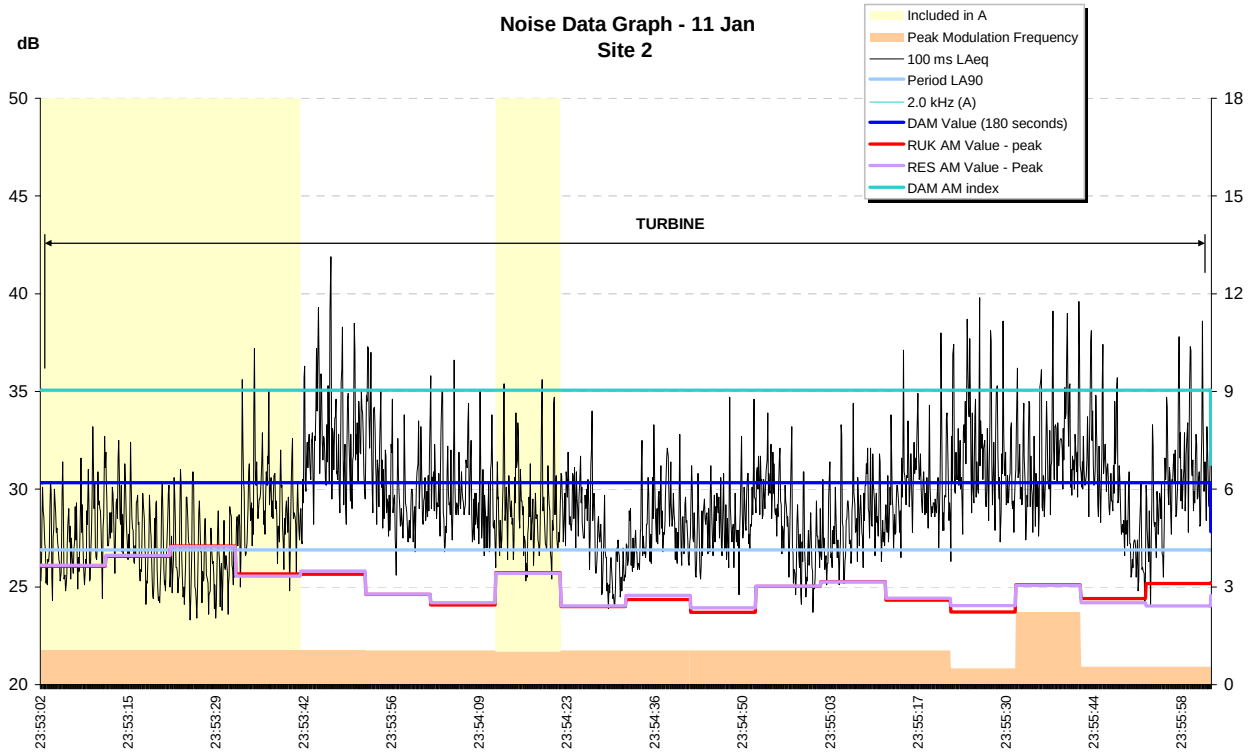


Figure 58: Site 2 - 11 Jan - 2356

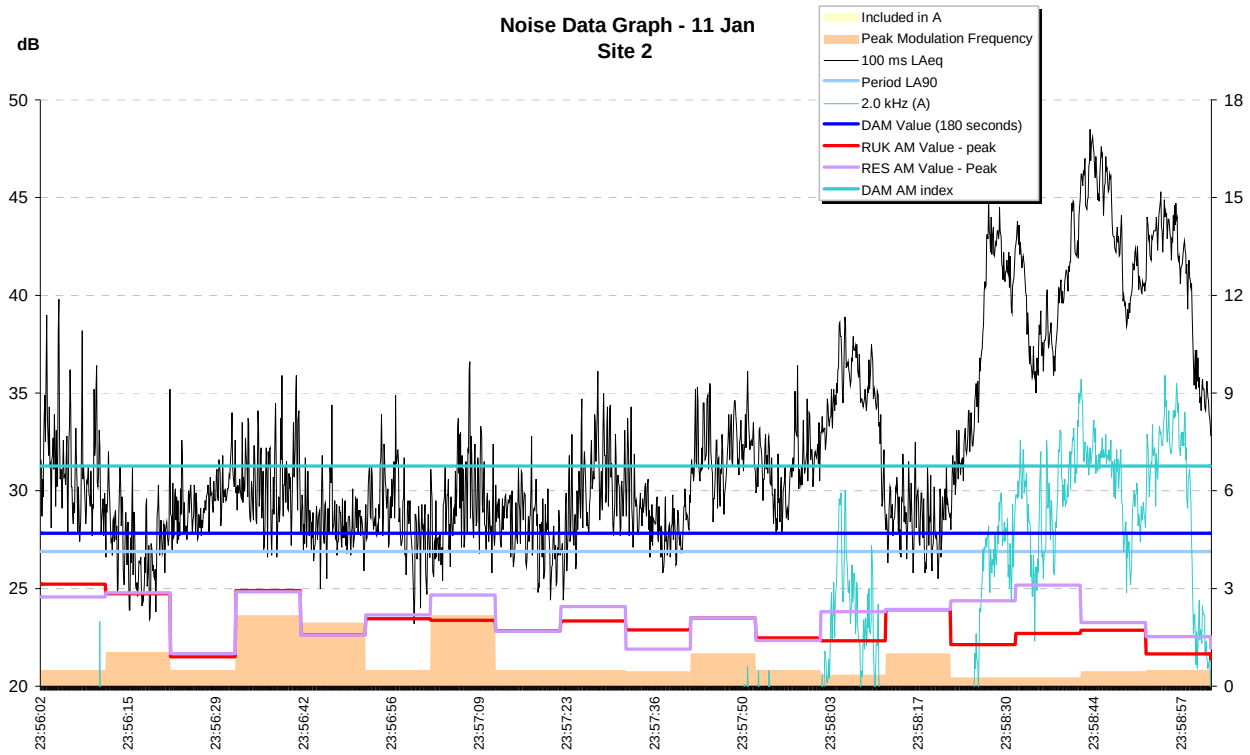
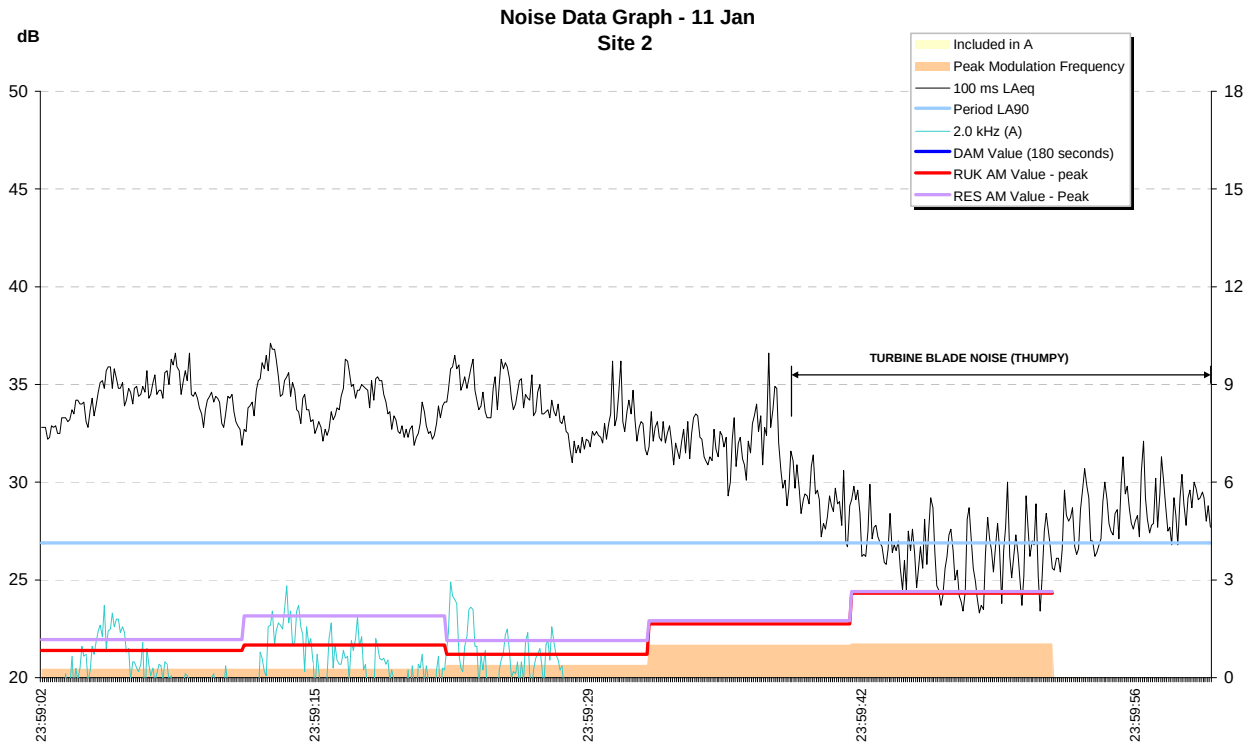


