7.46 **Site 5 - 8th May 00:00 - 00:50.** Site 5 provides a large bank of test data upon which to test the AM conditions and assessment methods. The site is a wind farm consisting of eight large wind turbines and data has been recorded since the turbines were operational. This has provided a good range of test conditions including tests with turbines on and off, low level (low peak to trough) AM and EAM with a significant peak to trough variation, up to 15dB(A). This first example from 8th May provides a period without the turbines operating followed by a period with the turbines operating. A stark contrast in the noise environment can be observed with turbines on and off. The results are summarised in table 6 below. The Renewable UK results in square brackets below indicate the A value derived assuming a constant blade pass frequency of 0.74Hz. This is in contrast to the A value derived uniformly across the tables 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.

Table 6: Summary of results - Site 5 - 8 May

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating	
					DAM	AM index
0000	No audio data.	No. Less than 3dB P-T.	No. Nothing consistent with BPF. [A = 0.4]	No. All <2.5.	1.6 1.6 1.7	1.7 1.7 1.8
0010	No audio data.	Yes. (≈7dB).	No. Not enough data points. [A = 2.3]	Yes. A few >2.5.	1.6 1.5 3.3	1.7 1.5 4.5
0020	No audio data.	Yes. (≈6-8dB).	A = 4.1 [A = 4.1]	Yes. Lots of periods >2.5..	4.6 4.7 4.3	6.6 6.8 6.1
0030	No audio data.	Yes. (≈5-7dB).	A = 3.8 [A = 3.8]	Yes. Lots of periods >2.5.	3.9 4.6 4.4	5.5 6.6 6.3
0040	No audio data.	Yes. (≈6-8dB).	A = 3.8 [A = 3.8]	Yes. Lots of periods >2.5 but also lots missed.	4.5 4.4 4.6	6.5 6.3 6.6
0050	No audio data.	Yes. (≈5-9dB).	A = 3.0 [A = 3.2]	Yes. Lots of periods >2.5 at start.	4.6 2.3 1.8	6.6 2.9 2.0

Figure 73: Site 5 - 8 May - 0000

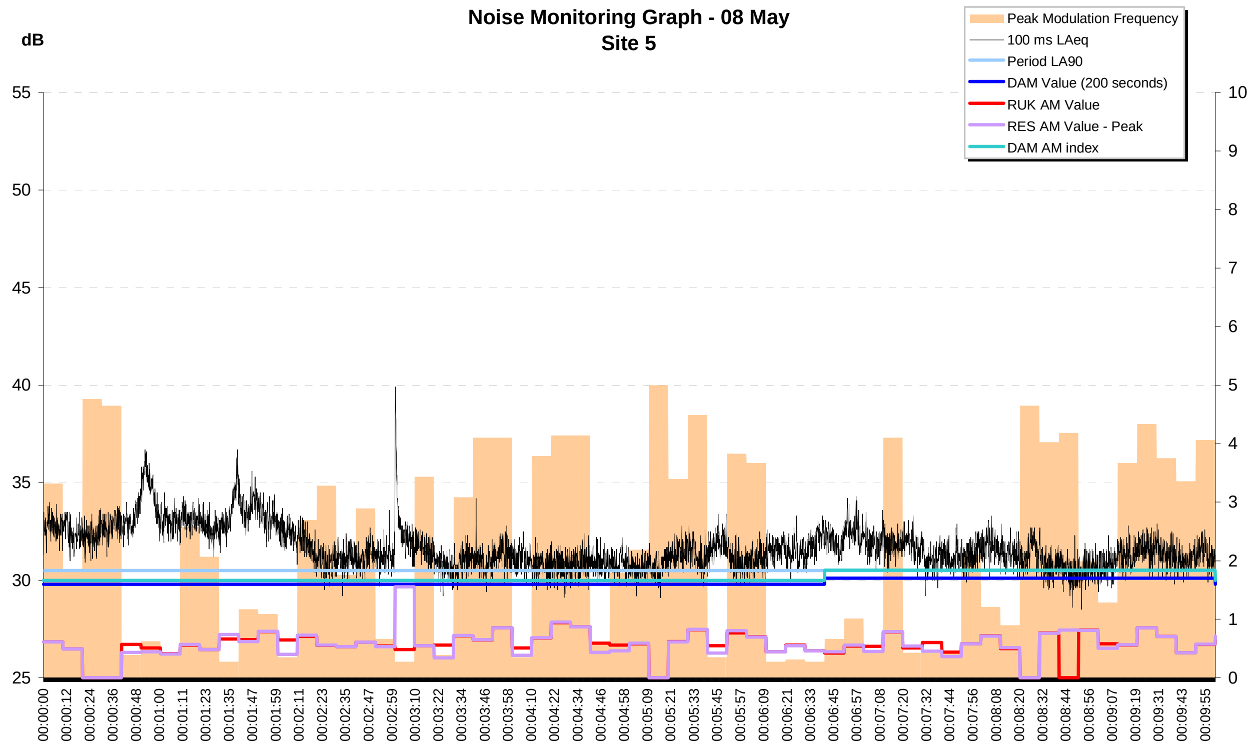


Figure 74: Site 5 - 8 May - 0010

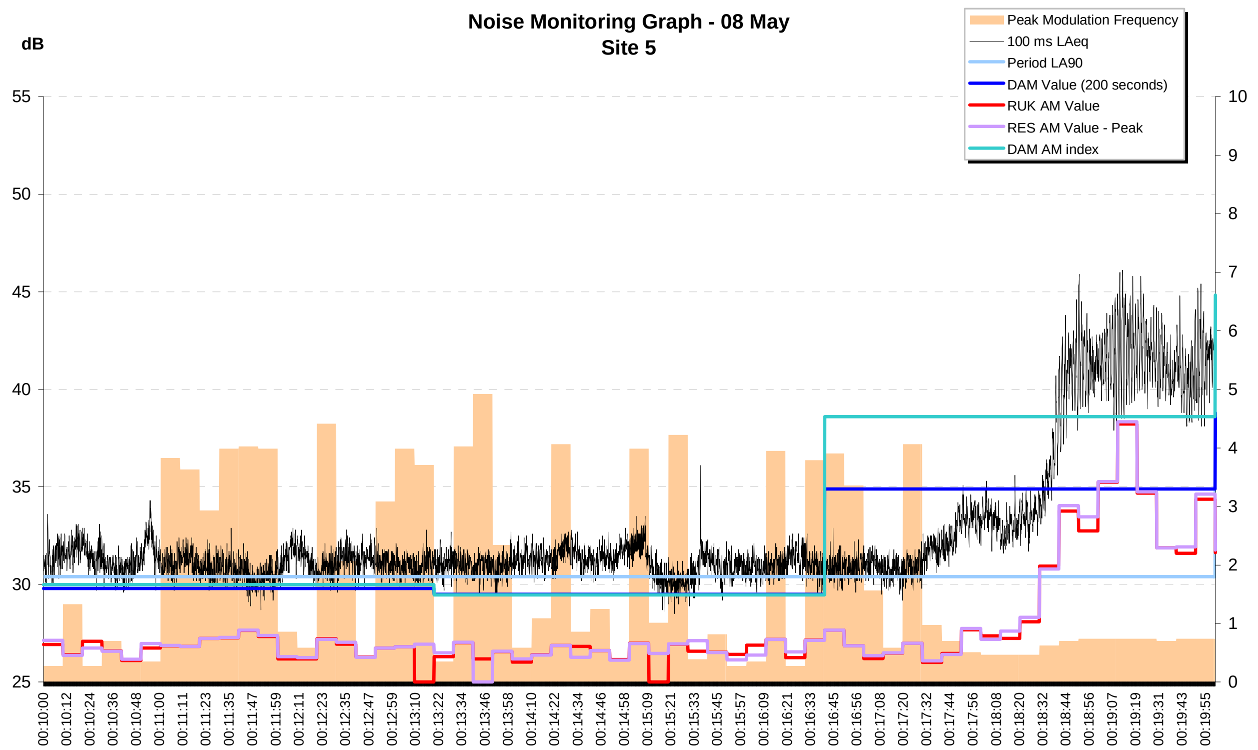


Figure 75: Site 5 - 8 May - 0020

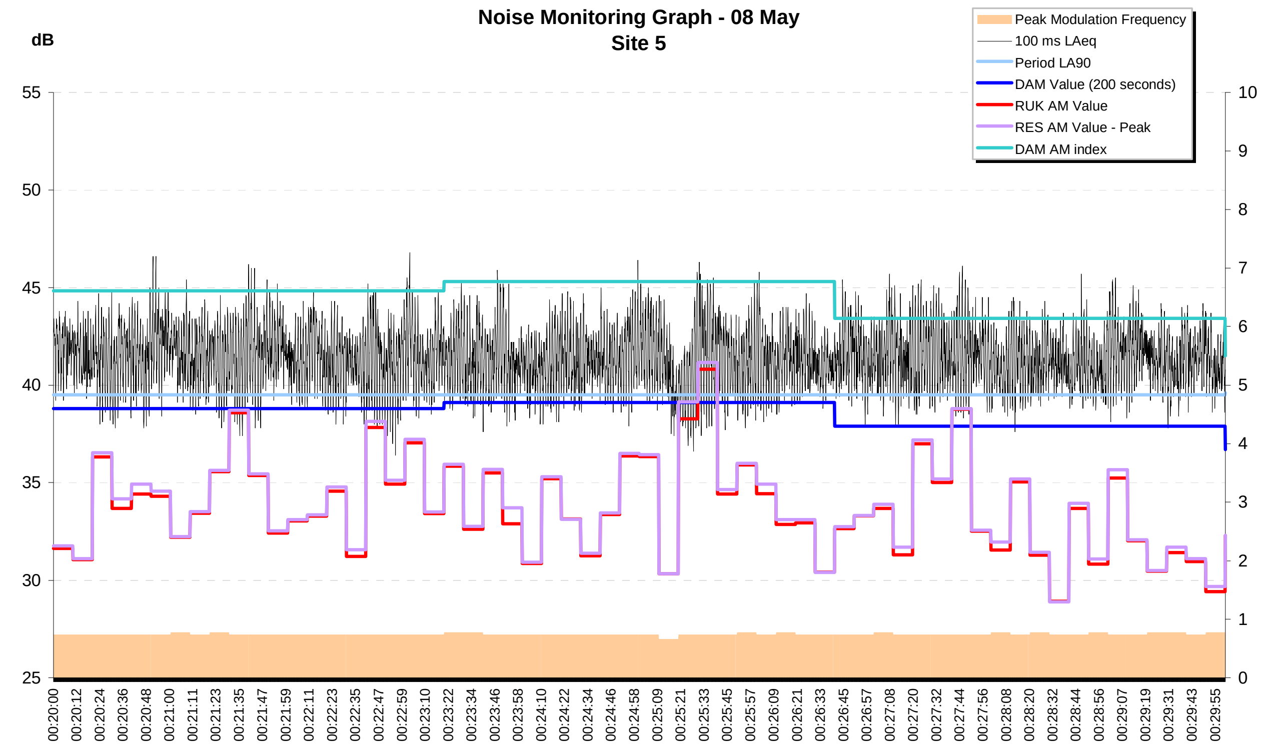


Figure 76: Site 5 - 8 May - 0030

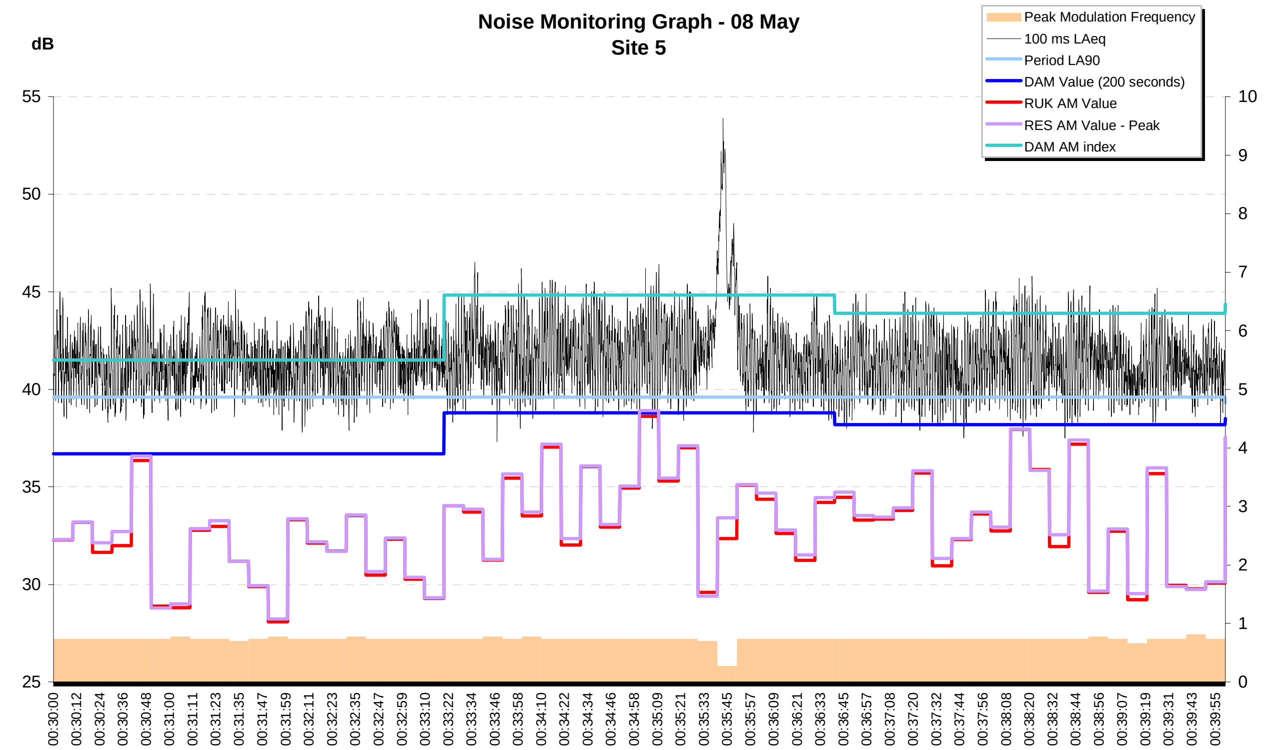


Figure 77: Site 5 - 8 May - 0040

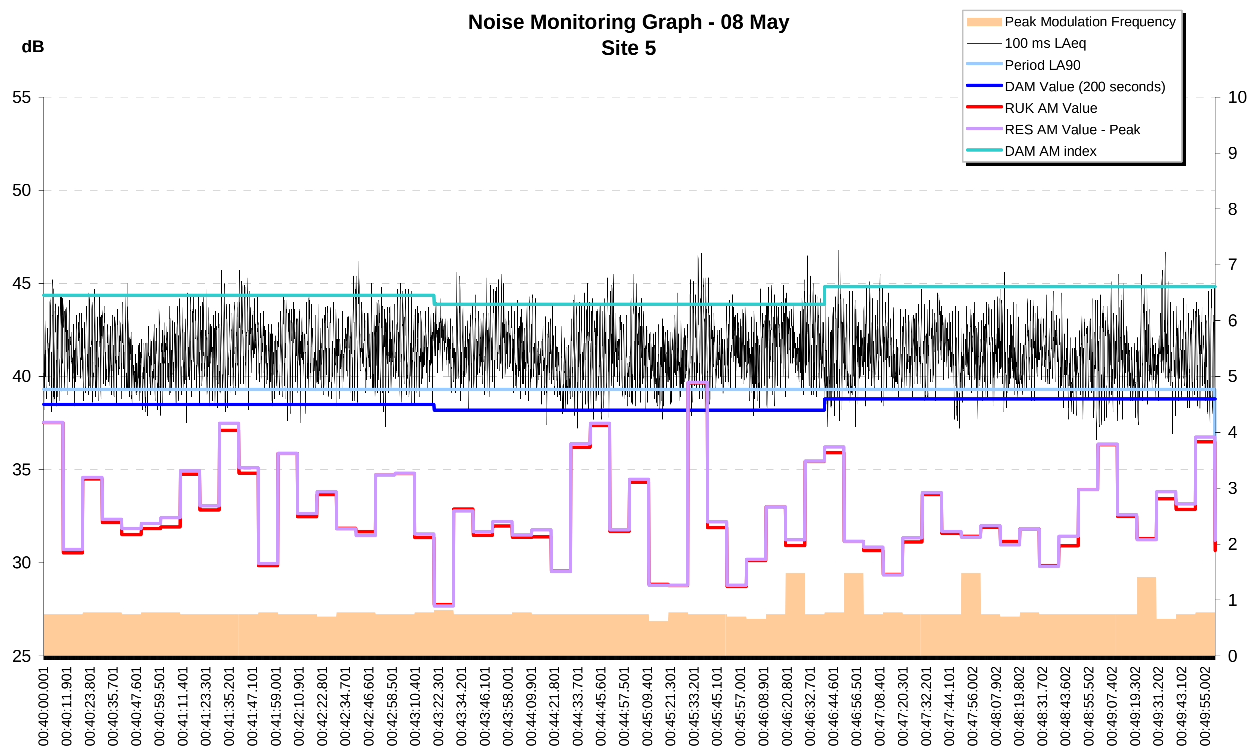
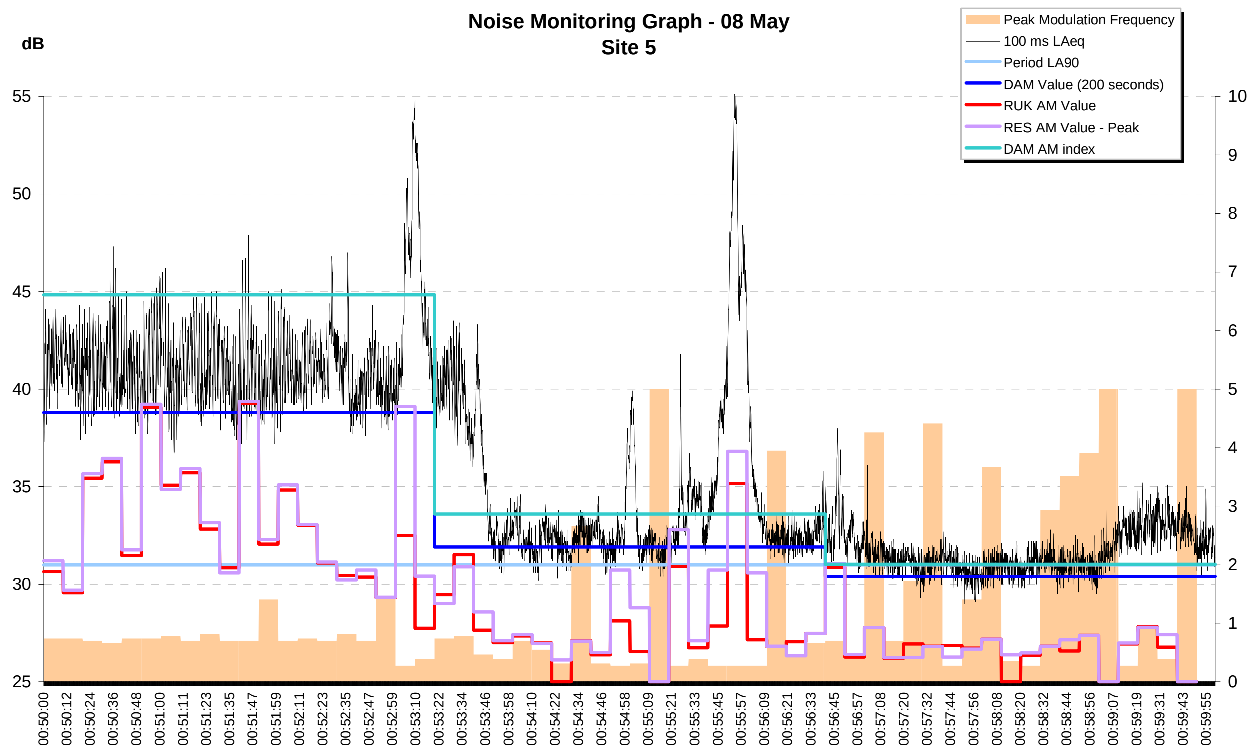


Figure 78: Site 5 - 8 May - 0050

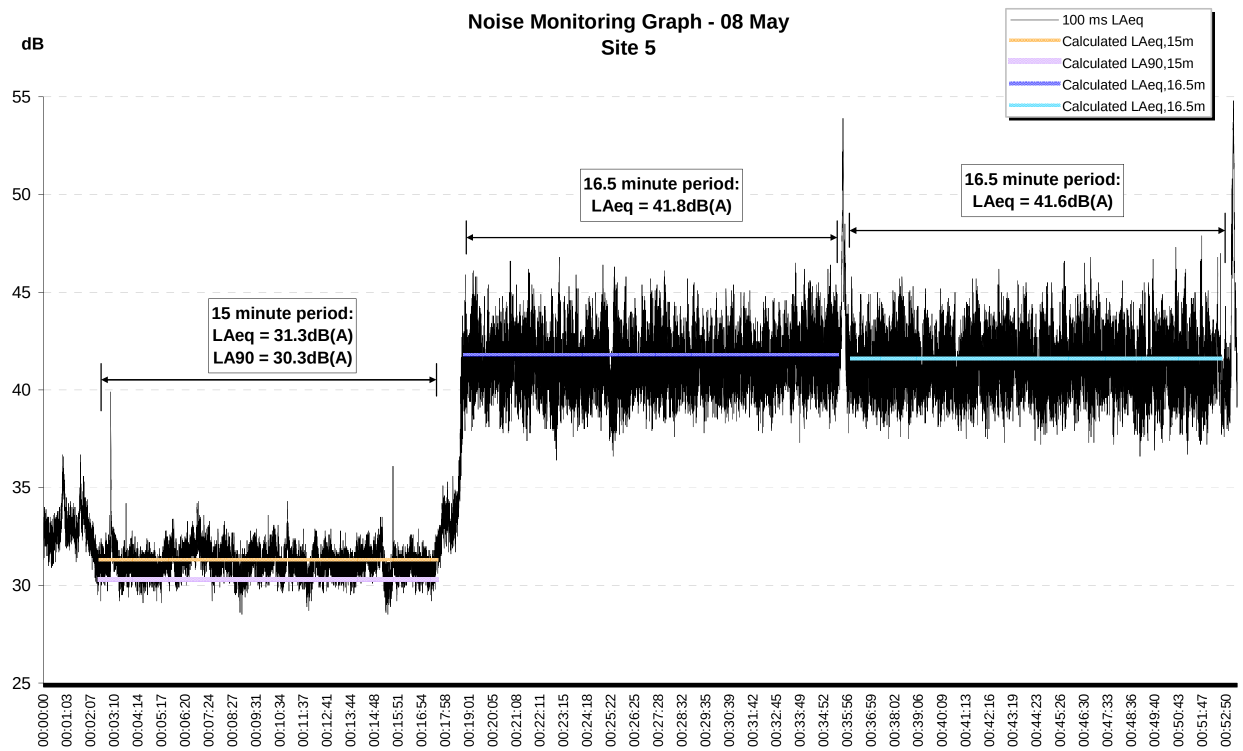


7.47 This example provides periods with the turbines on and off, allowing separate assessment of source noise and background sound under the same conditions. This allows a BS4142 assessment to be made.[45] The BS4142 assessment has been included in a separate results table below and is illustrated graphically below in figure 79.

7.48 Both the new (2014) and now superseded (1997) versions of the standard have been used to assess noise impact to provide context with a long established rating criterion and the changes in the new criterion. In brief the assessment uses the measured LAeq of the turbine noise, in comparison to the LA90 prescribed by ETSU-R-97, and compares this to the background sound level (LA90) in the absence of the turbine noise.

7.49 The turbine noise should be corrected for other ambient noise in the environment (termed residual noise), an estimate of which can be made from the preceding period without turbine noise. Decibel penalties are added to the overall LAeq noise level of the turbines for noise character.

Figure 79: Site 5 - 8 May - 0000 - 0100 - BS4142 assessment.



[45] This is not possible in other cases, at least by strictly following the methodology of the standard, as there are no two consecutive periods at a reasonably high wind speed (i.e. when turbines would operate) with turbines on and off.

Table 7: BS4142 assessment - Site 5 - 8 May

	BS4142:1997	BS4142:2014
Measured background sound level	30.3dB LA90,5min	30.3dB LA90, 15min
Measured ambient noise level	41.7dB LAeq, 33min	41.7dB LAeq, 33min
Measured residual noise level	31.2dB LAeq, 5min 31.4dB LAeq, 5min (use 31.3dB LAeq, 5min)	31.3dB LAeq, 15min
Calculated turbine noise level (specific noise level)	41.3dB LAeq	41.3dB LAeq
Character penalty	+5dB for modulating character	Arguable +3 / +6dB for 'other sound character' and 'intermittency / readily distinctive'
Rated turbine noise level	46.3dB(A)	44.3 - 47.3dB(A)
Difference between rated turbine noise level and background sound level	+16dB	+14dB - 17dB

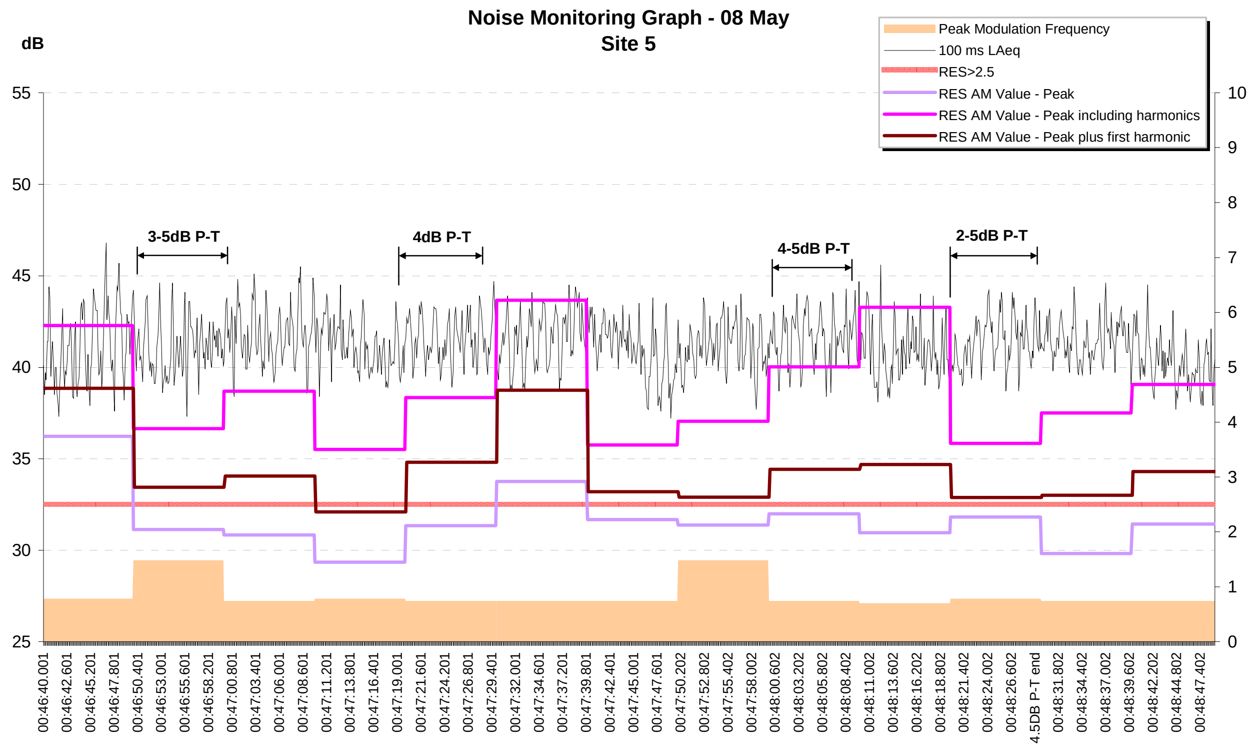
7.50 **Preliminary discussion - Site 5 - 8 May.** The clean and uncorrupted nature of the noise trace in this case allows all methods to derive AM values fairly consistently and facilitates direct comparison between rating methods. One issue highlighted with the RUK method is that where AM impacts for a small proportion of the 10 minute period the entire period is missed. This is true at 00:10 where the last minute of the period contains AM but there are not enough 10s data points to derive an A value. This could be important for assessing frequency and duration of impact.

7.51 The Den Brook identification of AM and peak to trough level are again consistent with the DAM rating method and the AM index well reflects the typical peak to trough level. The DAM rating method well identifies insignificant modulation up to 00:18 and correctly attributes a higher DAM value to represent the impact during the last minute of the 10 minutes beginning at 00:10. It also appears uninfluenced by extraneous noise at the end of the period. This is most likely because the noise is not impulsive, for example like bird noise, but has a slower rise and fall, which does not skew the methodology.

7.52 The RES Den Brook method is again consistent with the Den Brook method for identifying the presence of AM. However, it is noted that despite there being continuous AM many periods assessed using the RES method are below the EAM trigger value of 2.5 and so would be discarded as not EAM. This is not an issue where there are many example periods above an AM value of 2.5, but could be a significant problem in cases where there are fewer periods above 2.5. It could also be an issue if frequency and duration were assessed using the RES method. An example is given in figure 80 below.

7.53 Figure 80 is approximately 2 minutes long. Plotted on the graph is the RES AM value calculated in accordance with the RES methodology. This AM value is calculated only using the energy in the first peak of the modulation spectrum. It is shown as the lilac line on the graph. Also plotted on the graph is the RES AM value if the energy at other dominant peaks, i.e. harmonics in the modulation spectrum, are included. The RES AM value calculated using just the first peak and the second peak (first harmonic) is also plotted on the graph in brown. The RES AM value including all harmonics is shown in bright pink.[46] The red horizontal line gives the cut off value of 2.5. Labels have been provided above some of the 10s periods to indicate the typical peak to trough variation of the wind farm AM.

