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Cotton Farm Wind Farm long term community noise monitoring 4 years on: testing compliance and AM control methods.

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ABSTRACT

The Cotton Farm Wind Farm in East Anglia, UK, has been operating for approximately 4 years. There have been significant and widespread community complaints. Despite compliance testing by the operators and assessment of nuisance by the local authority, significant complaints continue without any resolution. A lack of clear guidance on how to assess AM is the reasoning of the local authority for failure to act and the operator's compliance testing has shown that the wind farm can, in a reduced operational mode, meet its limits. In 2013 MAS Environmental established a permanent monitoring station to record and publish data online, located 600m from the nearest turbine. This allows correlation of impact upon the community and establishes a library of wind farm noise data. This paper reviews the long lasting impacts of the wind farm and using data from the community monitoring station investigates how a 'compliant' wind farm continues to cause significant disturbance. The averaging processes used by many when assessing compliance with ETSU-R-97 are examined in relation to specific complaints and the new UK Institute of Acoustics and WSP / Parsons Brinckerhoff methodology for quantifying and assessing AM is tested. Using real world data from a site where there are continuing complaints, this paper assess whether current methodologies for assessing noise impact are fit for purpose.

Keywords: Wind Farm Noise, Amplitude Modulation, Compliance Monitoring

1. INTRODUCTION

In 2013 MAS Environmental Ltd (MAS) established a permanent monitoring station to record and publish online data from the Cotton Farm Wind Farm. The provision of the equipment was funded by local community donations. Cotton Farm Wind Farm comprises 8 Senvion (formerly REpower) MM92 2.05MW turbines with a total capacity of 16.4MW located between the villages of Graveley to the east, Great Paxton to the west and Toseland to the south in Cambridgeshire UK. The nearest dwellings are approximately 600 metres from the turbines.

At the planning stage the issue of AM and its likely occurrence at nose sensitive receptors was discussed. The consultant appointed by the developer argued against any AM controls, which were being sought by the local residents. The consultant noted " the small potential for increased levels of AM to occur does not justify accounting for it in addition to the noise assessment methodology presented in ETSU-R-97..." and concluded "Given the very small number of occurrences of increased levels of ‘blade swish’ or AM, it is my view that an appropriate way to control the potential for the noise from a wind farm to contain increased levels of AM is by way of statutory nuisance action." (1). Four years later Cotton Farm Wind Farm continues to produce significant and prolonged periods of AM far beyond any expectation of AM in ETSU-R-97 and no statutory nuisance action has been taken to resolve the continued community complaints.

Since commissioning, noise generated by the turbines has generated a large number of complaints. A letter recently published in the UK Institute of Acoustics (IoA) "Acoustics Bulletin" sought to dispel this fact (2), stating that the reported high volume of complaints was misleading based on freedom of information requests showing that in 2016 there had been only 2 complaints of wind farm noise to the local authority (3). Despite acknowledgements from the local authority that complaints had not been properly recorded[1] and that there are problems in the system for recording complaints (4) there appears an ongoing cause by those working with the wind industry to contend that wind farm complaints are rare. MAS have been copied in to only a small sample of complaints from those affected, but the evidence of a noise problem at Cotton Farm Wind Farm is overwhelming. There are multiple complainants generating a high volume of consistent noise complaints for over 4 years. This is all supported by historical logging of measured noise levels at the community monitoring station.

The case at Cotton Farm and its misleading reports of complaints published in the IoA Acoustics Bulletin perhaps highlights at the misfortune of those affected the flaws in the local authority complaints logging system but also the disregard, disbelief and disdain with which those affected by a noise nuisance can often be treated. It is also noteworthy that the World Health Organisation itself states that "only 15-25% of people identified as "highly annoyed" by noise in social surveys are estimated to complain" (5). Thus, even a minority of complaints, albeit not the case at Cotton Farm Wind Farm, is indicative of a much larger issue.

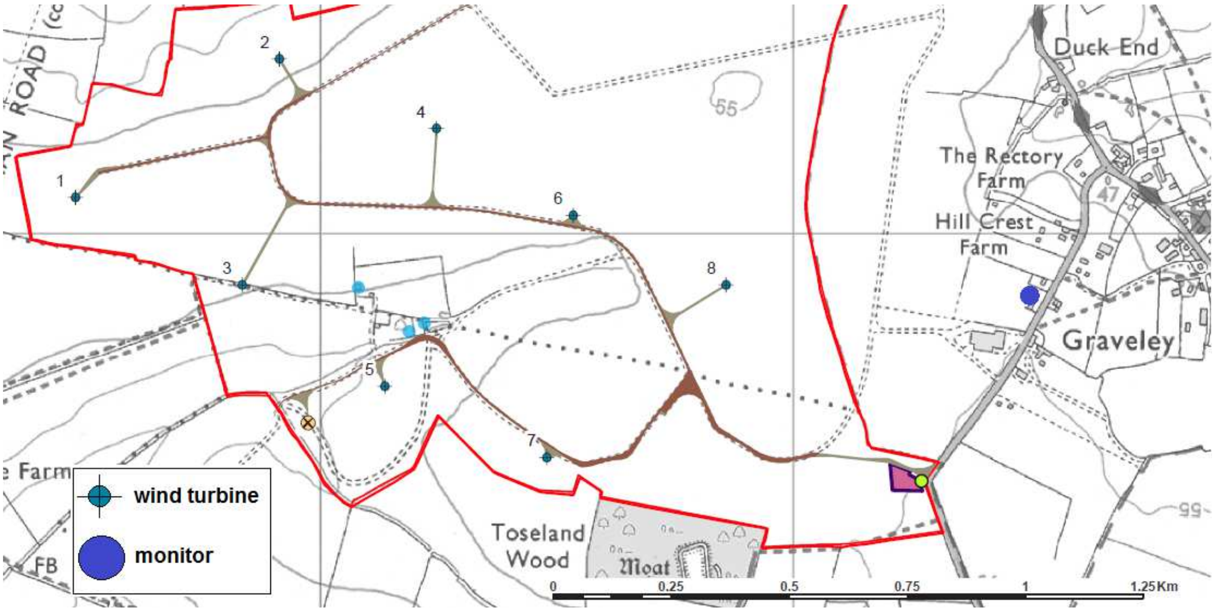

Figure 1: Location of wind farm and community monitoring station

2. COMPLIANCE AND AM CONTROL

2.1 Compliance with ETSU-R-97 limits

Wind farm noise in the UK is measured and assessed for compliance using the LA90 index. Following a complaint to the local authority a compliance testing exercise is typically undertaken in accordance with ETSU-R-97 (6). The guidance in ETSU-R-97 requires noise to be measured and assessed in accordance with the meteorological conditions that caused the complaint. At least 20-30 measurements should be taken within the critical wind speed (associated with complaints) to give a reliable estimate of turbine noise.