Figure 59: Site 2 - 11 Jan - 2359



7.24 **Preliminary discussion - Site 2 - 11 Jan.** The initial analysis of site 2 on 11 January again shows that the methods are fairly consistent in being able to identify the presence of AM. Importantly in this case it assumes that the RUK method allows the blade pass frequency to vary between short periods, i.e variable between 1.05Hz and 1.56Hz, which was not allowed in the example above for site 2 on 31 December. If assuming a constant blade pass frequency of 1.56Hz then many periods of AM would be missed or underrated by the RUK method. The relevance of this is discussed further in the main discussion section below.

7.25 Figure 51 above appears to show that the RUK and RES methods are uninfluenced by the occurrence of duck noise as the rate at which the ducks quack sufficiently skews the peak modulation frequency to the extent that it would not be classed as consistent with the blade pass frequency. See the 10s period at 23:41:45 labelled 'turbine' and the 10s period at 23:42:58 labelled 'ducks'.

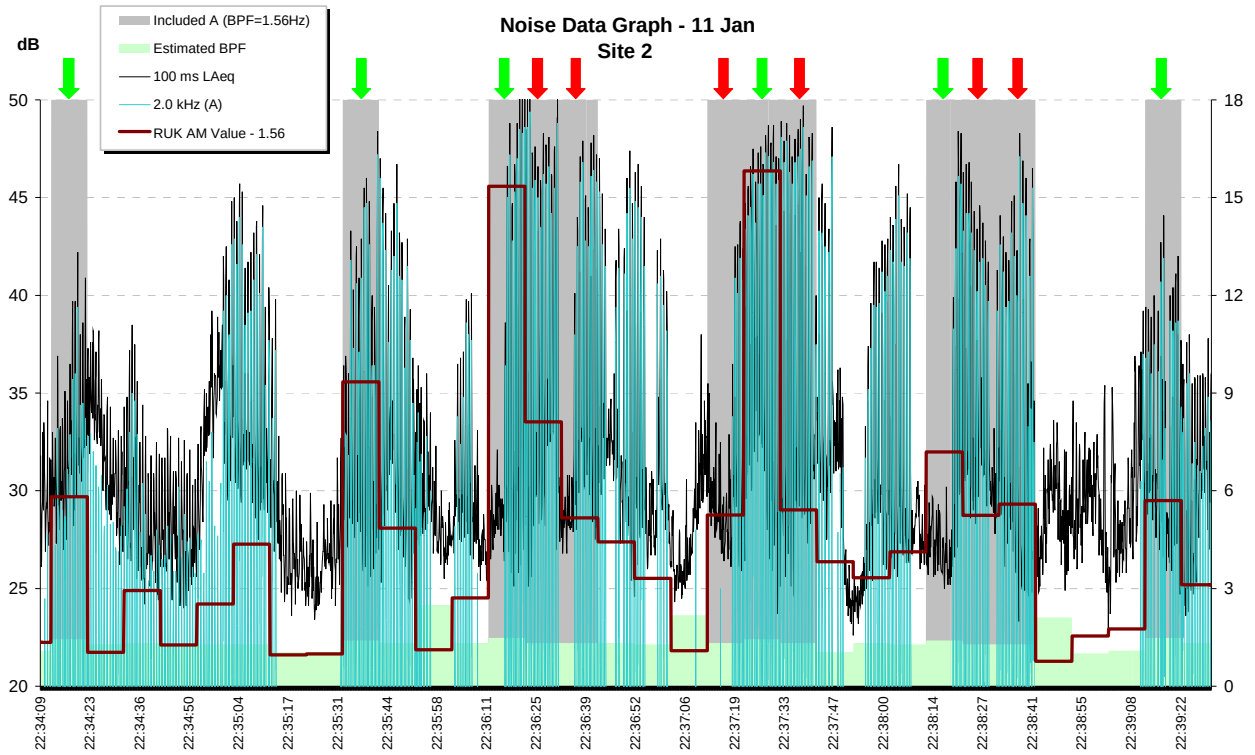
7.26 In contrast figures 52 and 54 show periods dominated by duck noise, which result in a high 10 second AM value as derived from the RES and RUK methods. Two periods heavily dominated by duck noise have also been included in the overall 10 minute A value despite the AM value being largely attributable to ducks. See in particular the 10s period in figure 52 at approximately 23:45:47 and in figure 54 at 23:49:26. The A value for this latter 10s period is 10.1.

7.27 Even using the RUK method as originally intended, i.e. assuming a constant blade pass frequency of 1.56 to derive the A value and then checking for consistency between peak modulation frequency and blade pass frequency after the A value is derived, problems occur with this methodology.

7.28 Figure 60 below shows an excerpt from the 10 minute period at 22:30. The 10s AM values included in the overall RUK 10 minute AM value are highlighted in figure 60 by the grey blocked periods. These indicate the 12 highest AM values in the 10 minute period. Also plotted on the graph is the 100ms LAeq (black trace) and the 2kHz third octave band (A weighted, blue / teal trace) which is indicative of the duck noise. The brown line gives the RUK 10s AM values.

7.29 The arrows at the top of the graph indicate whether the 10s period has a peak modulation frequency consistent with that of the blade pass frequency (1.56Hz in this case). Red arrows indicate inconsistent peak modulation frequencies and blade pass frequencies and green arrows consistent peak modulation frequencies and blade pass frequencies. Thus, a grey blocked period with a green arrow above it indicates that the 10s AM value would be included in the overall RUK 10 minute AM value. It can be seen that the RUK method as originally written also fails to differentiate between periods where the noise level and AM value are dominated by duck noise and those which are solely attributable to turbine AM.

Figure 60: Site 2 - 11 Jan - 2234 - example of RUK method including extraneous noise



7.30 The Den Brook peak to trough level and DAM rating / AM index are less consistent than in other examples and this is likely due to the corrupting influence of duck noise and other extraneous noise sources. Where there is a lot of duck noise the DAM rating and AM index can be easily skewed.

7.31 The RES method identifies the presence of AM consistently with the Den Brook method. There are only a couple of exceptions where there are problems with the RES methodology. At 21:50 the Den Brook method identifies clear AM; however, due to the very strong tonality of the turbine noise during this period the peak modulation frequency is frequently disrupted. Thus, the peak modulation frequency is not consistent with the blade pass frequency of the turbine, as defined using the RES approach, despite all noise being generated by the turbine. This means that periods dominated by turbine noise would not be identified using the RES method.