Figure 80: Site 5 - 8 May - 00:46 - differences in RES rating of AM values



7.54 Despite a fairly consistent modulating trace throughout the period only two 10s periods breach a RES AM value of 2.5, using the RES methodology with just the energy at the first peak of the modulation spectrum. Adding in energy from other harmonics to derive the AM value consistently increases the AM value above the value of 2.5. However, the value including all harmonics increases the difference between consecutive 10s periods sometimes erratically and in some cases there is a large difference in AM value despite there being little difference in modulation depth. Calculating the RES value using just the peak and first harmonic does provide compromise between the higher and sometimes erratic values obtained if including all harmonics and the values which are often too low to indicate AM obtained if using only the peak value. The RES method for identifying EAM is further discussed in the main discussion section below.

[46] This will typically include up to the 3rd or 4th harmonic.

7.55 **Site 5 - 11th October 05:00 - 06:00.** This period has been included in analysis as representative of a borderline period of AM. The results are summarised in table 8 below. For brevity only the first and last three 10 minute periods are provided graphically below. 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 8: Summary of results - Site 5 - 11 October

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating[47]	
					DAM	AM index
0500	Steady lower level noise, likely from wind farm noise though not 100% clear from audio. Some extraneous vehicle noise towards end of period.	No. Less than 3dB P-T.	No. Too few consistent with BPF.	No. All <2.5.	1.9 1.8 1.7'	2.2 2.0 1.8
0510	Steady lower level noise, some wildlife noise and plane noise in second half of period.	No. Less than 3dB P-T.	No. Too few consistent with BPF	No. All <2.5.	1.9 4.4' 2.1	2.2 6.3' 2.5
0520	Some road and rail noise at start of period, then steady lower level noise and more road traffic noise towards end of period.	No. Less than 3dB P-T.	No. Too few consistent with BPF	No. All <2.5.	2.2' 1.8 2.0'	2.7' 2.0 2.4'
0530	Some blade swish just audible, tonal whine in data but not clear if from turbines. AM just audible towards end of period.	Yes. (≈3-4dB).	A = 1.5	No. All <2.5.	2.2 2.5 2.4	2.7 3.2 3.0
0540	Wind turbine noise clearly audible, AM and blade swish. Some road traffic noise.	Yes. (≈3-4dB).	A = 1.7	No / borderline. One example >2.5.	2.3 2.5 2.3	2.9 3.2 2.9
0550	Wind turbine noise audible but reduces throughout period. Some bird noise and road traffic noise towards end of period.	Borderline. (≈2-3dB).	A = 1.3	No. All <2.5.	2.2 2.1 2.5'	2.7 2.5 3.2'

47 ' denotes the presence of potentially corrupting extraneous noise.

Figure 81: Site 5 - 11 Oct - 05:00

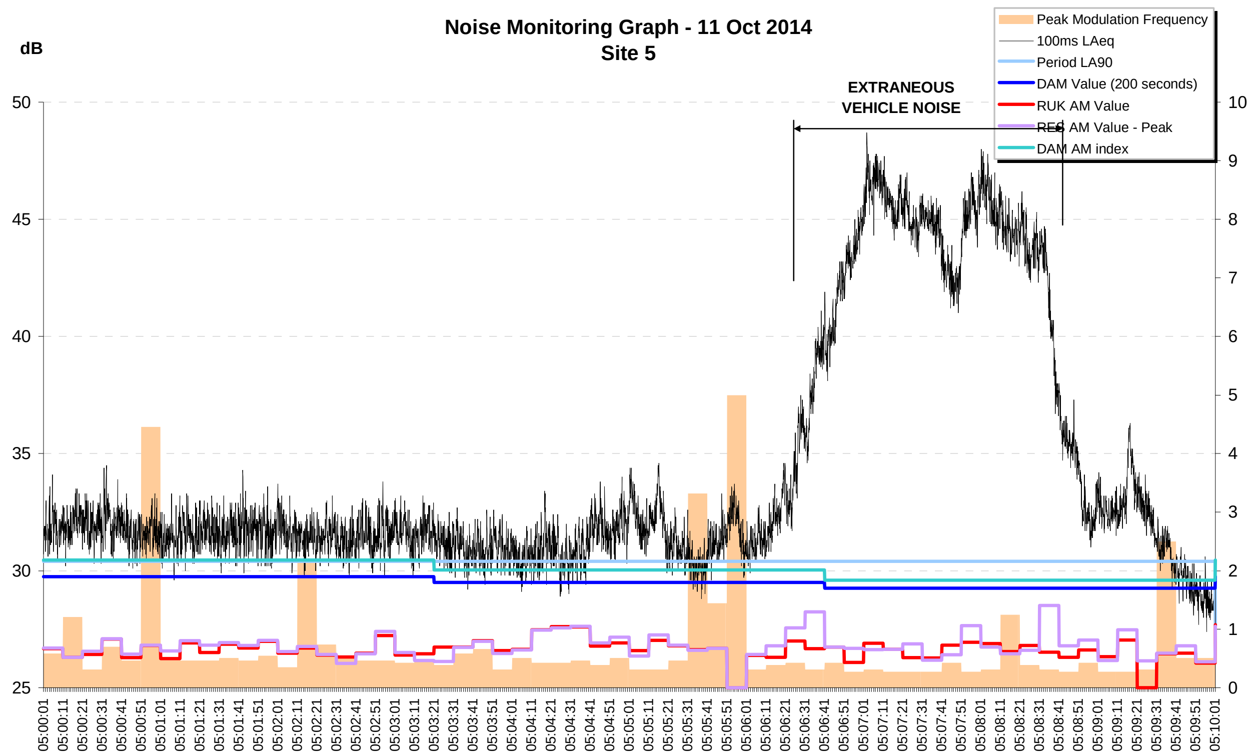


Figure 82: Site 5 - 11 Oct - 05:30

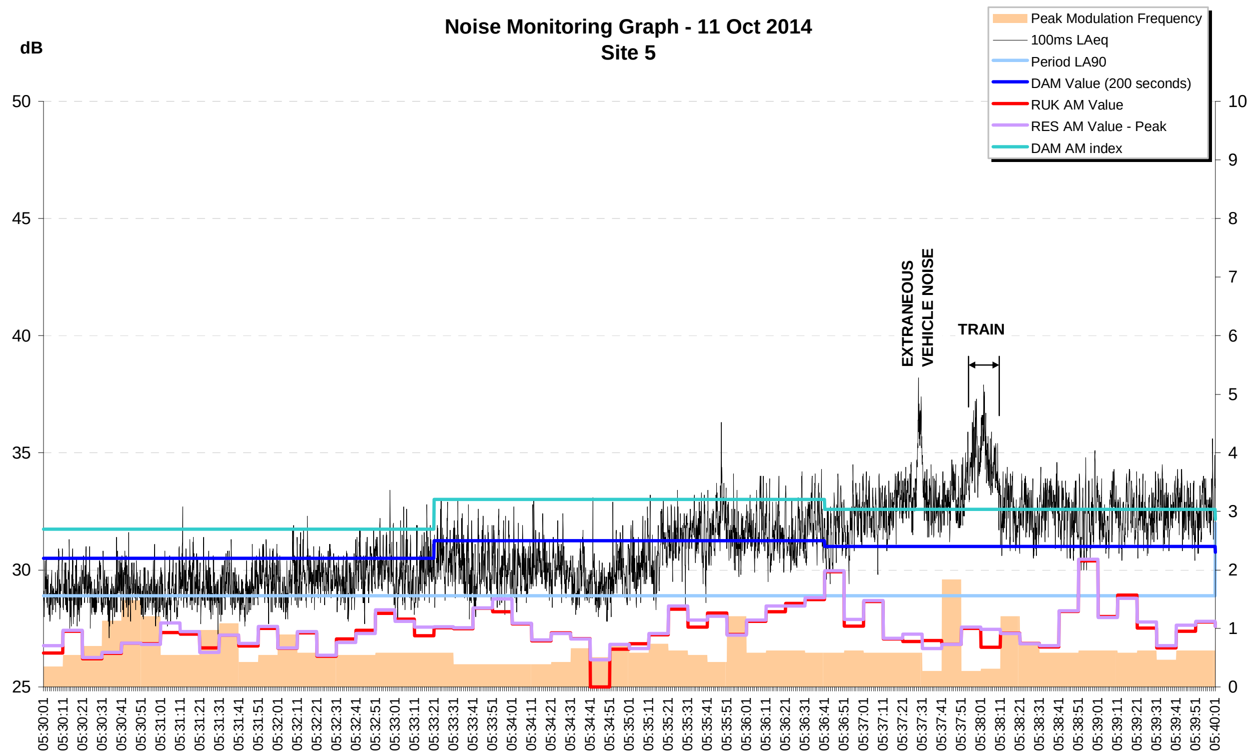


Figure 83: Site 5 - 11 Oct - 05:40

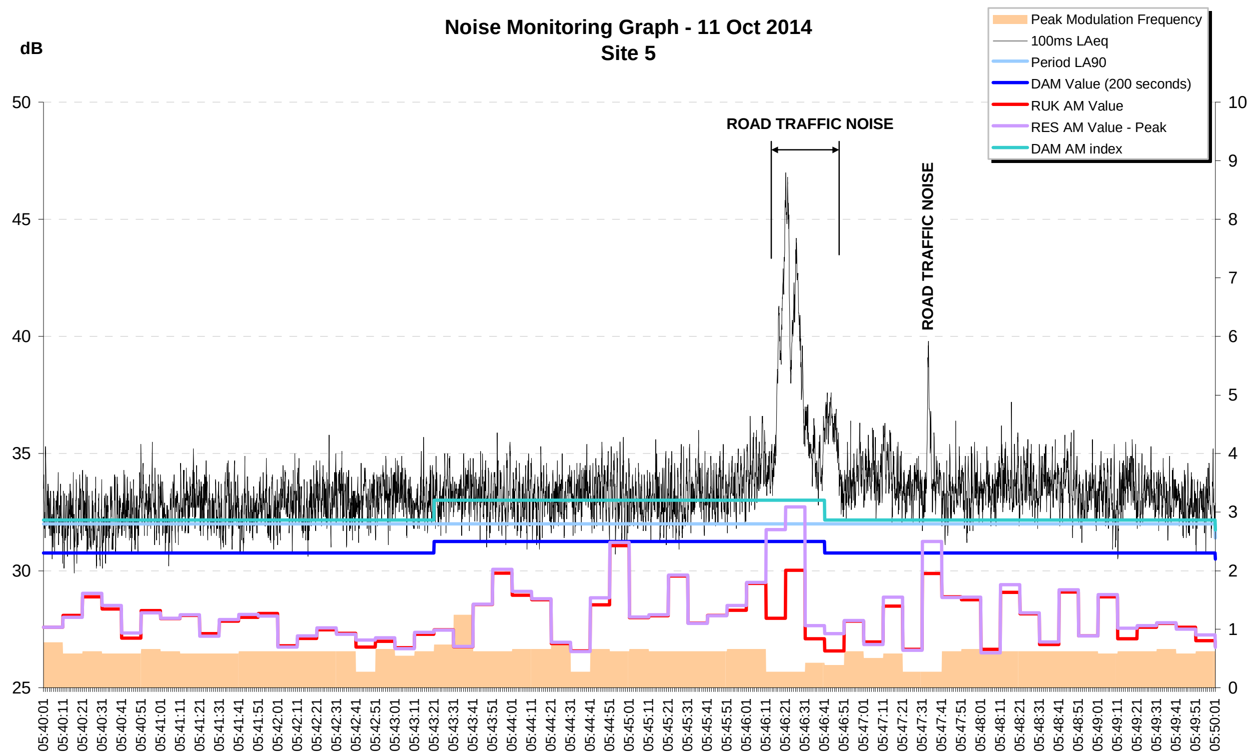
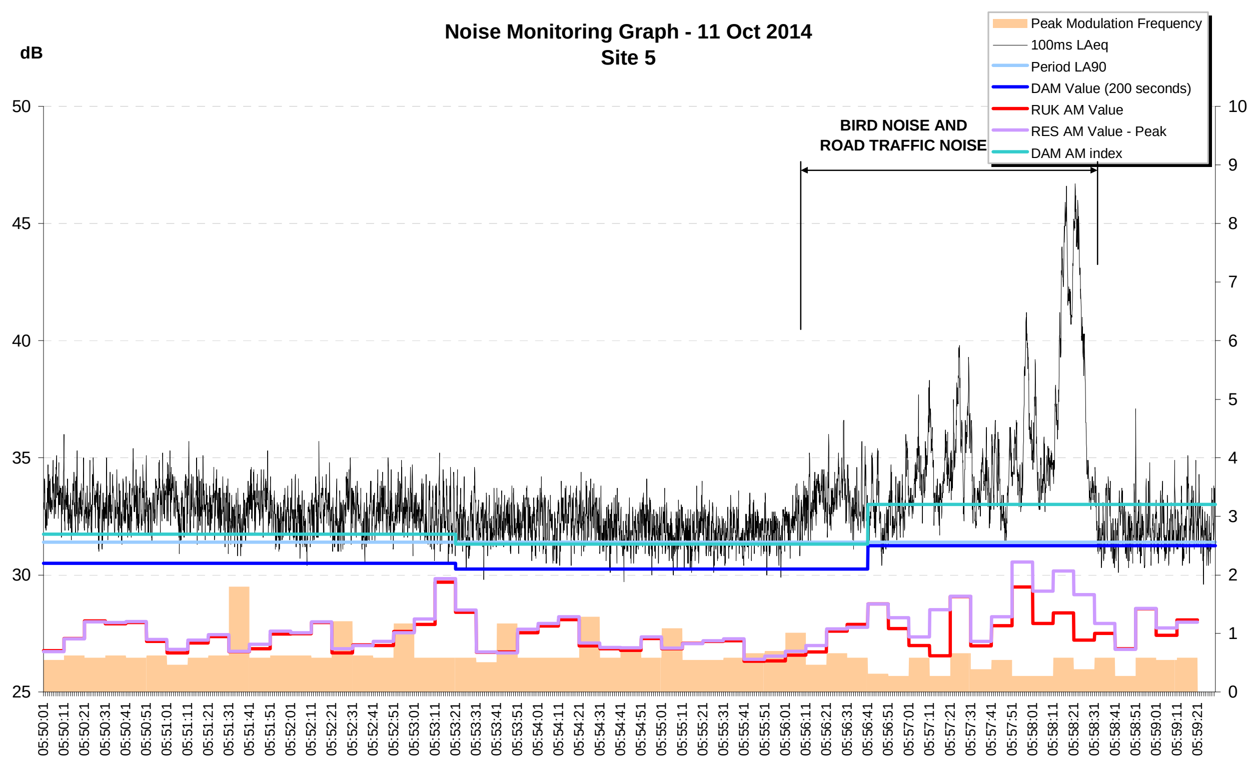


Figure 84: Site 5 - 11 Oct - 05:50



7.56 **Preliminary discussion - Site 5 - 11 October.** This borderline AM data set provides some useful comparisons for the onset points of the different AM methods. All three methods are unanimous that there is no AM during the first 10 minute period. Thereafter the DAM rating method is skewed by the presence of extraneous noise, plane noise, at 0510 but otherwise well assesses the presence of AM and is consistent with the Den Brook method. The RUK method is consistent with the Den Brook method in being able to derive an A value for the last three periods only and thus identifying a level of EAM. The RES value fails to identify the presence of AM in any period, perhaps with the exception of 05:40, but this is questionable with only one 10s period being triggered. If the RES AM value is calculated using energy at harmonics, rather than just the first peak in the modulation spectrum, then EAM is indicated in the last three periods.

7.57 Note: it is unlikely that the data from 11th October in isolation would be considered a breach. It is indicative of other adverse impact that would need to be demonstrated to some extent. Again, such decisions relate to frequency and duration of impact and consideration of the *de minimis* rule.

7.58 **Site 5 - 31st December 04:00 - 05:00.** This is an example of AM where there is little extraneous noise contributing to the overall noise trace. The period is dominated by wind farm noise and it is clear from audio recordings that the weather conditions are fairly windy. Whilst wind gusts are audible wind does not corrupt the noise trace. The AM is fairly erratic and varies significantly in peak to trough level over short periods. Thus, over a period of a few seconds the peak to trough of the modulating wind farm noise will vary by approximately 4dB and then to up to 15dB. The results are summarised in table 9 below. For brevity only the last three 10 minute periods are provided as figures below.

7.59 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 9: Summary of results - Site 5 - 31 December

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating[48]	
					DAM	AM index
0400	All noise from wind turbine and AM. Some wind gusts and wind noise but turbine noise clearly dominant.	Yes. (≈7-12dB).	A = 4.1	Yes. Lots of periods >2.5.	5.8 5.1 4.7	8.4 7.4 6.8
0410	Wind farm noise and AM loud and dominant. Some wind noise which appears to coincide with periods where AM is not in sync. AM variable in terms of clarity and loudness.	Yes. (≈5-9dB).	A = 4.1	Yes. Lots of periods >2.5.	4.9 6.0 4.8	7.1 8.7 6.9
0420	Wind farm noise and AM dominant. Some noise from wind. Whipping / lashing noises from wind farm. Some road traffic noise.	Yes. (≈5-8dB).	A = 3.0	Yes. A few periods >2.5 but also lots missed.	4.5 4.8 4.4	6.5 6.9 6.3
0430	Wind farm noise and AM noise dominant. Some plane noise but turbines still clearly dominant in soundscape. AM more intermittent towards end of period.	Yes. (≈5-9dB).	A = 3.4	Yes. Lots of periods >2.5.	4.3 5.2 4.7	6.1 7.5 6.8
0440	Wind farm noise dominant, windy but not much corrupting noise. AM more intermittent with sudden loud peaks. Some extraneous noise from local road traffic.	Yes. (≈5-15dB).	A = 2.9	Yes. Lots of periods >2.5 but also lots missed.	4.7 4.0' 4.2	6.8 5.7' 6.0
0450	Wind turbine noise still dominant but more extraneous noise from wind and road traffic. Church bells audible at end of period.	Yes. (≈5-8dB).	A = 3.0	Yes. A few periods >2.5 but also lots missed.	3.9 4.9 3.6	5.5 7.1 5.0

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

Figure 85: Site 5 - 31 Dec - 04:30

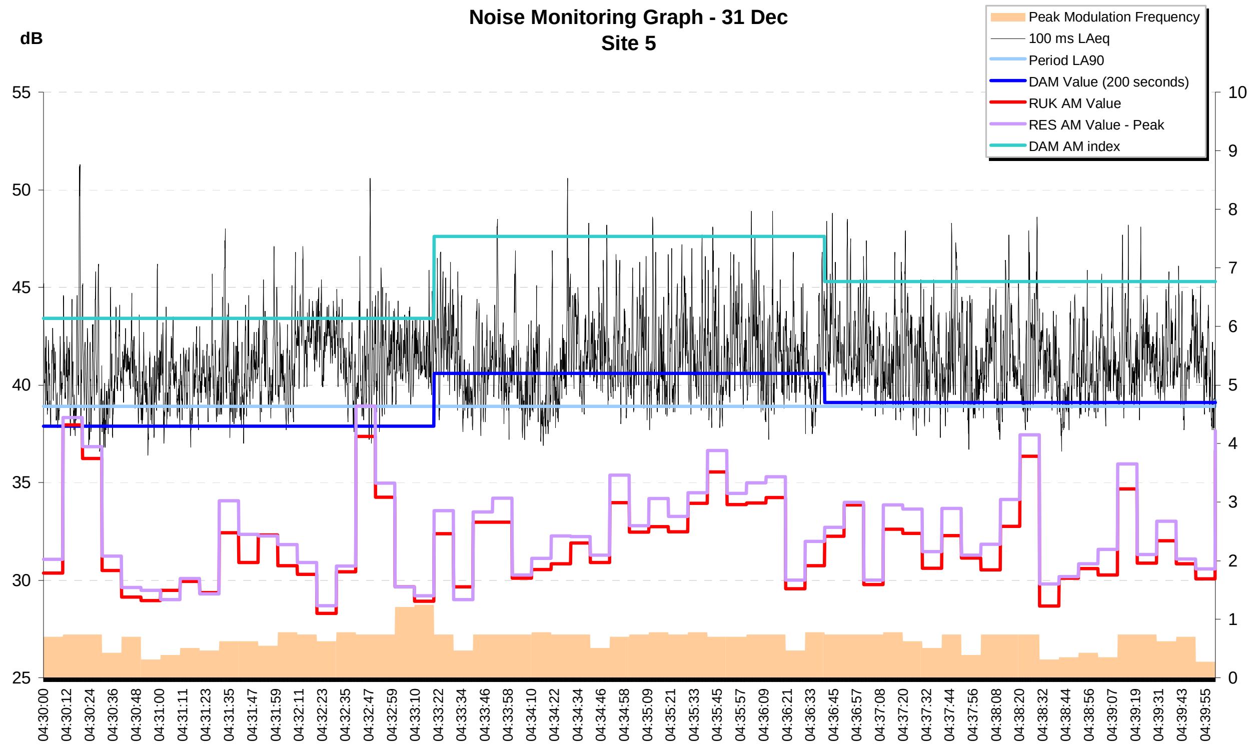


Figure 86: Site 5 - 31 Dec - 04:40

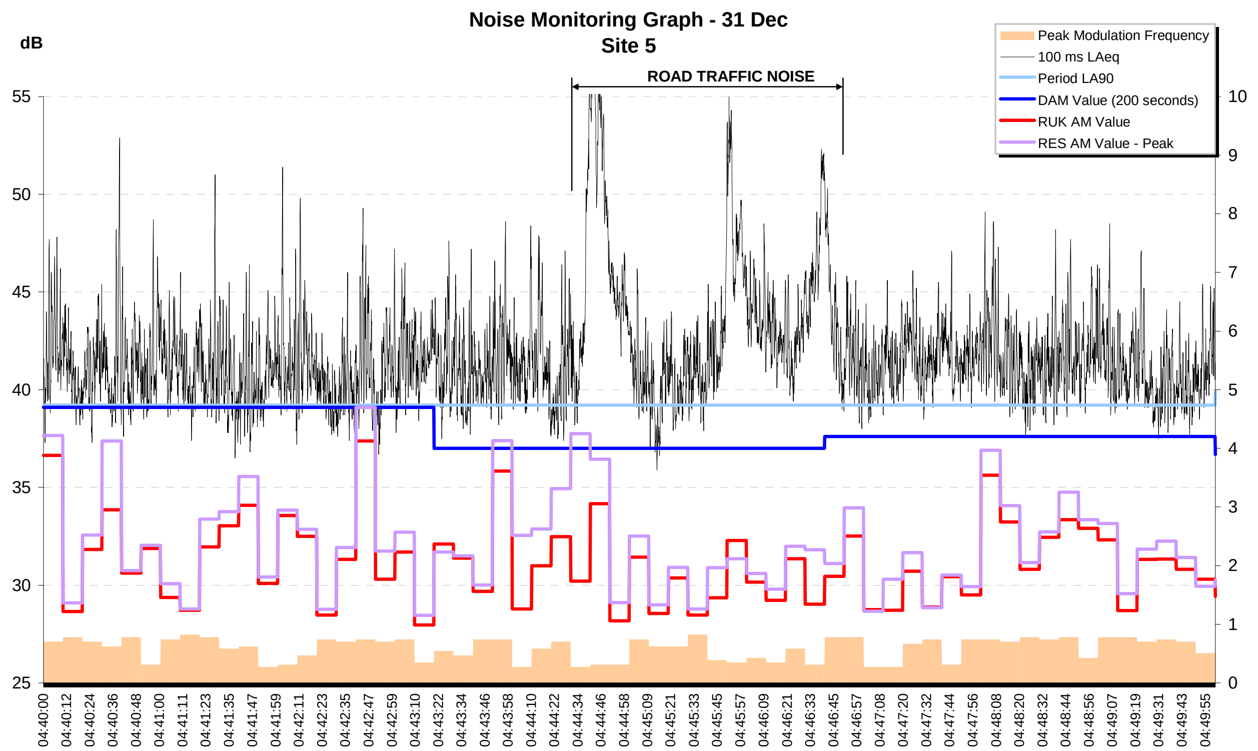
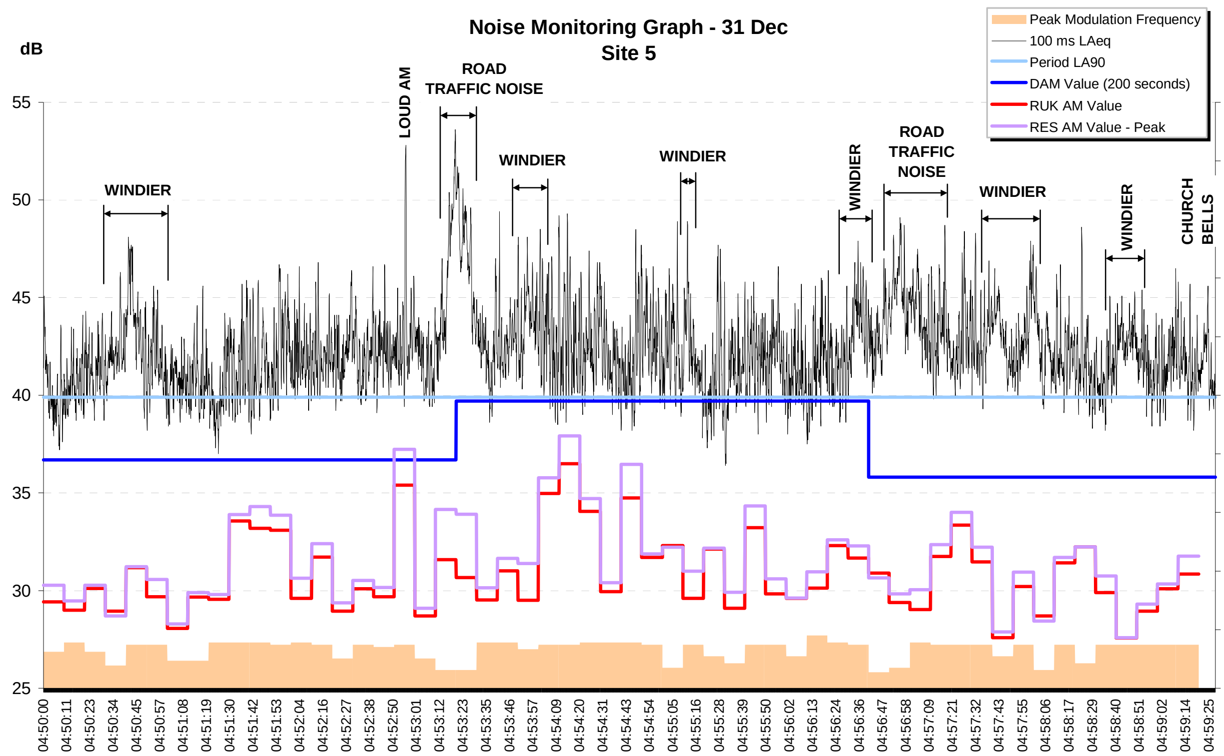


Figure 87: Site 5 - 31 Dec - 04:50

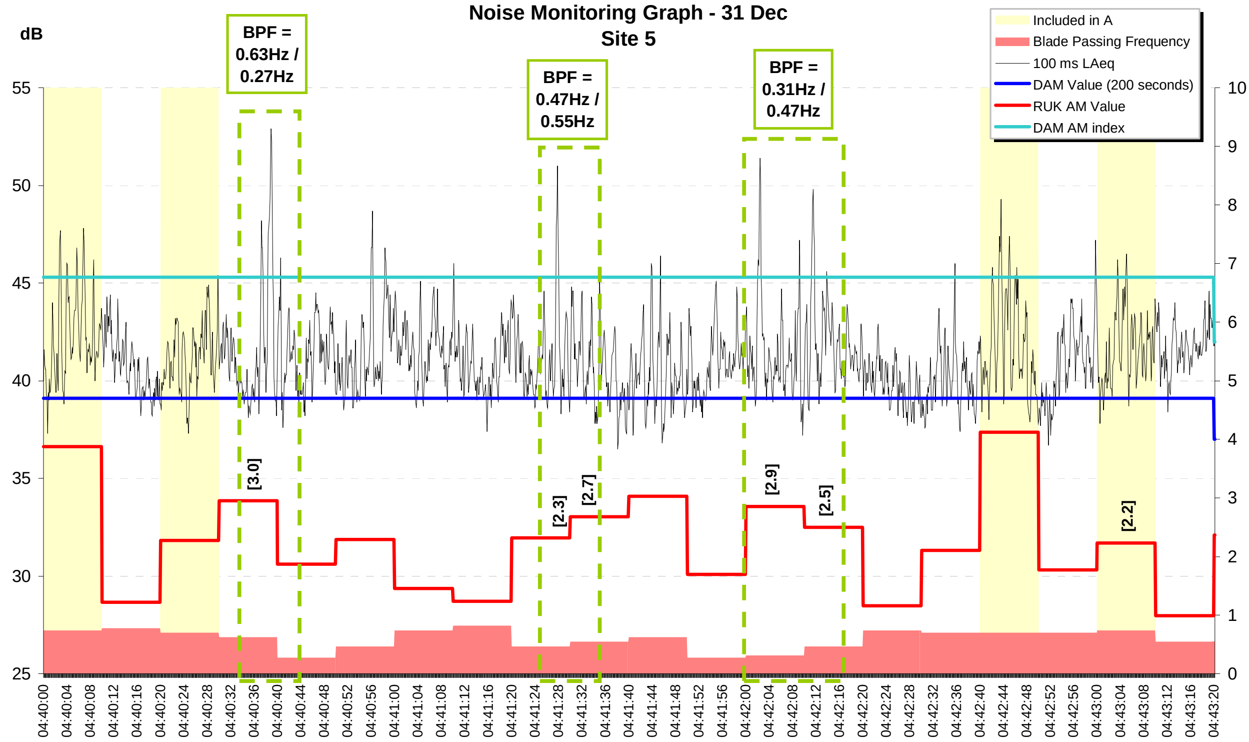


7.60 **Preliminary discussion - Site 5 - 31 December.** The examples from this period demonstrate again that all methods are consistent in identifying AM. The DAM values are slightly lower than a typical peak to trough obtained visually from the graphs using the Den Brook method but the AM index derived from the DAM value very well represents the typical AM peak to trough level. However, the DAM value and the AM index do not well identify or represent some EAM peaks of up to 15dB peak to trough. Discrepancy in deriving a blade pass frequency consistent with that of the turbines again proves problematic for some of the RUK and RES results.