Whilst the intent of ETSU-R-97 is to establish conditions under which complaints arise and assess these on a more localised basis, for example one evening at a time as with the majority of other UK noise conditions, the trend in most compliance testing exercises is to measure and assess over a period of weeks or months. It is generally assumed that downwind conditions will result in worst case noise levels and complaints and a long term average is derived.

2.2 Compliance testing at Cotton Farm Wind Farm

Compliance testing for the Cotton Farm Wind Farm was requested by the local authority and this was undertaken by Hayes McKenzie Partnership Ltd on behalf of the owner of the wind farm. Initial testing in 2013 was undertaken with the turbines running in a curtailed mode and this revealed that the

[1] This is recorded in correspondence between local residents and officers at the local authority.

noise limits at a property representative of the community monitoring station were met by a minimum of 2dB. A second period of testing with the turbines running in an unrestricted mode found that the noise limits were being exceeded. Preliminary checks by MAS have found that whilst long term averages generally show compliance, shorter periods of analysis, for example on an evening by evening basis, indicate breaches of noise limits.

Whilst complaints from the Cotton Farm Wind Farm do reference noise level, they also describe the intrusive character of the noise as a "pronounced whomph", "whoosh", "swish" and "roar", namely linked with amplitude modulation noise (AM). ETSU-R-97 noise limits do not include the characteristic AM experienced at this site. At the time of ETSU-R-97's writing, swishing from turbine blades was identified but in the region of 800-1000Hz, it was reported as most apparent less than 50m from the base of the turbine and of the order of 2-3dB peak to trough, diminishing with distance. The type and level of AM measured from Cotton Farm Wind Farm in the community is entirely different to that considered in ETSU-R-97. As such the compliance testing undertaken for Cotton Farm Wind Farm deals with noise level only and not AM.

2.3 AM control

A minority of wind farms in the UK have been approved with a planning condition to control AM. In 2009 the Den Brook Wind Farm was approved with a condition that considered the regular occurrence of AM in excess of 3dB (as a peak to trough value in the A weighted time series) in the far field as unreasonable. MAS still uses this as a test of unreasonable AM and where this is found there is typically prolific AM with much greater peak to trough modulation. This analysis can be performed visually using time history graphs and verified with audio recordings as necessary. As such it does not require any proprietary software or specialist knowledge / expertise.

Other methods for assessing AM have been tested and reviewed though found to be lacking in different respects (7). In August 2016 the UK Institute of Acoustics Amplitude Modulation Working Group (IoA AMWG) published a methodology for rating AM (8). This was followed by a report produced by WSP / Parsons Brinckerhoff (WSP) on behalf of the UK Government Department of Energy & Climate Change (DECC) incorporating the IoA AMWG AM methodology in to a proposed penalty scheme that was argued could be used to control AM with a planning condition (9).

Greater detail on the methodology and results of both groups' findings / methods can be found in the relevant documents referenced above. In brief, both methods rate and assess noise in 10 minute periods. The IoA AM method assesses AM in band limited 10 second periods based on an FFT in the time domain. Following a series of analyses and tests, if sufficient (50%) 10 second periods with wind turbine AM are found, the 90th percentile of the 10 second ratings is used as the 10 minute AM value. The WSP report recommends using this 10 minute value to apply a penalty for AM to the ETSU-R-97 noise limit. The penalty ranges from 3-5dB. Fundamental floors with a penalty approach applied to ETSU-R-97 limits have been highlighted historically (10, (11).

3. TESTING AM CONTROL

3.1 Summary of analysis

The following sections discuss tests of the IoA AM method and associated WSP penalty approach using the library of data measured from the Cotton Farm community monitoring station. Complaints from the wind farm continue with no clear plan for resolution. Modifications were planned to the turbine blades at the end of 2016; however, this was not completed until early spring 2017. The blades at the wind farm now have serrations and whilst this was expected to help to address AM the residents have perceived little change in noise impact. Much of the analysis discussed below is based on data measured since the blade modifications and at the time of writing significant AM impact is still being recorded (see for example: http://www.masenv.co.uk/%7Eremote_data/plot.php#170522021000.2).

3.2 Example 1 - IoA AM method rates extraneous noise as wind turbine AM

AM is readily audible throughout much of the evening period of 30th April 2017 and a quick visual analysis of the time history graphs, as displayed on the Cotton Farm Wind Farm community monitoring station website, clearly shows periods of peak to trough modulation in the region of 5-7dB(A). The graph below shows an extract from the period 20:00 - 20:10 where a WSP penalty of 5dB is found to be applicable based on an IoA AM rating of 12.

The graph shows the band limited (100-400Hz) 100ms LAeq, upon which the AM analysis is performed. The peaks of noise in the 100-400Hz band limited LAeq are reduced from the overall A weighted trace, some peaks of noise are removed altogether but much of the pattern in noise levels remains the same. The graph is labelled to show the main sources of noise, namely people playing with their dog in the garden. On occasions some AM is audible but this is not readily distinguishable on the graph and extraneous noise dominates. The horizontal dark green line shows the WSP penalty and the pale green horizontal lines show the IoA AM ratings for each 10 second period. Whilst some AM is heard, this is for the minority of the time and the AM values are seen (and heard) to be mainly influenced by extraneous noise. Thus, the IoA method includes periods of extraneous noise as wind farm noise. This is a fundamental flaw with the methodology. Inclusion of extraneous noise has been a long running, though unfounded, criticism of other approaches.

