The Inaudible Soundscape of a Wind farm
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Summary

Whilst people become habituated to transport noise the opposite occurs for long term exposure to wind turbine noise. People become sensitised to the noise that in the end affects them and in extreme cases requires these people to abandon their homes. Typical noise targets are applied external to the dwellings and do not address internal noise environments. A pilot study of using inaudible wind turbine noise from field measurements inside a dwelling found sensitised people to respond to the inaudible wind turbine noise as a sensation in their heads and legs. The pulsing nature of the wind turbine time signature and the nature of the fluctuations of such signals to the perception by test subjects is discussed.

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1. Introduction

In January 2015 our report into the Cape Bridgewater wind farm [1] was released in Australia and generated considerable discussion in acoustic circles around the world in relation to the presentation of new data concerning the operation of a wind farm. The study was not an investigation in terms of the normal compliance concept for a wind farm but was a study that responded to specific issues of disturbances reported by residents following the commencement of operations at the wind farm.

After initial consultation with residents, in terms of their ongoing disturbances experienced from their perception as a result of the wind farm, the wind farm operator provided a specific brief for our investigation being:

Noise and vibration measurement shall be undertaken to determine certain wind speeds and certain sound levels that relate to the disturbance reported by specific local residents.

The study brief was NOT to:

- Conduct a normal A-weighted acoustic compliance method,
- Undertake a socio-acoustic study, or
- Undertake a health investigation, and
- Specifically, did not include a control group as the study was only related to six specific local residents.

Because of the project brief for the investigation, a different approach to that normally encountered in acoustic compliance testing was undertaken. The approach necessitated extensive discussions with residents to identify the disturbance that they were experiencing.

In discussing the disturbances the residents experienced, it became apparent the typical acoustic descriptors of noise do not cover the adverse impacts that were being experienced. This led to the use of additional descriptors being added to a social survey, that being the addition of the concept of “vibration” and, separately the concept of “sensation”.

In our view the approach of investigating the complaints concerning the Cape Bridgewater wind farm are similar to our approach in investigating complaints from industry, or for that matter noise from licensed premises (music from night clubs) where it is essential to listen to the subjective assessment of the complainants to ascertain any audible characteristics, time or other relevant parameters that may relate to the level of disturbance.

2. Soundscape of a Wind Farm

Unbeknownst to us, the investigation at Cape Bridgewater, and our report describing the acoustic emissions of the wind turbine “noise” with respect

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to that perceived by the residents falls into the definition of a “Soundscape” contained in the syllabus for a course titled “Soundscape Studies” available at the RMIT University in Australia [2].

The course describes a soundscape:

“***An environment of sound (or sonic environment) with emphasis on the way it is perceived and understood by the individual, or by a society. It thus depends on the relationship between the individual and any such environment***”.

The author was invited to present a paper in the soundscape session of the Acoustical Society of America’s meeting in Jacksonville in 2015 [3]. It would appear from the outcome of that meeting that the Cape Bridgewater study, whilst not originally defined as a soundscape study, may very well be the first soundscape study into a wind farm.

In the intervening period we have undertaken research in relation to the qualification of infrasound as perceived by people, investigation into the capability of presenting or reproducing exact replica of the original signal of a wind farm and investigation into the accuracy or appropriateness of exposing people to inaudible infrasound that has been generally attributed to wind farms.

The issue of concern in our previous work is that in many cases it is impossible to ascertain the A-weighted level of noise attributed to a wind farm by reason of the acoustic environment of the area and the relatively low levels of wind farm noise that may be audible (or not), but still give rise to disturbance.

For most wind farm assessments that have been undertaken around the world, it appears that the noise attributed to the wind farm at residential receivers is one of a theoretical/predicted noise level.

The regression analysis method of utilising the overall A-weighted noise level versus wind speed assumes that the background noise is a combination of turbine and ambient noise that are then averaged and compared with measurements prior to the operation of the turbines upon which a regression analysis is used to indicate the average noise level thereby leading to the determination of noise emission from the turbines?

But if the A-weighted level of the turbines cannot be actually measured, then how does one define the soundscape?

If the regression analysis is based upon a background level, then how does that relate to an Leq level that is the result of pulsating emissions from the turbines?

If most assessments of wind farms are related to an external measurement, then how does that relate to impacts inside dwellings?