7.61 Figure 88 below shows the 3 minute period beginning at 04:40. Plotted on the graph are the 10s periods included in the RUK 10 minute AM value ('A'), see the 10s periods highlighted in pale yellow, and also the blade pass frequency (peak modulation frequency) as derived using the RUK method.[49] There are three periods highlighted by dashed green lines where all noise is from the wind turbines and there is a significant peak to trough variation. The 10s AM values of the periods enclosed by dashed green lines, which are not included in the overall 10 minute AM rating, are greater than the AM value for the 10s period at the end of figure 88 but that has been included in the derivation of the overall 10 minute AM value. These values have not been included as the blade pass frequency is not consistent with the blade pass frequency of the turbines. In this case the blade pass frequency of the turbines is taken as 0.74Hz and is derived from preceding data. Consistent blade pass frequency data is taken as +/- 10%. The AM values are indicated in square brackets in figure 88 below.

[49] As opposed to the peak modulation frequency, which is derived using the RES method shown in other graphs.

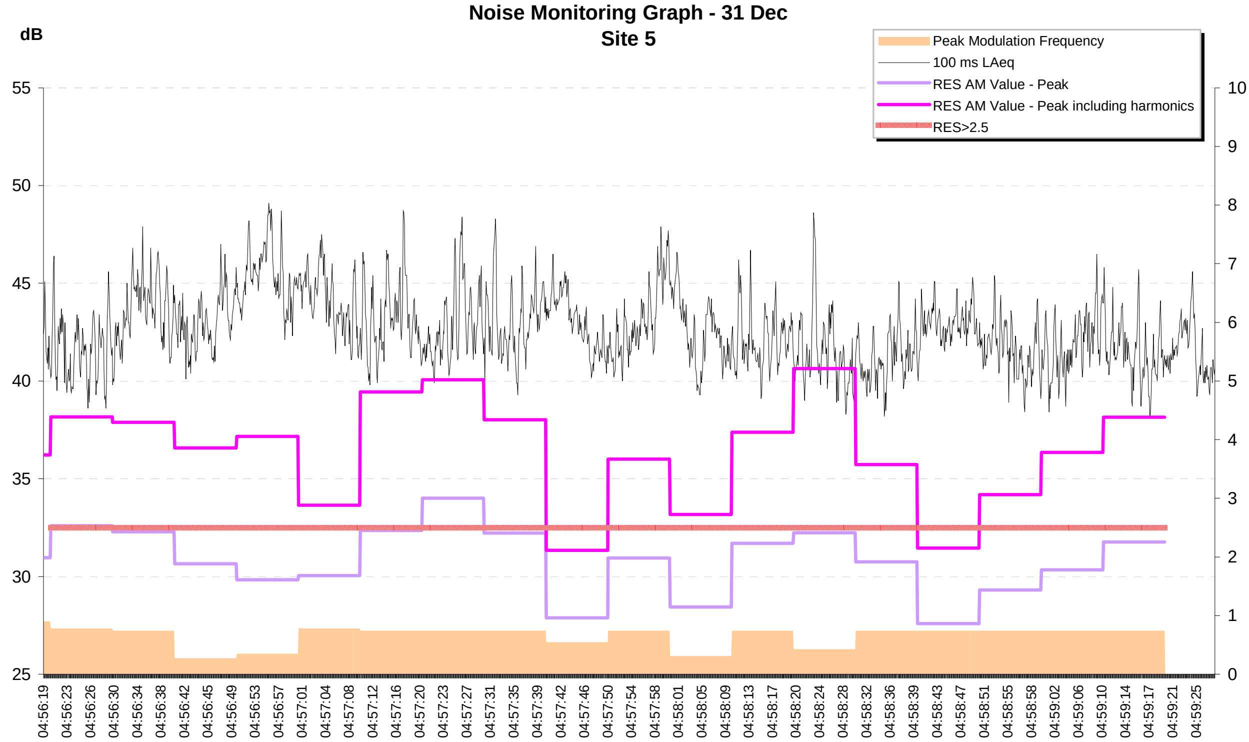
Figure 88: Site 5 - 31 Dec - 04:40 - example of inconsistent RUK blade pass frequencies.



7.62 The above highlighted periods (dashed green lines) are also missed using the RUK method as written and assuming a constant blade pass frequency of 0.74Hz. This indicates that the AM values derived by the RUK method for each 10 minute period may not be representative of higher peak to trough EAM and so the peak to trough modulation that residents may find most disturbing. It suggests that the 10 minute A value derived by the RUK method is somewhat arbitrary and does not always reflect or relate to the impact experienced

7.63 The RES method also misses periods of significant AM. Figure 89 below is 3 minute period where the RES method identifies only a few periods of AM greater than 2.5. This is despite the period being dominated by wind turbine noise and AM.

Figure 89: Site 5 - 31 Dec - 04:56 - example of RES method missing periods of AM.



7.64 Plotted on figure 89 above is the RES AM value including just the energy in the first peak of the modulation spectrum (lilac trace) and also the energy in all peaks of the modulation spectrum, i.e. the harmonics (pink trace). This allows more energy to be included in the derivation of the AM value. The red horizontal line gives the EAM trigger value of 2.5. The A weighted noise trace is dominated by wind farm noise and all modulation is attributable to the turbines. The RES method using only the energy at the first peak in the modulation spectrum only identifies one period of AM greater than 2.5, whereas inclusion of energy at harmonics identifies significantly more AM in the period in accordance with the reality of the situation. Whilst the AM value including energy in the harmonics is quite variable it does better reflect the peak to trough level of the AM.

7.65 **Site 5 - 6th October 00:00 - 05:00.** This period allows a longer period of wind farm noise to be analysed using the different AM methodologies and assessments. Wind farm noise was constant between 00:00 and 05:00 but in contrast to some of the sites assessed above the clarity of the AM was often 'muddied', likely due to the interactions of noise from multiple turbines. The results are summarised in table 10 below. For brevity only one 10 minute graph from each hour period has been given below. The Renewable UK results in square brackets below indicate the A value derived assuming a constant blade pass frequency of 0.74Hz. This is in contrast to the A value derived uniformly across the tables and analysis which uses the peak modulation frequency from each individual 10s period and includes a check for consistency between peak modulation frequency and blade pass frequency.

7.66 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 10: Summary of results - Site 5 - 6 October

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating[50]	
					DAM	AM index
0000	Constant wind farm noise and AM. Sometime AM is a long whoomph / whoosh and timing is out. Church bells audible near start.	Yes. (≈4-7dB).	A = 4.2 [A = 4.2]	Yes. Lots of periods >2.5.	4.4 4.8 4.8	6.3 6.9 6.9
0010	Constant dominant wind farm noise and AM.	Yes. (≈4-7dB).	A = 3.5 [A = 3.5]	Yes. Lots of periods >2.5 but lots missed.	4.6 4.5 4.6	6.6 6.5 6.6
0020	Wind farm noise and AM dominant, more roar and less defined modulation for periods towards end.	Yes. (≈4-9dB).	A = 3.6 [A = 3.6]	Yes. Lots of periods >2.5 but lots missed.	4.7 3.9 4.5	6.8 5.5 6.5
0030	Wind farm noise and AM entirely dominant. Some long whoomph / whoosh.	Yes. (≈4-9dB).	A = 2.4 [A = 2.5]	Yes. Only a few periods >2.5 and lots missed.	3.5 4.0 4.0	4.9 5.7 5.7
0040	Constant wind farm noise, less modulation in middle of period.	Yes. (≈3-7dB).	A = 2.5 [A = 2.5]	Yes. Only four periods >2.5 and lots missed. Variable BPF.	4.0 3.3 3.6	5.7 4.5 5.0
0050	Constant dominant wind farm noise and AM. Lower frequency modulation and mid frequency blade noise. Some sudden loud peaks of AM.	Yes. (≈4-7dB).	A = 2.8 [A = 2.9]	Yes. Only a few periods >2.5 and lots missed.	3.6 4.0 4.6	5.0 5.7 6.6
0100	Constant wind farm noise and AM.	Yes. (≈5-8dB).	A = 3.2 [A = 3.3]	Yes. Lots of periods >2.5.	4.7 4.4 4.3	6.8 6.3 6.1
0110	Some insect noise at start but wind farm noise and AM constant and dominant. Slightly quieter than previous period. Much lower frequency and whoomph towards end of period.	Yes. (≈6-10dB).	A = 4.5 [A = 4.5]	Yes. Lots of periods >2.5.	4.3 5.1 5.5	6.1 7.4 8.0
0120	Constant wind farm noise and AM.	Yes. (≈5-8dB).	A = 3.9 [A = 3.9]	Yes. Lots of periods >2.5. Some periods missed.	4.4 4.7 5.0	6.3 6.8 7.2

[50] ' 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[50]	
					DAM	AM index
0130	Constant wind farm noise and AM. Some wildlife noise and some road traffic noise at end of period, turbine noise clearly audible above road traffic noise.	Yes. (≈5-11dB).	A = 4.1 [A = 4.1]	Yes. Lots of periods >2.5.	5.1 5.6' 5.0	7.4 8.1 7.2
0140	Wind turbine noise and AM dominate. Significant AM.	Yes. (≈6-10dB).	A = 4.5 [A = 4.5]	Yes. Lots of periods >2.5.	5.8 5.7 5.6	8.4 8.3 8.1
0150	Some road traffic noise at start and some wind noise but turbine noise and AM dominant and constant.	Yes. (≈5-10dB).	A = 4.1 [A = 4.1]	Yes. Lots of periods >2.5.	5.0 5.5 5.4	7.2 8.0 7.8
0200	Constant wind farm noise and AM.	Yes. (≈5-9dB).	A = 3.6 [A = 3.6]	Yes. Lots of periods >2.5. Some periods missed.	5.2 5.1 5.2	7.5 7.4 7.5
0210	Constant wind farm noise and AM. Some wind.	Yes. (≈5-9dB).	A = 4.1 [A = 4.1]	Yes. Lots of periods >2.5. Some periods missed.	5.5 5.2 5.4	8.0 7.5 7.8
0220	Constant wind farm noise and AM. Lower frequency whoomph and mid frequency whoosh.	Yes. (≈5-10dB).	A = 4.1 [A = 4.1]	Yes. Lots of periods >2.5.	5.8 5.3 5.8	8.4 7.7 8.4
0230	Constant wind farm noise and AM. Some road and rail noise but wind farm noise dominant.	Yes. (≈5-10dB).	A = 4.2 [A = 4.2]	Yes. Lots of periods >2.5.	5.4 5.3 5.9	7.8 7.7 8.6
0240	Constant wind farm noise an AM. Less clarity towards end of period but much more lower frequency whoomph.	Yes. (≈5-9dB).	A = 4.0 [A = 4.0]	Yes. Lots of periods >2.5. Some periods missed.	5.0 5.3 4.3	7.2 7.7 6.1
0250	Constant wind farm noise and AM. Lower frequency at start, becomes slightly out of sync during middle of period but dominant lower frequency and mid frequency AM again soon after.	Yes. (≈5-9dB).	A = 3.9 [A = 3.9]	Yes. Lots of periods >2.5.	4.8 4.9 5.1	6.9 7.1 7.4
0300	Constant wind farm noise and AM. Some periods with less clarity. Significant lower frequency AM towards end of period.	Yes. (≈5-10dB).	A = 4.4 [A = 4.4]	Yes. Lots of periods >2.5.	5.2 5.8 5.3	7.5 8.4 7.7

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating[50]	
					DAM	AM index
0310	Constant wind farm noise and AM, periods where AM fades in and out of synchronicity.	Yes. (≈5-11dB).	A = 4.1 [A = 4.1]	Yes. Lots of periods >2.5.	5.2 5.5 5.7	7.5 8.0 8.3
0320	Constant wind farm noise and AM.	Yes. (≈5-10dB).	A = 4.4 [A = 4.4]	Yes. Lots of periods >2.5. Some periods missed.	5.6 5.9 5.6	8.1 8.6 8.1
0330	Constant wind farm noise and AM. Some road traffic noise during middle of period.	Yes. (≈5-9dB).	A = 4.3 [A = 4.4]	Yes. Lots of periods >2.5. Some periods missed.	5.1 5.4 5.2	7.4 7.8 7.5
0340	Constant wind farm noise and AM. Some wildlife noise. AM less consistent and fades in and out of synchronicity. Some wind.	Yes. (≈5-11dB).	A = 4.3 [A = 4.3]	Yes. Lots of periods >2.5. Some periods missed.	5.9 5.9 5.2	8.6 8.6 7.5
0350	Constant wind farm noise and AM. Some periods with less clarity.	Yes. (≈5-11dB).	A = 3.7 [A = 3.7]	Yes. Lots of periods >2.5. Some periods missed.	5.1 5.2 5.5	7.4 7.5 8.0
0400	Constant wind farm noise and AM, periods where AM fades in and out of synchronicity.	Yes. (≈5-10dB).	A = 4.5 [A = 4.5]	Yes. Lots of periods >2.5.	5.7 5.4 6.5	8.3 7.8 9.5
0410	Constant wind farm noise and AM. AM becoming more erratic sudden loud peaks and lack of sustained synchronicity.	Yes. (≈5-11dB).	A = 4.5 [A = 4.5]	Yes. Lots of periods >2.5.	5.7 6.0 5.7	8.3 8.7 8.3
0420	Some wind, AM and wind farm noise constant but AM erratic.	Yes. (≈5-12dB).	A = 4.6 [A = 4.6]	Yes. Lots of periods >2.5. Quite a few missed.	6.4 5.8 5.9	9.3 8.4 8.6
0430	Significant lower frequency AM and erratic AM with high peak to trough variation, particularly towards end of period. Wind farm noise constant throughout. Some wind noise.	Yes. (≈6-14dB).	A = 5.1 [A = 5.1]	Yes. Lots of periods >2.5. Quite a few missed.	5.7 5.7 6.6	8.3 8.3 9.6
0440	Erratic AM, longer periods of consistency than previous period. Significant lower frequency wind farm noise and AM. Some wind noise.	Yes. (≈6-13dB).	A = 5.0 [A = 5.0]	Yes. Lots of periods >2.5. Quite a few missed.	6.1 5.8 6.5	8.9 8.4 9.5

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating[50]	
					DAM	AM index
0450	Windier periods with audible wind gusts, erratic AM. Constant wind farm noise and AM with significant peak to trough difference.	Yes. (≈6-15dB).	A = 5.3 [A = 5.3]	Yes. Lots of periods >2.5.	6.9 5.6 6.0	10.1 8.1 8.7
0500	Some wind noise. Constant AM and wind farm noise. AM is erratic with sudden loud peaks and periods of lesser modulation. Some road traffic noise at end of period.	Yes. (≈6-14dB).	A = 4.7 [A = 4.7]	Yes. Lots of periods >2.5.	6.4 5.9 6.3	9.3 8.6 9.2
0510	Some distant road traffic noise but turbine noise and AM dominant. More wind noise and road traffic noise interspersed throughout period.	Yes. (≈6-13dB).	A = 4.9 [A = 4.9]	Yes. Lots of periods >2.5.	5.8 5.3 6.4	8.4 7.7 9.3
0520	Wind turbine noise and AM dominant. Erratic AM. Road traffic noise and wind noise throughout period.	Yes. (≈6-13dB).	A = 5.4 [A = 5.4]	Yes. Lots of periods >2.5. Quite a few missed.	6.4 5.7 6.2	9.3 8.3 9.0
0530	Wind turbine noise and AM dominant. Some road traffic noise and wind noise. Erratic AM trace in middle of period.	Yes. (≈5-12dB).	A = 4.2 [A = 4.2]	Yes. Lots of periods >2.5.	5.3 5.7 4.7	7.7 8.3 6.8
0540	Wind turbine noise and AM dominant. Wind noise and road traffic noise interspersed throughout period.	Yes. (≈5-10dB).	A = 4.1 [A = 4.1]	Yes. Lots of periods >2.5. Quite a few missed.	4.7 4.9 5.0	6.8 7.1 7.2
0550	Wind turbine noise and AM dominant. Some significant peaks. Much windier towards end of period.	Yes. (≈5-10dB).	A = 3.7 [A = 3.7]	Yes. Only a few periods >2.5 and lots missed.	4.9 4.0 4.5	7.1 5.7 6.5

Figure 90: Site 5 - 6 Oct - 00:30

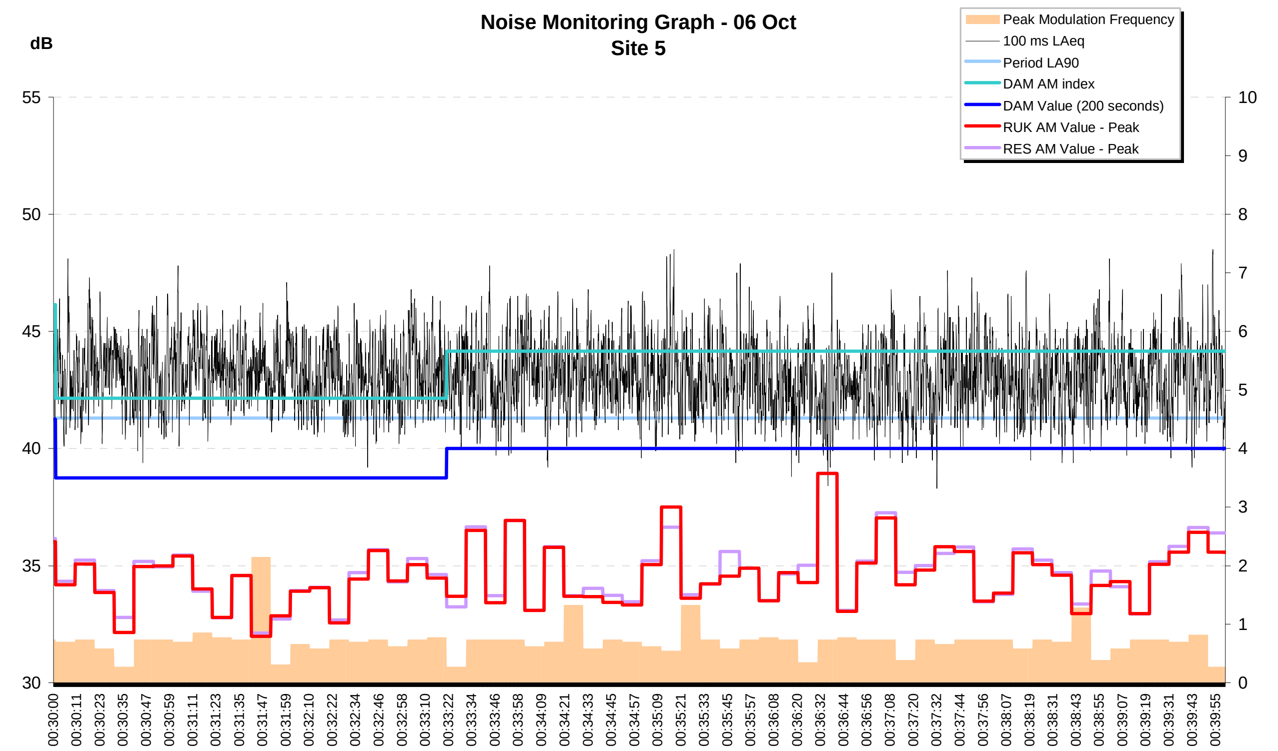


Figure 91: Site 5 - 6 Oct - 01:40

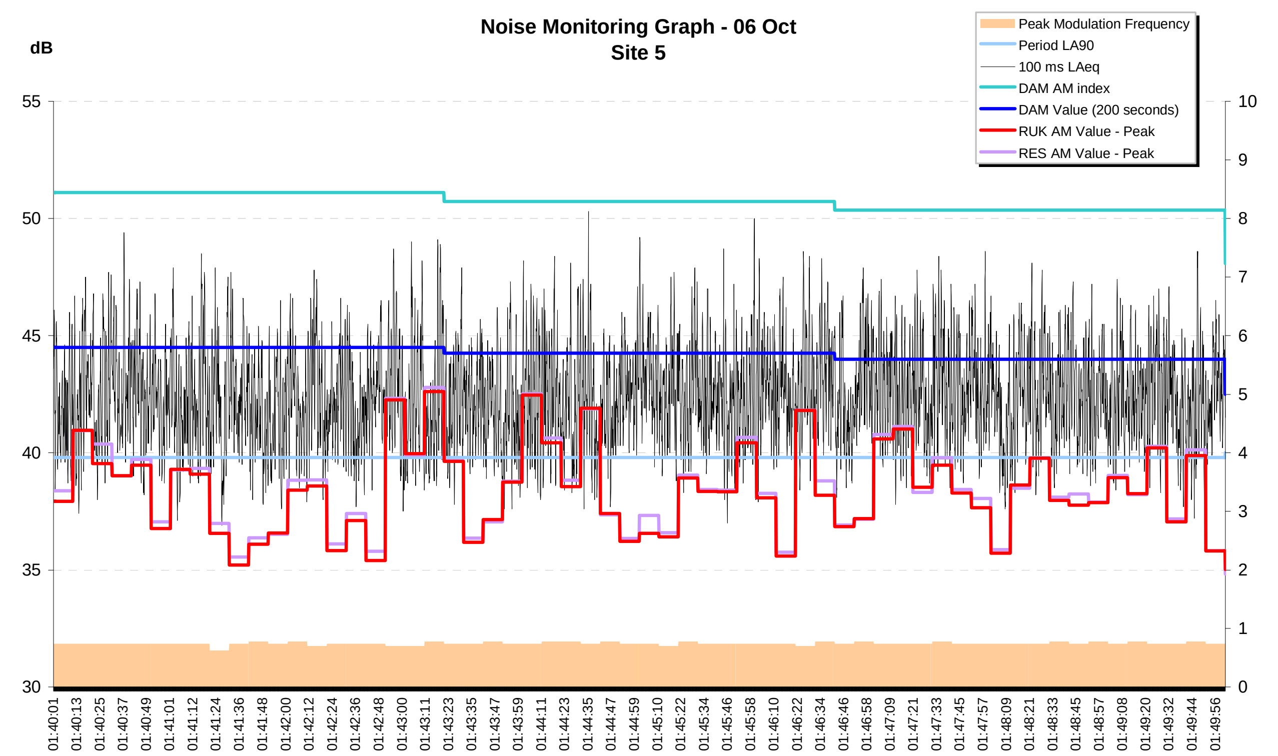


Figure 92: Site 5 - 6 Oct - 02:40

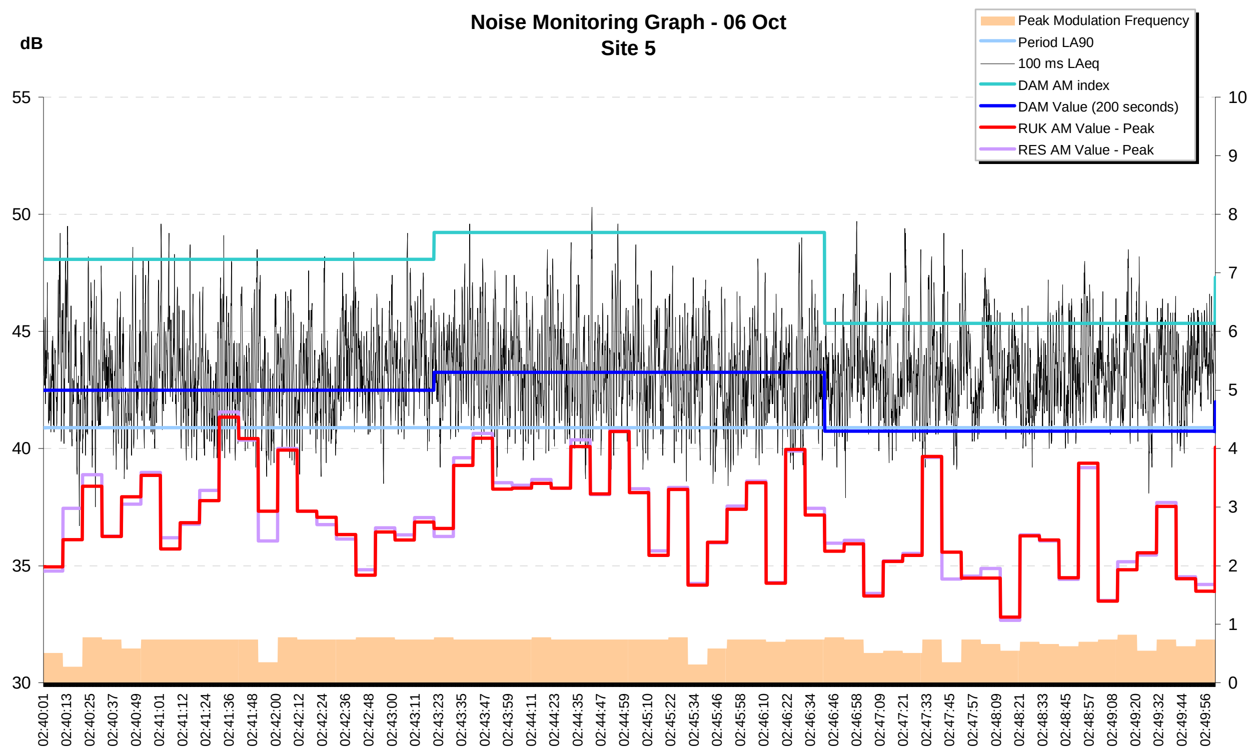


Figure 93: Site 5 - 6 Oct - 03:20

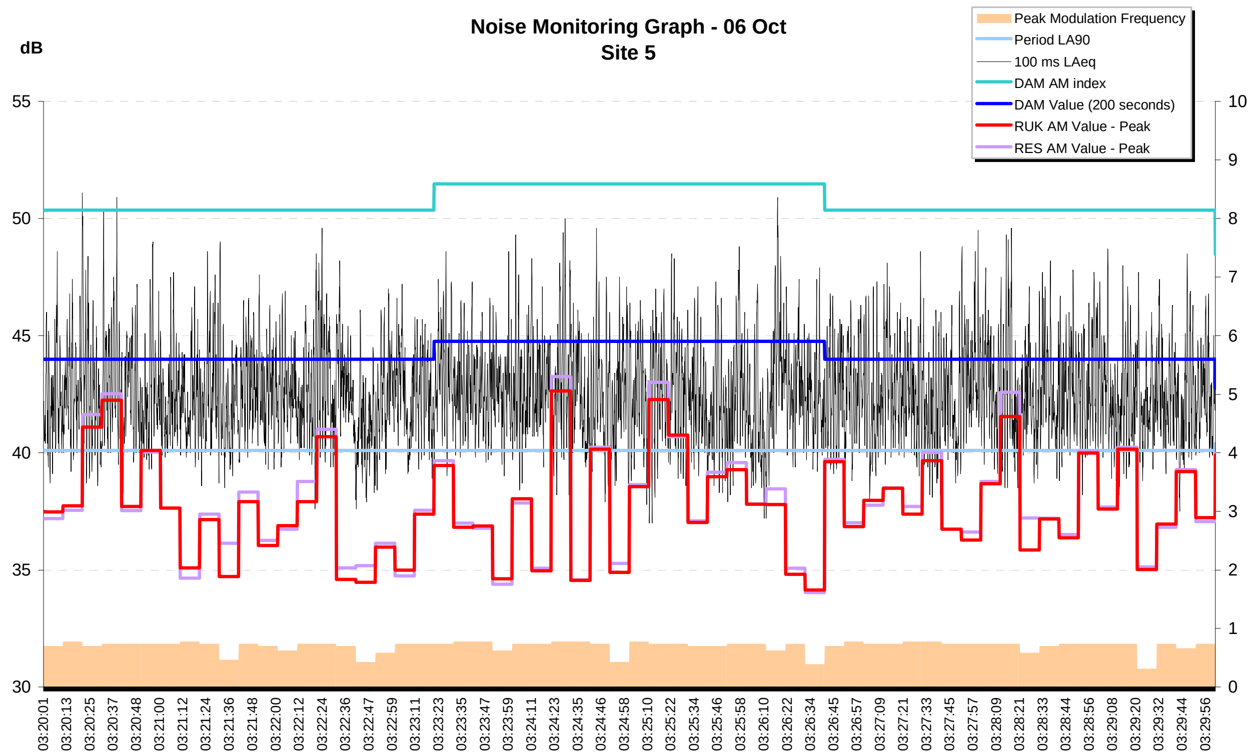


Figure 94: Site 5 - 6 Oct - 04:30

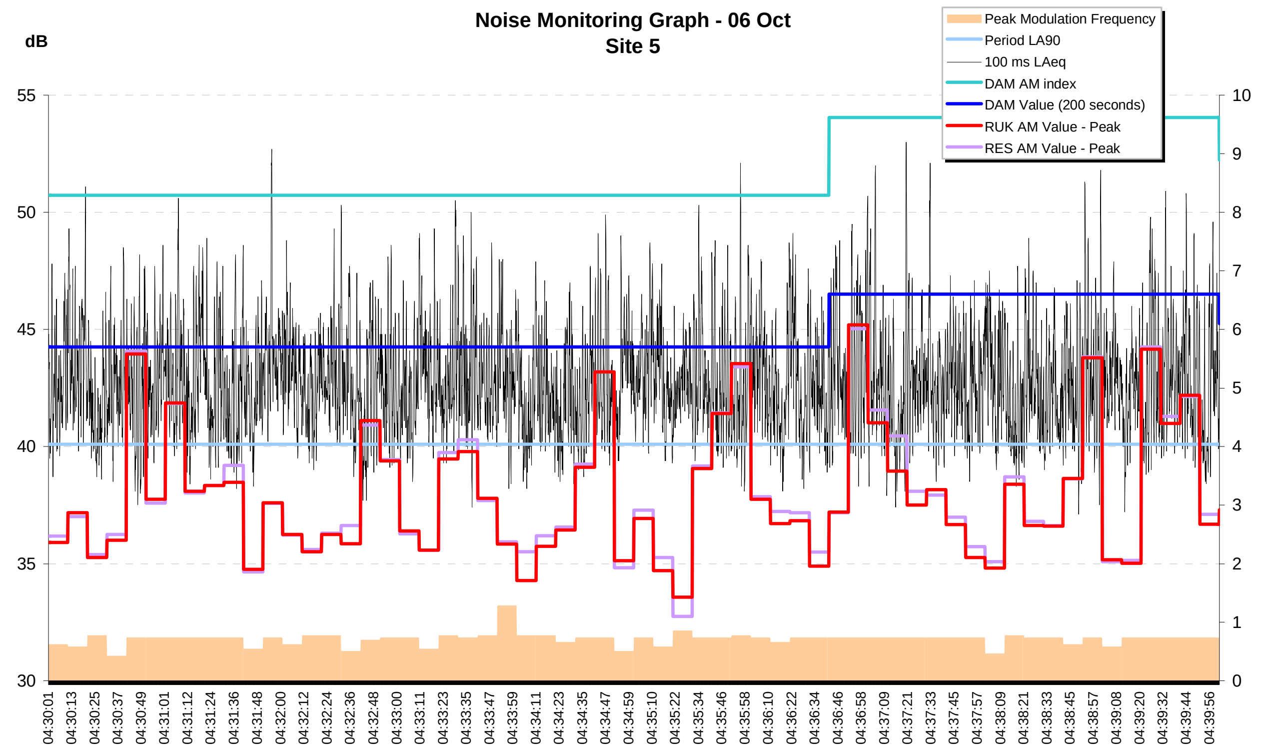
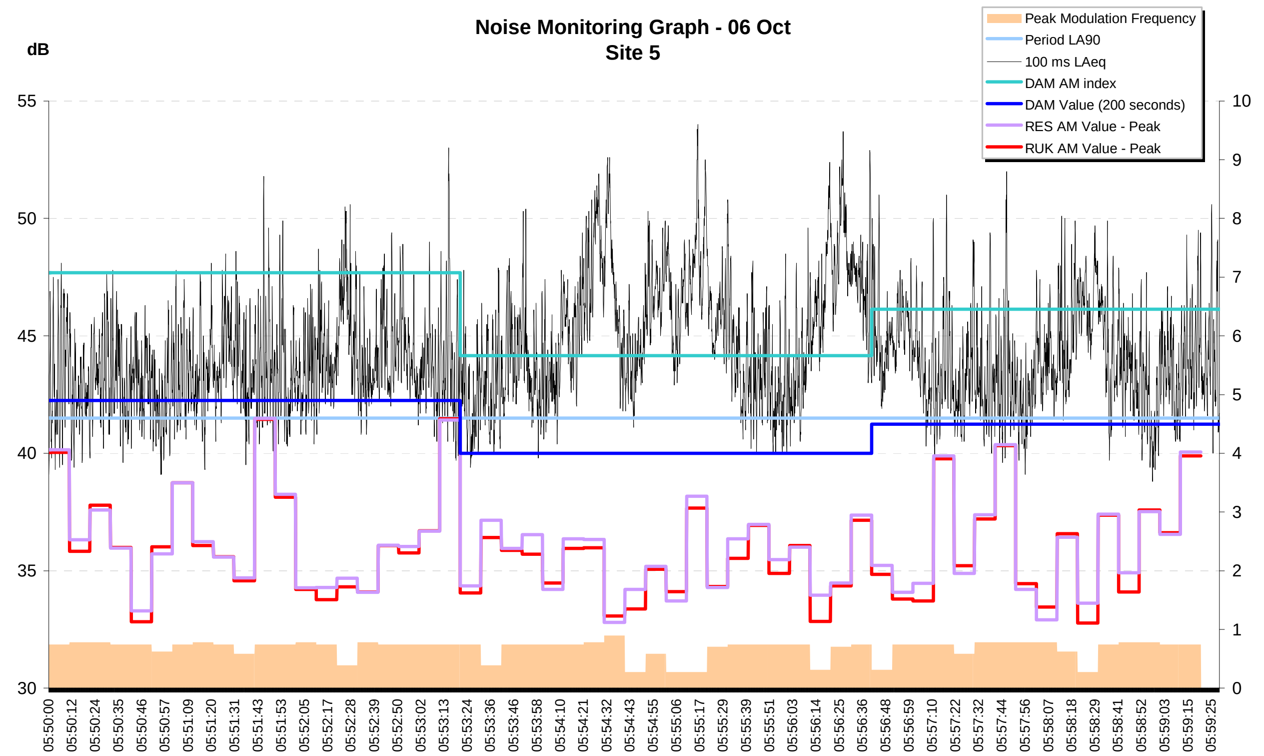