7.32 **Site 3 - 10th June 00:01 - 01:00.** In contrast to sites 1 and 2, both smaller single turbines, site 3 has two large wind turbines. To facilitate data processing for the DAM rating method the analysis for site 3 has been chunked into periods of approximately 3 minutes and 20 seconds, slightly longer than above which used periods of approximately 3 minutes. The other methods are assessed in 10 minute periods as above. This means that for each full 10 minute period there are four DAM / AM index values; however, the first and last DAM / AM index values straddle the end / beginning of the adjacent 10 minute periods. This is evident with reference to the graphs below.

7.33 Further, the data set is not a complete hour period. The first and last 10 minute periods assessed below are not complete 10 minute periods; the first is 9 minutes 43 seconds and the last 5 minutes 8 seconds. The results are summarised in table 4 below.

7.34 All graphs for site 3 are given below table 4 in 10 minute periods. Periods of AM are clearly identifiable by the nature of the 100ms noise trace; however, some periods have been labelled to clarify periods of uncorrupted wind turbine noise and AM. The RUK results in square brackets below indicate the A value derived assuming a constant blade pass frequency of 0.55Hz. This is in contrast to the A value derived uniformly across the tables (not in brackets) and analysis which uses the peak modulation frequency for each individual 10s period and includes a check for consistency with the blade pass frequency of the turbines. The value of A in square brackets does not include a check for consistency with the blade pass frequency of the turbines. This check occurs after the derivation of the A value in the RUK condition methodology and if the A value exceeds zero.

7.35 In this table an indication of whether the DAM rating is likely to have been influenced by extraneous noise is also given and denoted by a ' after the DAM value. This is provided to facilitate comparison of values that are and are not influenced by extraneous noise and to provide an indication of the typical range of DAM values that are derived from EAM data.

Table 4: Summary of results - Site 3 - 10 June

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating	
					DAM	AM index
0001	Wind turbine noise audible from start. Extraneous noise from local road traffic noise, birds and a cow. Wind turbine thump in middle and at end of period.	Yes. (≈3-5dB). Just above 28dB LAeq.	No. Not enough periods with consistent BPF. [A = 1.5]	No. Maybe if use local BPF.	3.1 3.1 [3.1]	4.2 4.2 [4.2]
0010	Still some distant and local road traffic noise but turbine noise dominant and clear AM.	Yes. (≈4-7dB).	A = 3.3 [A = 2.7]	Yes. Lots of periods >2.5.	[3.1] 2.8 3.6 [3.0]	[4.2] 3.7 5.0 [4.0]
0020	Still some distant and local road traffic noise but turbine noise dominant and prevalent. Significant AM towards the end of the period and little extraneous noise.	Yes. (≈6-10dB).	A = 5.7. Lots of examples. [A = 5.7]	Yes. Lots of periods >2.5.	[3.0] 4.1 5.0 [6.4]	[4.0] 5.8 7.2 [4.0]
0030	Still significant turbine noise but much more extraneous noise from road traffic spread throughout period.	Yes. (≈4-8dB).	A = 2.8. Lots of inconsistent BPFs. [A = 2.7]	Yes. A few periods >2.5.	[6.4] 3.4 3.2 [4.0]'	[4.0] 4.7 4.4 [5.7]'

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating	
					DAM	AM index
0040	Extraneous noise near microphone at start of period and road traffic noise, but still constant turbine noise which is uncorrupted during middle period. Some noise from geese but turbine noise louder.	Yes. (≈4-7dB).	A = 2.8. Lots of inconsistent BPFs. [A = 2.8]	Yes. A few periods >2.5. Lots below 2.5 or inconsistent BPF.	[4.0]' 4.7' 4.0 [4.2]	[5.7]' 6.8' 5.7 [6.0]
0050	Turbine noise and AM dominant. Some road traffic noise and some noise from geese but turbines dominant. Thump noise towards en d of period.	Yes. (≈4-8dB)..	A = 2.9 [A = 2.9]	Yes. A few periods >2.5. Lots below 2.5 or inconsistent BPF.	[4.2] 3.6 4.3 [4.6]	[6.0] 5.0 6.1 [6.6]
0100	Lots of turbine noise and AM but interspersed with road traffic noise.	Yes. (≈3-7dB).	A = 2.4 [A = 2.4]	Yes. A few periods >2.5. Lots below 2.5 or inconsistent BPF.	[4.6] 3.6 3.6'	[6.6] 5.0 5.0'