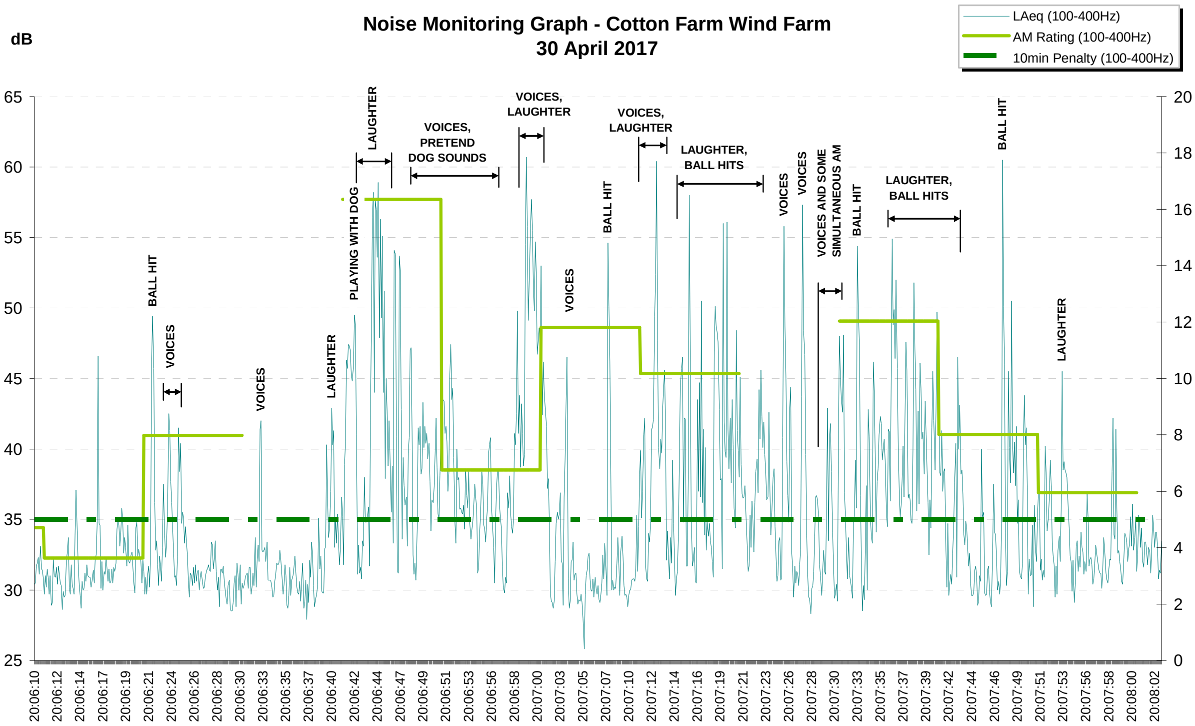

Figure 2: Cotton Farm Wind Farm 30 April 2017. Example showing periods of extraneous noise given an IoA AM rating

3.3 Example 2 - Conflict in which data band width to use

The IoA AM method requires the measured data to be split in to three third octave band frequency limited bandwidths, 50-200Hz, 100-400Hz and 200-800Hz. Whichever bandwidth provides the highest overall AM values should be used to assess and rate AM. This is decided by plotting the AM values for each bandwidth (50-200Hz, 100-400Hz and 200-800Hz) against the 100-400Hz bandwidth AM values, drawing a best fit line through the points plotted for each bandwidth and seeing which gives the highest overall results, i.e. looking for a best fit line above all the others. The example provided in the IoA AM document summarising the method gives a clear example showing that the 100-400Hz bandwidth should be used. This example is reproduced below as figure 3.

The IoA method does not specify how much or how little data can be included in any of the analysis, including when plotting scatter plots for determining which frequency bandwidth should be used for the final AM rating analysis. Clearly AM can vary in dominant frequencies and this is often reflected in descriptions of the sound varying from "swish", which may be associated with the 200-800Hz bandwidth and a "whoomp" or "thump" that may be associated with the 50-200Hz bandwidth.

The graphs below in figure 4 show the scatter graphs for periods analysed for AM at Cotton Farm Wind Farm. The top two graphs (A & B) show the period analysed on 1st May 2017 00:00 - 04:59. The second row of graphs (C & D) shows a slightly longer period that includes the evening of 30th April 2017, 21:00 - 23:59. The bottom two graphs (E & F) show other periods included for analysis on the 8th, 9th and 10th April 2017 namely evening and early morning periods (20:00 - 23:59 and 00:00 - 03:59).

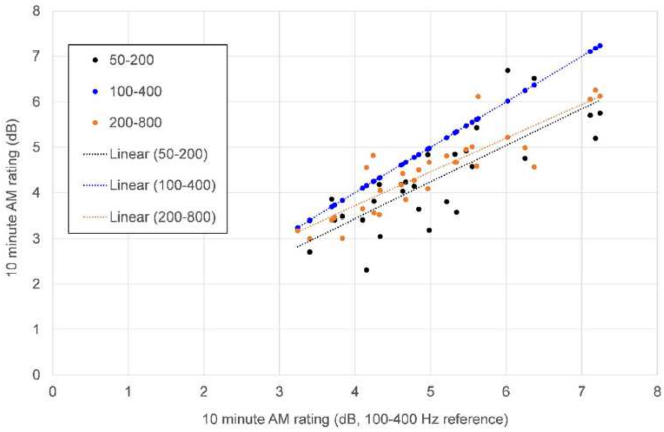

Figure 3: Comparison of ratings obtained with different frequency bands. This example shows that the 100-400Hz range should be used. (Taken from Fig 4.3.1 of the IoA AM Final Report.