Figure 95: Site 5 - 6 Oct - 05:50



7.67 **Preliminary discussion - Site 5 - 6 October.** The above table and graphs review a long period of AM occurring from the wind farm and test how the different AM assessment methods rate this noise. All four methods correctly identify the presence of AM.

7.68 Both the RES and RUK methods provide erratically changing AM values for each 10s period despite there being constant wind farm noise and AM throughout the periods. This is particularly evident in figures 90 and 93 above. In figure 93 the wind farm noise and AM is constant in occurrence throughout the period though the peaks and troughs vary. It seems unlikely that human perception and reaction to a 10 minute period of noise would vary so erratically between acceptable and unacceptable noise as implied by the RES and RUK values. It is therefore questioned whether such variable and erratic metrics truly reflect human response to noise and can be used to judge acceptability of impact.

7.69 Despite identifying and rating AM, the RUK overall 10 minute A value often fails to include periods where there is significant AM. This generally arises where the AM is erratic and there is a single loud peak. Two examples are given below. The green dashed boxes highlight high peaks of AM usually preceded by periods containing less AM. Subjectively these peaks stand out, have a specific character and draw attention to the noise.

7.70 These periods are missed in this case not due to inconsistent blade pass frequency but because the AM value attributed to the 10s period is not as high as other periods. It is questioned whether an AM rating method that misses these periods is accurately assessing the aspect of the noise that is disturbing to the listener. Further investigation reveals that lower AM values are often attributed to periods with erratic AM with sudden high peaks because of the detrending process in the RUK algorithm. The detrending process essentially flattens the underlying variation in the noise level and so can raise troughs, reduce peaks and overall reduce the AM value derived.

Figure 96: Site 5 - 6 Oct - 04:36 - example of RUK missing significant peaks of AM

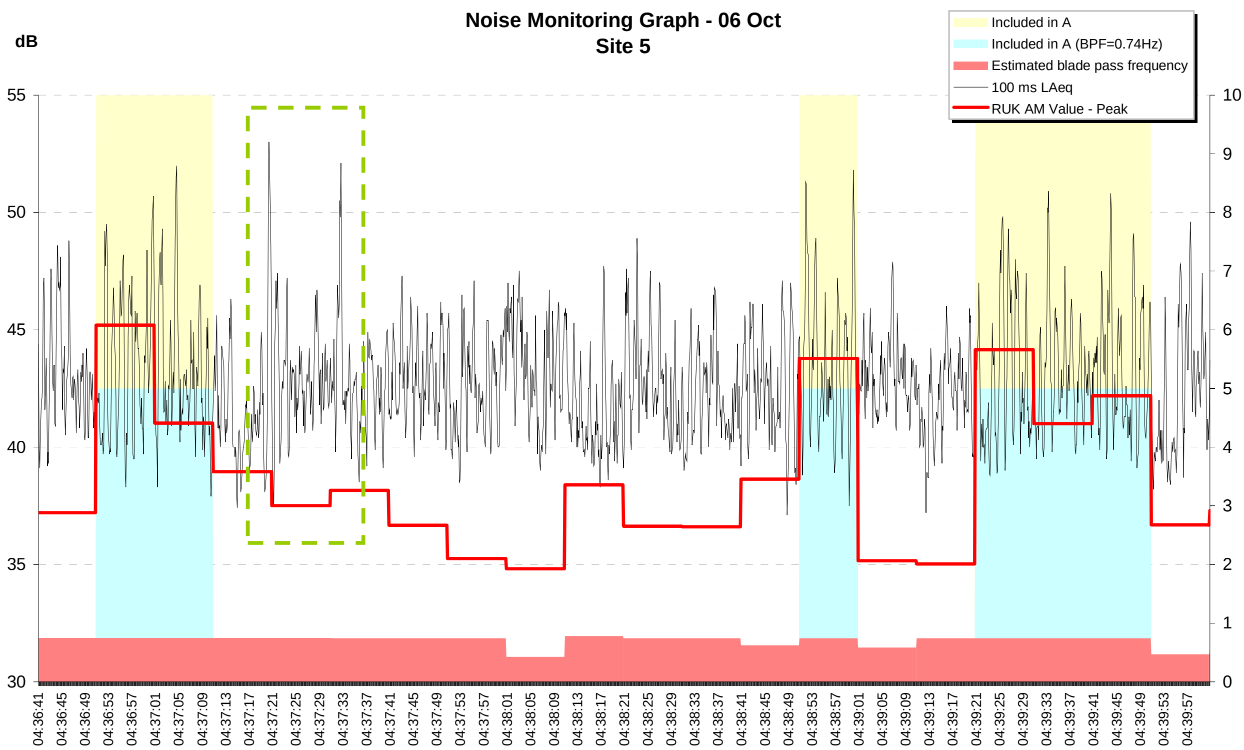
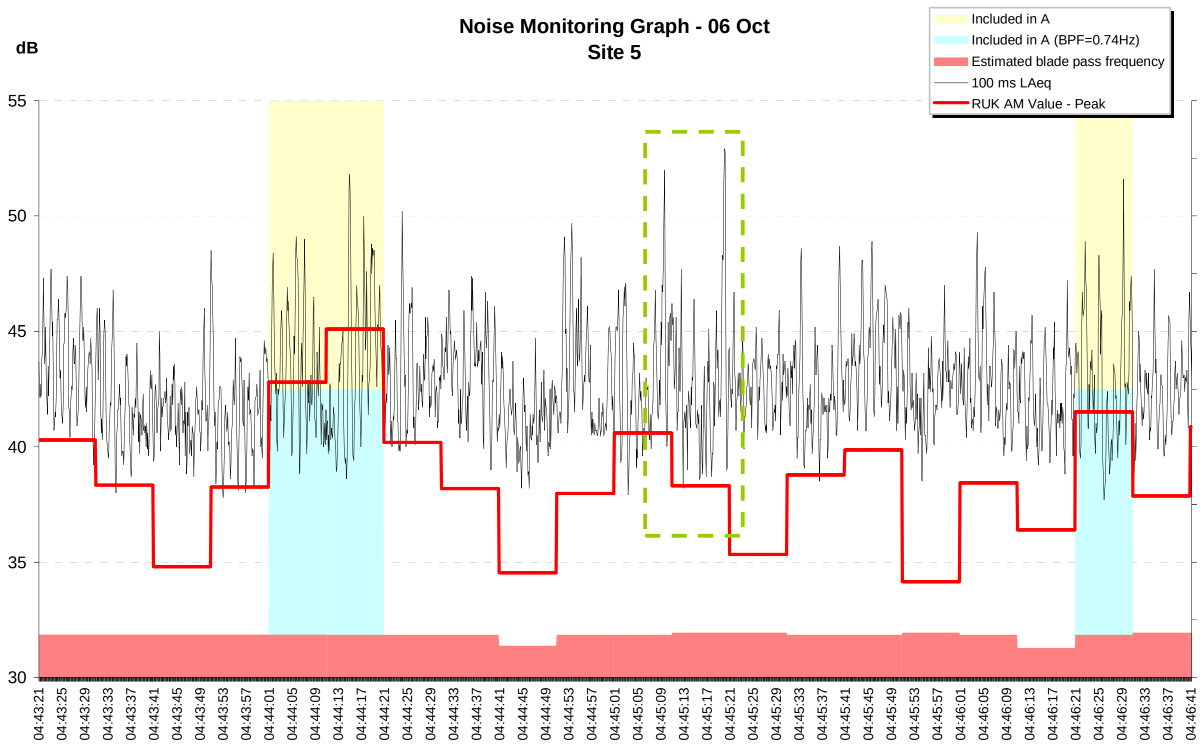
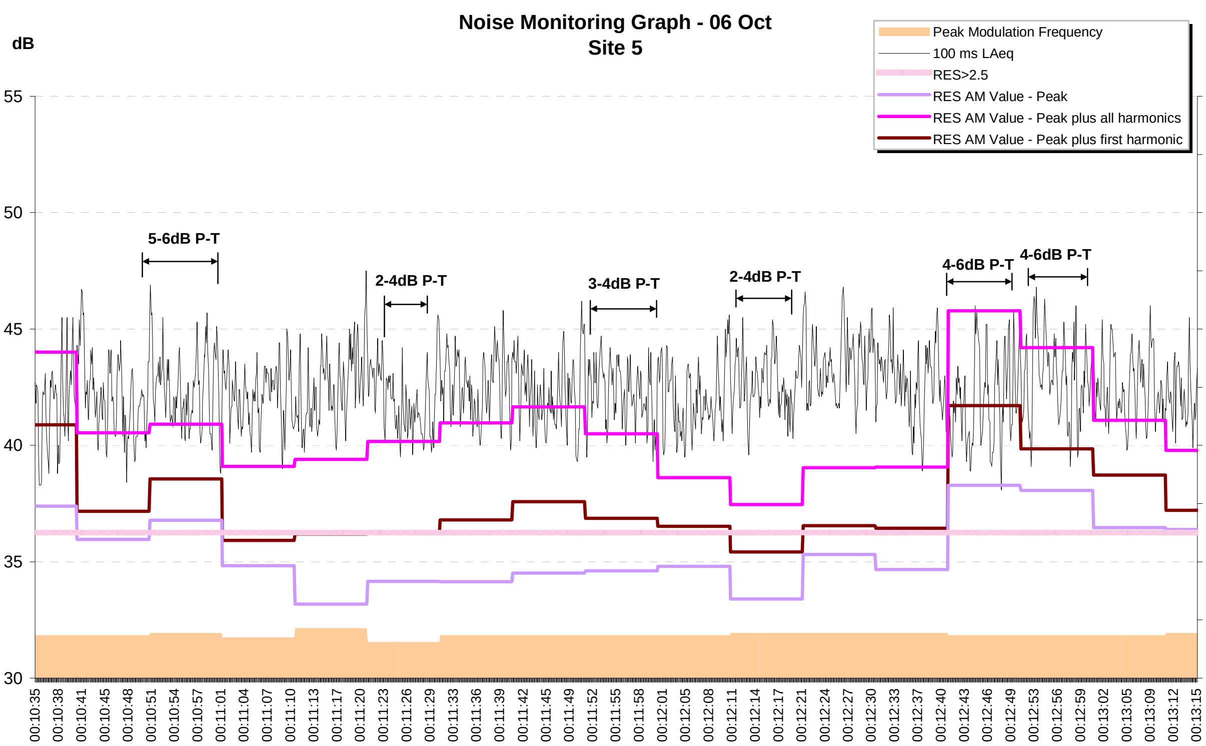


Figure 97: Site 5 - 6 Oct - 04:43 - example of RUK missing significant peaks of AM



7.71 The RES method correctly identifies AM in all periods; however, there are often significant periods of AM that are not classified by the RES method as EAM, i.e. with a consistent blade pass frequency and value of A greater than 2.5. An example is shown in figure 98 below.

Figure 98: Site 5 - 6 Oct - 00:10 - example of RES methods for rating AM



7.72 The graph shows a period at 00:10, plotted on to the graph is the 10s peak modulation frequency (estimating the blade pass frequency, orange blocks) and the RES AM values using energy just in the first peak (lilac), energy in the first peak and second peak (first harmonic) (brown) and using all peaks, i.e. the first peak and all harmonics (pink). The horizontal line shows the value of 2.5, which is the value that must be exceeded to qualify for further assessment using the RES Den Brook condition and is indicative of EAM.

7.73 Using the RES method as originally written, using just the first peak, many periods of AM are missed despite the peak to trough level being greater than 3dB and so qualifying as EAM under the original Den Brook method. If the RES method includes the first peak and the first harmonic then the values of A are a little higher, only a couple of periods are missed and many are borderline or just above the 2.5 value. Inclusion of all the harmonics results in a much higher value, which does appear to relate well to the peak to trough variation but can also be quite variable.

7.74 The Den Brook method identifies all periods as containing EAM and the peak to trough difference indicates the severity of these periods. The DAM rating works well with the data to provide consistent values. The DAM value typically represents the lower AM value range identified from visual inspection of the graphs. The values increase with the peak to trough difference but not significantly. The highest DAM values obtained are in the region of DAM=6-7. This is approximately half of the most severe peak to trough differences identified in the A weighted noise trace. However, when converted to an AM index the DAM method works better at representing typical peak to trough values. In this case the AM index tends to fall within the mid to upper range of AM peak to trough values observed from visual inspection of the graphs. Very high peak to trough values, in the region of 15dB(A), are not well acknowledged by the AM index values. It is likely that the irregularity of these very high peak to trough differences causes them to have little impact on the DAM rating / AM index. This raises similar concerns with the RUK method with regards to how accurately the rating method reflects subjective impact, though generally the method works well to describe typical peak to trough level.

7.75 **Site 6 - 27th September 07:00 - 08:00.** This data is taken from a site where there is no wind farm noise. It is used to compare the different assessment methods and whether they might generate false positives, i.e. indicating wind farm AM where there is none. It should be noted that the Den Brook and DAM methods for rating AM are not heavily prescriptive, i.e. they are not designed to be run automatically and / or as a simple algorithm. They require pre judgements, as do all noise conditions, that the data that has been measured and is to be analysed contains the noise that is under investigation.

7.76 Whilst a DAM value can be obtained for the data, it should not be taken as evidence that the method is flawed. This site is included primarily as a test for the RES Den Brook and Renewable UK methods which are designed to be automated processes.

7.77 The results are summarised in table 11 below. For brevity only the first and last graph from the hour period is given below. The Renewable UK results in square brackets below indicate the A value derived assuming a constant blade pass frequency of 0.63Hz. This value was chosen at random and is similar to the blade pass frequencies measured at the sites assessed above. The use of a constant value is in contrast to the A value derived uniformly across the tables and analysis which uses the peak modulation frequency from each individual 10s period and includes a preliminary check for consistency between peak modulation frequency and blade pass frequency.

Table 11: Summary of results - Site 6 - 27 September

Time	Description	Den Brook triggered? (approximate peak to trough value)	Renewable UK (RUK) AM value	RES Den Brook triggered?	Japanese rating	
					DAM	AM index
0700	Dominated by bird noise.	No. Nothing that looks or sounds like AM.	No. Inconsistent BPF. [A = 4.1]	Yes. Some periods >2.5. Only five periods >2.5 with consistent BPF.	10.0 9.8 13.1	14.2 14.0 17.8
0710	Some plane noise and lots of bird noise. Voices towards end of period.	No. Nothing that looks or sounds like AM.	No. Inconsistent BPF. [A = 3.1]	Yes. Some periods >2.5. Only three periods >2.5 with consistent BPF.	9.2 7.7 9.6	13.2 11.2 13.7
0720	Some plane noise, some distant traffic and farming noise. Lots of bird noise.	No. Nothing that looks or sounds like AM.	No. Inconsistent BPF. [A = 4.0]	Yes. Some periods >2.5. Only two periods >2.5 with consistent BPF.	9.7 8.9 11.8	13.8 12.8 16.4
0730	Some plane noise, road traffic noise and lots of bird noise.	No. Nothing that looks or sounds like AM.	No. Inconsistent BPF. [A = 3.8]	Yes. Some periods >2.5. Only three periods >2.5 with consistent BPF.	6.3 7.3 7.3	9.2 10.6 10.6
0740	Lots of bird noise, some plane noise and road traffic noise in second half of period.	No. Nothing that looks or sounds like AM.	No. Inconsistent BPF. [A = 3.0]	Yes. Some periods >2.5. Only two periods >2.5 with consistent BPF.	7.8 6.4 7.7	11.3 9.3 11.2
0750	Bird noise, nearby engine noise, nearby agricultural activity.	No. Nothing that looks or sounds like AM.	No. Inconsistent BPF. [A = 3.9]	Yes. Some periods >2.5. Only four periods >2.5 with consistent BPF.	5.6 11.8 7.7	8.1 16.4 11.2

Figure 99: Site 6 - 21 Sep - 07:00

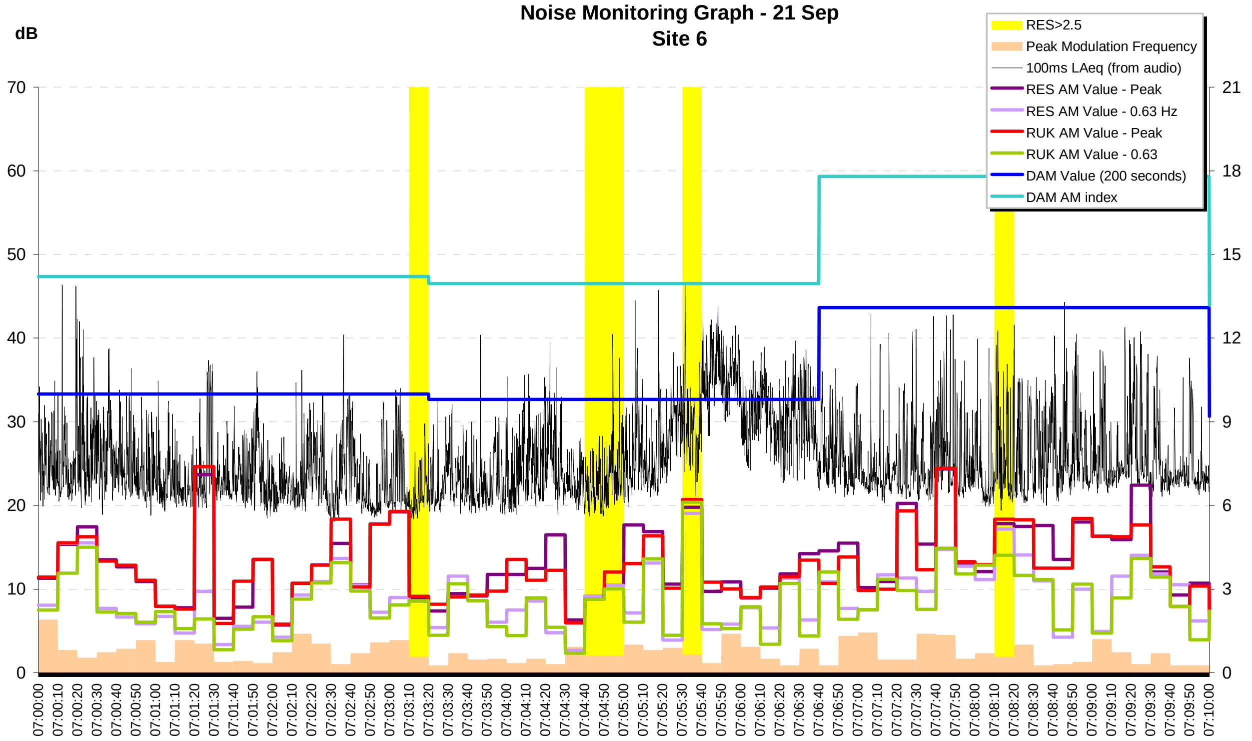
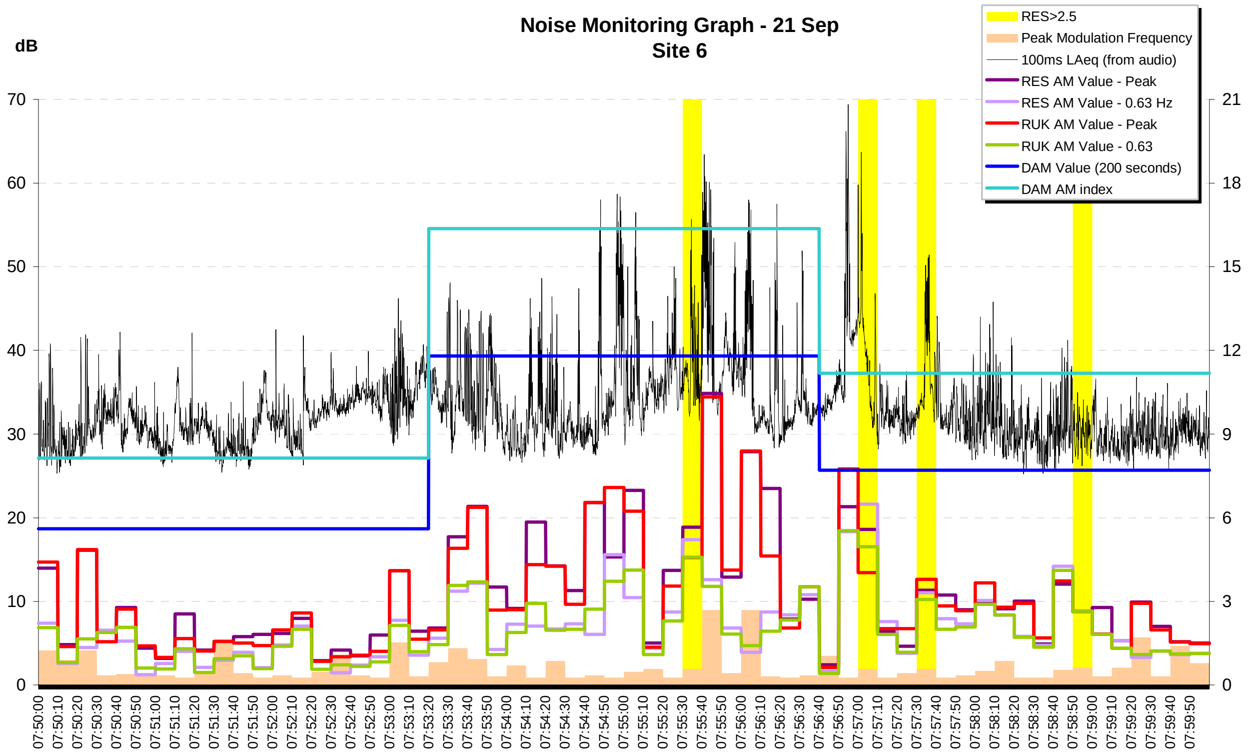


Figure 100: Site 6 - 21 Sep - 07:50



7.78 **Preliminary discussion - Site 6 - 21 September.** The analysis from site 6 shows how each assessment method would rate the data for AM. As noted above, it is important to emphasise that both the Den Brook and the DAM method are not prescriptive and so cannot be run as a simple algorithm or automated AM detection method. As with other noise conditions they require the assessor to ensure that the data measured is not corrupted by extraneous noise and that it actually contains the noise complained of (or under investigation). With this in mind, the data from site 6 contains no data that looks like AM, from basic visual inspection of the graphs, and nothing that sounds like AM, from quick review of the audio data, and as such both the Den Brook and DAM rating methods would not indicate the presence of EAM.

7.79 The RUK and RES Den Brook methods are intended to be run as an automated process that can be implemented as an algorithm to deal with large quantities of data, thus requiring little human input or judgement.

7.80 There are additional data series shown on the above figures in comparison to the figures from sites 1-5. Both the RES and the RUK AM values have been calculated assuming a constant blade pass frequency of 0.63Hz and also by calculating the AM value using the peak modulation frequency for each individual 10 second period. Thus there are two lines showing RES AM values and two lines showing the RUK AM values.

7.81 The yellow highlighted periods indicate those that trigger the RES criterion for presence of EAM. The AM values for these periods have been calculated using a constant blade pass frequency of 0.63Hz. They indicate periods that have an AM value greater than 2.5 and a peak modulation frequency consistent with that of the blade pass frequency, in this case assumed to be 0.63Hz +/-10%. Whilst the RES method identifies 30% of periods as having an AM value greater than 2.5, only a few of these periods are consistent with the blade pass frequency. This indicates that with a preliminary analysis, and without the blade pass frequency verification checks that appear later in the algorithm, the RES method would highlight this data as containing significant periods of EAM. Even after further checks verifying consistency with the blade pass frequency there are enough periods that meet the RES criteria to conclude that EAM arises. Only when checking the audio data, which is a check made after significant data processing (but is an early feature of the original Den Brook condition), would it be concluded that there is no EAM in the data. This data shows that the RES method produces false positives. This is the case when calculating the RES AM value from the peak modulation frequency of each individual 10s period and when inputting a constant blade pass frequency value. This is a significant flaw in the method.

7.82 The Renewable UK method has also been tested assuming a blade pass frequency of 0.63Hz. The Renewable UK method does include the requirement early on in the algorithm to remove any data that is corrupted. However, there is no clarification of what is meant by 'corrupted' or how this should be achieved without looking at the data graphs or listening to the audio data. It is unlikely that visual or audio checks would be undertaken prior to running the RUK algorithm as otherwise there would be no difference or benefit to the data processing time of the RUK method and the original Den Brook method (or the DAM method).

7.83 Running the RUK method requires the assessor to calculate the AM value for each 10s period and then average the top 12 AM values from each 10 minute period to get a value for A. If this value is greater than zero then a check is made that the data is consistent with the SCADA data of the turbines. Running the RUK method as written, the average AM value for each 10 minute period, as shown in table 11 above, ranges from 3.0 - 4.0. Thus it indicates significant AM. However, on further checks it would be identified that a number of these periods did not have a peak modulation frequency consistent with that of the assumed blade pass frequency (0.63Hz in this case). Using the RUK method but calculating the AM value based on the peak modulation frequency from each individual 10s period it is clear at an earlier stage that there is insufficient data with a peak modulation frequency consistent with the blade pass frequency to enable a calculation of the 10 minute A value. Thus, the RUK method requires a substantial amount of data processing before concluding that the data does not contain EAM. Modifications to this method as used in this work package do reduce the amount of processing before it can be concluded that there is no EAM, but significant data processing is still needed to obtain this result.

8 Assessment with BS4142

8.1 Historically suggestions have been made, primarily by those not working with the wind industry, for assessment of wind farm noise using BS4142. The BS4142 standard provides an assessment of industrial noise and importantly in this case also allows an adjustment to the noise for specific character features.

8.2 There are clear advantages to the use of BS4142 for assessment of wind farm noise that contains noise character. The standard is familiar to local authorities, who are primarily responsible for enforcing noise complaints. It has been tried and tested over a number of years, is built on accumulated experience and the process of assessment is transparent and easy to understand. It has proved effective in the vast majority of industrial installations.