Figure 61: Site 3 - 10 June - 0001

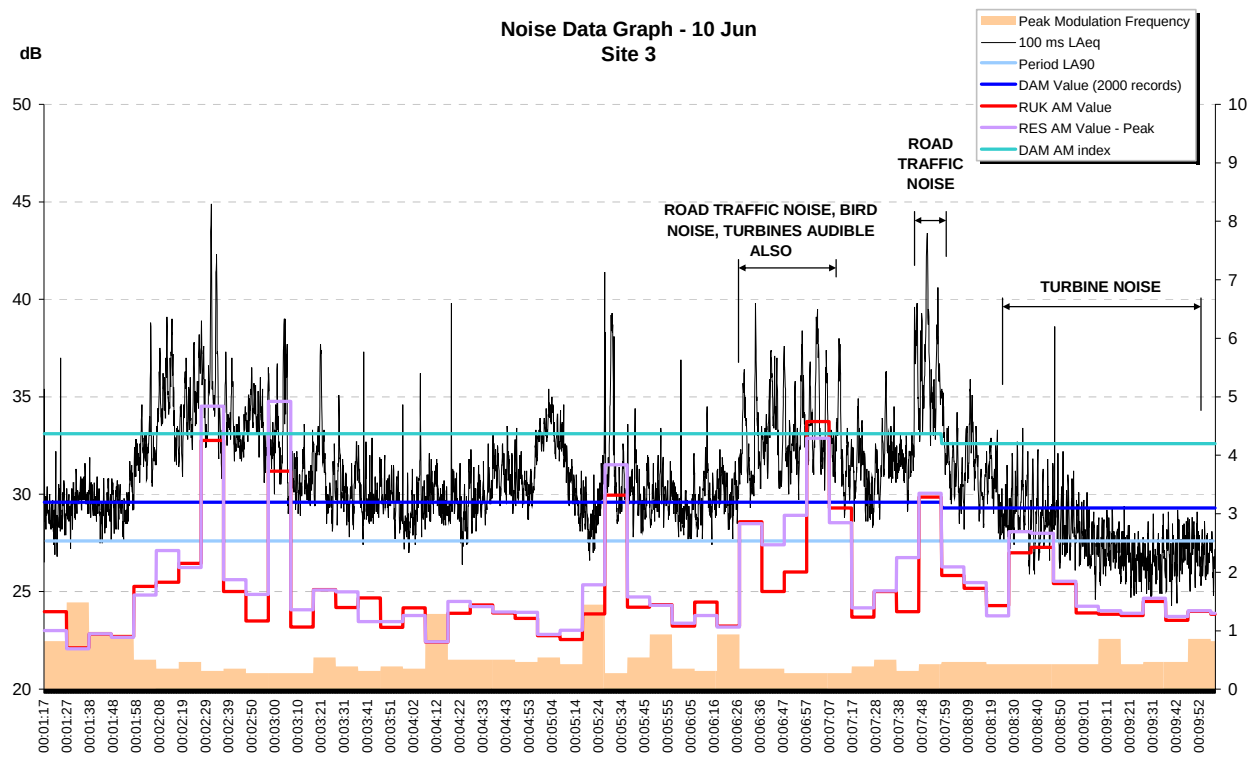


Figure 62: Site 3 - 10 June - 0010

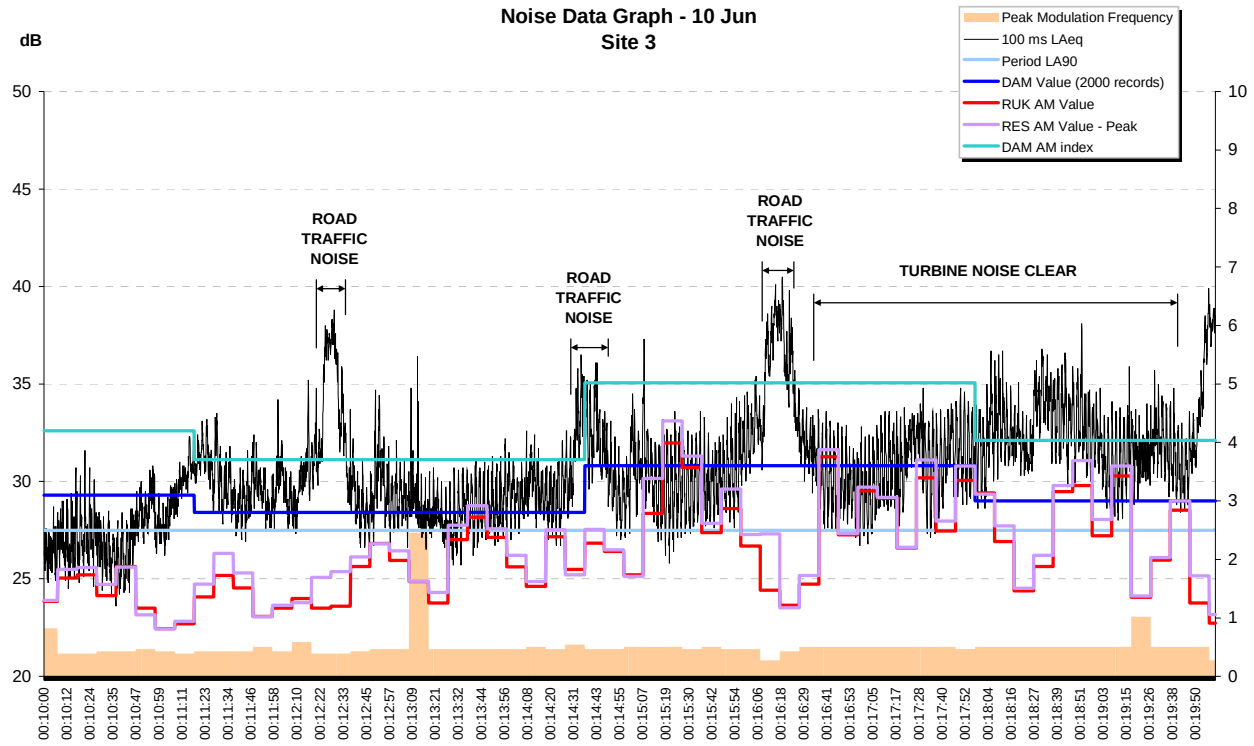


Figure 63: Site 3 - 10 June - 0020

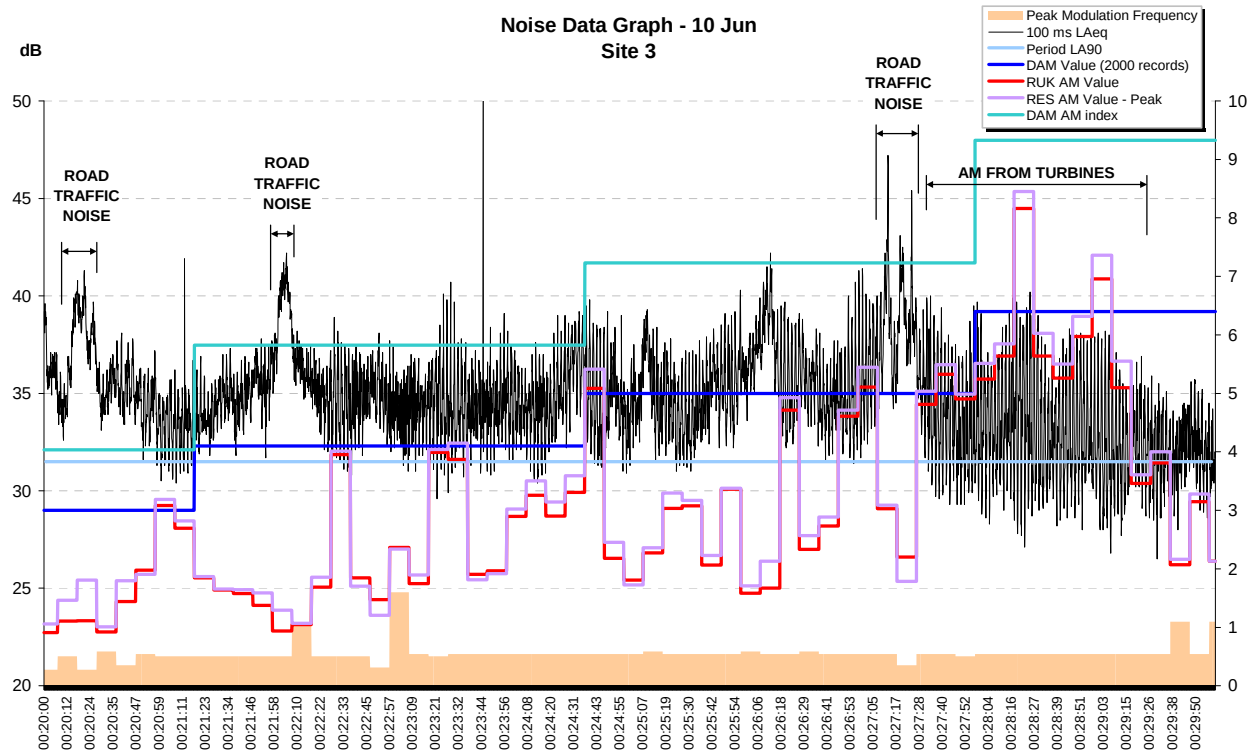


Figure 64: Site 3 - 10 June - 0030