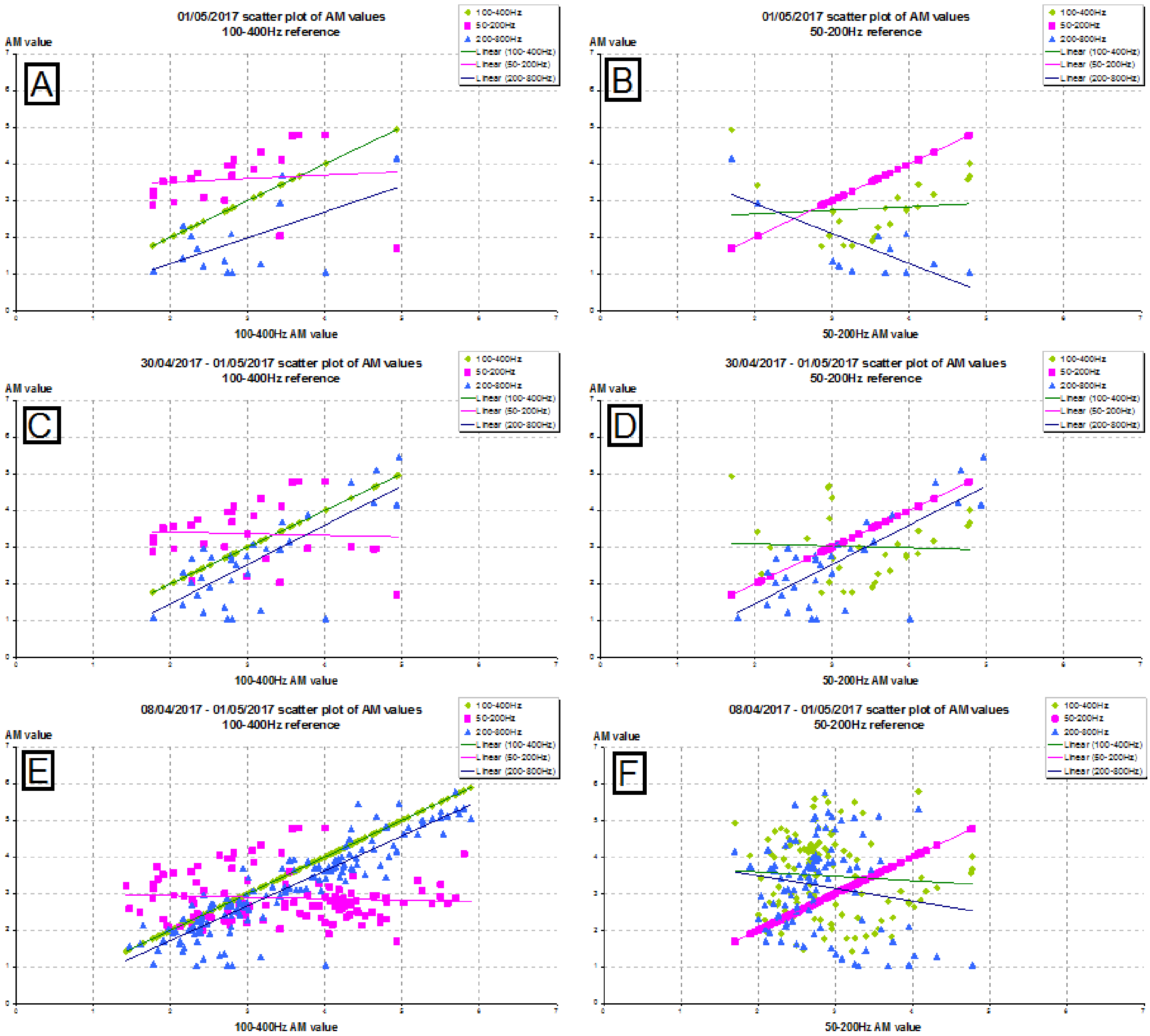

Figure 4: Scatter plots showing difference in the bandwidth to use for deriving AM values depending on number of periods used and reference values used.

The first column of graphs in figure 4 shows the AM values for each frequency bandwidth plotted against the AM values for the 100-400Hz band, as required by the IoA AM methodology. However, there is no reasoning provided in the IoA AM methodology for plotting values against the 100-400Hz bandwidth and plotting the AM values against different reference (x-axis) values (i.e. using the other bandwidths) can give different answers that often shift preference away from using the 100-400Hz band. The second column of graphs shows the AM values for each frequency bandwidth but plotted against reference values of the 50-200Hz bandwidth.

Graph A, using data only from 1st May and using 100-400Hz reference values, presents a muddled picture of which bandwidth should be used to assess AM, there is no best fit line that is clearly and consistently higher than the others. AM values between 2 and 3 on the x axis are higher using the 50-200Hz bandwidth (pink best fit line) but AM values between 4 and 5 on the x axis are higher using the 100-400Hz bandwidth (green best fit line). Graph B, using data only from 1st May but plotted against the 50-200Hz bandwidth values clearly suggests that the 50-200Hz AM values should be used (the pink best fit line is fairly consistently above the others). As more data is included the picture is less clear. Graph E shows a preference for 100-400Hz values to be used whereas graphs D and F still show some preference for the 50-200Hz values.

Thus, not only does the method provide conflicting answers depending on how much data is included but it would be very easy for two different people analysing the data for AM to obtain quite different answers depending on which bandwidth is chosen for analysis.

3.4 Example 3 - Same IoA AM rating but difference in compliance

The purpose of the IoA AM method is simply to provide a value for the AM that has been measured. The aim of the WSP report was to recommend how excessive AM might be controlled using a planning condition. The two examples below show how the WSP method fails to achieve a consistent approach to penalising AM. Both examples have the same AM rating value (as defined using the IoA AM method) and attract a similar penalty. However, due the LA90 values of the measured noise one example of AM is acceptable whereas the other isn't. This demonstrates the strong dependence that the WSP method still places on noise level rather than noise character (AM). It is noted that the ETSU-R-97 limits are in place to control the noise level of wind farm noise in the UK and the purpose of the IoA AM method and WSP control is to penalise AM. The examples below indicate that it is the level of noise that is still being penalised and not the level of AM that is measured.

The graph below shows an extract from the period 22:00 - 22:10 on 8th April 2017.

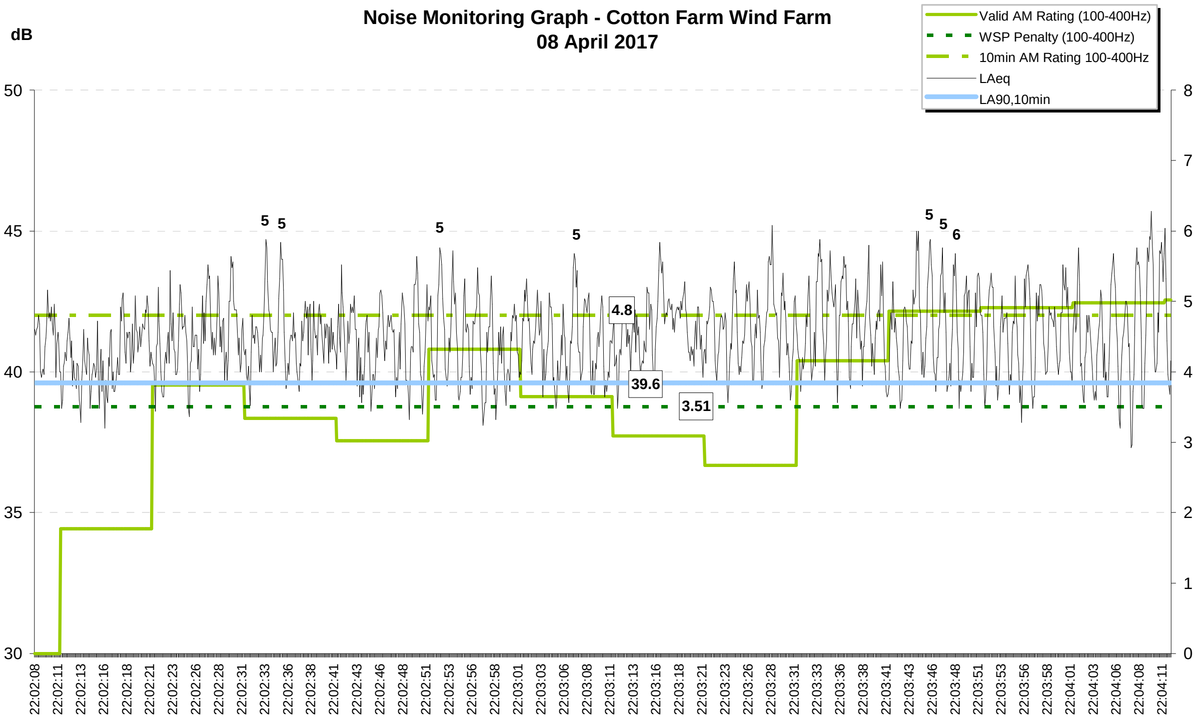

Figure 5: Cotton Farm Wind Farm 8 April 2017. Example showing AM rated by the IoA AM method as 4.8 and that exceeds the noise limit using the WSP penalty by 7dB.