8.3 The main difference in approach between ETSU-R-97 and BS4142 is that ETSU-R-97 allows an increase in permitted noise compared to BS4142 in recognition of the need for renewable energy. The way in which this increase is facilitated in ETSU-R-97 removes the assessment of the noise in context with the character of the area. The ability to assess noise in context is arguably one of the key features of BS4142 that has made it so successful.

8.4 There are difficulties with introducing a BS4142 assessment for wind farm noise with character. The procedures prescribed by ETSU-R-97 and the subsequent Institute of Acoustics Good Practice Guide to the Application of ETSU-R-97 are at odds with BS4142. It is unlikely that BS4142 could be used in conjunction with current wind farm guidance.

8.5 In keeping with the majority of noise standards BS4142 assesses noise using the LAeq parameter. This was discarded in favour of the LA90 for wind farm noise due to assertions that the LAeq would be too easily influenced by extraneous noise. The LA90 was considered a good representation of the underlying wind farm noise level. It is noted that this approach and the conception of ETSU-R-97 was at a time when character features such as AM were not envisaged. However, clearly AM is a prevalent feature of modern wind turbine noise and the LA90 parameter cannot by definition accurately provide a measure of AM.

8.6 Whilst ETSU-R-97 was published in 1996/1997, the same year that the now superseded BS4142:1997 was published (and drafts were in circulation), ETSU-R-97 is based on the 1990 version of BS4142. [51, 52] ETSU-R-97 loosely adopts some of the principles of BS4142 but also misses some key and crucial points. This is particularly evident with reference to the BS4142:2014 version of the standard.

8.7 The issue of low background sound levels has been raised as a problem with regard to implementing BS4142 for assessment of wind farm noise. At page 51 of ETSU-R-97 it quotes BS4142:1990:

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[51] British Standards Institution (1997) *BS4142: Method for rating industrial noise affecting mixed residential and industrial areas*. London: BSI.
[52] British Standards Institution (1990) *BS4142: Method for rating industrial noise affecting mixed residential and industrial areas*. London: BSI.

> *"The method is not applicable for assessing the noise inside buildings or when the background and specific noise levels are low.*
>
> *Note. For the purposes of this Standard, background noise levels below 30dB and rating levels below 35dB are considered to be very low."*

8.8 Significantly, the wording of this changes in the 1997 version of the standard (changes are highlighted in bold):

> *"The method is not suitable for assessing the noise **measured** inside buildings or when the background and **rating** noise levels are **both very** low.*
>
> *Note. For the purposes of this Standard, background noise levels below 30dB and rating levels below 35dB are considered to be very low."*

8.9 In the case of wind farm noise with character the 1997 wording allows an additional 5dB to that quoted by ETSU-R-97. With the ETSU-R-97 wording BS4142 should not be used when the specific noise level is low. Applying the 1997 wording it is both the background and the rating level that must be very low before the standard cannot be used. This allows more scope than the ETSU-R-97 wording as both background and rating level must be low and by referring to the rating level rather than the specific noise level, there is an additional 5dB leeway when noise has character.

8.10 In any event as reported by a National Physical Laboratory (NPL) study on the application of BS4142:1990, these lower limits were included largely due to limitations of instrumentation (i.e. noise floor of the equipment used).[53] Such concerns are no longer relevant. The typical noise floor of a type 1 sound level meter is 16-18dB(A). Furthermore, the argument becomes largely irrelevant as the new version of the standard removes this requirement altogether.

8.11 **BS4142 as a planning condition.** A standard BS4142 noise condition for power plants will allow noise impact of 'marginal significance' as termed using the 1997 version of the standard. Typically:

> *The rating level shall not exceed the lowest consistent background noise level by more than 5dB in accordance with BS4142 during weather neutral conditions.*

8.12 Whilst this wording raises issues of its own the principle is clear.

8.13 Another issue raised by those opposed to the use of BS4142 for assessment of wind farm noise is the variable wind farm noise level and background sound level with wind speed.

8.14 BS4142:2014 states that measurements of the background sound level should be made under weather conditions that are representative and comparable to weather conditions when the specific sound occurs or could occur. This is also a requirement of ETSU-R-97, which states at page 87 that:

[53] Porter, N. D. (1995). *Study of the Application of British Standard BS 4142:1990 "Method for Rating Industrial Noise Affecting Mixed Residential and Industrial Areas" (The Data Sheet Study)*. Teddington: National Physical Laboratory.

"...a log [of] times at which the turbine noise is most intrusive, taken by the complainant, will enable the developer to establish the conditions which require further investigation.

Measurements should be taken in representative conditions and not for example when the wind is in a direction rarely encountered."

8.15 Thus, the emphasis on replicating the conditions (including meteorological conditions) under which complaints occur (or are likely to occur) between BS4142 and ETSU-R-97 is consistent. The background sound level and the turbine noise level should be established under similar conditions. This could include wind speed, wind direction and wind shear, which are all measurable with the use of meteorological masts on site and / or at the dwelling. Thus, if complaints only occur between 5m/s and 6m/s and under high wind shear conditions, then this is when both wind turbine noise and background sound should be measured. The measurement of background sound and wind turbine noise under the same conditions could also be facilitated by the cooperation of, or requirement of, the turbine / wind farm owner and the running of on/off tests.

8.16 A further difficulty raised by those opposing use of BS4142 is that the standard cautions against making measurements in wind speeds greater than 5m/s. This is primarily to reduce corruption of noise measurements. The 1997 and 2014 standards do not state that measurements cannot be made above 5m/s but highlights the need to assure that measurements remain uncontaminated. BS4142:1997 states:

"Use an effective windshield to minimize turbulence at the microphone.

NOTE. For the purposes of this standard, windshields are generally effective up to windspeeds of 5m/s."

8.17 BS4142:2014 states:

"Take precautions to minimize the influence on the measurements from sources of interference...

An effective windshield should be used to minimize turbulence at the microphone.

NOTE Windshields are generally effective up to windspeeds of 5 m/s^{-1}."

8.18 Thus, the advice is not that measurements cannot be made above 5m/s but that this is the point at which interference might occur. The primary aim of the 5m/s limitation is to prevent corruption of noise measurements and so if it can be shown that wind above 5m/s has not corrupted the measured noise level then the measurement is valid. Oversized wind shields are commonly used to measure background sound levels for wind farm background sound surveys. The data measured using oversized wind shields typically ranges up to 10-12m/s and this data is regularly included in surveys as valid (uncorrupted). As such there should be no issue in preventing wind corruption within a BS4142 assessment and if there are concerns an oversized wind shield can be used.

8.19 This aspect was also discussed by the National Physical Laboratory study. It notes with specific reference to the application of wind farm noise:

"Commercially available wind turbine generators do not start turning until their cut in wind speed, typically 5m/s, has been achieved. However, this is the wind

speed at the noise source and not necessarily at the assessment position. Therefore, although the limits set for weather conditions are principally about minimising extraneous effects on meter readings, the existence of these limits seems to preclude the use of the standard for this particular application."

8.20 This text highlights the somewhat contradictory implication that the standard cannot be used for wind turbines where the wind speeds at hub height are above 5m/s but wind speeds at ground level may be below 5m/s. This is likely to be the case in high wind shear conditions, which are also the conditions most commonly coinciding with complaints. This point is further illustrated with the data from the long term monitoring station at site 5 where noise measurements and 10m height meteorological measurements are made simultaneously at a nearby dwelling. The data on 6 October summarised above in table 10 is a clear example of EAM. The wind speed at turbine hub height is sufficient to generate wind farm noise and significant peak to trough variation, up to 15dB(A). The 10m height wind speed measured between 00:00 and 05:00 on 6 October ranges from 1.8m/s - 4.0m/s and thus would satisfy the precautionary wind speed constraints of BS4142.

8.21 Discussion in the NPL study again highlights the issue of low background sound levels. It references the title of the standard for assessing noise in mixed industrial and residential areas so questioning its application in quiet rural areas. It is noted that the revised standard is simply titled 'Methods for rating and assessing industrial and commercial sound' and again that reference to very low background sound levels is now removed from the standard.

8.22 Thus, there appear no strong or logical arguments against the use of BS4142, with perhaps the exception that it could undermine the application of ETSU-R-97. Due to the conflicts between assessment processes in ETSU-R-97 and BS4142, assessment and rating of wind farm noise with character using BS4142 would have to be separate and stand alone from ETSU-R-97. This does not mean that BS4142 must replace ETSU-R-97. The levels set in ETSU-R-97 relate to steady continuous noise and only consider noise character with reference to a tonal penalty. Thus, ETSU-R-97 could be used where there is no risk of AM or to set noise levels for the benign and anonymous element of wind farm noise (notwithstanding the high levels of noise permitted at night time). ETSU-R-97 does not provide for any assessment of noise character from AM and hence additional controls, such as those offered by BS4142, are required.

8.23 The new BS4142:2014 revises the application of a single 5dB character penalty and expands this to a rating of noise for tonality, impulsivity, other sound characteristics (not specifically tonal or impulsive) and intermittency. This is similar to the Renewable UK proposed condition, which also recommends cumulative penalties for amplitude modulation and tonality. Thus, BS4142:2014 is not dissimilar to other AM assessments currently proposed by others and could be used to deal with AM and tonality simultaneously. This has a clear benefit over the RES and RUK methods for assessing AM, which did not work well in cases where there was both strong tonality and AM.

8.24 Because there are rarely periods where the wind farm or wind turbines are shut down, apart from when there is insufficient wind for them to turn, there are few periods where a comparable background sound level and wind farm noise level (specific noise level) can be determined for the purposes of BS4142 assessment. This same problem arises with ETSU-

R-97 and thus forced stopping of turbines is required for an ETSU-R-97 assessment no different to the requirements of a BS4142 assessment. The exception in the data above was at site 5 on 8th May, which was soon after the turbines were installed and hence on/off testing was taking place. The BS4142 assessment figure and table for site 5 on 8th May are replicated below for ease of reference.

Figure 101: Site 5 - 8 May - 0000 - 0100 - BS4142 assessment.

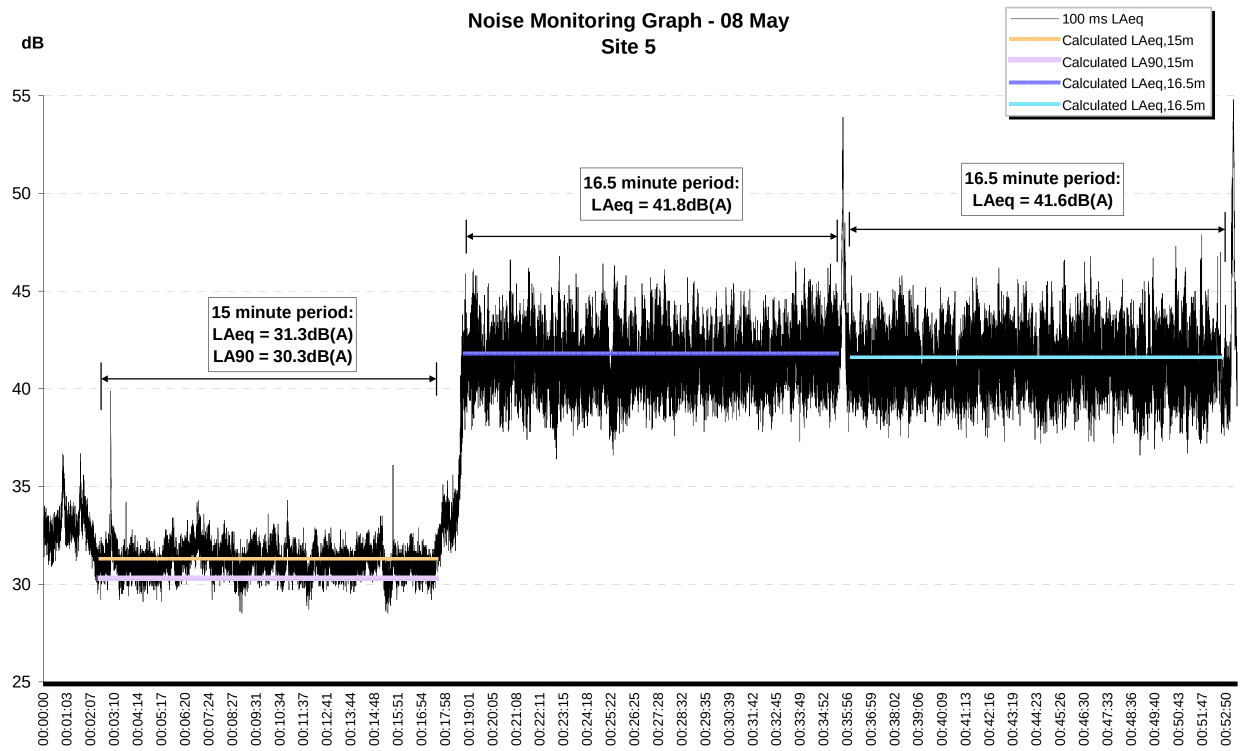


Table 12: BS4142 assessment - Site 5 - 8 May

	BS4142:1997	BS4142:2014
Measured background sound level	30.3dB LA90,5min	30.3dB LA90, 15min
Measured ambient noise level	41.7dB LAeq, 33min	41.7dB LAeq, 33min
Measured residual noise level	31.2dB LAeq, 5min 31.4dB LAeq, 5min (use 31.3dB LAeq, 5min)	31.3dB LAeq, 15min
Calculated turbine noise level (specific noise level)	41.3dB LAeq	41.3dB LAeq
Character penalty	+5dB for modulating character	Arguable +3 / +6dB for 'other sound character' and 'intermittency / readily distinctive'
Rated turbine noise level	46.3dB(A)	44.3 - 47.3dB(A)
Difference between rated turbine noise level and background sound level	+16dB	+14dB - 17dB

8.25 In this case the BS4142 method works well in clearly identifying excess noise.

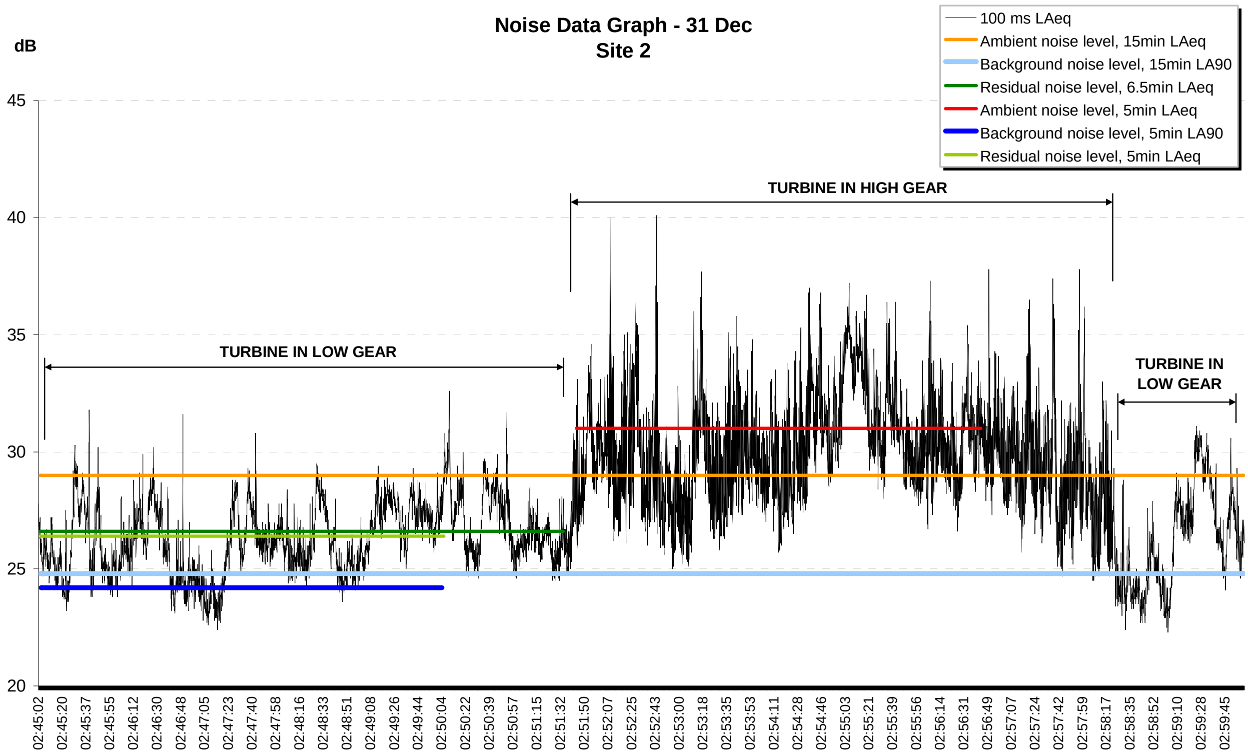
8.26 In the absence of other periods where there is a clear differentiation between turbine noise levels and background sound levels it is difficult to test this method on wind farm noise. Approximations can be made and the data from site 2, where there are clear gear changes and so distinct changes in noise level, has been used to estimate likely impact using BS4142. It is noted that this assessment does not follow the standard as written as the background sound level is not the true background sound level but the noise level generated by the turbine in the lower gear mode operation. Thus, the assessment provides an indication of minimum impact. Both the 1997 and 2014 versions of the standard are compared in table 13 below. Figure 102 below illustrates the assessment periods and labels the relevant noise levels used for assessment.

Table 13: BS4142 assessment - Site 2 - 31 Dec

	BS4142:1997	BS4142:2014
Measured background sound level	24.2dB LA90, 5min	24.8dB LA90, 15min
Measured ambient noise level	31.0dB LAeq, 5min	29.0dB LAeq, 15min
Measured residual noise level	26.4dB LAeq, 5min	26.6dB LAeq, 6.5min
Calculated turbine noise level (specific noise level)	29.2dB LAeq	25.2dB LAeq
Character penalty	+5dB for modulating character, tonality and intermittency	- Tonality: 2-4dB (tone is clearly audible but intermittent so does not show in third octave band analysis) - Impulsivity: 3 - 4 - 6dB (blade noise is impulsive and clearly perceptive, Nordtest values give a penalty of 3-4dB) - Intermittency: 3dB (turbine noise clearly cuts in and out of high gear operation) Total: 8-13dB
Rated turbine noise level	34.2dB(A)	33.2 - 38.2dB(A)
Difference between rated turbine noise level and background sound level	+10dB	+8dB - 13dB

8.27 The table clearly shows that the turbine noise would be rated as causing significant adverse impact. It is noted that an assessment with residual noise and background sound levels uninfluenced by turbine noise would result in a greater difference between rated turbine noise level and background sound level thus indicating greater severity of impact. Furthermore, the period used to represent the ambient noise level was dominated by wind turbine noise. The ambient noise level could therefore be reasonably used as the specific noise level without any reduction for residual noise. Again, this would increase the assessment's indication of adverse impact. This assessment shows that BS4142 works well to identify adverse impact.

Figure 102: Site 2 - 31 Dec - 02:45 - 0300 - BS4142 assessment.



8.28 The above initial assessments indicate that BS4142 works well and successfully identifies periods of adverse noise impact. Ideally further tests are needed to verify these initial findings; however, this would require cooperation of wind farm and wind turbine owners and an agreement to turn turbines on and off for testing. It is unlikely that the opportunity will arise voluntarily.

9 Discussion

9.1 The above analysis indicates that there are existing methods for assessing and rating AM that work well, or work to some extent, at correctly identifying and penalising EAM noise. Rather than adding further to the debate, and potentially prolonging adoption of controls, it is recommended that approaches already proposed be adapted where possible to form a workable method for assessing and controlling EAM. This should be based on informed recommendations using empirical findings, including the results of the above analysis, feedback from those responsible for enforcing controls and subjective response to EAM. As noted, methods have been shown to work with AM data and enable identification of AM. Some methods work better than others. Whilst many are seeking a single unified approach to the assessment of AM, to date there has been difficulty in achieving an agreed approach between local authorities, local residents and those working for and with the wind industry. Clearly there are benefits to a unified approach and arguably the planning regime requires a single applicable condition or approach that can be applied across applications. This work package has shown that there are various methods that could be applied, that can work for assessing AM and that provide reasonable consensus as to what is and is not acceptable impact.

9.2 **Control using BS4142.** As shown above the methodology of BS4142 works well for assessing the impact of wind farm noise with character. Rather than an 'add on' condition to the ETSU-R-97 noise limit, as proposed by the RUK method, or a stand alone condition, as proposed by Den Brook, RES and the DAM rating, BS4142 could be used as a separate assessment tool. Thus, ETSU-R-97 would be discarded for the purposes of assessing wind farm noise with character, namely AM, once the wind farm is operational and if complaints have been received. As noted above ETSU-R-97 would remain the main assessment method but with the caveat that it only applies where there is no noise character and with the exception of non modulating tonality.[54]

9.3 Issues raised previously to prevent use of BS4142, such as low background sound levels and wind speed measurement, have been addressed and resolved in the above discussion. The remaining issue in conflict with the principles of ETSU-R-97 is the balance to be achieved between the need for renewable energy and adverse impact on residential receivers. There is therefore argument for increasing the indicative thresholds of adverse impact given in BS4142 if it is to be applied to renewable energy, for example in the same way as minerals development.

9.4 BS4142:1997 assessed impact as marginal at a difference between rated noise level and background sound level of +5dB and complaints likely when the difference was around +10dB. BS4142:2014 now states that the greater the difference between rating level and background sound level the greater the magnitude of impact. A difference of around +5dB is likely to indicate adverse impact and a difference of around +10dB is likely to indicate significant adverse impact.

9.5 As noted above (para 8.11), historically conditions for power generation facilities have been set a limit of the rating level not exceeding +5dB above background sound level.

[54] For example the type of modulating tonality exhibited at site 1.

Thus, there is arguably scope to increase the level above this for renewable energy. It is proposed that where BS4142 is used to assess wind farm noise with character the level of acceptability is increased to +10dB above the background sound level.

9.6 Support for this level can be found in current guidance on minerals extraction found in the Planning Practice Guidance (PPG).[16] There are clear parallels between noise conditions for minerals extraction and renewable energy. Both seek a balance between minimising adverse impact at residential receivers and the need for minerals extraction / renewable energy. Both are limited to development locations where the resources naturally occur. Although the PPG ultimately recommends minimising impact at night time to a minimum, noise levels during daytime and evening are recommended not to exceed background + 10dB.

9.7 **Den Brook.** The Den Brook condition worked well for assessing impact at all of the test sites above. The two disadvantages of the condition are that it does not readily relate to psychoacoustic response and it is not designed to be automated.

9.8 To address the first issue of psycho-acoustic response, it is worth noting that none of the conditions or methods proposed to date truly account for the psycho-acoustic response of those affected by wind farm noise with character. The scope of this work package deals only with audible AM and does not address the potentially cumulative impact of other features such as tonality, irregularity, lower frequency AM components etc. The Den Brook method does not differentiate between the severity of AM. However, this aspect does not necessarily present a real problem for enforcing against unreasonable impact from AM and a judgement of severity is necessarily built in to the assessment of those aiming to enforce the condition.

9.9 It is important to read and apply the Den Brook condition in context. The condition was drafted assuming the same principles that have applied to planning enforcement over several decades. At a basic level this includes ensuring that the noise that has been measured is attributable to the wind farm and is not adversely influenced by other extraneous sources.

9.10 Once the assessment of impact is made, as with any planning condition, the assessor must use their judgement as to whether the severity or frequency of impact is sufficient to successfully enforce against. In many cases this includes a judgement of whether the evidence will withstand the scrutiny of the courts. The Den Brook condition is therefore not intended to be treated as a simple trigger level. One period of exceedance, i.e. a regular 3dB variation in noise level with an average level greater than 28dB LAeq, is highly unlikely to be upheld as a breach of condition.

9.11 As an example consider a factory with a noise limit of 35dB(A). To measure the noise from the factory an assessor would either attend noise measurements, to ensure that the noise was solely attributable to the factory, or otherwise make the necessary measurements or calculations to enable determination of the factory noise level in isolation. Unattended measurements would require further analysis to validate the factory noise. If the factory noise level was measured at 36dB(A) this would be a breach of the limit; however, a single breach at 36dB(A) is highly unlikely to be enforced as it is *de-minimis*. The measurement uncertainty of the equipment or conditions under which measurements were taken could easily be argued as +/-2dB and as such the factory could be argued as compliant. It is not until breaches of the noise limit were regularly in the region of 38dB(A) that there would be confidence of a sustained breach. This level is above the uncertainties mentioned above and is double the energy of the noise limit.

9.12 Frequency and duration are also important factors to consider when enforcing breaches of planning conditions. A single breach of the factory's noise condition in the region of 45dB(A) could be enforced as this is 10dB(A) above the noise limit. A single breach of 36dB(A) would be unlikely to be actioned. Breaches of 36-37dB(A) occurring regularly might be enforced and several breaches in excess of 38dB(A) would likely be enforced. Thus, as with all planning conditions there is some common sense and reasoned judgement to be made when using the Den Brook condition. Planning enforcement guidance touches on this aspect as well as expediency of enforcement.

9.13 Historically the 3dB(A) modulation depth specified in the Den Brook condition has been treated as a trigger level rather than applying the judgements illustrated in the example above. As with the factory example, it would not be until the modulation depth was regularly greater than 3dB(A) that the condition could be successfully enforced. For example, regular modulation in the region of 5-6dB(A) would likely be considered for enforcement. Borderline breaches of the condition would be considered *de minimis*.

9.14 Applying this approach to the Den Brook condition, as was originally intended, the method works well and effectively controls adverse impact without placing unduly restrictive controls on development. The Den Brook criteria is not designed as a strict trigger value as implied by others. Thus, it is considered that the Den Brook method can still be successfully implemented as written.

9.15 Automation becomes far less of an issue when following the Den Brook condition with the application of basic planning enforcement principles discussed above. There is only a need to process a significant amount of data if there are not many occurrences of EAM exceeding 3dB(A) peak to trough. In this case it is more likely that there is not a significant problem and enforcement is not necessary. If there are a number of occasions where the peak to trough level is in the region of or greater than 5-6dB(A) peak to trough then months of data analysis is not required. Similarly where there is EAM with a peak to trough level of 10-15dB(A) few separate occurrences would be needed to demonstrate adverse impact.

9.16 Going forward, if the Den Brook condition is to be used to assess AM it should be noted that this only assesses that specific noise character. The overall wind farm noise level would still be assessed in accordance with ETSU-R-97 and tonality included in the form of a penalty applied to the ETSU-R-97 limit. If the Den Brook condition, or criteria, is to be used as a trigger value, i.e. one or two exceedances indicative of a breach, then the peak to trough level value needs to be increased from 3dB(A) to around 6dB(A). However, it is recommended that the Den Brook condition is not used as a simple trigger value.

9.17 **DAM.** The DAM method provides a means for determining a value of AM. In itself it is not a condition and no indication of severity of impact is provided by the authors of the DAM method, only that at a DAM rating of approximately 1.7dB (corresponding to an AM index of approximately 2.0) is sensible.

9.18 The tests above indicated that for some sites the DAM methodology gave a good indication of typical peak to trough level of AM. Generally the DAM value represented the lower end of the range of peak to trough values. However, the AM index in most cases well approximated the typical peak to trough level. In some cases the AM index underestimated the peak to trough level of isolated but very high peak to trough AM (in the region of 15dB(A)) This could be due to the erratic and sporadic nature of these peaks, but it indicates that the DAM rating range may be too restrictive or may not adequately account for situations that contain more erratic peak to trough AM.

9.19 The DAM value cannot be used as a condition on its own (at least in its current form) but the AM index may be used in most cases to determine the typical level of modulation. To counter the issues of the AM index underestimating some AM peak to trough levels, the DAM AM index could be treated as a means for determining whether a threshold value is exceeded. With reference to table 14 (see below) the maximum DAM values tended to be at DAM=7-10. Where peak to trough modulation was lower, around 4-5dB peak to trough, the DAM values were between 4 and 6. A DAM value of around 3.5 or AM index of around 5 could be considered as a trigger value for EAM. As with the Den Brook method, there is no prescriptive means for assessing frequency and duration of impact and what may be considered an acceptable level of EAM occurrence.

9.20 **RES.** The RES method did successfully identify periods of EAM when the noise trace was clean, i.e. clear peak to trough modulation and no significant tonality, and when it was uncorrupted by extraneous noise. However, testing identified the tendency for the RES method to miss periods of EAM and to significantly underestimate the peak to trough difference in many examples. It was found that including the first harmonic when calculating the AM value improved identification of EAM and this also increased the AM value so that there were more examples where the AM value and the peak to trough level were similar.

9.21 The RES method was not found to be robust as an automated method. It included periods of extraneous noise in the assessment of AM and also identified AM in data where there was no wind farm noise at all. Thus, if using the RES method to make any judgement of AM impact there would still need to be significant human input to check results and this defeats the benefit of having an automated method. It is considered that the RES method is not suitable for use as an independent test for EAM.

9.22 It is noted that the RES method has not been fully tested in this work package. Without ready access to SCADA data the peak modulation frequency derived from the data cannot be checked against the rotational frequency of the turbines as logged by the SCADA data. Thus, there is no measure of how well the method actually works when looking for consistency of peak modulation frequency and SCADA data. This is a limitation of the assessment of the RES method in this work package.