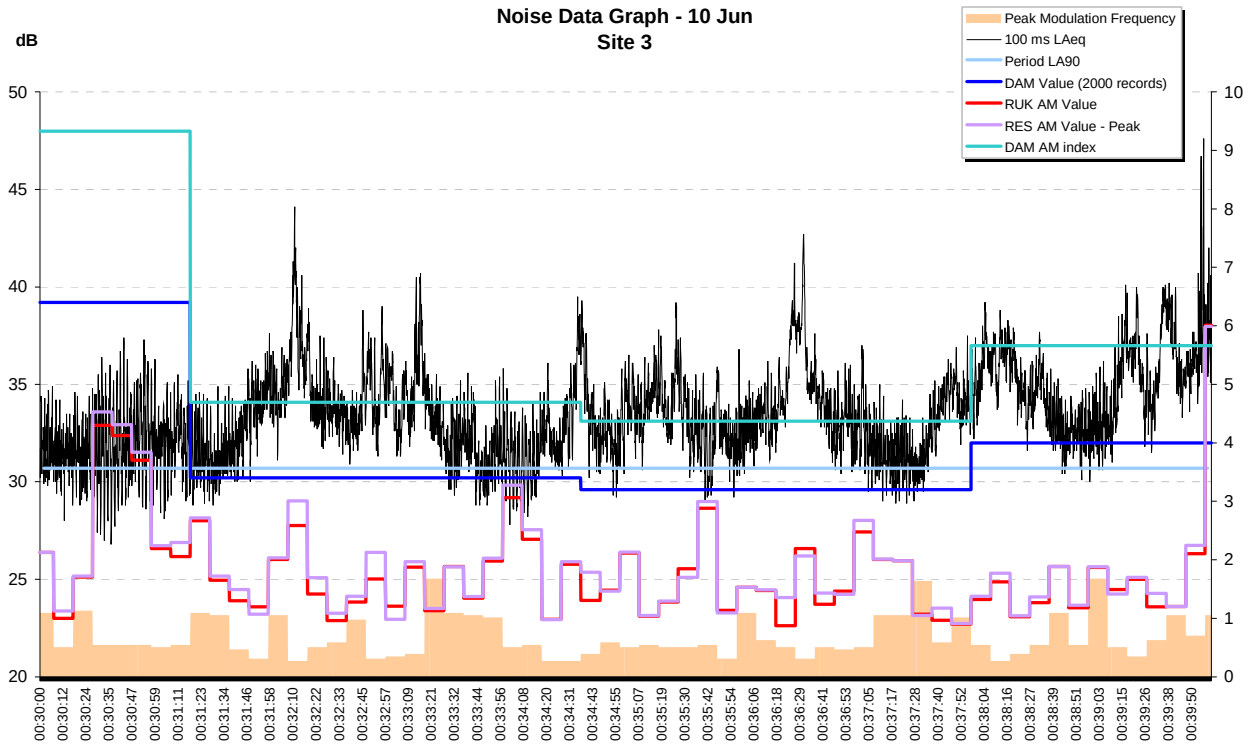


Figure 65: Site 3 - 10 June - 0040

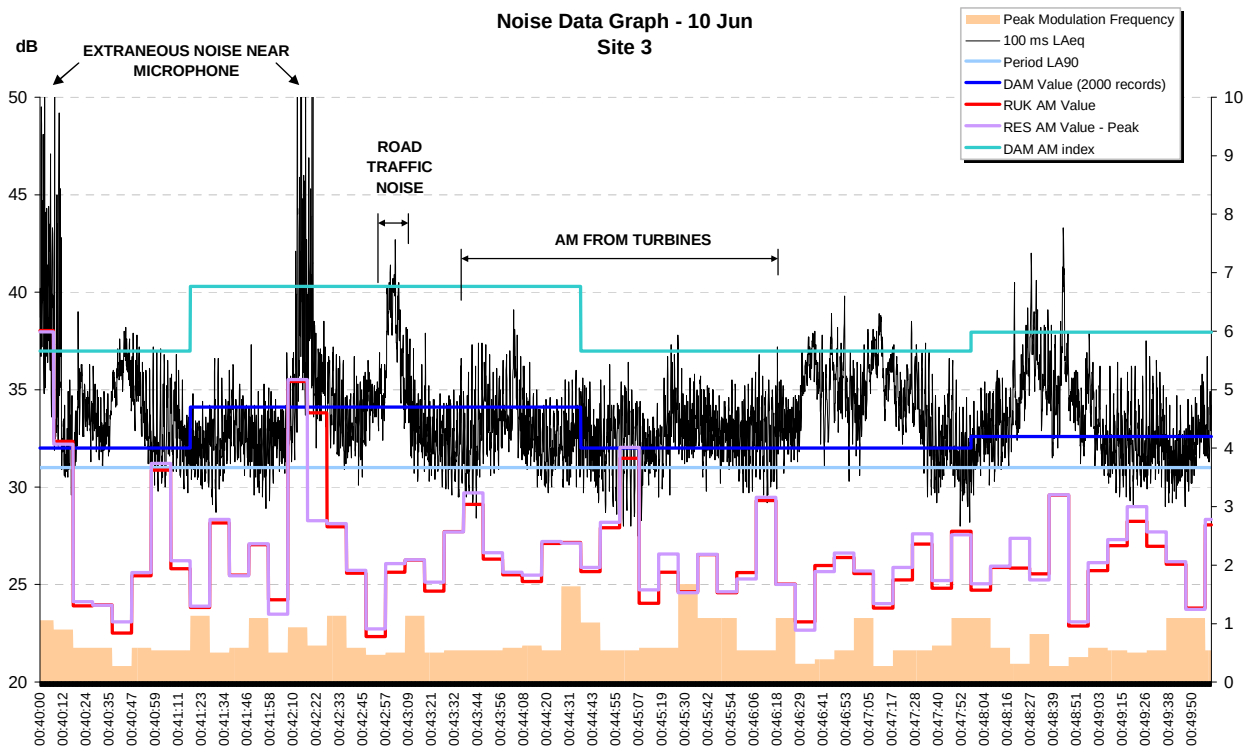


Figure 66: Site 3 - 10 June - 0050

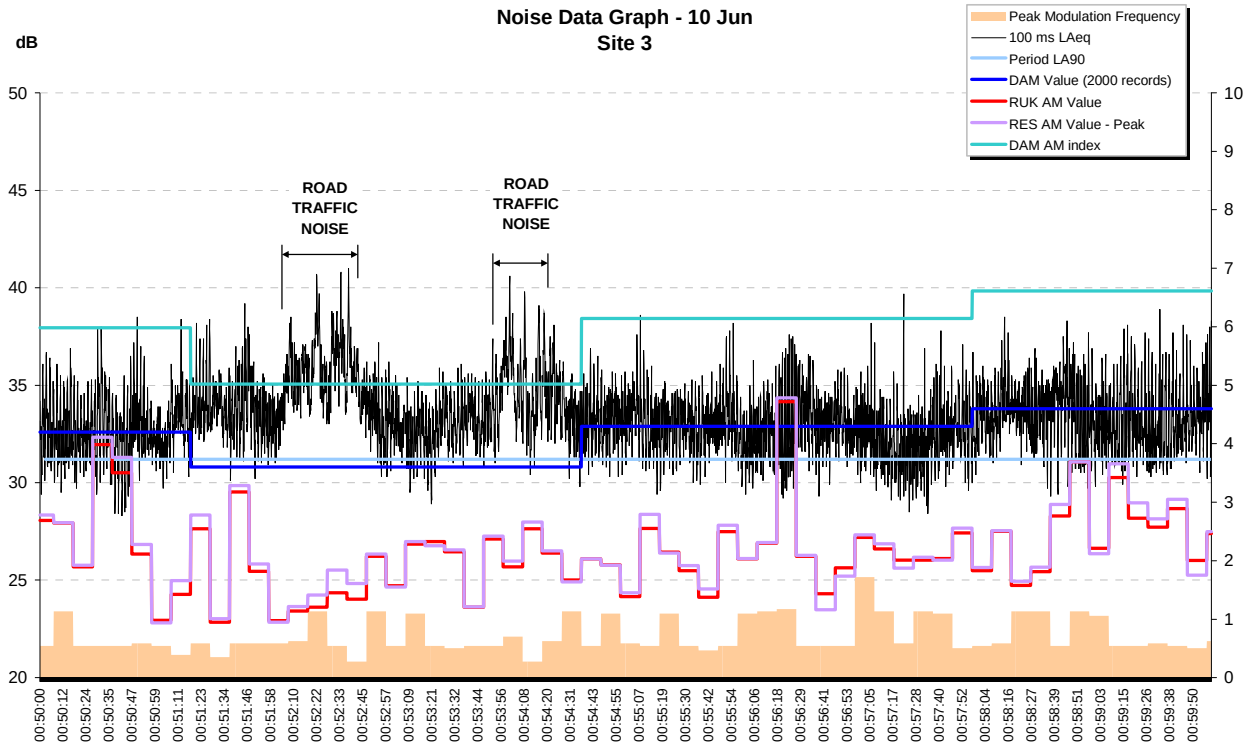
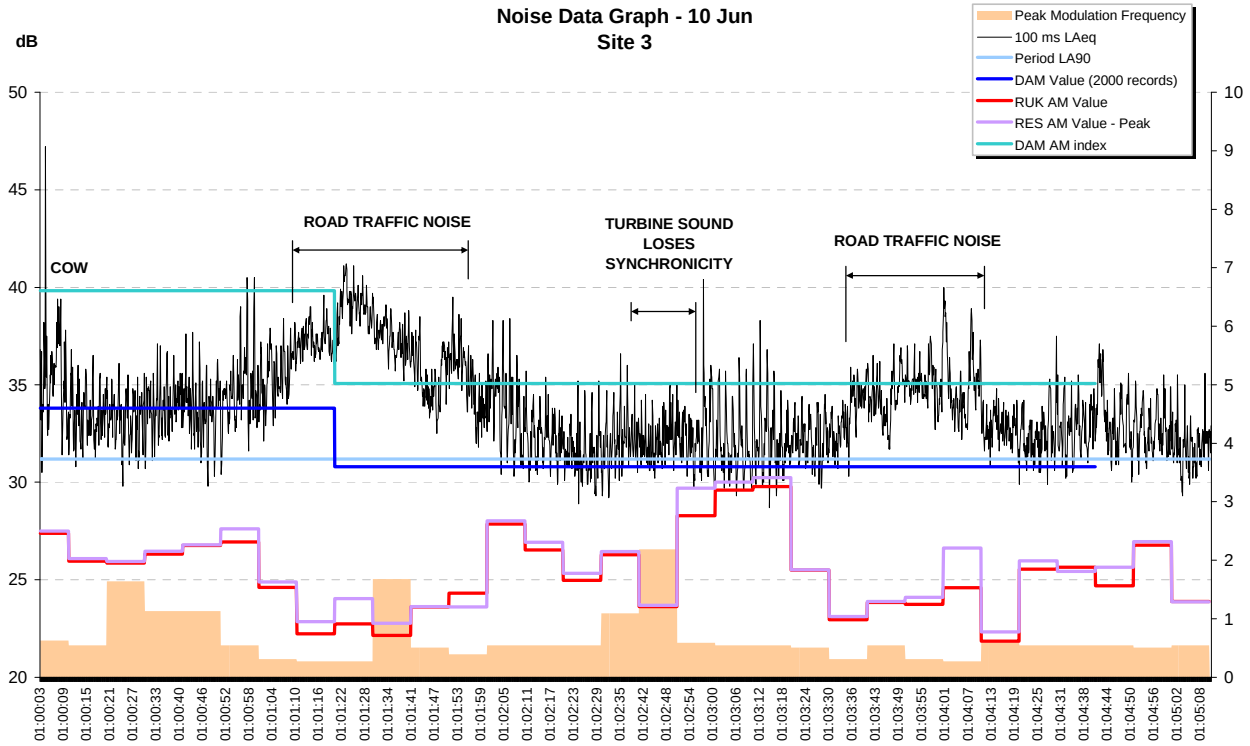