Inside dwellings the presence of infrasound and low frequency signatures that vary in level and may be below the nominal threshold of hearing are often found. In such cases environmental authorities dismiss complaints based on inaudibility.

Having attended and conducted extensive measurements in dwellings in proximity to wind turbines we are often faced with a situation that residents can detect the operation of the turbines when my staff and I have been unable to detect any noise or sensations. To us the turbines are inaudible, but residents sense the operation of the turbines. Why?

This question has constantly been in the back of my mind in relation to the assessment of wind turbines, in that if we look at a narrowband analysis we can see discrete infrasound signals are occurring inside rooms. In 2013, I determined from field testing at the Waterloo wind farm that if we have a narrowband FFT LAeq analysis using 0 to 25 Hz for 400 lines, when there is the presence of signals in the region of 4 to 5 Hz and those levels exceed 50 dB(Z) then the residents who have been sensitised to the wind farm can clearly identify the operation of the turbines – without seeing them.

We have utilised the concept of narrow band measurements in the infrasound region to identify the operation of turbines versus the natural environment – because the FFT of the pulsations give rise to this signature [4]. The unique situation in the Cape Bridgewater study of having the wind farm turned off completely (for the purpose of cabling at the high voltage substation) gave the opportunity to measure before and after the turbines were shut down and started up (on multiple occasions), to identify the acoustic environment with and without the turbines and thereby prove the presence of narrow band signature in the infrasound region.

Some people have sought to utilise the concept of infrasound from turbines as a potential level of disturbance. This is despite such levels of infrasound being significantly below the threshold of hearing that has been attributed to the infrasound region. The fact that they find no response when restricted to only a synthesised infrasound [5] and the full spectrum of the actual sound is a relevant issue [6].

Some people have considered the use of “wind turbine” infrasound on its own with the notation that such levels are inaudible to support the concept of a nocebo effect.

For example, much weight has been given to work from Crichton (in New Zealand) where several papers [7] [8] have claimed that the use of inaudible pure tones in the infrasound region to be an appropriate test for identifying the nocebo effect of wind turbines.

Crichton [9] [10] presents an argument for the nocebo effect for “wind farm infrasound noise” by the statistical analysis of the observations but provides limited information in terms of the qualification of the “infrasound signal”. From the advice given to test subjects as to the presence of wind farm infrasound (versus “sham” infrasound) there is a conclusion the nocebo effect is a result of the power of suggestion. However, examination of the data reveals that the use of actual wind farm infrasound did not occur. The results of the testing cannot claim and reliance on actual wind farm infrasound.

In one case Crichton used a 5 Hz tone at a level of 45 dB as the “infrasound” triggering signal and in another case used a tone at 9 Hz around 54 dB with the suggestion in the papers that the single pure infrasound tone is similar to that from wind turbines.

From our measurements of wind turbines using narrow band analysis we have been unable to find a single 5Hz or 9 Hz tone at a constant level from wind farm installations.

Figure 2 reproduces a graph from the main report for the Shirley wind farm [11] that shows the discrete peaks in the infrasound region. The green trace is the external measurement whilst the blue trace is the internal measurement. Both traces show a slight peak at the blade pass frequency with the 2nd, 3rd, 4th and 5th harmonics being clearly evident. The internal levels do not show a distinct single peak at either 5 Hz or 9 Hz used by Crichton. Superimposed over the measured levels for the Shirley wind farm study in Figure 2) is an overlay of the manufacturer’s free field response of the Mackie HRS 150 used in the Crichton study (shown in orange) [12] to indicate the frequency response of that sub-woofer. The dotted lines are an extension of the roll off from the manufacturer’s data sheet. Apart from the limitation of the response of the speaker/amplifier combination [13] it can be seen from the result of the Shirley Wind Farm graph that the production of just a single tone at either 5 or 9 Hz cannot be presented as “wind farm infrasound”.