The AM shown in figure 5 above is fairly consistent, some typical peak to trough values are shown on the graph as 5-6dB(A). The 10 minute IoA AM rating is 4.8 resulting in a WSP penalty of 3.51. Following the WSP method for applying the penalty to the measured wind farm noise level, assuming in this case that there is no significant reduction to the LA90 for background sound, the rated wind farm noise level is 43dB LA90, 10min. The 10m high wind speed measured at the community monitoring station during this period was 3m/s. The wind speed derived from the hub height wind speed (as required by the planning condition) is likely to be higher thus resulting in a higher noise limit if enforced in reality. However, the noise limit at 3m/s is 36dB LA90. Thus, the period below exceeds the noise limit by 7dB.

The graph below shows an extract from the period 03:20 - 03:30 on 1st May 2017. The AM is more erratic (less regular and constant) during this period, some typical peak to trough values are shown on the graph as 5-8dB. The 10 minute IoA AM rating is 4.93 resulting in a WSP penalty of 3.55, similar to the example on 8th April shown in figure 4 above. Following the WSP method for applying the penalty to the measured wind farm noise level, assuming in this case that there is no significant reduction to the LA90 for background sound, the rated wind farm noise level is 36dB LA90, 10min. The 10m high wind speed measured at the community monitoring station during this period was 3m/s. The wind speed derived from the hub height wind speed (as required by the planning condition) is likely to be higher thus resulting in a higher noise limit if enforced in reality. However, the noise limit at 3m/s is 36dB LA90. Thus, the period below meets the noise limit and is compliant.

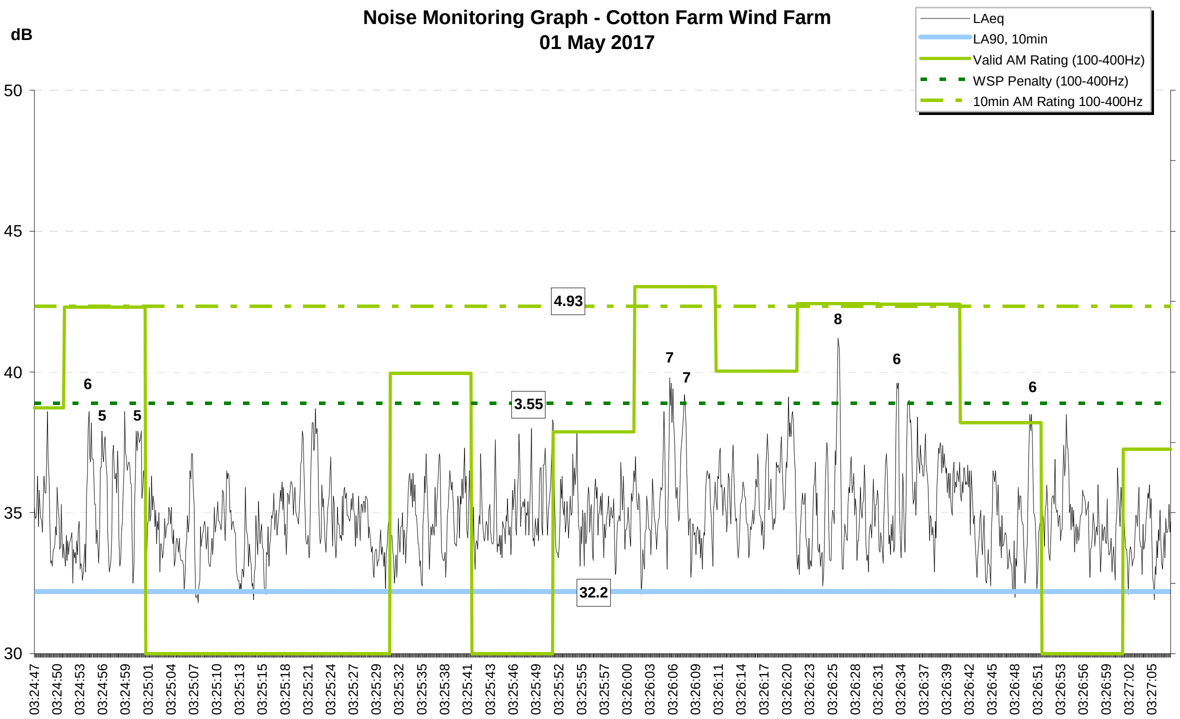

Figure 6: Cotton Farm Wind Farm - 1 May 2017. Example showing AM rated by the IoA AM method as 4.93 but that meets the noise limit using the WSP penalty and so is compliant.

Thus, two periods of AM with similar IoA AM values are considered unacceptable in one case and acceptable in the other using the WSP penalty approach. This is despite both examples having a similar AM peak to trough variation and consisting of a sound environment dominated by AM.

3.5 Example 4 - Erratic periods of AM missed by the IoA AM method

The graphs below show excerpts from four periods where AM is very similar in peak to trough level, shape and character. The audio indicates that there is mixing in the wind farm sound with periods where very clear peaks emerge but also periods where AM can be heard but mixed in with other wind farm sounds, such as multiple peaks of noise from multiple turbines / blades.

The audio and visual analysis shows that the periods are entirely dominated by wind farm noise and characterised by AM. However, checks within the IoA AM method result in discarding periods of AM often when the trace is not as 'clean' as other periods. This results in many periods of AM being excluded despite ongoing impact. As the IoA method requires at least 50% of periods within a 10 minute analysis period to provide 'valid' AM values, several 10 second periods where the AM is not 'clean' enough for the IoA AM method to identify it as wind farm AM results in a whole 10 minute period of impact being excluded from analysis and essentially discounted from the investigation of impact, treated like a period where there is no wind farm noise or AM.