Figure 67: Site 3 - 10 June - 0100



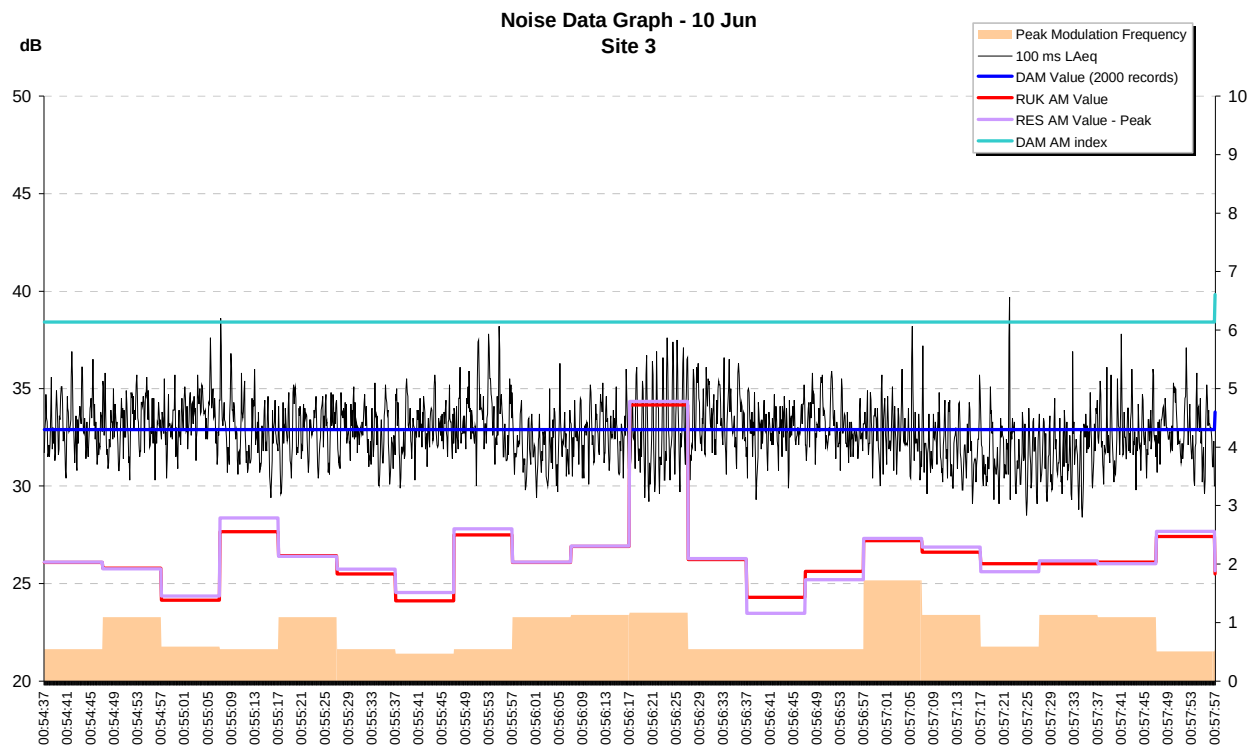
7.36 **Preliminary discussion - Site 3 - 10 June.** Whilst there are fewer periods upon which to assess the methods for this site there are some interesting implications for how each method analyses the presence of AM. The RUK assessment method identifies AM in all periods apart from the first, where there is more extraneous noise. This repeats the finding that the RUK method does not well detect AM when there is a lot of extraneous noise.

7.37 The DAM rating and AM index deal fairly consistently with the presence of AM and do not appear to be adversely influenced by the presence of extraneous noise as has been the case at other sites, with perhaps the exception of extraneous noise at 0042. This is likely due to the gradual increase and decrease in extraneous noise, in this case road traffic noise, compared to impulsive peaks of bird noise found at other sites. The DAM value is slightly lower than the typical peak to trough level identified by the Den Brook method but when converted to the AM index it well reflects typical peak to trough level.

7.38 The Den Brook method identifies AM in all periods. The RES method appears most influenced by extraneous noise in this data set. This is evident when the two turbines do not produce synchronised AM noise and the AM noise sounds muffled. An example is given in figure 68 below.

7.39 Figure 68 is a 3 minute 20 second long extract from figure 66 above.

Figure 68: Site 3 - 10 June - 0054



7.40 The noise trace is entirely dominated by turbine noise. However, as noted above there are periods where the uniformity and apparent synchronicity of the turbines reduces. The sound becomes more muffled or the modulation changes rhythmic pattern, though AM is still clearly present and audible. This has the effect of disturbing the derived peak

modulation frequency. Both the RES and the RUK methods of deriving the blade pass frequency are equally affected. For the RES method the inconsistency of the periods with the global blade pass frequency means that these periods are discarded as periods with no EAM. Whilst in this case is does not prevent positive identification of EAM, because there are still enough periods greater than 2.5 with a consistent blade pass frequency, it does indicate potential failure of the method where turbine sound is not well synchronised / does not result in a clear AM trace.

7.41 **Site 4 - 29th Sep 00:10 - 00:40.** Site 4 was chosen as a site, which contains wind farm noise but was measured at distance from the turbines and under meteorological conditions that resulted in insignificant AM despite wind farm noise being fairly dominant in the noise environment. The results are tabulated in table 5 below and the graphs are given below this. The data has been analysed in 10 minute periods with the DAM rating method given for each 3 minute period. Thus, there is a 1 minute period at the end of each 10 minute period, which has not been assessed using the DAM method.