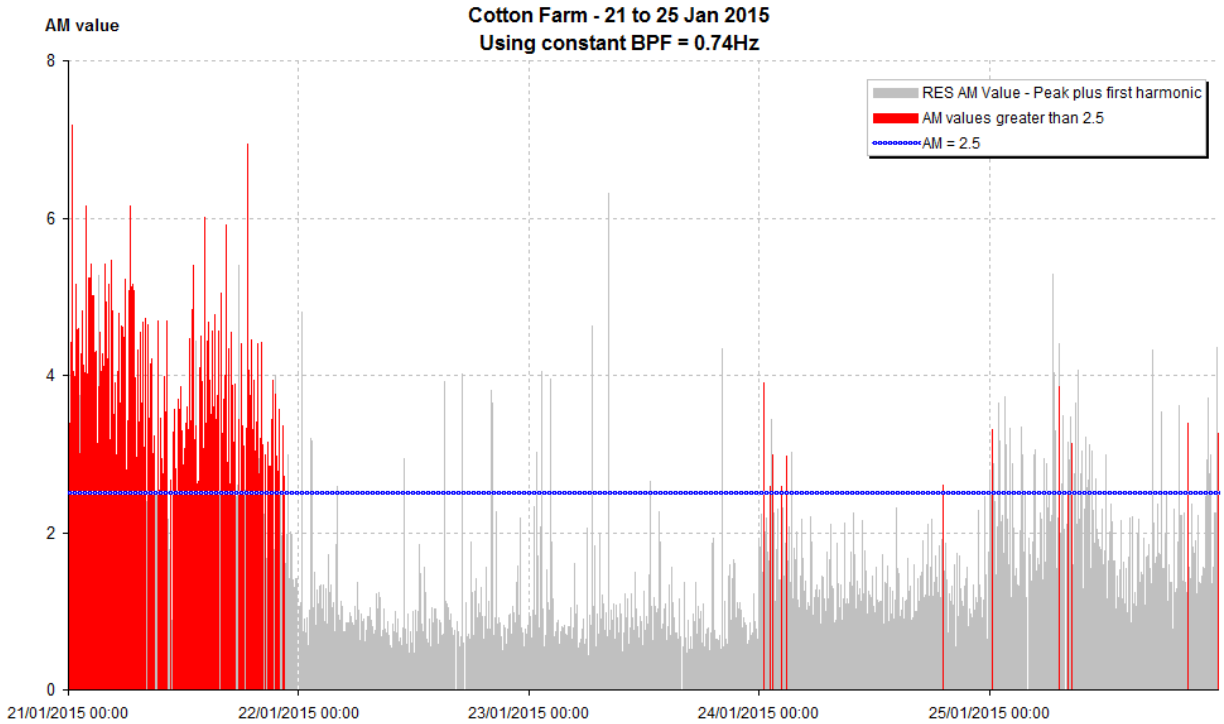
9.23 Whilst the RES method is not suitable in its current form as a standalone assessment method, with slight modification it successfully and consistently identified EAM. The RES method could be used as part of an AM control for identification of periods of data where there may be EAM. For example, where a data logger has been left to record noise for a period of several weeks the RES method could be used to target periods for investigation of EAM. This has been explored further below.

9.24 **RES method including first harmonic.** As noted above, some modifications are needed to the original RES methodology to better aid detection of AM. First and foremost, it is suggested the first peak and the first harmonic are both included in the calculation of the AM value for each 10s period. Rather than use as a standalone method the RES method could be used as a tool for identifying periods of EAM in a large amount of noise data, i.e. as a highlighting tool. This has been tested using the Cotton Farm Wind Farm (site 5) noise data.

9.25 Cotton Farm Wind Farm data from 21st January 2015 - 25th January 2015 has been used to test the modified RES method. Only data between the hours of 00:00-03:00 has been tested. As noted above the RES method does not work well when there is extraneous noise, selection of the period 00:00-03:00 minimises the likelihood of extraneous noise corruption. Audio and visual analysis of the data confirmed the presence of EAM on 21st January and 25th January. On 22nd and 23rd January there was no clear wind farm noise AM. On 24th January there was AM and EAM but also considerable extraneous noise from wind, transportation noise sources and a burglar alarm sounding until approximately 02:10.

9.26 The RES algorithm was run assuming a constant blade pass frequency (peak modulation frequency) of 0.74Hz. This was found to be the typical blade pass frequency of the Cotton Farm turbines as identified by the analysis at site 5 above. The AM value for each 10s period was calculated assuming a blade pass frequency of 0.74Hz and using the energy in the peak and first harmonic of the modulation spectrum. A check was then made to ensure that the peak modulation frequency for the 10s period was consistent (taken in this case as +/-10%) with the blade pass frequency (0.74Hz). Any period with a consistent blade pass and peak modulation frequency and resulting in an AM value greater than 2.5 was highlighted. The results are given in figure 103 below.

Figure 103: Modified RES method - identification of EAM assuming BPF=0.74Hz

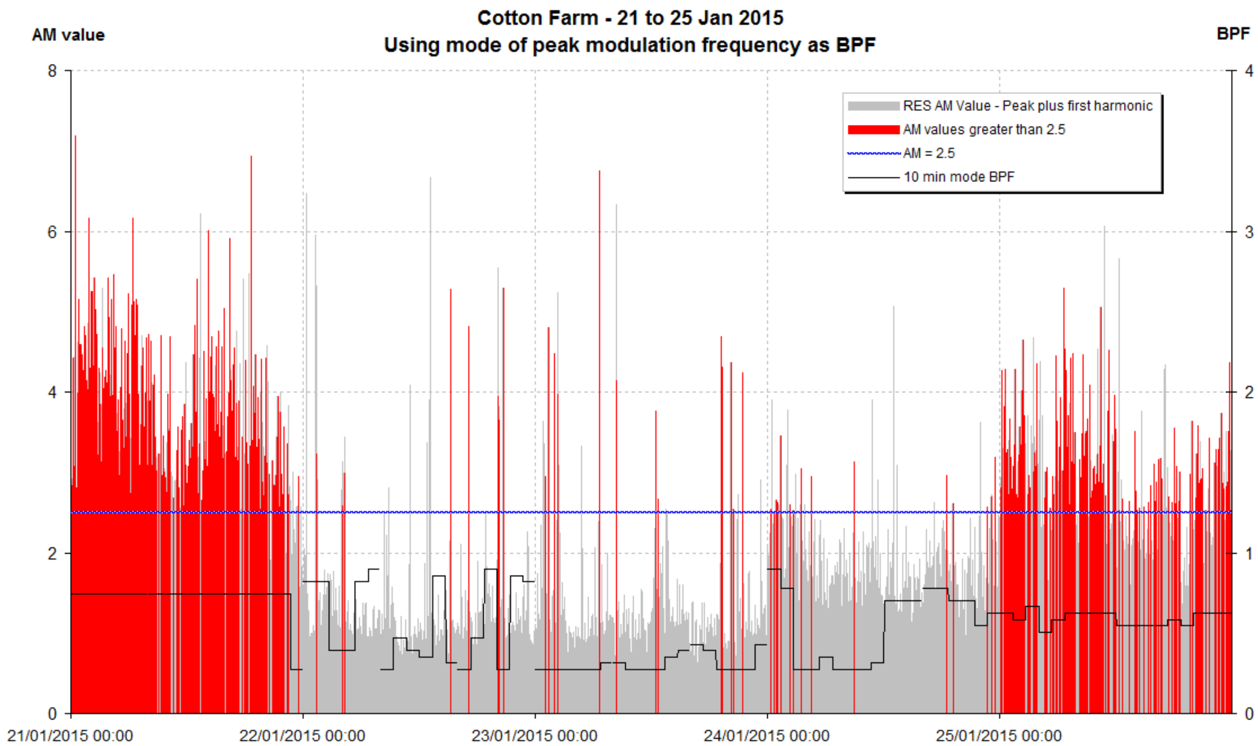


9.27 The red lines on figure 103 above indicate periods where the RES EAM trigger value of 2.5 has been exceeded. The nature of EAM is that it arises for sustained periods. Rather than using the modified RES method to investigate every period highlighted the assessor should look for blocks of highlighted periods. Single or isolated periods are more likely spurious results and it is only blocks of highlighted periods, such as that occurring on 21st January, that would be treated as indicative of EAM and therefore worthy of detailed investigation.

9.28 Whilst the above figure is a positive indication that the RES method can work as a tool for identifying periods of EAM, it highlights the real problem of assessing EAM where the blade pass frequency varies and using an automated method. This is also an issue for the RUK method. Audio analysis confirmed a sustained period of EAM on 25th January 2015. The peak modulation frequency (blade pass frequency) of the wind farm noise data on 25th January 2015 is 0.63Hz. This does not fall within the consistency check of +/-10% of 0.74Hz, the peak modulation frequency / blade pass frequency identified on 21st January, and so has been discounted as EAM. Clearly there is a need for variability in defining the blade pass frequency for long periods of data analysis.

9.29 The RES method was run a second time and further modified. Rather than using a constant assumed blade pass frequency, the mode peak modulation frequency was identified for each 10 minute period and this was used as the blade pass frequency to calculate the 10 second AM values within the 10 minute period. The results are given in figure 104 below. Also plotted on figure 104, referenced against the right hand side y-axis, is the 10 minute mode blade pass frequency.

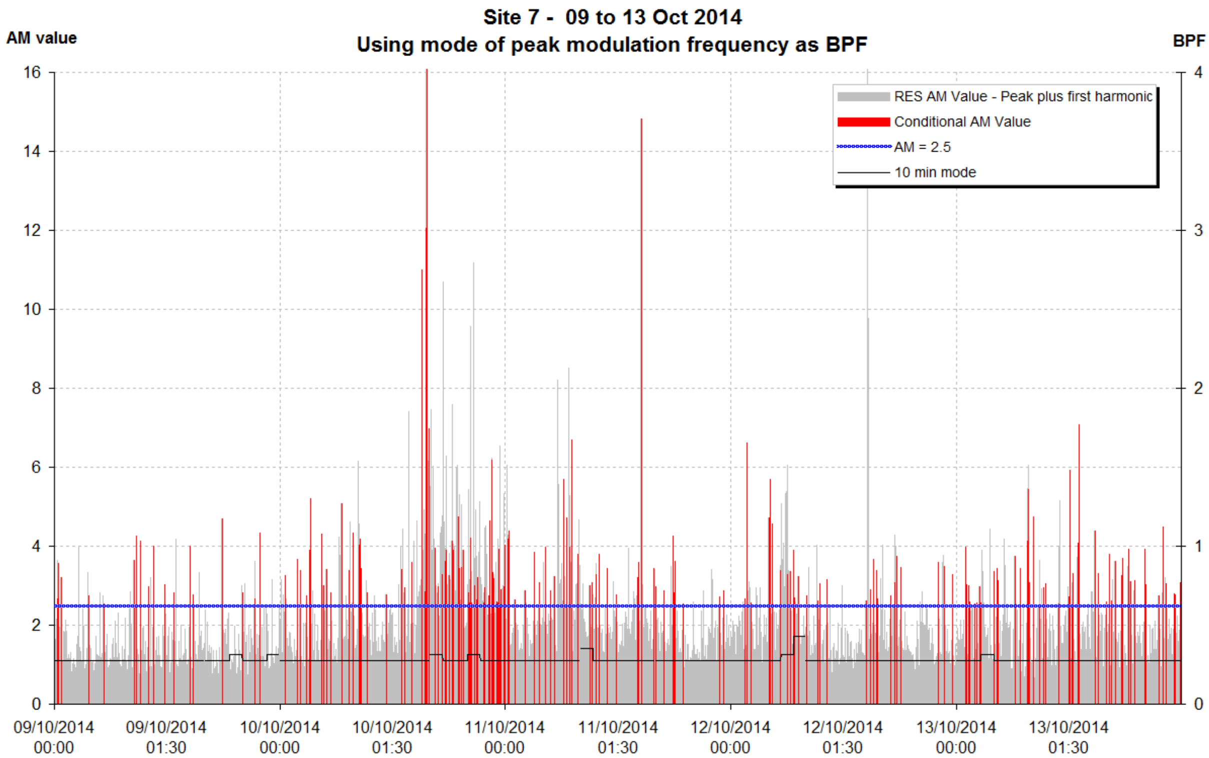
Figure 104: Modified RES method - identification of EAM assuming 10 minute mode BPF



9.30 As shown in figure 104 above, the modified RES method using a mode blade pass frequency now identifies AM on 25th January 2015. The mode blade pass frequency approach does however appear to increase the number of spurious results. Both methods failed to identify sustained periods of EAM on 24th January, this could be partly due to the interference of the burglar alarm noise.

9.31 The modified method, using the peak and first harmonic and the 10 minute mode peak modulation frequency as blade pass frequency, was tested with a week of real world data where there was no wind farm source. The results are presented in figure 105 below.

Figure 105: Modified RES method - identification of EAM - non wind farm data

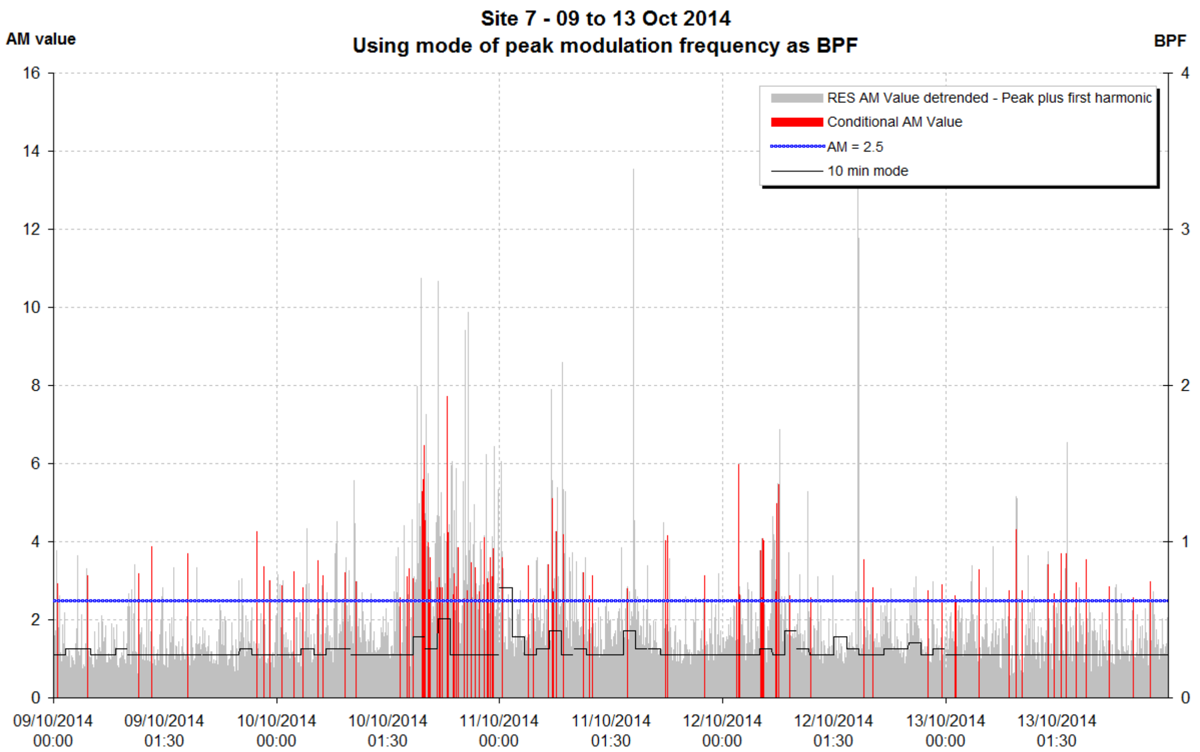


9.32 Figure 105 above indicates a number of periods that could be indicative of EAM, i.e. a fairly high number of spurious results, but only one more consistent block of data points potentially indicating EAM on 10/10/2014, after 01:30. This suggests that the modified RES method does not work well at excluding periods of modulating non wind farm noise.

9.33 However, with a little further interpretation it is clear that the results are not indicative of EAM. For example, the mode blade pass frequency is plotted on the right hand side y-axis and shows a very low peak modulation frequency typically around 0.27Hz. Whilst it may be evident from review of the peak modulation frequency that this data does not indicate the presence of EAM it does not provide a simple, obvious visual indicator as originally sought and as apparent in figures 103 and 104 above.

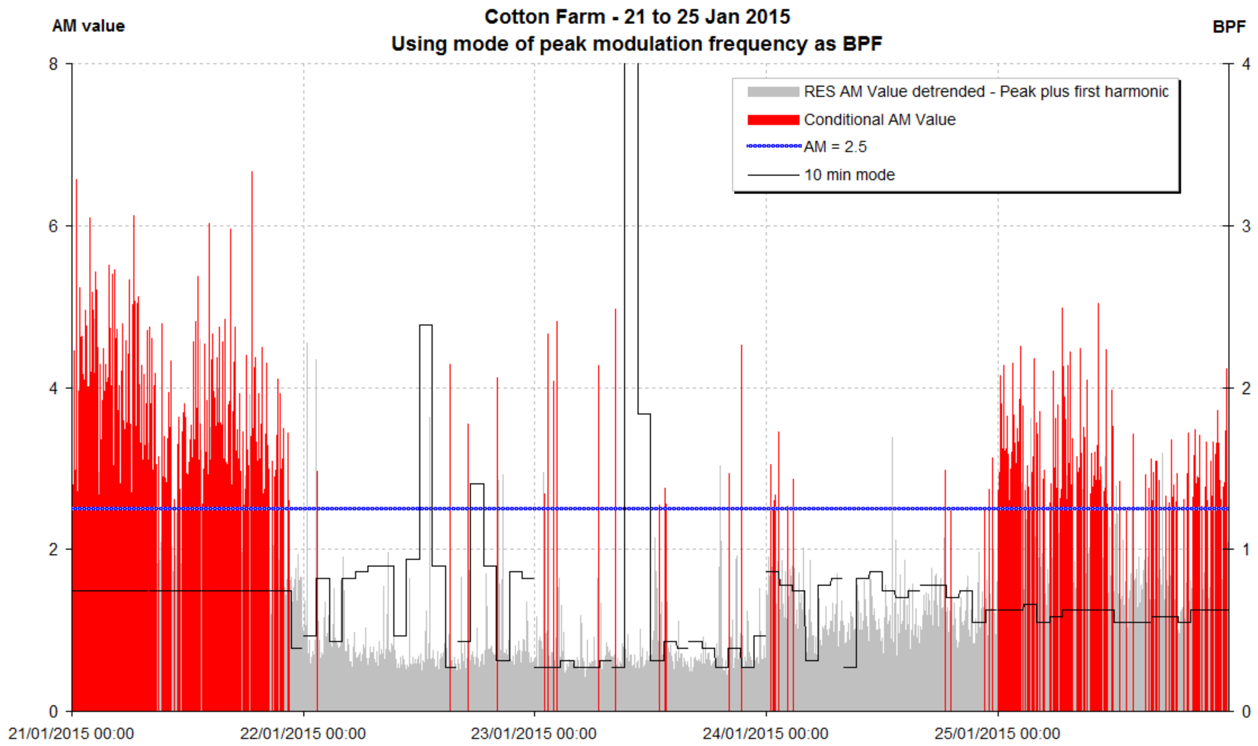
9.34 The RUK algorithm is similar to the RES algorithm up to the stage of deriving an AM value. The only difference between the methods is the de-trending process. The RUK method uses a 5th order polynomial, the RES de-trending is essentially flat. Whilst in most cases this results in a lower AM value derived from the RUK method, it does help to eliminate peak modulation frequencies in this lower range (around 0.27Hz). The modified RES method has therefore been further amended to include this 5th order polynomial de-trending process. The modified RES method is still based on energy at the peak and first harmonic and assumes the 10 minute mode peak modulation frequency as the blade pass frequency. The revised results for figure 105 are presented in figure 106 below.

Figure 106: Modified (de-trended) RES method - identification of EAM - non wind farm data



9.35 The de-trending does reduce the number of spurious results, but EAM is still indicated on 10th October 2014 after 01:30. The de-trended values still provide a good indication of EAM in the January 2015 Cotton Farm data (site), see figure 107 below.

Figure 107: Modified (de-trended) RES method - identification of - Cotton Farm wind farm data January 2015



9.36 In summary, the RES method can be modified to provide a better EAM identification tool, though it is noted that the current modifications are by no means perfect. Reasoned judgements would still need to be made by the assessor, including where it might be worth investigating highlighted periods and whether the mode peak modulation frequency (blade pass frequency) is likely to be turbine related.

9.37 This analysis highlights some of the issues with seeking an automated process and suggests that ultimately there will always be a need for human judgement. The time taken to make this judgement following automated data processing may not be any quicker than making a human judgement at the outset of assessment, as required by the Den Brook and DAM methods. Thus, the modified RES method could be used to highlight periods for EAM investigation with the caution that periods of EAM may still be missed and spurious results produced. This is far from ideal for a proposed automated method.

9.38 **Renewable UK (RUK).** It is first noted that the RUK method has not been fully tested. As with the RES method, the RUK method requires that the peak modulation frequency derived from the data is checked against the turbine SCADA data. In the tests above the blade pass frequency has been taken as the most commonly occurring peak modulation frequency where there is clear, uncorrupted AM. In reality there could be other influencing factors that result in differences between the SCADA data and the peak modulation frequency derived from data.

9.39 The Renewable UK method did identify periods of AM but problems also arose with the methodology, similar to those discussed in relation to the RES methodology. The RUK method could not distinguish between AM and AM influenced by extraneous noise. At site 2 the RUK condition could not distinguish between EAM and duck noise. This is a significant flaw for what aims to be an automated method. The AM values derived from the RUK method did not reflect the typical peak to trough level of AM and often significantly underestimated impact due to averaging of values where there was no AM or where the method had not correctly identified AM.

9.40 The RUK method aims to control EAM impact by applying a penalty to the overall wind farm noise limit. The most significant finding is that even where an AM value was successfully and accurately achieved the resulting penalty would be minimal, this is shown in tables 14 and 15 below. It is noted that the assessment of the RUK method in this work package provides a best case for assessment of EAM.

9.41 In reality the RUK method will generate much lower penalties than indicated by this analysis primarily due to the convoluted averaging process prescribed in the methodology. For example, the RUK method states that where AM is not found for a 10 minute period, as there is no peak in the modulation spectrum, the AM value for that 10 minute period is 0. This allows many periods of EAM to be averaged with periods without EAM, i.e. values of 4-5 averaged with values of 0. This effectively dilutes the impression of impact and misrepresents the value of EAM that has been measured. Arguably the averaging of AM values addresses frequency and duration of impact; however, as discussed above and below the way in which this is achieved undermines any prospect of control.

9.42 In all cases tested no enforcement would have resulted from the RUK method of AM assessment. With reference to table 15 in all but two cases even the maximum penalty of 5dB would not have triggered any enforcement. Even if the penalty did trigger enforcement the effect would be minor, the average noise level would only need to be slightly reduced and thus the peak to trough modulation could continue more or less unchanged. If the penalty range was increased, and the method used to derive the A value resulted in higher AM values, in most cases it is likely that the resulting enforcement action would require only a few decibels reduction from the overall turbine noise level. Thus, there is no requirement to restrict the intrusive AM character that is complained of. Enforcement is limited to a slight lowering of the overall LA90 level. The LA90 index does not relate to AM impact. The RUK method does not therefore control EAM.

9.43 In separate international papers produced by researchers at MAS Environmental Ltd it has been shown that if a maximum penalty of 5dB, as proposed by RUK, was applied to ETSU-R-97 limits it would not prevent or remotely change / control EAM problems due to the difference between those limits and the LA90 levels at which EAM occurs.[55] A penalty control for EAM applied to the ETSU-R-97 limits is not therefore considered feasible.

9.44 It is considered that the RUK method fails in a number of respects. It does not relate to impact, it does not control impact, it does not correctly identify EAM in a number of situations. The RUK method still involves manual checks to be made and as such there is no clear benefit over non automated methods. The RUK method is not an effective or workable control of AM.

[55] Large, S., & Stigwood, M,. (2014). The noise characteristics of 'compliant' wind farms that adversely affect its neighbours. *Internoise 2014.* Melbourne, Australia, 16-19 November 2014.

9.45 Whilst there are clear benefits to a penalty type approach, for example it can simply be added on to the current ETSU-R-97 assessment method and noise limits, the RUK approach categorically fails to provide an effective control of EAM. Significantly higher penalties would be needed for the current RUK method to have any remedy for unreasonable periods of EAM. Even if higher penalties could be derived and applied further tests would be needed to show that the reduction in noise limit resulting from the penalty resulted in an acceptable noise environment.[56]

9.46 A mathematical means for assessing AM, as proposed in the RES and RUK methods, has benefits for providing a uniform assessment approach and ultimately leading towards an automated process. However, the current algorithms have significant problems both in terms of failure rates for identifying EAM, the need for manual input and manual checks and providing a value that bears little relation to the impact experienced.

9.47 **Means of control.** At the beginning of this work package various different means for control of environmental noise were highlighted. This included review of noise controls for various sources where absolute limits are set, where guideline values are given depending on frequency of noise impact and time of day of noise impact and contextual controls were implemented, i.e. assessment in relation to the existing background sound environment.

9.48 The RES method and arguably the DAM and Den Brook methods give threshold AM values. Once this threshold value has been exceeded the noise is unreasonable and must be mitigated. There is no assessment of context (background sound environment) or frequency and duration (how often it impacts). They consider only AM and not the combined impact of noise level, noise character, frequency and duration.

9.49 BS4142 attributes a penalty for noise character and then combines assessment of noise character and noise level to be judged relative to the background sound environment. This provides a context based approach and includes combined assessment of noise level and noise character. There is arguably no consideration of frequency and duration of impact, though as discussed above this would occur out of necessity if action to enforce noise impact were taken.

9.50 The RUK method derives a penalty and applies this to a threshold limit. There is no assessment of context. Arguably there is some assessment of frequency / duration caused by the averaging of AM values over the 10 minute period and with respect to wind speed. As noted above, this averaging process undermines the control by watering down periods of adverse impact. In this respect it does not provide an effective means of assessing frequency and duration or the number of disturbing events over time. This method of averaging is considered unhelpful as adverse effects of impact are not addressed due to the inclusion of periods of reduced or no impact. The RUK method appears to aim means of control between threshold noise limits and also a context based assessment, following BS4142. However, it has been shown repeatedly above that the means of control fails to effectively control impact. The failure appears to arise from a combination of the

[56] For example, if night time wind farm noise were complained of and a following assessment a penalty of 8dB applied reducing the noise limit from 43dB LA90 to 35dB LA90, would this a) prevent EAM and b) result in an acceptable noise environment?

parameter used to measure the noise to which the threshold limit applies (i.e. the LA90) and underrating of noise character by the method used to derive a character penalty (i.e. the RUK algorithm and resulting "A" value).

9.51 Notwithstanding the inherent flaws with the RES method as a standalone EAM control, e.g. false positives and failure to identify periods of EAM, the RES, DAM and Den Brook methods could be implemented in their current form with the understanding that frequency and duration are considered as an inherent part of planning enforcement that need to be adjusted for. However, these methods would still fail to consider context (background sound environment and character of the locality) and time of occurrence. The latter is less problematic as experience indicates that EAM tends to be an evening / night time problem. An understanding of the need for stricter controls at night time could therefore be built in to any proposed condition.

9.52 The Code of Practice on Environmental Noise Control at Concerts and the IoA Good Practice Guide on the Control of Noise from Pubs and Clubs, set threshold limits based on how often impact occurs. A similar approach could be used to control EAM and would provide a more rigid means for assessing frequency and duration than that relying on the professional judgement of those taking enforcement action. However, knowing where to set the limit of acceptability is not simple.

9.53 There is currently little knowledge or understanding of how features such as frequency and duration, context with background sound environment and time of occurrence specifically impact on the perception of EAM. Based on experience gained from impact of other noise sources it is expected that the more frequent and long lasting the EAM the more intrusive. Evidence suggests that those impacted by noise with character do not habituate to the noise but conversely become sensitised.[57] This is also supported by the anecdotal evidence of those who regularly suffer impact from EAM.

9.54 Noise impact at night time is typically treated as more intrusive and the greater the difference between background sound and the noise source (with specific character) the greater the adverse impact. Whilst these assertions may be made there is little research evidence to support them and there remain other features of EAM that set it aside from the impact of other types of noise.

9.55 EAM is a longitudinal impact and the occurrence of EAM is unpredictable. There are no controls over the time of day that it can occur and when it does occur, persistent weather patterns often mean EAM impacts several consecutive days / nights. At the time of writing there is no clear means by which EAM can be assessed in context and for aspects such as frequency and duration.

9.56 Deriving a dose response for EAM is unlikely to be practical as there are so many different exacerbating and contributing factors. However, it is common for all noise with character that the more periods of intrusion, the longer the noise occurs, the more noise penetrates dwellings and cannot be escaped, the more noise sensitive periods are effected (i.e. sleep vs. labour or rest and relaxation), then the greater or more extreme the impact will be. It

[57] Flindell, I.H. and Walker, J.G. (2004) Environmental Noise Management, in Fahy, F. and Walker, J. (*eds*) *Advanced Applications in Acoustics, Noise & Vibration*. London: Spon Press, pp.183-235.

is suggested that in the absence of any clear dose response relationship assessment of these aspects remains addressed through subjective, professional judgement and on the basis that intrusion of more sensitive activities and areas of a dwelling should be prevented. As the Japanese studies have identified, AM is a “common occurrence” causing “serious annoyance”. Any control needs to address both of these factors.

9.57 **Desirable criteria for proposed EAM condition.** The above discussion has outlined how each method assesses EAM and how this relates to control of impact. In section 3 above the following objectives were set as additional desirable criteria for any proposed method or condition identifying and controlling AM:

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.[58]

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.

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 desire for the condition to be workable with large amounts of data and therefore be largely automated.

f. Most importantly it must be shown that the condition is effective, the conditions must prevent periods of adverse AM.

9.58 Each of the above criterion have been discussed separately below with examples from the above data analysis referenced where appropriate. In most cases BS4142 has not been discussed as this has been tested extensively over the years and has been shown to work well as a mechanism to control excess noise with character, albeit from other industrial noise sources. As such, BS4142 is already considered to satisfy the criterion highlighted in a, b, and d above. Discussion on c, e and f is provided below.

9.59 For reference a brief summary of the results for each site is provided in table 14 below. The table shows whether EAM was correctly identified by each method. For example 5/5 indicates that all periods of EAM were correctly identified, 6/5 indicates that whilst all EAM periods were identified an additional period that did not contain EAM was also identified as containing EAM (false positive). A rating of 4/5 indicates that a period that contains EAM has been missed (false negative). The table also indicates the typical value of EAM either as a rated value, penalty value or typical peak to trough level. As the DAM

[58] The latter has been shown to be problematic for methods based on a single defined blade passing frequency assessed using FFT.

method provides only a means to derive a value for AM and no prescriptive methodology for excluding extraneous noise or defining acceptability only the DAM values and AM index values have been provided in the table.