The top two graphs show two extracts from ten minute periods at 01:30 and 01:40. The band limited LAeq is plotted to show the noise trace upon which analysis is performed. There is little observable difference between the two graphs. However, the first graph attracts a WSP penalty of 3.63, the second does not attract any penalty (a penalty of 0 as the IoA AM value is 0). Similarly the bottom two graphs show two extracts from ten minute periods at 02:30 and 02:40. The first graph does not attract a penalty but the second attracts a WSP penalty of 3.68. The two periods look and sound very similar. Thus, the IoA AM method is easily prone to missing many periods of AM, failing to result in an AM penalty and thus significantly underestimating the severity of impact.

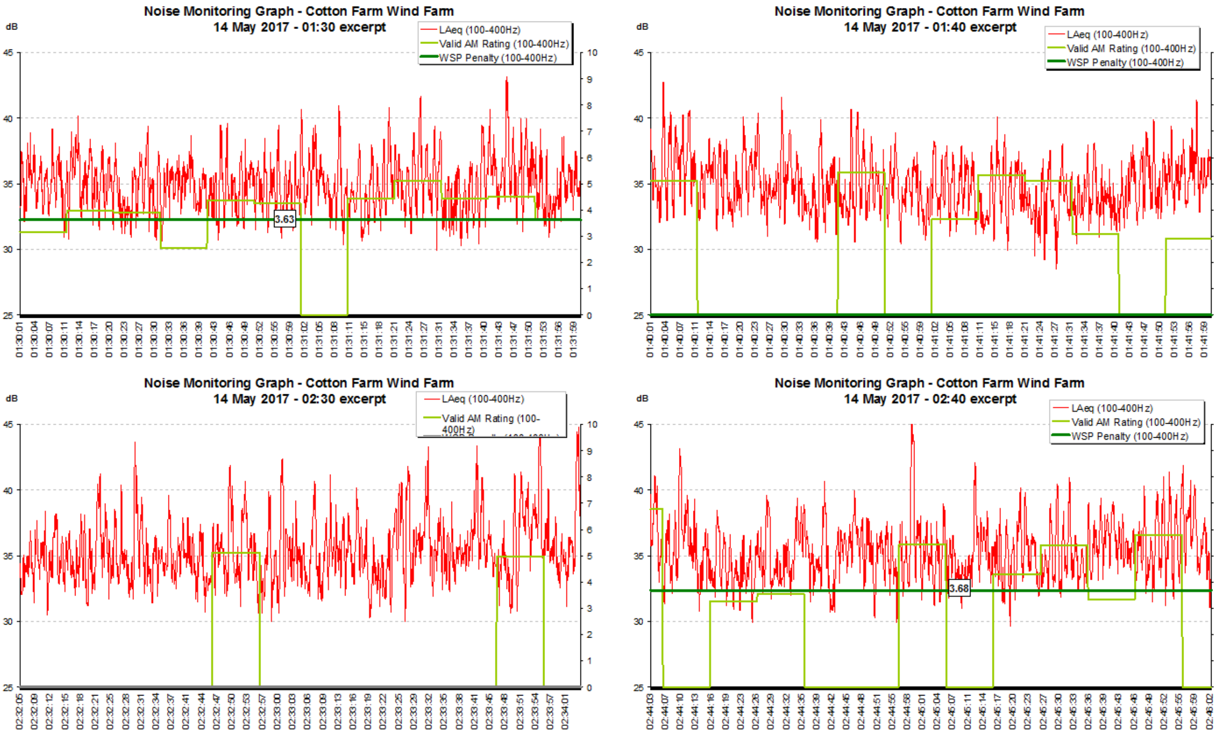

Figure 7: Cotton Farm Wind Farm - 14th May 2017. Examples of AM with some periods excluded from analysis (i.e. not counted as AM) and very similar periods that are included in analysis (counted as AM).

3.6 Example 5 - Upwind AM

The community monitoring station at Cotton Farm Wind Farm has provided numerous examples of upwind AM. This is of note not only as wind farm noise monitoring typically excludes all periods that are not downwind of the wind farm but also as it contradicts some of the basic assumptions detailed in the IoA method, which are based on the Renewable UK research (12). The IoA method states that the type of AM that occurs at residential distances is caused by transient stall of airflow over blades and that this is heard primarily downwind of the rotor blade. The IoA method also repeats the assertion made in the Renewable UK research that where this type of AM does occur, it is occasional, though it can persist for several hours. However, as shown by the wealth of data recorded by the community monitoring station at Cotton Farm, AM with significant peak to trough modulation occurs in most wind directions and its occurrence is regular, not occasional, and can persist for several days.

The graph below shows AM with a peak to trough variation regularly of 6-7dB(A) and the 10 minute AM value for the period using the IoA method is 4.48. However, as the AM occurs in upwind conditions (an ENE wind) it is highly likely that this period would be excluded from analysis. If the period was included in the analysis, it suffers from the flaw in the WSP method where periods with a low overall noise level can contain AM without being penalised. The measured LA90 for the period 01:00 - 01:10 is 34dB LA90,10min. With a WSP penalty of 3.42 the rated wind farm noise level (assuming no reduction for background sound) is 37dB LA90,10min. The 10m measured wind speed is 2m/s; however, if this were representative of the hub height wind speed (standardised to 10m height) the wind farm would not be operational and so it is fair to assume (based on data of typical differences) that the hub height wind speed is around 5m/s. This results in a 10m height standardised wind speed of 4m/s (and is based on the standardised wind speed method required by the noise condition). The noise limit at 4m/s is 37dB and so the period is compliant with the limit and no action is required.