Table 5: Summary of results - Site 4 - 29 Sep

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating	
					DAM	AM index
0010	Wind turbine noise (roar) in background, lots of wind noise. Some AM audible in wind lulls.	No. Less than 3dB P-T.	A = 0.5	No. All <2.5.	1.2 1.4 1.4	1.0 1.3 1.3
0020	Still fair amount of wind noise but periods where wind farm noise and AM just audible.	No. Less than 3dB P-T.	A = 0.6	No. All <2.5.	1.4 1.4 1.6	1.3 1.3 1.7
0030	Wind at start but then turbine noise and AM clearer. AM distinct approximately half way through period.	No. Less than 3dB P-T. Maybe 2 periods with ≈3dB P-T but *de minimis*.	A = 0.9	No. All <2.5.	1.6 1.8 1.6	1.7 2.0 1.7
0040	Less wind noise, wind farm noise audible. Clearer modulation towards end of period.	No. Less than 3dB P-T.	A = 0.8	No. All <2.5.	1.8 1.7 3.7	2.0 1.8 5.2

Figure 69: Site 4 - 29 Sep - 0010

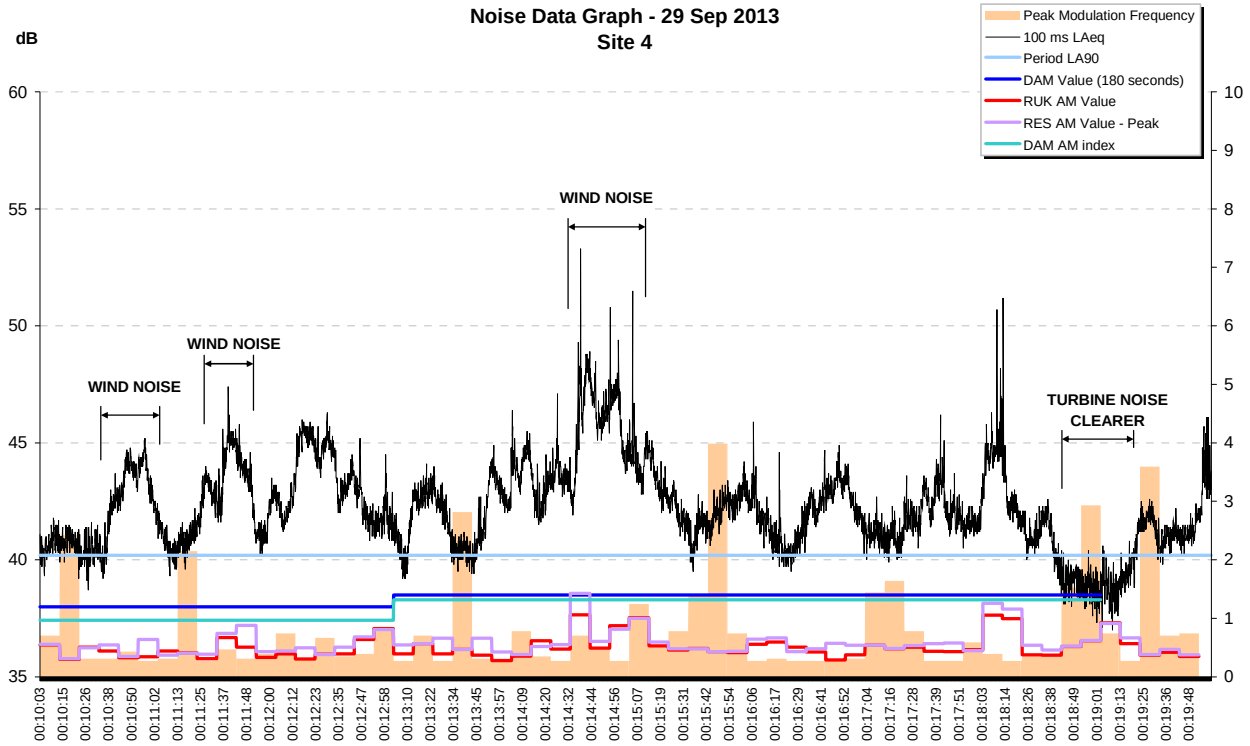


Figure 70: Site 4 - 29 Sep - 0020

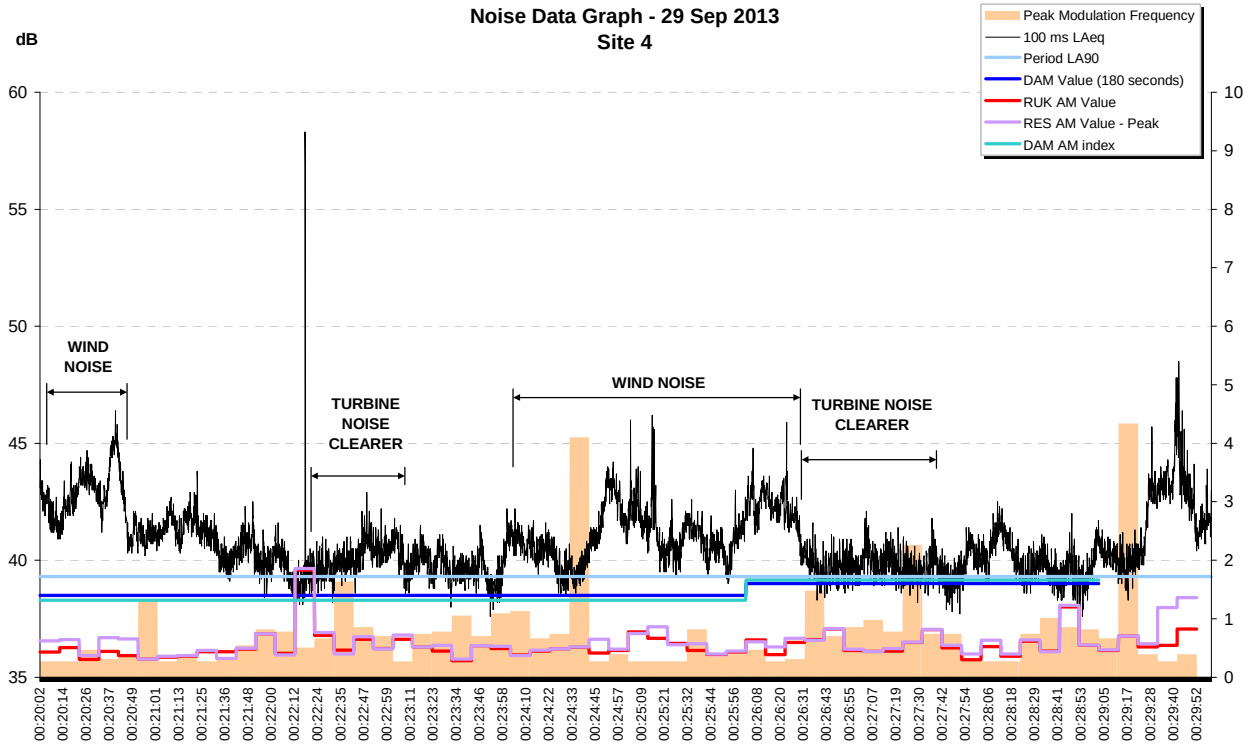


Figure 71: Site 4 - 29 Sep - 0030

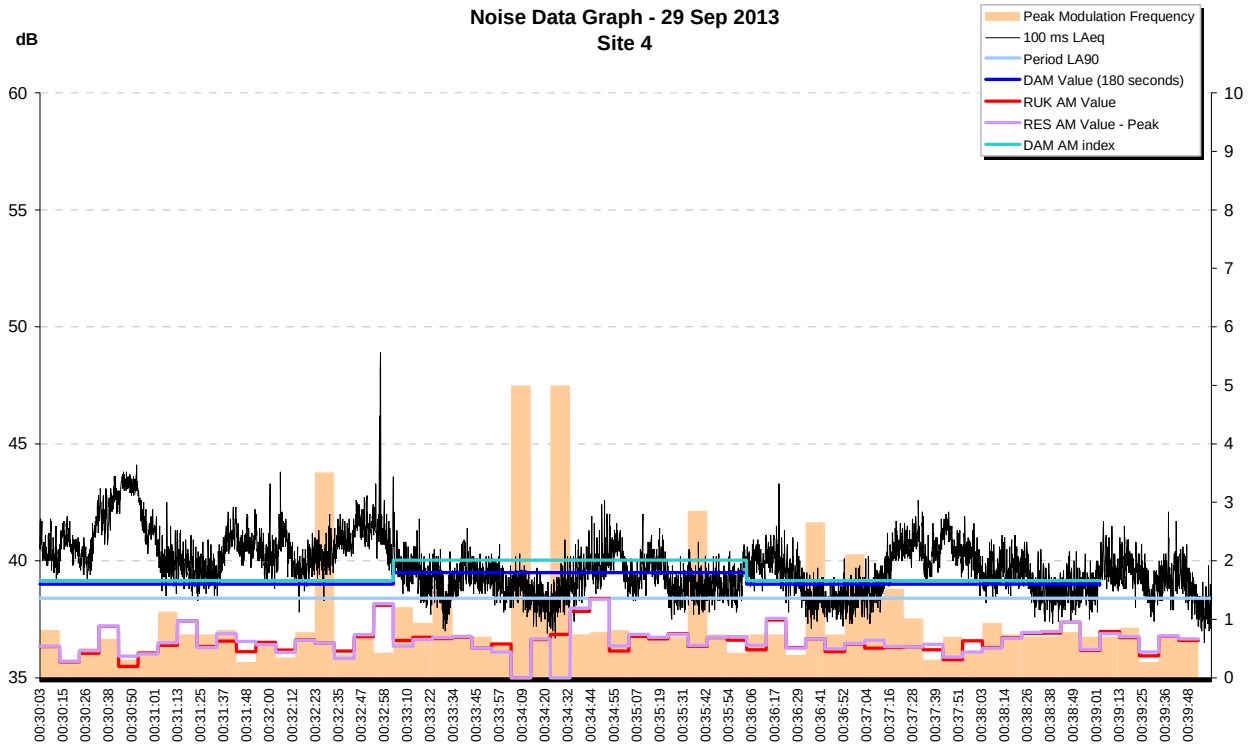
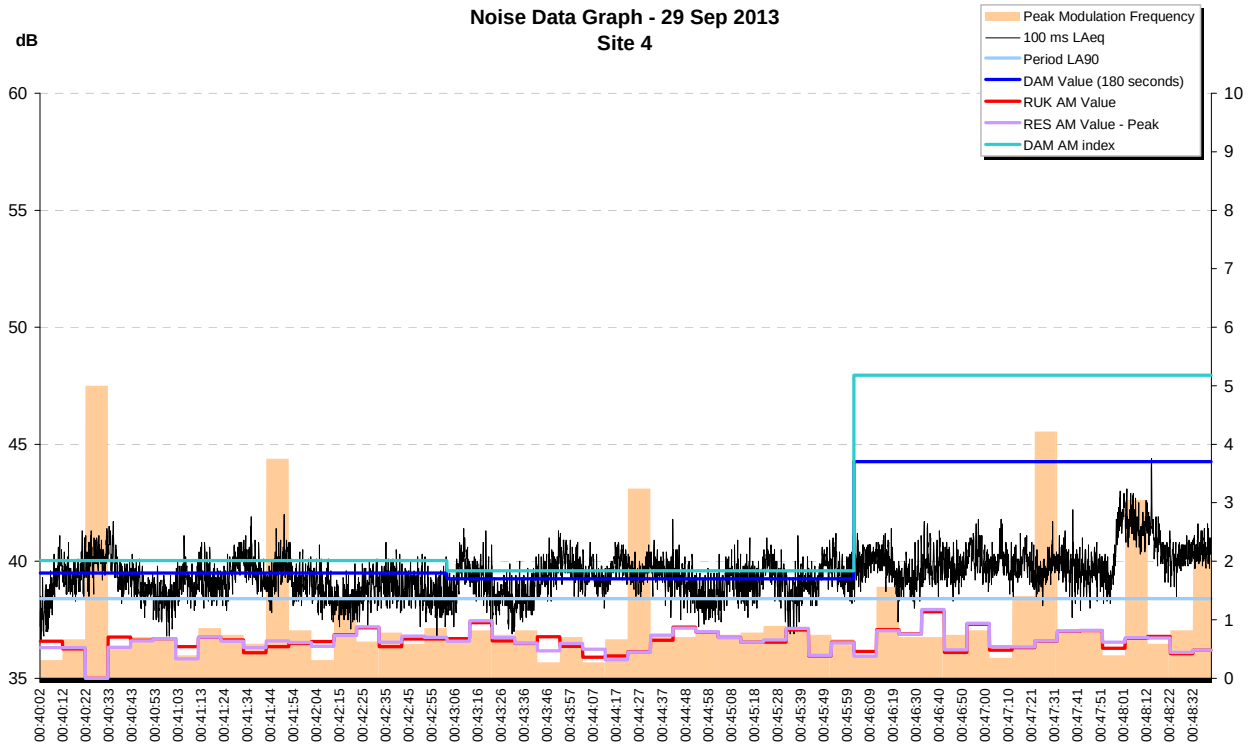


Figure 72: Site 4 - 29 Sep - 0040



7.42 **Preliminary discussion - Site 4 - 29 September.** All four methods worked well in identifying AM that would not be considered excess or unreasonable. The Den Brook method criterion of 3dB(A) peak to trough was not breached and the DAM rating only exceeded 1.7, the point at which the trace is considered 'fluctuating', on three occasions.[43] However, the last 3 minute period of 0040, show in figure 72 above, results in a higher DAM value (3.7) and AM index (5.2). This indicates EAM is present but with reference to the noise trace and the Den Brook method this period would not be considered EAM.

7.43 The DAM method could be influenced by extraneous noise at the very end of the 0040 period. Whilst this might suggest that the DAM method and AM index are overly sensitive or slightly mis-calibrated at the point where fluctuation sensation arises / where the noise might be considered EAM, other periods indicate consistency of the DAM method in determining EAM or no EAM. As such this result is considered an exception to an otherwise consistent rating method.