Table 14: Summary of results

Site date	Over view	Den Brook		Renewable UK				RES Den Brook		DAM		BS4142
		EAM correctly identified	Comment	EAM correctly identified	Average A value[59]	AM penalty[60]	Comment	EAM correctly identified	Comment	EAM correctly identified	Comment	
Site 1 07 Sep	8 periods total, **7** with EAM	Y	7 ten minute periods where EAM noise evident. P-T 3-4dB and 7-11dB	Y	4.0	3.3	Only 2 ten minute periods where EAM noise evident. Badly influenced by ext noise and inconsistent BPF.	Y	3 ten minute periods where EAM noise evident. Badly influenced by ext noise.	Y	Periods without ext noise[61] DAM= 5-8 (AM index = 7-12)	
Site 2 31 Dec	8 periods total, **6** with EAM	Y	6 ten min periods where EAM noise evident. P-T 4-15dB.	Y	4.4 (2.75)	3.4	5 ten minute periods where EAM noise evident. Badly influenced by inconsistent BPF.	Y	5 ten minute periods where EAM noise evident.	Y	Periods without ext noise DAM= 2-7 (AM index = 2-10)	+10 (1997) / +8-13 (2014)
Site 2 11 Jan	22 periods total, **20** with EAM	Y	20 ten min periods where EAM noise evident. P-T 4-11dB.	Y	3.3 [3.0]	3.1	22 ten minute periods where EAM noise evident (i.e. valid A values could be derived)	Y	22 ten minute periods where EAM noise evident (values >2.5).	Y	Periods without ext noise DAM= 3-7 (AM index = 4-10)	
Site 3 10 June	7 periods total, **7** with EAM	Y	7 ten min periods where EAM noise evident. P-T 4-10dB	Y	3.3 (2.8)	3.1	6 ten minute periods where EAM noise evident. Lots of inconsistent BPFs.	Y	6 ten minute periods where EAM noise evident. Problems with inconsistent BPF	Y	Periods without ext noise DAM= 3-6 (AM index = 4-9)	

[59] Numbers in curved brackets have been averaged to include 10 minute periods where AM was not found and consequently an A value of zero has been assigned to that period. Numbers in square brackets are an average of the values derived using a constant blade pass frequency.
[60] This assumes the highest A value derived for the period and indicates the magnitude of penalty that would be applied. Clearly the results would differ for a larger data set if the character of the AM varied significantly from that in the examples used.
[61] Periods / results that are influenced by extraneous noise have not been included in this summary table.

Site date	Over view	Den Brook		Renewable UK				RES Den Brook		DAM		BS4142
		EAM correctly identified	Comment	EAM correctly identified	Average A value[59]	AM penalty[60]	Comment	EAM correctly identified	Comment	EAM correctly identified	Comment	
Site 4 29 Sep	4 periods total, **0** with EAM	Y	0 ten min periods of EAM	Y	0.7	0	4 ten minute periods where EAM noise evident. (i.e. valid A value derived and could be included in overall analysis).	N	0 ten minute periods where EAM evident.	N	DAM = 1.2-3.7 (AM index = 1-5), generally DAM / index = 1-2. i.e. not 'sensible'[62]	
Site 5 8 May	5 periods total, **5** with EAM	Y	5 ten min periods where EAM noise evident. P-T 5-9dB	Y	3.7 (2.45) [2.9]	3.2	4 ten minute periods where EAM noise evident is use local BPF and consistency checks, OR 6 if use global BPF and no checks.	Y	5 ten minute periods where EAM noise evident.	Y	DAM = 3-5 (AM index = 4-7)	+16 (1997) / +14-17 (2014)
Site 5 11 Oct	6 periods total, maybe **2** with EAM	Y	2 ten min periods where EAM noise evident. P-T 3-4dB	Y	1.5 (0.75)	0	3 ten min periods where EAM noise evident. (i.e. valid AM values could be derived)	N	0 ten minute periods where EAM noise evident.	Y	DAM = 2-2.5 (AM index = 2-3)	
Site 5 31 Dec	6 periods total, **6** with EAM	Y	6 ten min periods where EAM noise evident. P-T 5-15dB	Y	3.4	3.1	6 ten minute periods where EAM noise evident.	Y	6 ten minute periods where EAM noise evident.	Y	DAM = 4-6 (AM index = 6-9)	
Site 5 6 Oct	36 periods total, **36** with EAM	Y	36 ten min periods where EAM noise evident. P-T 5-15dB	Y	4.1 [4.1]	3.3	36 ten minute periods where EAM noise evident.	Y	36 ten minute periods where EAM noise evident though lots of periods missed.	Y	DAM = 3-7 (AM index = 4-10)	

[62] 11/12 3 minute periods rated as not sensible, one 3 minute period where DAM rating and AM index indicated EAM.

9.60 **"a: The condition must work with real world data".** A range of data sets have been analysed above including those from single turbines and multiple turbines. Data that obviously and less obviously contains extraneous noise has been tested along with data that contains wind farm noise but not necessarily that which might be classed as EAM.

9.61 Firstly it is worth noting that all methods could detect certain defined forms of AM from real world data. However, there were periods of AM not identified by some of the methods, periods where some methods indicated that there was AM but there was none and some methods allowed extraneous noise to be included in analyses also giving false indications of AM or allowing extraneous contribution to the AM value. The final period analysed at site 5 provided five hours of wind farm noise that could be tested using all methods apart from BS4142.[63] The wind farm noise and AM was fairly clean and consistent, there was always wind farm noise and AM present and there was minimal extraneous noise. At times the AM trace could be unpredictable and erratic. However, all methods identified AM in this data and the rating of the AM within each methodology was consistent across the 5 hour period. This is a good example of where there are few problems at least in implementing the AM assessment methods. However, it does indicate that if a certain data type is used for analysis, results can be gained that support the efficacy of any of the methods despite other data types demonstrating errors and / or other inefficient outcomes (e.g. the need for data checks).

9.62 It is apparent from the data at site 1 that the RUK and RES conditions do not work well when there are significant extraneous noise sources mixed with the wind farm noise. Arguably these periods would be excluded from analysis before the data is processed. However, to know that the periods included extraneous noise would involve listening to the audio data for each 10 minute period or reviewing the graphs for each 10 minute period prior to running the algorithm. This would involve manual processing and so defeats any benefit of having an automated process. It serves no additional benefit to that which can be achieved using the Den Brook condition or DAM method.

9.63 If periods containing extraneous noise and wind farm noise were not discarded at an early stage then the analysis showed that both the RES and RUK methods would ultimately exclude these periods at a later stage, due to an 'inconsistent' blade pass frequency. Whilst these methods excluded periods where there is extraneous noise, significant time is spent data processing before the decision to exclude data is made. This is not efficient and has no benefit over manual methods of assessment (i.e. DAM / Den Brook).

9.64 In any event the RES and RUK methods also exclude periods where there is a combination of extraneous noise, wind farm noise and AM. They therefore exclude periods valid for analysis because the algorithm cannot separate out the extraneous noise from the wind farm noise. At many sites extraneous noise can be a common element particularly at certain times such as during the dawn chorus.

9.65 As becomes more apparent with further data processing the RUK and RES methods only work well when there is a clear and clean AM trace. This is not a significant problem for the RES method, which only seeks a value greater than 2.5, if there are periods of clear

[63] BS4142 could not be tested due to a lack of periods (with turbines off) from which a reliable background sound level could be obtained.

and clean AM mixed with periods where the trace is less clear. It is not a problem for deriving an AM value using the RUK method, a value can still be derived, but the values are typically lower than those obtained for a cleaner trace though the subjective impression of impact is similar. Thus, rather than preventing an assessment of EAM where there is extraneous noise or a 'muddied' AM trace the RES and RUK methods underestimate impact. Unclear or 'muddied' traces are a common feature of many conditions and localities around wind farms.

9.66 Significantly, the inability of the RES and RUK methods to work well where there is not a clear and clean AM trace suggests that the methods cannot be reliably used to assess frequency and duration of impact. Many valid periods may be missed due to extraneous noise and many periods may be missed because the clarity of the trace results in lower AM values being derived.

9.67 It also suggests that the RES and RUK methods should not be used as part of an averaging process (where such an approach is contemplated). Many points would be missed from the averaging process and thus an unrepresentative figure derived. Inability of the RES and RUK type methods to accurately assess AM due to inconsistencies between peak modulation frequency and blade pass frequency is a recurring theme found across the sites assessed.

9.68 Other problems identified with real world data and the derivation of a blade pass frequency for the RUK and RES methods were highlighted by the data from site 2. This contained both tonal 'resonances' and also had a variable blade pass frequency. [64] Whilst the tonal noise was solely attributable to the turbine, the tonality reduced the strength of modulation in the A weighted trace and disrupted derivation of the peak modulation frequency. This resulted in periods being missed from the RES / RUK analysis. This again reinforces the inability of the RES and RUK methods to work well where there is not a clean modulating trace and suggests that these methods will not accurately assess turbines / wind farms that have multiple, interacting character features. It is likely that interacting character features would be perceived by a listener as more intrusive than AM alone; however, the RUK and RES methods would assess it as less intrusive.

9.69 The variable blade pass frequency is a significant problem for the RES and RUK methods if simply analysing the data assuming a constant blade pass frequency. As demonstrated in the results tables at site 2, tables 2 and 3, when assuming a constant blade pass frequency AM values are much lower in the lower gear than would be attributable if the correct blade pass frequency had been used. This is also demonstrated by the data from site 5 in January 2015 and the modified RES analysis discussed above. These examples indicate that an automated process founded on rigid blade pass frequency information cannot be used to accurately reflect the impact of variable gear turbines or data where the blade pass frequency varies.

9.70 Operation of the turbine at site 2 in the lower or higher gear mode is unpredictable and often erratic and as such there can not be an easily automated process that reliably assesses periods with variable blade pass frequency without significant human

[64] Periods where the modulating tonality became louder and moved from modulating tonality to a constant tonal sound for a brief period. This was found to disrupt the derived peak modulation frequency.

intervention. Similarly, with reference to site 5 and the January 2015 data, without prior knowledge that turbines may be operating at different rotational speeds, significant periods of EAM may be missed from automated blade pass frequency analysis by falsely assuming a single, consistent blade pass frequency. Sites with multiple turbines exhibiting different blade pass frequencies or where the received signal is a result of more than one turbine blade pass signal are also likely to present difficulties for the RES and RUK methods.

9.71 Analysis at site 5 also indicates that there may be problems with the RUK method where consistent AM does not occur for long in a 10 minute period and so there are insufficient 10 second values from which to gain an A value (upon which the method defines and relies) above 0. This was the case at site 5 when turbines were only switched on in the last minute of a 10 minute period. Similar problems arose where extraneous noise occurred for significant portions of the period preventing a 10 minute A value above 0 being calculated, despite AM being clearly audible. This adds further evidence that the RUK method misses periods of EAM and again suggests that the method will only work in cases where there is a clean and constant AM trace unaffected by other noise sources.

9.72 The Den Brook rating method worked well with real world data including where there were extraneous noise sources. This is ultimately because it relies on visual inspection of the graphs and ensuring that the data gathered is attributable to the wind farm / turbine, not an extraneous noise source, prior to analysis. Significant problems would only arise for the Den Brook method where much of the noise trace was obscured by extraneous noise, for example AM might be clear and distinguishable from other extraneous noise in audio data, but if there is no clear visual indication of AM on a graph periods might be overlooked. This was not a significant problem in the cases analysed above, particularly with the use of audio and spectral data which was easily used to identify the presence of AM from extraneous noise at site 1.

9.73 The DAM rating method works well where there is no extraneous noise but can be significantly influenced where the extraneous noise source has a sudden onset and / or a significant peak to trough variation. A plane passing over or distant road traffic noise, because of its steady rise and fall, does not appear to corrupt the DAM rating.

9.74 Another feature of the DAM rating, highlighted at site 5, was an apparent limit of DAM values in the region of 6-7. This resulted in AM index values of up to around 10 at site 5 which was fairly representative but still underestimated significant peak to trough variation of up to 15dB(A). Lower DAM / AM index values were found at site 5 compared to site 1 and site 2. The peak to trough levels were similar a sites 1, 2 and 5. The main difference between sites 1 and 2 and site 5 is the number of turbines and variation in background sound level. The AM at site 5 was also more erratic and this could explain the lower DAM rating.

9.75 At site 5 there are 8 turbines operating and thus, in the absence of AM noise the background sound level is still dictated by the turbine noise. At sites 1 and 2 there are single turbines, smaller turbines and as such the noise level varies to a greater extent and background sound levels can fall lower in lulls of wind turbine noise. Thus, the DAM rating could be influenced by the background sound level or absence of background sound level depending on the number and size of turbines. The results from site 5 suggest that the

DAM AM index generally reflected typical peak to trough variation quite well; however, it was influenced by other noise sources and for some types of erratic AM it was not necessarily an accurate measure. As such it is not necessarily a representative measure of AM peak to trough level in all cases. However, the DAM ratings were consistent both in identifying EAM and rating significance of impact. It could therefore be used to assess AM relative to a trigger value or to confirm typical modulation level throughout a period if erratic peaks could be accounted for by other means, for example simply by visual identification. It is understood the DAM method was not designed to work with faster rotating turbines and this may be another factor for the variance with smaller turbines that rotate more quickly and more erratically.

9.76 **"b: The condition must be comprehensible and practicable to implement".** Any accepted method for rating AM should allow local authorities and those affected some understanding of what is and isn't acceptable in terms of EAM and the way in which this is demonstrated, not least as this enables an assessment of impact rather than providing a simple rating value. The condition should not be accessible only to those with specialist knowledge or software.

9.77 All four methods tested do require a basic level of acoustic knowledge at least in interpretation of the acoustic terminology. In terms of computational capacity and complexity the Den Brook condition is by far the easiest to implement. The data simply needs to be processed in to graphs showing how the noise level varies with time and ideally accompanied by audio data. From this there are three basic steps, ensure that the data is AM (by looking and listening and possibly as an extra measure, band pass filtering) establishing whether there is a regular 3dB(A) (or more) change in noise level and confirming that the average noise level is greater than 28dB(A).

9.78 The DAM method requires a little more understanding of how noise levels can be measured, but essentially it is a basic process of subtracting two different ways of measuring the noise (fast and slow) and looking at the range of the result (the difference between the L5 and L95). Again, this allows a fairly easy understanding of how AM is measured and assessed.

9.79 The RUK and RES methods require a much higher level of understanding, to fully understand how the data is manipulated and how meaning might be attributed to the result. On the face of it the approach is fairly simple, AM is analysed by looking at how much energy there is in a defined period that modulates at the rate of the blade passing frequency of the turbine / wind farm. However, the way in which this measure of AM is achieved and how it relates to the subjective impact of the AM is complex.

9.80 Whilst software has been provided in order to run the process without having to understand the underlying processing methods, this does leave the method open to abuse and misunderstanding and without transparency for correlation of results with actual impact. There are also variations in how the method could be implemented. For example the RUK method begins by asking the assessor to enter a blade pass frequency. This can be applied to any amount of data, from one 10 minute period to a whole day or week of data. This allows significant scope for inaccuracies especially resulting from variable blade pass frequencies, for example as the turbine rotational speeds change with increasing or decreasing wind speeds. This is exemplified with reference to the RES method and data at site 5 from January 2015. Here it was shown that entering a single blade pass frequency for a week of data would miss periods of EAM because of the variation of blade pass frequency throughout the period. Even automatic detection of blade pass frequency presented difficulties in this case.

9.81 The RUK and RES methods also require a check of consistency between the peak modulation frequency derived from the data and the blade pass frequency of the turbines. This requires those assessing the data to have access to the turbine SCADA data, which may not be forthcoming. It could also introduce uncertainty and variation in results as the consistency check will depend on which turbine blade passing frequency is used, which is used if they differ between turbines or if an average value is taken, over what period of time should the be average taken? The reliance on SCADA data is a significant limitation. Furthermore an approximate assessment of EAM cannot be made from a brief snapshot of data and not without a certain amount of data, some of which may not be accessible, and not without significant processing time.[65]

9.82 As noted above, the RUK software requires the assessor to first enter the blade pass frequency of the turbines. This is arguably unknown without the SCADA data and in such a situation a preliminary analysis must be made. There is no guidance as to how the blade pass frequency might be decided upon from any preliminary analysis. Hence again, the methodology is not transparent and is open to interpretation with different interpretations giving different results.

9.83 The RES and RUK methods contain processes and terminology with which many will be unfamiliar. The processes used to analyse the data cannot be easily replicated without specialist software. In this sense the method is not truly open access. It is also difficult to see how the resulting data analysis relates to the measured noise (or peak to trough) level or subjective impact. Where values are averaged a real time analysis of impact with resulting AM values is not possible. Essentially the RES and RUK methods aim to evaluate the amount of energy that modulates (occurs) at a frequency consistent with the blade pass frequency of the turbines, i.e. it looks at the energy of the regular blade noise caused by turbines rather than other simultaneously occurring noise that does not have the same periodicity. However, despite the intent, the value that arises from the RES and RUK methods does not relate to the typical peak to trough level. The RUK penalty has little effect on controlling or reducing impact. As such it is difficult to attribute any meaning to the derived value(s).

9.84 **"c: The condition should relate to the impact it is being designed to prevent... take account of the psychoacoustic response... and reported complaints in existing cases".** In most cases, including those assessed above, residents have not complained that the noise is loud but have described other features that largely relate to the noise character. Whilst there have been studies that have aimed to establish subjective response relationships with objective measures it is still unclear how this directly relates to the impact of noise character. In many instances of noise with specific character, acceptability relates to the

[65] The effects of atmospheric refraction and distance on blade passing frequency are additional complicating factors that cannot be factored into the assessment but are additional real variables that need to be considered. The consideration of atmospheric effects is outside of the scope of this work package.

audibility of the specific characteristics in and around the home and not its actual "A" weighted sound energy level.

9.85 Amplitude modulation as a character feature has often been described as a peak to trough level as this is easily identifiable from visual inspection of a graph showing noise as it varies with time. The above data analysis and summary table 14 show that whilst all methods can successfully identify AM there is discrepancy between methods as to how AM is rated.

9.86 Furthermore, peak to trough variation is one of several factors affecting impact of AM. Care is needed if peak to trough level is considered in isolation and applied on a progressive scale rather than simply evaluating its existence / occurrence at unacceptable levels. The latter provides a line of acceptability that could be easily adjusted if other characteristics are present. It also provides a line of acceptability that once exceeded is considered unacceptable. This type of control would at the same time control, admittedly by indirect means, other factors of AM contributing to disturbance by simply requiring the intrusive character to be eliminated. Control of other or multiple AM factors would be more complicated to incorporate in to a progressive scale of unacceptability.

9.87 The two examples of EAM tested with BS4142 indicate that the assessment methodology would work well to control periods of EAM that are considered unacceptable by residents and where periods demonstrate intrusive characteristics in the measured data. Importantly BS4142 can account for the character of the area (background sound level) in the absence of the wind farm noise, which has anecdotally been reported as an important feature of psychoacoustic response to wind turbine noise. [66]

9.88 At sites 1, 3 and 4 the DAM rating method was found to be fairly consistent with the typical peak to trough level of the AM. At site 2 and 5 there were some significant peak to trough variations where the DAM rating and AM index did not well reflect the impact. The maximum AM index found from data at site 5, using the DAM method, was in the region of 10-11, whereas there were numerous examples of AM modulating by up to 15dB peak to trough. For periods where AM is more erratic and has higher, sporadic peak to trough variation the DAM method may not well reflect subjective impact.

9.89 The Den Brook and RES Den Brook method simply have thresholds above which the noise is identified as EAM. This was triggered for periods affected by EAM by both methods and as such does reflect the subjective impact and indication of complaints as it triggers above the given EAM threshold. The main criticism of this type of approach is that there is no gradation of impact. Thus, one case of AM might be considered less severe than another but there is no way to identify this using the Den Brook / RES methodologies. Whilst this might be considered a disadvantage it is noted that this area is substantially unresearched and further speculation as to how the impact of AM might be rated differently, accounting for peak to trough level, decibel level, tonality, unpredictability and other associated character features is far beyond the scope of this work package. Though there is scientific

[66] It has long been recognised that the character of an area influences expectation of noise and the extent of noise impact. There is no reason or evidence for this to differ in the case of wind farm noise.

support for use of a threshold of acceptability it is generally considered unknown how these factors (peak trough level, tonality etc) interrelate.[67]

9.90 The Renewable UK method provides an average AM value 'A' for each ten minute period but then converts this to a penalty that is applied to the overall noise level of the turbines. Typical ten minute A values are summarised in table 14 above and further in table 15 below. In most cases the A values derived for each 10 minute period significantly underestimate the level of peak to trough variation. There appears to be a much narrower range of values that result from the RUK method compared to the range indicated by the peak to trough modulation. For example peak to trough values of AM range from 2-15dB whereas the RUK A values range from 0-4.4. The implementation of the penalty resulting from the RUK A values has been discussed in detail above and is also addressed further below. It was found that in no cases did the RUK penalty result in control of impact, thus in no cases did it restrict adverse impact. The RUK method has been found to be ineffective and as such does not relate to the impact that it is designed to prevent.

9.91 **"d: The condition should be transparent. The methodology of the condition should be clear and detail any data manipulation or filtering steps".** A summary of each method assessed above and the steps involved in using the method are illustrated in figure 108 below. The figure provides a brief summary of the basic steps. More detail and specific data processing methods to achieve the RES and RUK steps can be found in the wording of the RES and RUK methodologies.

9.92 The DAM and Den Brook methods require the least number of steps to achieve an AM value / assessment result. The RES method has the most steps. Whilst there are clear steps in each method the processes that achieve these steps are vague and not clearly defined. This could lead to differences in the results gained from the same method and it leaves them open to interpretation. In turn this means the most lenient interpretation would have to be applied (resulting in lowest AM values) as ultimately the control of planning conditions is to the criminal standard of proof and compliance would have to be assessed beyond all reasonable doubt.

9.93 The Den Brook and, it is assumed, the DAM method require initial confirmation that the data is AM and is generated by the wind turbine / wind farm. This is not specifically defined in either method, but is presumed logical in implementing these methods just as it would be for any other noise condition implemented in the UK. In simple terms if the EAM values are triggered by noise other than wind farm noise then it is not a breach as the condition only controls wind farm noise. It would be for the enforcement body to demonstrate this.

9.94 The first step in the RUK method is to remove corrupted data; however, it is unclear and not defined what constitutes 'corrupted data' or indeed how this is decided. For example, 'corrupted' may simply relate to the removal of rain affected periods, as is the case with an ETSU-R-97 assessment. 'Corrupt' could also convey the need to remove extraneous noise, as with the Den Brook and DAM methods, and / or removal of instrument electrical corruption such as influence of the instrument noise floor. However, the RUK method

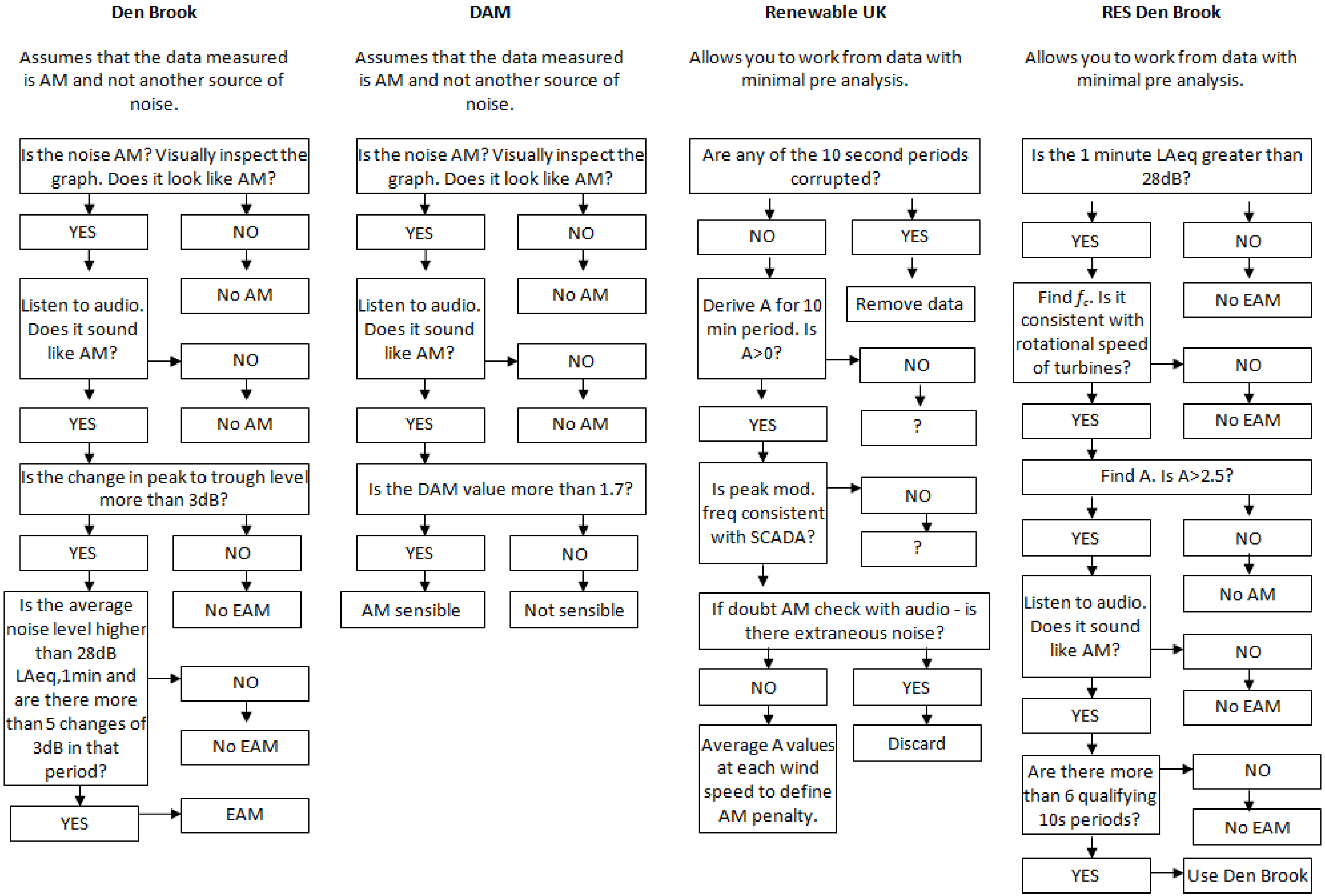
[67] Yokoyama, S., Sakamoto, S., & Tachibana, H. (2013). Perception of low frequency components contained in wind turbine noise. *5th International Conference on Wind Turbine Noise.* Denver.

clearly aims to minimise human judgement, i.e. time spent looking at the graphs or listening to the audio, and so it seems unlikely and illogical to visually or audibly review the data at this stage. If so the method would serve no benefit over the Den Brook method and the audio check specified later in the RUK method would be redundant / duplication.

9.95 An issue in clarity arising with both the RES and RUK methods is the check for consistency with the blade pass frequency (rotational speed of the turbines) or SCADA data. There is no definition of 'consistent', how often consistency checks should be made and how such judgements should be made. Where turbines have variable rotational speeds or where multiple turbines might cause variation in the blade pass frequency there could be differences between what is and isn't considered consistent. Checks using a simple parameter range, for example +/- 10%, might still require significant human input, which again defeats the benefit of an automated process. The +/-10% rule was adopted in this work package for simplicity but is itself problematic as it allows more leeway for inconsistency where turbines have a higher rotational speed than those with a lower rotational speed.

9.96 As discussed in reference to point 'b' above, the manipulation of the data is not always clear in the RUK and RES methods and the AM values that arise from these methods do not well relate to the peak to trough level of the turbine noise. AM values arising from the DAM method also do not reflect peak to trough variation in some erratic cases.

Figure 108: Comparison of methodology for each AM method assessed



9.97 **"e: be workable with large amounts of data and therefore be largely automated".** The desire for an automated process has largely been driven by the wind industry and those working for the wind industry. Whilst there are obvious benefits of ability for processing large amounts of data, this need has historically never been raised as a need or requirement of any other noise condition including those formed for wind farm noise under ETSU-R-97.

9.98 ETSU-R-97 controls are directed at a small sample of data points either side of a critical wind speed to determine a value at that wind speed. In recent times this approach has been interpreted by many as long term averaging despite the lack of any reasoned basis for such an approach. Other industrial noise sources typically have a noise condition attached to their operation, which states a noise level based on a short term period that should not be exceeded. It is the decision of those enforcing the condition to use their professional and expert judgement as to whether there are clear exceedances of the condition and whether these might be considered a breach or simply *de minimis* as they are too infrequent.

9.99 The Den Brook method is the method which potentially involves the most human input and judgement particularly where large amounts of data processing is required or desired; however, this is not necessary to validate community impact. Once the trace (the shape) of the turbine AM has been established for a particular site it is easy to identify this visually on graphs allowing extensive periods to be checked quickly. Assuming that the data can be analysed in to graphs in a program such as excel, the resulting data analysis need not be laborious and a night (23:00 - 07:00) of data can be analysed within a few minutes. Spectral data can also be used to quickly identify periods that are and are not affected by AM, as demonstrated at sites 1 and 2. The most time consuming judgement is perhaps the number of periods needed to demonstrate EAM before action is taken. For example, it is unlikely that action would be taken to enforce AM based on measurements from one evening period with 3dB(A) peak to trough modulation occurring only for an hour or two.

9.100 BS4142 arguably also requires significant human input; however, in the history of the use of this standard there has been no requirement or need to automate the process for the purpose of assessing compliance of industrial noise sources with their noise conditions. An automated result could be designed to some extent, for example to automatically pick out background sound levels, wind farm noise levels and potentially a typical EAM value; however, this would likely still rely on human input in obtaining appropriate data sets and verification checks would be needed. It is important to recognise that assessing compliance or breach of wind farm EAM does not require knowledge of EAM occurrence all the time, it only requires evidence of sufficient breaches such that it is clearly not *de-minimis*. A series of spot checks could verify this, especially if obtained during observed measurements.

9.101 The DAM method could be easily used on large amounts of data; however, the analysis above indicates that the DAM method can be easily skewed by extraneous noise sources. As such prior to any automation of the DAM method the data would need to be scrutinised to ensure that the data was unaffected by extraneous noise. This evaluation stage appears to be the process that the automated methods aim to avoid.

9.102 The RES and RUK methods are designed to be automated processes. However, before the RES and RUK methods can be run there is a basic level of data processing involved to ensure that data is in the correct format to be run with the software.

9.103 The data analysis above has indicated that there are significant problems with the automation of the RES and RUK methods. The methods do not work well when there are inconsistencies with or issues deriving the blade pass frequency. This occurs when there is wind farm noise and extraneous noise in the same period and when there are other character features of the turbine noise, for example tonality. It can cause periods of AM to be missed or can cause the AM value derived to be much lower than it should be as necessary to reflect subjective impact.

9.104 Whilst the RES and RUK methods could be run on large data sets and therefore be largely automated, there would be significant periods missed and in many cases unrepresentative values would be derived. The analysis above also highlights periods where the method fails to exclude extraneous noise. This is a significant disadvantage to any method that aims to be automated. As many periods of EAM are missed and periods with extraneous noise need to be excluded, the RUK method and to some extent the RES method require larger sets of data before an indication of EAM impact can be provided. It seems unlikely that these methods would be successful using shorter, attended periods of monitoring and selected analysis of periods of impact.

9.105 The RES and RUK conditions require human checks to be made, which undermines the aim of automation. Both require a check of consistency with blade pass frequency. This could arguably be automated if 'consistent' was formally defined. Where the blade pass frequency is variable, due to gear changes, where there are changes in wind speed affecting the rotational speeds of the turbine or where there are different rotational speeds of different turbines on the same wind farm, human intervention and correction would still be needed.

9.106 Both RES and RUK methods also require the audio data to be checked to confirm that the AM value derived is attributable to AM noise. With both methods this check does not appear until significant data processing time has been spent. This contrasts with the Den Brook and DAM methods, which exclude irrelevant periods at the start of the method by listening to the audio data and before any significant period of time has been invested in processing the data. Thus, although the detection of AM could be automated there are significant flaws with both methods. The additional checks (e.g. audio checks) that both the RES and RUK conditions require do not save time over the non automated Den Brook and DAM methods.

9.107 It is difficult to envisage a fully automated process that accurately assesses AM. The RES and RUK methods aim to characterise AM by approximating the AM variation as a regular sine wave, but AM rarely approximates a sine wave and typically occurs within what is essentially a random signal. As such there will always be the need to listen to the data to verify AM and automation can only really work where there is no other corrupting noise.

9.108 Furthermore the primary purpose of any control is to consider periods of adverse intrusion and how these periods impact on residents, not a long term assessment of averages which include periods of EAM along with the periods of less or no AM. This is a key failing of the RUK, and to some extent the RES, approach and appears to arise as a symptom of the automated process.

9.109 **"f: ...it must be shown that the condition is effective, the conditions must prevent periods of adverse AM".** This is really the key aim of any AM assessment method, a condition is not fit for purpose if it does not control periods of significant adverse impact. Table 14 above summarises the results from each site for each assessment method tested.

9.110 The Den Brook method identified EAM in all of the periods affected by EAM. At site 4 where there was wind farm noise but no EAM the Den Brook condition was not triggered. The Den Brook condition also worked well in distinguishing between borderline AM at site 5 on 11 October. At site 6, where there was no wind farm noise, the Den Brook condition did not trigger. The Den Brook condition therefore worked successfully in all cases. The only criticism that could be made is that it is simply a threshold value. No indication of EAM severity is given by the method apart from an approximate peak to trough range, which although provided in this work package is not required by the condition.

9.111 In the two cases tested with BS4142, the standard was shown to work well with wind farm data containing EAM and would effectively control adverse noise impact.[68]

9.112 The RES Den Brook method identified EAM in all periods affected by EAM with the exception of site 5 where there were some borderline periods. The RES method did not identify EAM at site 4 where there was only wind farm noise and no EAM. The method did identify EAM in the periods where there were significant periods of EAM but there were also numerous examples of EAM that were not identified by the RES method. Analysis has shown that the RES method of identifying EAM can be improved and better aligned with the original Den Brook method when either the first harmonic or all the harmonics are included with the first peak in the modulation spectrum to calculate the AM value.

9.113 However, at site 6 where there was no wind farm noise the RES method identified EAM using only the energy at the peak modulation frequency. This was the case even following checks of consistency between the assumed blade pass frequency and the peak modulation frequency. As such the RES method is susceptible to false positives.

9.114 The DAM method was affected by extraneous noise. With reference to periods where the rating was used only on wind farm noise the DAM rating method correctly identified EAM. The DAM method correctly did not indicate EAM at site 4, where there was no AM, with the exception of one 3 minute period. It also well distinguished between periods of borderline EAM and no EAM at site 5 on 11 October.

9.115 The Renewable UK method (RUK) is open to interpretation and as such different rating values of AM can be derived from the methodology. This work package has primarily derived AM values using a modified approach of the RUK method that typically results in higher values of A (for each 10 second period) than the RUK method as written, which inputs a constant blade pass frequency. Using the modified method higher 10 minute AM

[68] This is based on an assessment performed in accordance with the guidance including penalties applied for noise character and a difference between rated noise level and background sound level of +10dB (as opposed to +5dB which might be specified as a planning control).

values are derived and this presents a best case scenario for the RUK condition to control EAM. Notwithstanding the addition of this bias in the procedure to aid its assessment, the resulting RUK penalty did not exceed 3dB in any of the cases tested, resulting in no change or control over the wind farm noise. The 10 minute A values and the AM penalty that would be applied for each period has been calculated and is provided in table 14 above.

9.116 A separate more detailed table assessing the application of the RUK method is provided in table 15 below. This table gives the LA90 for each 10 minute period as well as the arithmetic mean of the LA90s assuming a constant wind speed at the site.[69] The table also gives the RUK penalty, derived from the arithmetic average of the A values for each 10 minute period, and the lowest ETSU-R-97 limit to which the penalty would be applied. The last two columns in the table give the difference between the rated wind farm noise level (LA90 noise level + penalty) and the minimum noise limit for each site for each individual 10 minute assessment period "Diff : Limit - (LA90 + P)" and also the difference between the average rated wind farm noise level (average of all the 10 minute periods assessed) and the minimum noise limit for each site for the whole assessment period "Diff : Limit - (Average LA90 + P)". A negative value indicates that the minimum noise limit is exceeded. Positive values indicate compliance with the limit.

[69] In accordance with the RUK condition the wind farm noise level would be derived by plotting a best fit line through the LA90 and corresponding wind speed values. In the absence of on site measured wind speeds an arithmetic average has been used as a substitute in this case assuming that all values in the period arose at the same wind speed.

Table 15: Summary of RUK assessment of AM sites 1, 2, 3 and 5

Site / date	Time	LA90, 10min	Arithmetic average LA90	RUK penalty (P)	Min night limit	Diff: Limit - (LA90 + P)	Diff: Limit - (Average LA90 + P)
Site 1 - 7 Sep	2220	25.4	26.4	3.3	35.0	6.3	5.3
	2230	26.3				5.4	
	2240	27.6				4.1	
	2250	27.1				4.6	
	2300	27.8				3.9	
	2310	26.1				5.6	
	2320	26.2				5.5	
	2330	25.0				6.7	
Site 2 - 31 Dec	0140	22.3	23.7	3.4	35.0	9.3	7.9
	0150	21.7				9.9	
	0200	24.5				7.1	
	0210	23.4				8.2	
	0220	23.6				8.0	
	0230	23.7				7.9	
	0240	24.8				6.8	
	0250	25.7				5.9	
Site 2 - 11 Jan	2020	26.3	26.5	3.1	35.0	5.6	5.4
	2030	25.8				6.1	
	2040	25.8				6.1	
	2050	25.0				6.9	
	2100	26.0				5.9	
	2110	27.2				4.7	
	2120	25.9				6.0	
	2130	26.8				5.1	
	2140	27.4				4.5	
	2150	27.0				4.9	
	2200	26.7				5.2	
	2210	25.7				6.2	
	2220	26.4				5.5	
	2230	26.6				5.3	
	2240	26.5				5.4	
	2250	26.5				5.4	
	2300	27.0				4.9	
	2310	26.8				5.1	
	2320	26.7				5.2	
	2330	26.7				5.2	
	2340	28.3				3.6	
	2350	26.9				5.0	
Site 3 - 10 Jun	0000	27.6	30.1	3.1	43.0	12.3	5.4
	0010	27.5				12.4	
	0020	31.5				8.4	
	0030	30.7				9.2	
	0040	31.0				8.9	
	0050	31.2				8.7	
	0100	31.2				8.7	

Site / date	Time	LA90, 10min	Arithmetic average LA90	RUK penalty (P)	Min night limit	Diff: Limit - (LA90 + P)	Diff: Limit - (Average LA90 + P)
Site 5 - 8 May	0000	30.5	35.1	3.2	43.0	9.3	4.7
	0010	30.4				9.4	
	0020	39.5				0.3	
	0030	39.6				0.2	
	0040	39.3				0.5	
	0050	31.0				8.8	
Site 5 - 11 Oct	0500	30.4	29.7	0.0	43.0	12.6	13.3
	0510	27.7				15.3	
	0520	27.8				15.2	
	0530	28.9				14.1	
	0540	32.0				11.0	
	0550	31.4				11.6	
Site 5 - 31 Dec	0400	38.7	39.0	3.1	43.0	1.2	0.9
	0410	38.7				1.2	
	0420	38.5				1.4	
	0430	38.9				1.0	
	0440	39.2				0.7	
	0450	39.9				0.0	
Site 5 - 6 Oct	0000	39.7	40.3	3.3	43.0	0.0	-0.6
	0010	40.7				-1.0	
	0020	41.1				-1.4	
	0030	41.3				-1.6	
	0040	41.2				-1.5	
	0050	41.4				-1.7	
	0100	39.0				0.7	
	0110	38.1				1.6	
	0120	40.4				-0.7	
	0130	40.0				-0.3	
	0140	39.8				-0.1	
	0150	40.0				-0.3	
	0200	40.2				-0.5	
	0210	40.2				-0.5	
	0220	40.2				-0.5	
	0230	40.5				-0.8	
	0240	40.9				-1.2	
	0250	40.7				-1.0	
	0300	40.5				-0.8	
	0310	40.7				-1.0	
	0320	40.1				-0.4	
	0330	40.4				-0.7	
	0340	40.2				-0.5	
	0350	40.2				-0.5	
	0400	40.2				-0.5	
	0410	40.1				-0.4	
	0420	39.8				-0.1	
	0430	40.1				-0.4	
	0440	40.1				-0.4	
	0450	39.9				-0.2	
	0500	40.2				-0.5	
	0510	40.4				-0.7	
	0520	40.4				-0.7	
	0530	40.7				-1.0	
	0540	40.8				-1.1	
	0550	41.5				-1.8	

9.117 With reference to table 15 above the overwhelming result of the RUK condition is that it does not enforce EAM. This is assuming the minimum noise limit that would be applicable in any case. Only at site 5 on 6 October is there potentially a *de-minimis* breach of the limit by 0.6dB. This margin of excess above the limit is highly unlikely to be pursued as a breach and is considered *de minimis*.

9.118 Furthermore, the noise limit at site 5 is assumed to be 43dB LA90. This is based on the minimum night time noise limit. In reality a higher noise limit is likely applicable as in this case the noise limit is based on the 10m measured wind speed rather than the 10m standardised wind speed to which the noise limits at this site are referenced. With the use of 10m standardised wind speeds and wind speed measurements taken from the hub height, as required by the noise condition at this site, it is highly likely that a higher noise limit would in reality be applicable. The RUK condition is shown therefore to be ineffective and incapable of enforcing adverse impact from AM.[70]

9.119 **False positives and inclusion of extraneous data.** The assessment of false positives, i.e. identification of AM where there is none, has been investigated as it is an erroneous criticism often made of the Den Brook method. The methods have been tested for false positives using data from a site where there was no wind farm noise. Similarly the methods have also been tested for false negatives (concluding that there is no EAM where there is EAM) where there is wind farm noise but also extraneous noise. Thus, it has tested whether the method can effectively filter out unwanted noise.

9.120 The second period of data at site 2 was included in analysis as much of the data was corrupted by duck calling noise. The duck's quacking often looks similar to AM and can occur with a regular periodicity. Whilst in some cases there did not appear to be much influence of the duck noise on the RES and RUK methods there were also periods where the influence of duck noise clearly skewed the RUK A value derived for a 10s period. It was also found that many periods clearly dominated by duck noise were included in the overall RUK AM value calculated for the 10 minute period. At site 1 the RUK method was also found to include extraneous noise in the derivation of A values.

9.121 The DAM value was also significantly influenced by the duck noise at site 2 but as noted above, the DAM methodology is not overly prescriptive and it is likely that the method would require extraneous noise periods to be removed prior to analysis. The Den Brook method, because of the reliance on visual inspection of graphs and checks with audio data (or spectral data) was not affected by the extraneous duck noise.

9.122 Data from site 6 was included to test the methods where there was no wind farm noise. As above, because the Den Brook method relies on visual and audio inspection, and because there was nothing in the data at site 6 that looked or sounded like AM, the Den Brook method did not identify the presence of EAM. A value for the DAM method could be derived from the data at site 6, and was heavily influenced by extraneous noise with a significant variation in decibel level but it is highly unlikely that this method would be

[70] Even if the limit was 43dB(A) there is then a process of averaging this breach with other compliant periods and it is likely the average over the entire night and many successive nights will be below 43dB(A). Even if a breach was identified, reducing the wind farm noise by 0.6dB will likely only increase the EAM, or not reduce it with no observable change evident.

applied without data checks first. The DAM method is not designed as a prescriptive algorithm.

9.123 Inclusion of data from site 6 was largely a test for the RUK and RES methods, which aim to achieve an automated process for identification and rating of AM. A blade pass frequency of 0.63Hz was chosen at random for this site, which is similar to the blade pass frequencies of the above sites 1-5. The RUK method did derive a 10 minute A value for each period. The value was similar to the values derived at site 5. Without further checks the RUK method indicates that the site had significant AM. Only at the point in the RUK method where the peak modulation frequency for the period is checked against the SCADA data (i.e. checked against the turbines blade pass frequency) would it be highlighted that there were inconsistencies. With reference to figure 108 above this check does not arise until significant data processing has already taken place.

9.124 The RES method also assumed a blade pass frequency of 0.63Hz. The initial run of the RES method, without checking for consistency of peak modulation frequency and blade pass frequency, found 30% of periods resulting in an A value greater than 2.5 thus indicating the presence of EAM. When the periods are checked for consistency with the blade pass frequency there are still a number of periods that meet the RES criteria and thus EAM is indicated. This is a significant finding and the identification of false positives by the RES method is a serious flaw in what intends to be an automated process.

9.125 The above discussion outlines the findings of detailed analysis and assessment of each AM assessment / rating method. The discussion highlights advantages and disadvantages of each method and lessons that can be learned from each approach. The advantages and disadvantages are summarised in table 16 below. To facilitate quick comparison and the relative merits of each method comments are rated with symbols to indicate good, ok (some problems) and bad (many problems).

Good	Ok (some problems)	Bad (many problems)
✓	?	✗

Table 16: Summary of positive and negative attributes of AM assessment methods

Test	Den Brook		RUK		RES Den Brook		DAM		BS4142	
Work with real data?	✓	Not affected by extraneous noise.	✓ ? ✗	Ok if the AM trace is clean. Does not work well when there is extraneous noise or other character features (tonality).	✓ ? ✗	Ok if the AM trace is clean. Does not work well when there is extraneous noise or other character features (tonality).	✓ ?	Ok if clean trace and no extraneous noise.	✓	Extraneous noise removed prior to assessment, uncertainty can be included.
Comprehensible & practicable to implement?	✓	Simple steps, easy to follow.	✗	Complex process. Need SCADA data.	✗	Complex process. Need turbine (SCADA) rotational data.	✓ ?	Simple steps but requires more post processing than Den Brook to get answer.	✓	Simple, easy to follow, established procedure.
Psycho-acoustic response?	?	Only gives a trigger value	✗	Value does not correspond to peak to trough level. Misses periods of significant AM.	?	Only gives a trigger value.	?	Gets onset correct and rates lower level AM well. AM index does not reflect isolated high peak to trough levels..	✓	Allows comparison with context of area and adds penalties for various noise characteristics
Transparent and clear?	✓	Easy to see how the condition rates AM.	?	Complex and undefined. Not clear on transformation between data and AM value.	?	Complex and undefined.	✓	Easy to see how the condition rates AM.	✓	Easy to see how result relates to impact.
Automated?	✗	Requires pre-analysis and audio checks.	✗	Audio checks needed. Includes periods of extraneous noise and misses periods of AM.	✗	Audio checks needed. Fails to exclude periods of extraneous noise and misses lots of periods of EAM.	✗	Skewed by periods of extraneous noise. Requires pre-analysis and audio checks.	✗	Parts could be automated but manual checks and input needed.
Effective?	✓	Consistently identifies EAM.	✗	Identifies and rates AM but penalty too low / subtraction from limit does not control adverse impact.	✓ ?	Identifies EAM but also misses lots of periods.	✓	Consistently identifies EAM.	✓	Tried and tested over many years. Identified adverse EAM and wind farm noise impact.
False positives?	✓	Pre analysis and audio checks prevent false positives.	✓ ? ✗	Fails to exclude extraneous noise. AM value can be derived where there is no wind farm noise, only when checks are made for consistency with BPF that method indicates no EAM.	✗	Method results in false positives. Fails to distinguish between extraneous noise and wind farm noise.	✓	Pre analysis and audio checks prevent false positives.	✓	Clear, defined methodology prevents false positives.

10 EAM control

10.1 The above discussion has highlighted significant issues with the RUK methodology and its proposed penalty applied to the ETSU-R-97 limit. The RUK method is fundamentally flawed, unfit for purpose and cannot be used as an effective or suitable means for EAM control. Significant problems have also been identified with the RES method of analysis and it is similarly recommended that this method, at least as a stand alone control, is discarded. However, the redeeming feature of the RES method is the means of control. It simply sets a trigger value and this control method, despite many examples of EAM being missed, in the majority of cases facilitated identification of EAM.

10.2 The DAM method could be influenced by extraneous noise and DAM values did not in some cases reflect the modulation peak to trough range of erratic EAM. However, it did successfully identify EAM and distinguish between borderline periods of AM and EAM. In most cases the DAM AM index gave a good representation of typical peak to trough level. The DAM method was much closer than the RES and RUK methods to representing the actual EAM peak to trough level. As such this method worked successfully as a means for deriving a trigger value or for providing a typical peak to trough level if erratic high modulation peaks were accounted for by other means.

10.3 The Den Brook and BS4142 methods provided the most consistently successful methods of identifying and rating EAM, though it is noted that BS4142 was tested on considerably less data than the other methods. BS4142 is advantageous as it assesses the cumulative impact of noise level and noise character. The Den Brook method is simple to apply and is not influenced by extraneous noise. However, it does not give any indicative gradation of severity of impact and any judgement of this is left open to the assessor.[71]

10.4 Going forward it is recommended that two separate assessment / enforcement methods for EAM can be used.

10.5 Where the noise from a wind farm is steady, continuous and anonymous ETSU-R-97 could continue to be used for assessment at the planning stage and for compliance testing.[72] Steady continuous wind farm noise may be classed as when the LAeq does not exceed the LA90 by more than 2dB, in accordance with the original assumptions of ETSU-R-97.

10.6 Where wind farm noise complaints indicate a variety of impacts including noise level, noise character, and / or tonality BS4142 can be used as a stand alone assessment independent of any other assessment, i.e. that of ETSU-R-97 compliance. The rating noise level of the wind farm / wind turbine noise should not exceed +10dB above the background sound level.

[71] Whilst the condition sets a threshold, i.e. the condition triggers and identifies non compliance or does not trigger, indicating no breach of condition, this does not mean that once the condition is triggered the wind farm must stop. An assessment must still be made as to whether it is expedient to enforce against a breach of condition.

[72] It may be appropriate to adjust the night time limit of 43dB LA90, which allows excessive night time noise and also possibly review use of LA90 which presents several problems including that it cannot be correctly mathematically adjusted for background sound influence. Furthermore it is noted that compliance testing in ETSU-R-97 does not specify a need for long term averaging of data points as now appears as common practice. Assessment of compliance requires 20 data points, 10 either side of the critical wind speed and this, for example, could mean no more than a few 10 minute period in four hours on any evening or night.

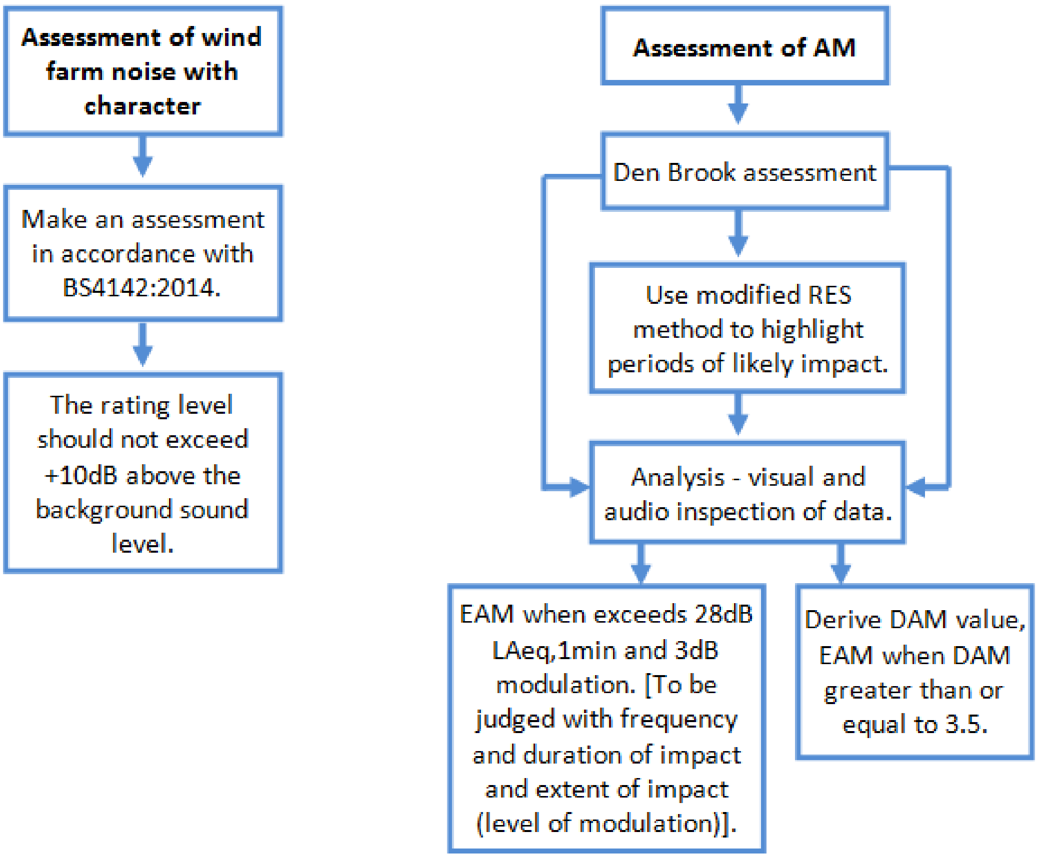
10.7 Where complaints relate specifically and primarily to AM, the Den Brook method should be used. Where appropriate or necessary, for example due to disagreement over the severity of impact, the RES and DAM methods can be employed to assist where data is challenged.

10.8 The conventional Den Brook assessment can be made to successfully identify periods of EAM. This must involve expert judgements of frequency and duration and importantly 3dB(A) modulation should not be treated as a simple trigger value.

10.9 Where problems arise in identifying periods of EAM the RES method can be used to aid identification of other periods affected by EAM. However, it is noted that the RES method misses periods of EAM and identifies false positives. The RES method should only be used as a tool to facilitate analysis and not relied upon for any assessment of impact, e.g. frequency and duration.

10.10 Where there is disagreement as to the extent of modulation level concluded from the Den Brook assessment, the DAM method can be used to derive an AM level. The DAM rating should be treated as a trigger value as it does not in all cases represent the higher peak to trough modulation of EAM. A DAM rating of 3.5 or above / an AM index of 5 or above is considered EAM. The testing protocol is summarised in figure 109 below.

Figure 109: Summary of recommended AM assessment methods



10.11 As with any noise condition it must be first ensured that the data being assessed is attributable to the wind farm. Where there is a substantial amount of data to process the RES method can aid identification of periods for focus of assessment. The BS4142 and AM assessment can be run as equivalent tests.

10.12 The best form of control would be a rated noise level as identified by BS4142: 2014 or the Den Brook metric where the problem noise is solely AM. The RES or DAM methods would not be specified in a condition but are simply acoustic tools which can be used to aid assessment, keeping their limitations at all times in mind. Controls would ideally be applied by reference to a code of practice that defines how the procedures of assessment work. Compliance would not be dissimilar to meeting environmental permit conditions as issued by the Environment Agency.

10.13 The code of practice could be subject to a trial period of testing to gain feedback on the practicalities and efficacy of use in the field, particularly by local authorities. The benefit of the code of practice in comparison to a planning condition is that this code of practice could easily be updated to include recommendations from this trial period and any other relevant feedback.

11 Conclusion and recommendations

11.1 The above analysis has shown that there are various ways in which AM can be assessed and EAM controlled. A primary finding of the testing is the failure of the Renewable UK method to effectively assess, rate and control AM. There are significant flaws with this method, it does not control EAM and as such it is recommended that this control mechanism is discarded as not fit for purpose. The findings of the RUK method indicate that a penalty type approach to enforcement of EAM, where applied to the ETSU-R-97 limit, will not reduce or remedy the case of complaints (i.e. the noise character) or noise impact where affected residents choose other coping strategies other than complaining.

11.2 All of the methods could be used with real world data although there is a clear need in all methods, though at different stages, to listen to the audio data to verify that the data measured is wind farm related. The RES, RUK and DAM AM values could all be easily skewed by extraneous noise and without audio checks would include extraneous noise in AM values. It is recommended that noise measurements of AM should be made simultaneously with continuous audio data so that audio checks can be made.

11.3 The RES and RUK methods propose an algorithm that is aimed to be transferable as an automated process. It is recommended that the RUK method is discarded due to significant flaws. The RES method is similarly flawed, though not to the same extent as the RUK method, primarily due to the means of EAM control. The RES method did not distinguish between AM and extraneous noise where data contained both. The RES method missed periods of EAM, though this is partly corrected through amendments to the algorithm suggested here. Most significantly the RES method identifies the presence of AM where there is none. It is recommended that the RES method for identifying AM is not used as a stand alone rating or assessment method. However, with modifications to the identification of AM and AM level the method could be used to complement other preferred approaches as a general acoustic tool. The evidence of this work package is that a fully automated assessment of AM is not possible with the current tools and means.

11.4 Conditions should be comprehensible, practicable and transparent. This was achieved to some extent by all methods but there were again issues with the RES and RUK methods. These methods lacked transparency with regard to the data manipulation and many convoluted steps reduce comprehensibility over the DAM, Den Brook and BS4142 methods. A primary issue of the RES and RUK methods is the need to check analysis of noise data against the turbine SCADA data. Problems also arise with the interpretation and application of SCADA data even when available, especially when there is more than one turbine and different rotational speeds. Furthermore SCADA data is not readily available and thus prevents all but the developer being able to readily assess impact. It is further noted that smaller turbines, to which any proposed AM control will inevitably be applied, may not record SCADA data with sufficient detail and may not record blade pass frequency or rotational speed at all. Averaged turbine rotational speed also introduces uncertainty and variability within results. Methods with a clear, practicable and easily understandable judgement of AM acceptability are preferred.

11.5 The use of BS4142 has been shown to work with wind farm noise data. Concerns raised previously with low background sound levels and influence of meteorological conditions, namely wind speed, have been addressed in revisions along with advancement of the science and quashed. The advantage of BS4142 over separate EAM assessment methods is the ability of BS4142 to assess noise level along with different noise character, including intermittency and tonality. BS4142 can also be used in conjunction with an assessment of wind farm noise level. It is recommended that for a holistic assessment of wind farm impact that BS4142 is the preferred method. This is consistent with industrial noise assessment in general including other energy producing systems with which wind energy competes.

11.6 Where there are generic wind farm noise complaints, including noise level, noise character etc, BS4142 should be used as a stand alone assessment independent of any other assessment, for example ETSU-R-97 compliance. The rated noise level of the wind farm / wind turbine noise should not exceed +10dB above the background sound level. This is higher than normal design parameters for other industrial noise sources. Flexibility for locality can be built into any adopted rating level. More discussion on the derivation of this value and the approach to applying and assessing using BS4142: 2014 is to follow in an addendum document detailing the proposed code of practice.

11.7 Where AM is assessed as an independent feature of noise impact, other methods can be employed but must be used separately and in addition to any assessment of noise level or other character features such as tonality or low frequency noise.

11.8 Where there are complaints relating to AM, the Den Brook method should be used and where appropriate or necessary the RES and DAM methods may be employed to assist assessment. Both the Den Brook and the DAM methods provide a threshold level above which EAM is considered present. EAM is considered an unacceptable feature of wind farm noise and thus its presence should be controlled.

11.9 There remains no objective means to assess frequency and duration of impact or other aspects of EAM that inherently influence perception. In the absence of research studying these effects it is recommended that such judgements remain an integral part of any enforcement action in the normal way, including what is expedient and in the communities' interests and what is *de-minimis*. Thus, the enforcement agency must use professional and reasoned judgement to address the extent of any breach and whether action is required to control it.

11.10 It is concluded that two separate assessment / enforcement methods of EAM can be used. As with any noise condition it must be first ensured that the data being assessed is attributable to the wind farm.

11.11 It is recommended that the detail of how to assess wind farm noise and EAM and what controls to apply should be set out in a code of practice. This should include recommendations and specifications for monitoring noise and detail regarding assessment of impact, which includes balancing the cumulative elements of general / steady wind farm noise with other additional compounding features (e.g. frequency and duration) and special noise characteristics. This is similar to the process found now with many forms of noise control such as environment agency permits / licences and noise level conditions based on BS4142.