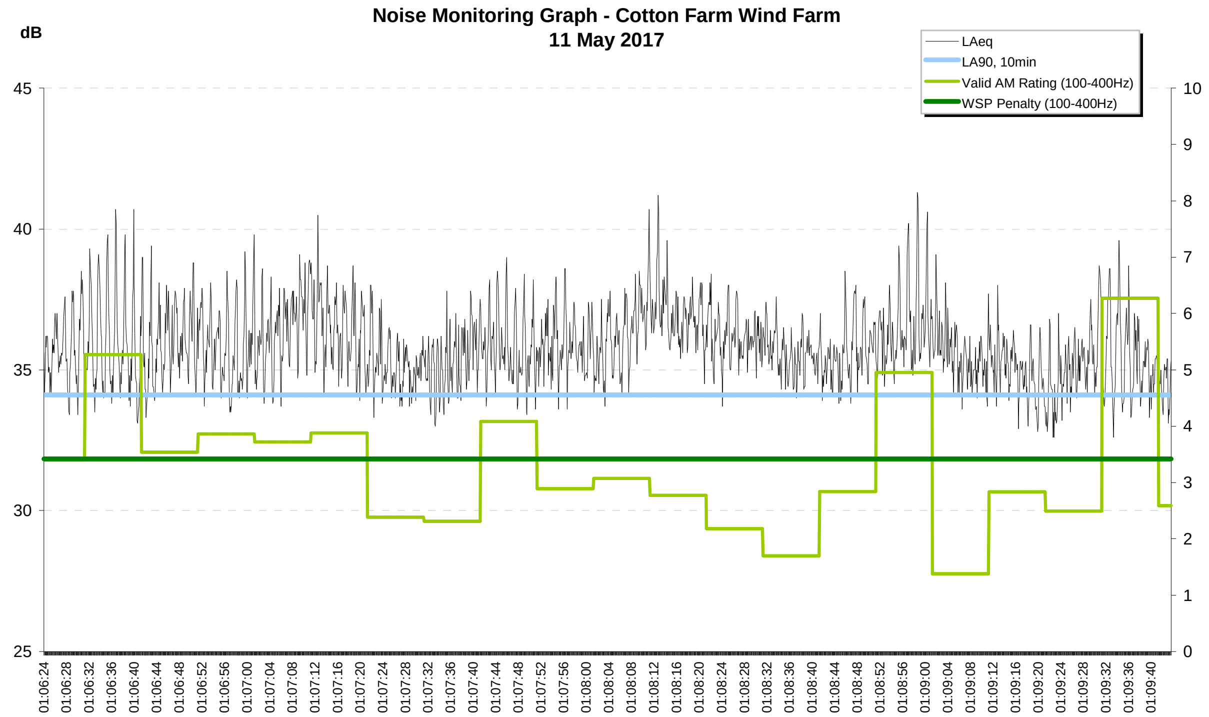

Figure 8: Cotton Farm Wind Farm - 11 May 2017. Example of upwind AM and failure of WSP penalty to deal with AM due to lower LA90

3.7 Example 6 - WSP penalty has no effect on severity of AM impact

The two examples below are taken from the same early morning period and demonstrate the final stage, i.e. the enforcement stage, of the WSP penalty approach. The WSP report states that if action is taken against the operator due to a breach then either the degree of AM has to be reduced below the 3dB rating threshold OR the overall penalised decibel level has to be reduced below the limit. Taking the latter approach there could be no need to reduce the level of AM.

The first example below was measured on 1st February 2017 and is an extract from a 10 minute period that breaches the noise limit both due to the wind farm noise level (LA90) but also due to the AM penalty. The measured LA90 is 39dB (assuming no reduction for background sound) and the IoA 10 minute AM value is 5.78. This results in a WSP penalty of 3.79. The 10m height measured wind speed is 4m/s resulting in a noise limit of 37dB LA90. Thus the period breaches the noise limit by 6dB.

Following the WSP approach, there are two options. Firstly, the level of AM (modulation depth) could be reduced below the 3dB rating threshold. The second example below (figure 10) shows an extract from a period on 1st February 2017, the same early morning period, but where there is no penalty applied as there is no IoA AM rating. In effect, the methods conclude that there is no AM, or not enough AM, worthy of penalty within this period. A simple visual comparison of the graphs demonstrates their similarity. The second approach would be to reduce the level of wind farm noise so that the level (and added AM penalty) are compliant with the limit. This means that the period shown in figure 6 above, from 1st May 2017, would be acceptable. Again, there is still prevalent AM. As such the two resolutions that WSP offers do not necessarily prevent excess AM from impacting in a similar way regardless of any penalty or rating applied.

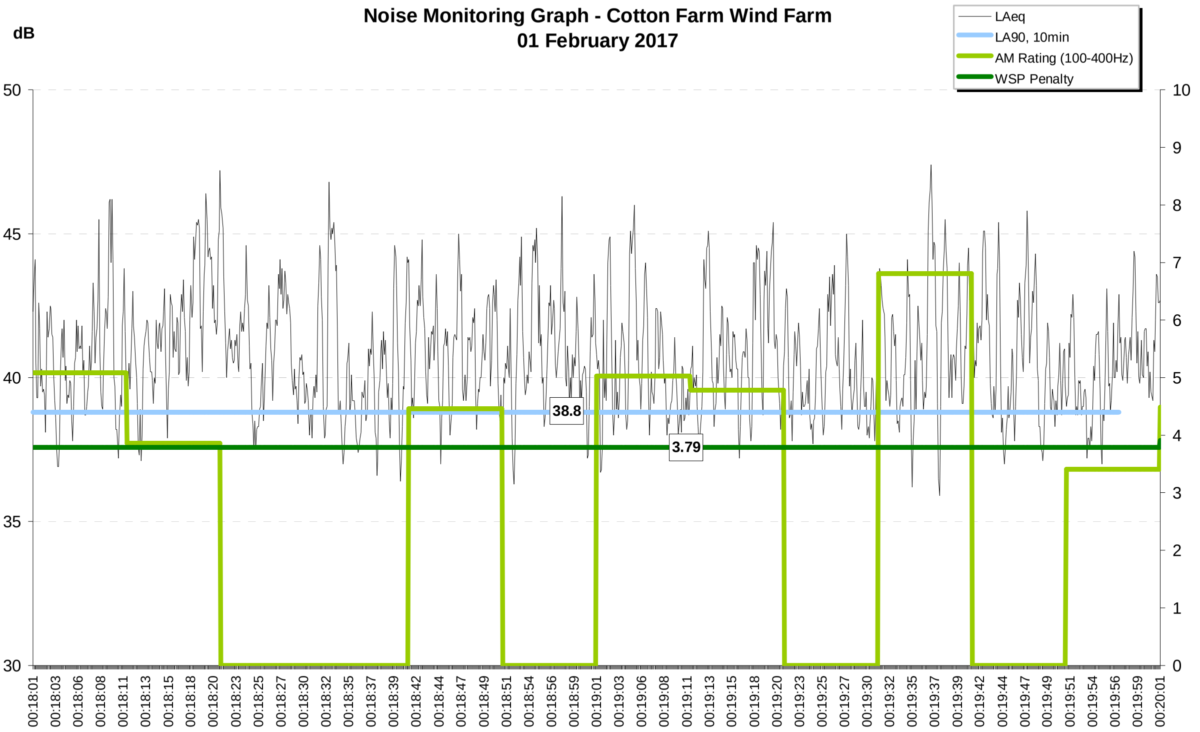

Figure 9: Cotton Farm Wind Farm - 1st February 2017. Example of AM period in breach of noise limit.