7.44 The RES method did not find any periods where the AM rating was more than 2.5dB and so successfully identified that AM was not excess. The RES AM value was also calculated using energy from the peak modulation frequency and harmonics of the peak modulation frequency, rather than just the energy at the peak modulation frequency as has been done for sites 1-3 above. This is not shown on the graphs above but inclusion of energy at harmonics of the peak modulation frequency is discussed in more detail below. The inclusion of this additional energy resulted in the methodology identifying five 10 second periods of EAM out of the whole analysis period. This should be considered insignificant or *de minimis*[44] and is a positive indication that inclusion of energy at harmonics of the peak modulation frequency would not unduly skew results towards the identification of EAM. The inclusion of harmonics in the derivation of the RES AM value is investigated further below.

7.45 The RUK method did allow an AM value to be derived, but these were typically very low, between A=0.5 and A=0.9. These values would not result in any penalty applicable to the turbine noise level. Whilst successful in some respects there is concern that these periods would be included in part of a wider analysis as specified in the RUK methodology. These periods could be averaged with periods that have a similar wind speed but where significant EAM occurred. This is likely to happen when combining periods of analysis in low and high wind shear conditions. The averaging process would reduce the level of AM penalty attributable to the wind farm noise level and so penalise periods of adverse impact by including periods when there is no EAM and when it is unlikely that complaints would arise. This is discussed further in the detailed discussion section below.

[43] It is noted in the research accompanying the DAM method that sensation of AM begins when the AM index is approximately 2dB, which correlates to a DAM of 1.7.

[44] *A legal term meaning too small to be meaningful or taken into consideration; immaterial. As a matter of policy, the law does not encourage parties to bring legal actions for technical breaches of rules or agreements where the impact of the breach is negligible. The term de minimis is taken from a longer Latin phrase, which translates into "the law does not concern itself with trifles."* Definition from: Thomson Reuters (2015) *De Minimis* [Online] Available from: http://uk.practicallaw.com/1-382-3382 [Accessed: 18/02/2015]