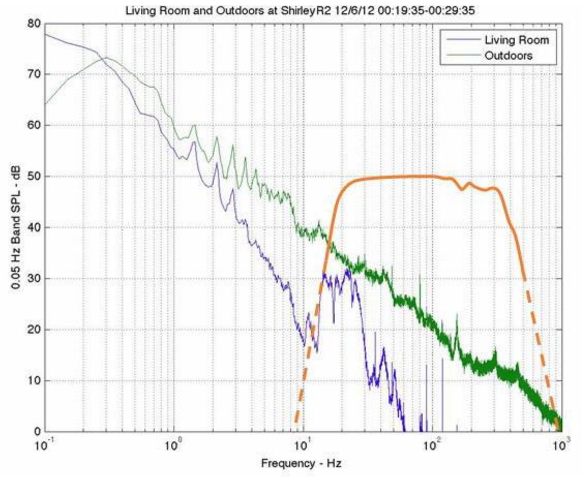

Figure 1: Shirley Wind Farm [11]

Walker has utilised the concept of taking a narrowband LAeq FFT spectrum of a signal and then digitising those individual frequencies to create a signal that in the time domain purports to have the same energy as the original signal. Tonin has used such a process for the assessment of inaudible infrasound from wind turbines.

Walker [14] utilised one of the spectrums presented in the Cape Bridgewater study recorded inside a dwelling and purported to conclude that the synthesised signal was the same as that generated by the turbines. However, when Walker's digitised time signal is compared with our original time signal it is obvious that the two signals are not the same.

It therefore is not surprising that if people are subject to an inaudible digitised signal that on an energy basis is the same as the original signal restricted when to just the infrasound region, but does not sound the same, then they would not get the same result as experienced by person subject to the original signal [5]. A foregone conclusion to support the nocebo concept but based on incorrect data.

Annex D of ANSI/ASA S12.9-2016/Part 7 [15], specifically warns against the use of infrasound signals that may have the same energy component but sound entirely different.

We undertook the exercise in our laboratory of having a system that could generate an infrasound signal associated with wind turbines [4]. For example, we could produce 95 dB at 1 Hz as a crystal-clear sine wave with the second and third harmonics 35+ dB down below the fundamental.

Subjecting people to the digitised infrasound from turbines versus the original signal (but restricting the material to the infrasound region) did not find any subjective results. We took the two signals and increased the speed of the sample 100 times and then listened to the signals. In terms of the digitised and the original there was no comparison, i.e. they are not the same.

We conducted investigations into the legitimacy or otherwise of the narrowband analysis of turbine signals [4] and formed the conclusion that because the signal was transient pulses that are of a very short duration then in terms of frequency analysis, the fundamental formula of BT =1 (B = bandwidth and T = sample time) is not satisfied.

Analysis of full spectrum WAVE files of wind turbines has revealed the presence of a dynamically pulsed amplitude modulation of the entire spectrum for both audible and inaudible sound that becomes the unique signature of turbines [16].

Of relevance to the inaudible soundscape of a wind farm is the presence of amplitude modulation in the low frequency region, that modulates at an infrasound rate, at or near the threshold of hearing that has been identified (in [16]) and may support the following proposal:

> “***Wind Turbine Syndrome, I propose, is mediated by the vestibular system—by disturbed sensory input to eyes, inner ears, and stretch and pressure receptors in a variety of body locations. These feed back neurologically onto a person's sense of position and motion in space, which is in turn connected in multiple ways to brain functions as disparate as spatial memory and anxiety. Several lines of evidence suggest that the amplitude (power or intensity) of low frequency noise and vibration needed to create these effects may be even lower than the auditory threshold at the same low frequencies. Re-stating this, it appears that even low frequency noise or vibration too weak to hear can still stimulate the human vestibular system, opening the door for the symptoms I call Wind Turbine Syndrome.” Pierpont 2009***

3. The spectrum inaudibility testing.

Having attended and conducted extensive measurements in dwellings in proximity to wind turbines were then often faced with a situation that residents can detect the presence in the operation of the signal. The residents have formed the view that “sensation” is a better description to “noise” or “vibration”.

We have observed a variability in impacts/distress for residents in proximity to wind farms. We have noted that over time some residents appear to become worse/more sensitised.

In our investigation of the properties of just the infrasound component of turbines or the full spectrum (over a few hours) I and my staff have experienced headaches and pressure sensations from levels that are classified as inaudible.

To address the perception of persons who may be considered sensitised to wind turbine noise and examine the claim of residents sensing the operation of the turbines without actually hearing the noise, a series of experiments were undertaken last year utilising persons in Australia [17] who have been identified as being sensitive to wind turbine noise, and low-frequency noise that exhibits pulsations occurring at an infrasound rate (“test group 1”).

In 2013 Schomer [18] proposed the possibility that a limited number of residents subject to noise from wind turbines may be experiencing motion sickness and suggested the construction of a test facility that utilise special transducers to extend down to very low frequencies (0.05 Hz or lower)]. Schomer proposed to undertake sensing tests that could then lead to further medical examinations on animals to develop an understanding why the phenomenon seems to affect some residents near wind farms and establish who are affected by wind turbine infrasonic emissions in various ways.

We have previously utilised one of our reverberation test chambers (having a volume of 126 m^3) with twelve 15” sub-woofers mounted in the aperture between the reverberation chambers to investigate threshold of sensation versus threshold of hearing in the infrasound region [6], and investigations into the “infrasound signature” from wind turbines [19], [20] & [21]. Those investigations were undertaken using pure tones or external (free-field) noise measurements of wind turbine noise.

The chamber has been used to investigate the generation of recorded wind turbine noise versus field measurements to identify the issue of pulsations across the entire spectrum and that the synthesis method that has been proposed for

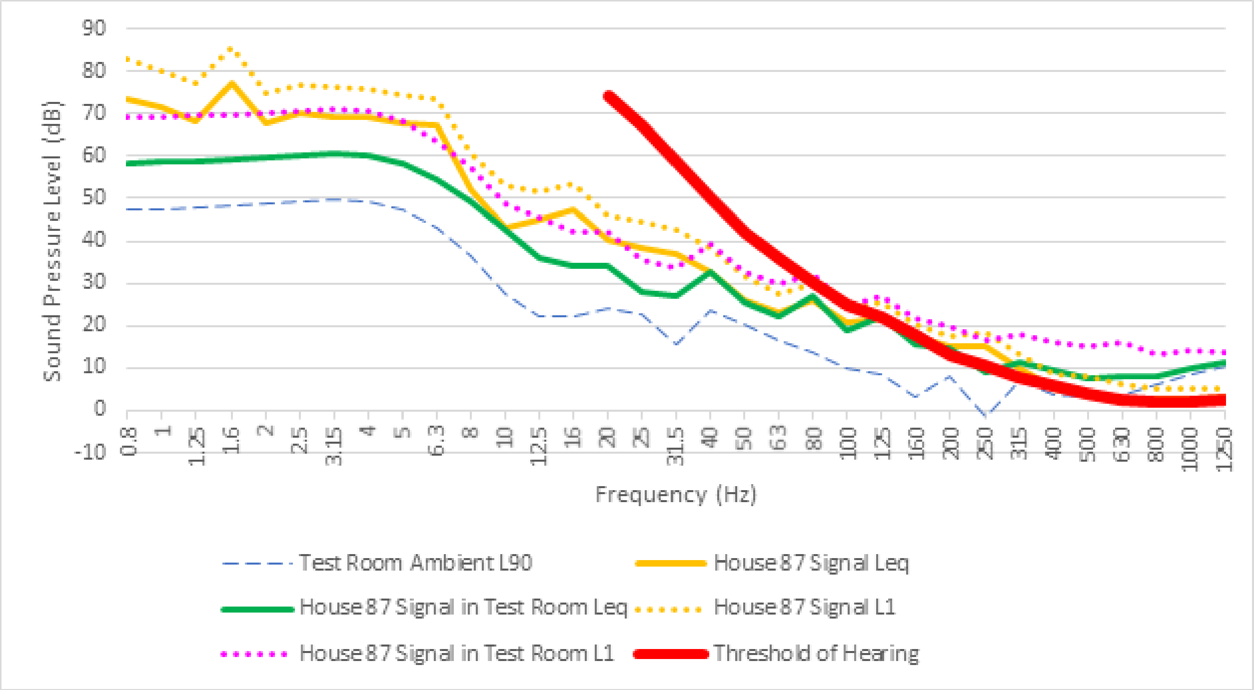

Figure 2: Spectra of Test Sample

creating the source signal over a wide band of frequencies [22] and a concept of synthesising a digital signal from analysed Leq FFT results but limited to just the infrasound region [5].

As discussed earlier, those investigations found the synthesised results did not agree with our analysis of the original external source data that has been obtained in the field. Utilising a synthesised signal from an averaged (Leq) FFT to produce a steady signal lacks the on/off transitions, transients and variations that existed in the original time record.

For the subject study the original wave files obtained at house 87 from the Cape Bridgewater study [1] was used with a focus on the region of 30 Hz – 1250Hz (i.e. specifically excluding infrasound). The source wave file signal obtained from measurements inside dwelling 87 at Cape Bridgewater, that has been used by several authors as a reference FFT Leq spectrum, was reproduced in the chamber utilising the sound system described above and provided the 1/3 octave band spectra shown in Figure 2. For the frequency range of interest, the reproduced signal approximated the original signal as a 10-minute Leq level.

As a pilot study, 9 persons identified as sensitive to wind turbine noise or pulsating low-frequency industrial noise (test group 1) attended our test chamber to participate in an experiment along the lines of the sensing tests in the format described by Schomer. A control group of 9 persons not previously exposed to turbine noise or pulsating low-frequency industrial noise (including 3 acousticians) participated in the same tests.

The reverberation room, with the addition of acoustic absorption treatment, satisfies the requirements of European Broadcasting Union Technical Document 3276 *Listening Conditions for the Assessment of Sound Programme Material: Monophonic and Two-Channel Sound* [23]. The maximum noise level under that standard for a mono signal is set at 85 dB(A). The distribution of absorption around the perimeter of the reverberation room leads to the absence of lateral reflections from wall surfaces. As the walls of the chamber are core filled blockwork, from sound intensity and vibration measurements it was established that neither the walls, floor or ceiling of the chamber were generating structure borne noise from the speakers mounted on the baffle in the aperture.

The levels that were generated in the room approximate the 1/3 octave band levels obtained in house 87 (in the Cape Bridgewater study) [1] over the range of 40 – 1250 Hz. The response that falls off below 16 Hz reflects the absence of any graphics or parametric equalisation, and the limitations of the A-D convertor.

Table 1 presents the measured sound levels of the generated and ambient levels in the test chamber, with the derived sound level contributions in both the Leq level and the L90 level.

By any of the general measurement parameters used for wind farm assessments, the test signal contribution is at or below the ambient level. Of relevance to researchers of wind turbine noise, the testing had the wind turbine noise contribution as an Leq level of 12 dB(A) in a background level of 23 dB(A).

Filter	L_x	*Ambient*	*Test Signal*	*Test Signal Cont.*
dB(Z)	Leq	69	69	60
	L90	57	57	49
dB(A)	Leq	24	24	12
	L90	23	23	9
dB(A) LF	Leq	8	10	8
	L90	-1	7	6
dB(C)	Leq	41	41	36
	L90	31	34	30

Table 1: Measured Levels and Derived Contributions of Test Signal

For the levels that were generated. the testing was undertaken in accordance with Australian Standard AS 1269.4 *Occupational Noise Management, Part 4: Auditory Assessment* [24] and the testing conducted in accordance with the ASA *Ethical Principles of the Acoustical Society of America for Research Involving Human and Non-Human Animals in Research and Publishing Presentations* [25]. An observer was present in the reverberation room during the testing.

The testing was conducted as multiple blind study tests. At no point in time were any of the participants advised what signal (if any) was being applied.

After a period of between 45 seconds to 3 minutes, all the 9 people in test group 1 could sense the presence of the wind turbine signal on 100% of the occasions in which the signal was presented, even though they were unable to hear the signal. At no point in time did any of these test subjects detect any audible signal.

One test subject (from the test group 1) identified a disorientation in the room where there was a perception of a tilt in the floor of about 20°.

The control group were exposed to the same test set up. After a period of some two minutes 2 people (including one a very distinguished Australian acoustician) could identify sensation, whilst the remainder of the control group never detected any sensation.

An extension of the sensation study was the identification of hotspots in the room and orientation of the observers to the speakers generating the test signal. Two consistent positions were identified by the test group who are sensitised to wind turbine noise. By use of a manikin we identified a very slight difference in the pressure level on either side of the head for the 2 positions [17] which has been suggested by Schomer [18] as a possible explanation for the detection of the operation of turbines

4. Conclusions

On December 4, 2017 the Administrative Appeals Tribunal (in Australia) handed down a decision in relation to Waubra Foundation vs ACNC [26]. The matter was heard by a Federal Court Judge and the Deputy President of the AAT in South Australia in relation to the revocation of a health promotion charity status.

Extensive evidence in relation to medical and acoustic impacts was provided. Reference to pages 141 to 148 of the Decision notes that a significant portion of sound emitted by wind turbines in the low-frequency range and that the dB(A) weighting system is not designed to measure that sound and is not an appropriate way of measuring it. Paragraph 470 of the Decision identifies “the lack of comprehensive studies which have combined objective health measurements with actual sound measurements in order to determine for a given population the relationship between the sound emissions of wind turbines, annoyance and adverse health outcomes”. This is a common situation in relation to the wind farm debate about noise in that there are no comprehensive studies to show that there is an adverse impact from wind turbines. However equally there are no studies to show that there is no adverse impact from wind turbines.

The soundscape of a wind farm is not the same as road traffic noise and therefore the use of criteria applicable to road traffic noise and based upon road traffic noise studies (WHO European night-time noise guidelines 2009) [28] do not provide the appropriate data to identify the dose-response curve of wind turbines noise emissions to determine what level of noise will protect residents from sleep disturbance or adverse health impacts.

Our investigations in relation to noise emission from operational wind farms in Australia has been undertaken to determine the noise signature emitted by those wind farms, to provide a source signal for the purpose of undertaking medical studies (by others).

In this regard it has been established that noise emitted from wind farms is not the same as that generated by road traffic noise and is certainly not a steady-state noise that is suggested by criteria contained on permits for wind farms in Australia.

The perplexing issue in relation to the investigation of noise complaints is the fact that people who have become highly sensitised to wind turbines can detect the operation the turbines without seeing them (contrary to claims by Leventhal [29]) when measured sound pressure levels are at or below the threshold of hearing.

Whether such people develop a lower threshold of hearing than the norm has been suggested as one possible reason. From our observations it is appears that persons who over time become sensitised to wind turbine noise have a lower tolerance to noise. However, in undertaking fieldwork and questioning the residents in their dwellings in many cases the issue is not one of hearing the turbines but one of sensing the turbines.

This sensation can come in different forms for various people and includes a pressure pulsation in the head or legs that has a periodic function in consistent with the blade pass frequency of the turbines. Other people can feel pressure in other parts of the body (throat or chest) and others feel a constant pressure and a tiredness. The examination or determination of the components of the body that give rise to these reported effects is outside our expertise.

As a result of our investigation into the acoustic signature of wind turbines we have developed visual tools to show the time signal is subject to amplitude modulation, frequency modulation and pulsations that can rapidly change throughout a simple 10-minute sample. These individual components of the raw signal can be both audible and inaudible when assessing external to residential dwellings in relatively proximity to a wind farm (in the order of 800 to 1200 m).

Inside the dwellings the signature of turbines is generally inaudible. However, the variations in levels when examining the time and frequency domain components of the signal exhibit what we have called a “dynamically pulsed amplitude modulation” that gives rise to a variation in the overall signal across the low-frequency and mid frequency components of the signal where the pulsation occurs at the blade pass frequency.

Our pilot study utilising a sound spectrum obtained inside the dwelling at Cape Bridgewater (that contains the dynamically pulsed amplitude modulation) but completely eliminating any infrasound components in the signal was found by all participants (test group and control group) to be inaudible yet 100% of the sensitised people (test group 1) were able to detect the presence of the signal when it was applied and could identify when there was no signal present.

From our experience the qualification of the audible soundscape of a wind farm is difficult if one is using dB(A) or dB(C) for the reasons identified above. However, there is an inaudible soundscape of a wind farm, both external to and inside dwellings that in our view is impossible to identify in terms of a dB(A) or dB(C) measurement.

The use of full-spectrum time signals with an analysis of one third octaves in a waterfall plot to which then one observes the variation in the 1/3 octave bands over time [29] is a tool that clearly shows the presence of the dynamically pulsed amplitude modulation to which our test group were able to identify the presence of the wind turbine signal even though they are unable to hear it.

Our proposal for the next step in this investigation was to bring 50 people from around Australia who had been identified as sensitive to wind turbines (in some cases having abandoned their homes) and undertake a repeat of the test pilot program to include other sources of inaudible noise (such as traffic, waterfalls, surf noise etc.) and those persons would be subject to EEG and heart rate monitoring (conducted by person so qualified).

The issue we face is lack of funding to be able to undertake that work.

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