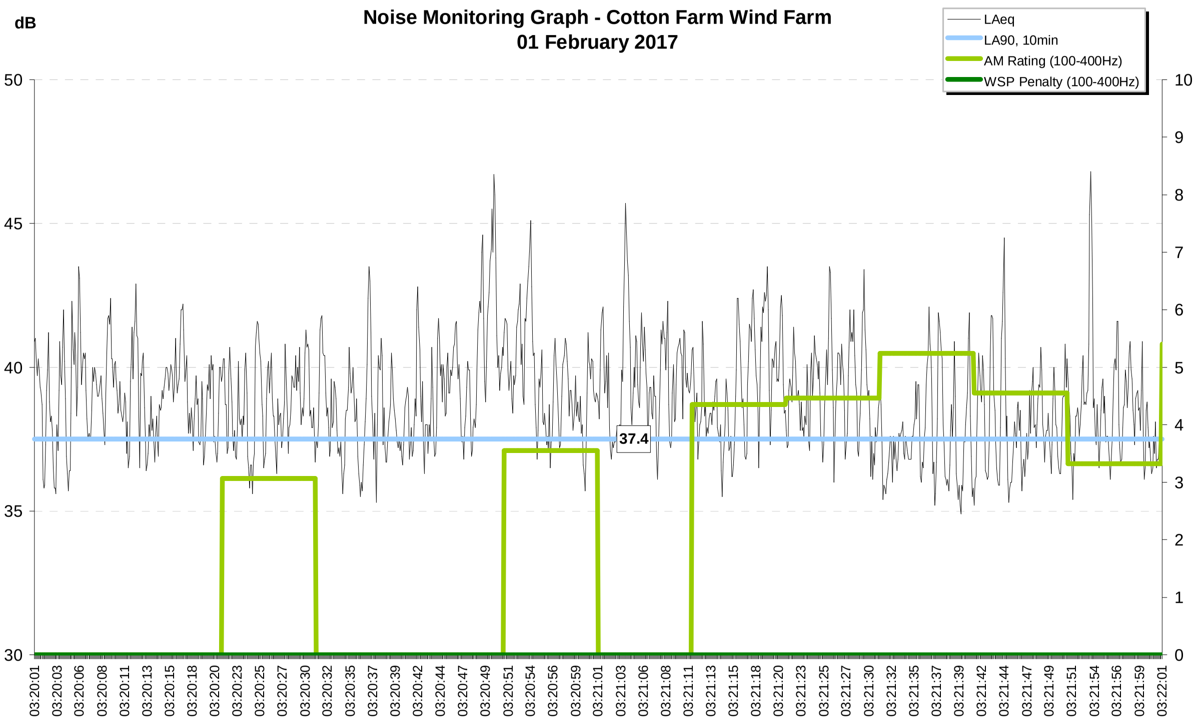

Figure 10: Cotton Farm Wind Farm - 1st February 2017. Example showing a period that is compliant due to lower LA90 and no 10 min IoA AM rating / WSP penalty. In contrast to the above period, this period is compliant.

4. CONCLUSIONS

The Cotton Farm Wind Farm has no controls on AM. At the planning stage those working to develop the wind farm did not consider there to be any risk, despite evidence presented to the contrary. 4 years later there are significant community complaints and no resolution. Cotton Farm Wind Farm produces significant AM in a range of conditions including in upwind conditions.

Recent methods have been published in the UK that seek to quell the debate on how to rate and assess AM. However, the above analysis demonstrates that these methods fail and are far from fit for use as an automated approach, detached from human judgements and input.

The above analysis provides a brief overview of some of the testing undertaken with the IoA AM method and the associated WSP penalty approach. Whilst in many cases where there is 'clean' AM a reasonable AM value can be obtained using the IoA AM method, it is by no means foolproof and is prone both to misuse and flaws within the methodology that ultimately results in significant periods of AM being missed or ignored. Such results could effectively be used to undermine community complaints. There are similar issues with the WSP penalty approach, which results in periods containing similar AM being penalised in one case but not in another.

The ongoing complaints at Cotton Farm Wind Farm indicate that the community have not become acclimatised to the wind farm noise or AM and complaints are well supported by the evidence provided by the community monitoring station. Whilst the local authority have looked to Government and professional bodies for guidance on how to assess and rate the noise complained of, the methods proposed by WSP and the IoA tested above do not provide a simple or reliable solution as claimed by their promoters.

The search for a completely automated assessment tool that can reliably and accurately detect and rate AM still seems far off. The long and technically complex processes employed by the IoA AM method do not have a significant advantage over a simple visual and auditory analysis of the data and they are subject to the same flaws that a more manual approach has historically been criticised for. Whilst assessment tools and methodologies can undoubtedly help to guide assessment our eyes and ears currently remain the most sophisticated analytical system for this type of noise.

ACKNOWLEDGEMENTS

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REFERENCES

1. Bullmore, A (2009) Proof of Evidence on Noise. Land at Cotton Farm, Offord Road, Gravely, St Neots, Cambridgeshire. PINS ref: APP/H0520/A/09/2119385
2. Lotinga, M (2017) "Don't be grossly misled by astonishing wind turbine noise complaint figures", *Acoustics Bulletin* Vol 42 No 2 March / April 2017: p61.
3. Lotinga, M (2017) "...but official figures reveal just <u>two</u> complaints last year ", *Acoustics Bulletin* Vol 42 No 2 March / April 2017: p61.
4. Gray, B (2017) "Wind farm noise <u>did</u> generate thousands of complaints...", *Acoustics Bulletin* Vol 42 No 3 May / June 2017: p62.
5. World Health Organisation (WHO) (2000) *Noise and Health* Copenhagen: WHO.
6. Great Britain. Department of Trade and Industry (DTI) (1996) *The Assessment and Rating of Noise from Wind Farms.* ETSU-R-97.
7. Large, S. (2016). A quantitative and qualitative review of amplitude modulation noise from wind energy development. *Internoise 2016*, Hamburg, Germany, 21-24 August 2016
8. Institute of Acoustics (IoA) Amplitude Modulation Working Group (2016). *A Method for Rating Amplitude Modulation in Wind Turbine Noise.*
9. WSP Parsons Brinckerhoff (2016). *Wind Turbine AM Review: Phase 2 Report.*
10. Large, S. (2014). Investigating amplitude modulation noise: what about character? *"AM, where to next for ETSU-R-97?"* IoA one day meeting on wind turbine noise. 20th March 2014. Newport, Wales.
11. Large, S. et al (2015). Wind Turbine Amplitude Modulation & Planning Control Study. Work Package 5 - Draft AM Condition. Independent Noise Working Group.
12. Renewable UK. Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect.