Submission to Standards New Zealand
with regard to
draft Standard DZ 6808:2009
Acoustics – Wind farm noise

from
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Major concerns in order of priority

1   The noise immission in any sleeping area, must meet the World Health Organization's recommendations to protect public health, and minimise sleep disturbance at night – a level of 30 deciBels (L_{Aeq}) for steady continuous noise. The draft does not ensure this.

2   Any low frequency noise components in the sound from the windfarm(s) should be limited to ensure room resonances are not set up in any sleeping area to the degree that sleep is disturbed. The draft treats this as of no significance.

3   Windfarm sound has distinct characteristics and is not masked by natural sounds such as that from the wind in trees. The background sound level should not be assumed to mask windfarm sound – as the draft Standard does.

4   The noise limiting criteria should not be based on the background sound level plus 5 dB or 40 dB whichever is greater. This is not sustainable management, as defined in the Resource Management Act. The criteria to meet should be a fixed value to comply with the WHO recommendations, and not related to the background sound at all.

5   There must be a simple method to show compliance (or non-compliance) with any noise rule set. The measurement metric and methodology used in the draft bring in quite unnecessary complications that prohibit any tests by local authorities to relate the noise immission to local noise ordinances. Once the windfarm is in operation there is little one can do to control its noise emissions under the present or draft standard. This is not acceptable.

6   If the WHO recommendations are to be met, the measurement metric should not be based on long term averages or L90, but be the time average level over a short time period (no more than 10 minutes).

7   Any noise prediction for design compliance must include all other wind farms within the locality, say, within 10 km. The draft considers only the noise from one windfarm at a time, excluding all others. The noise predicted at any noise sensitive location will be underestimated and perhaps greatly so.

8   The noise prediction and all working should be written out – as on a spreadsheet – including base data and any assumptions made, so that it may be verified by anyone. With a computer program one can get almost any answer one likes.

9   From experience, at distances over 2 kilometres, the prediction methodology greatly under-predicts the sound immission, often by more than 15 deciBels. Either a new prediction methodology should be produced – one that relates better to reality – or the Standard should use a protocol where prediction does not come into the equation.

Concern 1

The World Health Organization (WHO) has accumulated and précised the work of the leading experts in the world in order to produce recommendations for all countries to adopt to maintain and protect public health [1]. Of particular concern, for sound propagated at night, the level of *steady continuous noise* at any sleeping position shall be no greater than a time average level of 30 dB (L_{Aeq}).

Windfarm sound may be considered as steady continuous noise under NZS 6801:2008 clause 8.2 [2] and may be present in an area for weeks on end. Often this coincides with warm calm nights when people sleep with windows wide open or sleep outside on their deck. And on such nights the wind on the hill tops may still be more than sufficient to power the turbines even though it is calm on the valley floor. The Standard assumes that there will be a sound attenuation of 10 to 15 dB through the window opening before the sound reaches the sleeper (inside a bedroom). This is only correct on certain very limited occasions, such as when the sleeper is situated in the very centre of a symmetrical and uniformly furnished room – a spatial average position – and then only if the total window opening is less than a very small amount of the wall area. Most rural people, and it is the rural area where most windfarms are established, have their windows fully open on hot summer nights, and may sleep within a metre or so of the window, the opening of which may be up to 90% of the wall area and give no sound attenuation at all. There would also be no sound attenuation when they sleep on their deck, which is common, as often it is too hot to sleep inside with the limited ventilation in the typical New Zealand home.

Table 1 gives the sound attenuation for an open window as a percentage of the wall area, and this is based on a free-field sound level outside compared to the resulting spatial average sound level in a fully furnished room, which latter is assumed to give a reverberation time of 0.5 seconds.

It is hard to see how a sound attenuation of 15 dB would be achieved as stated in C5.1.2 of the draft standard even with a spatial average sound level inside - unless there was a very small opening (less than 3%) quite insufficient for proper ventilation.

Table 1   Sound attenuation through open window
Wall: 4 m x 2.7 m weatherboard, on 100 x 50 studs, 10 mm plasterboard, 75 mm batts in cavity

Octave band	Percentage of wall opening											
Centre Hz	3	5	7.5	10	20	30	40	50	60	70	80	90
31.5	12	11	10	9	6	5	4	3	2	1	1	0
63	11	10	9	8	6	5	4	3	2	1	1	0
125	12	11	10	9	6	5	4	3	2	1	1	0
250	15	13	11	10	7	5	4	3	2	2	1	0
500	15	13	11	10	7	5	4	3	2	2	1	0
1000	15	13	11	10	7	5	4	3	2	2	1	0
2000	15	13	11	10	7	5	4	3	2	2	1	0
4000	15	13	11	10	7	5	4	3	2	2	1	0
8000	15	13	11	10	7	5	4	3	2	2	1	0

It could be noted: The New Zealand building code Clause G4 – Ventilation requires that bedrooms have an opening in the plane of the wall of at least 5% of the floor area. In general, this relates to an open wall area of between 6% and 12%. This requirement is for ventilation alone and does not include any allowance for cooling in hot weather. To obtain an attenuation of 10 dB, in order for 40 dB outside to be attenuated to 30 dB inside, one would require less than 10% of the wall as an open window which could conflict with the G4 requirements, but this is a very moot point.

The only way to ensure that the WHO recommendations are met is to ensure that the sound level outside the window does not exceed 30 dB (L_{Aeq}). This should be the main limiting criterion for any windfarm.

- The sound from a windfarm shall not exceed 30 dB ($L_{Aeq,10min}$) outside any residence

Recommendation:
Page 18, Section 5.1.2 change "40 dB L90" to "30 dB ($L_{Aeq,10min.}$)"
Page 18, Section 5.2, change the design criteria from "…($L_{A90,10min}$)should not exceed the background sound level by more than 5 dB, or a level of 40 dB $L_{A90(10min)}$, whichever is the greater.", to "should not exceed 30 dB ($L_{Aeq,10min}$) in all conditions".

Concern 2
There have been numerous reports of low frequency noise penetrating closed windows and being heard more clearly indoors than outside [3, 4, 5]. Sounds below 125 Hz can excite room resonances and be amplified, significantly disturbing sleep and hence compromising health. The oscillation (or "modulation") of the sound shown in Figure 1 above adds to the irritation the sound gives to those trying to go to sleep, as reported in numerous case studies across the world.

The following tables show the resonances in a typical small 3m x 4m New Zealand bedroom Table 2, and in this writer's own bedroom Table 3.

Table 2 Primary room resonances for a 4m x 3m room, 2.4 ceiling height, 20°C.													
Vibration mode Length	1	0	0	1	1	2	0	1	0	2	1	0	2
Vibration mode Width	0	1	0	1	0	0	1	1	2	1	2	0	2
Vibration mode Height	0	0	1	0	1	0	1	1	0	1	1	2	0
Resonant frequency Hz	43	57	72	72	84	86	92	101	115	126	142	143	143

Table 3 Primary room resonances for a 5.5m x 4.5m room, 2.4 ceiling height, 20°C.													
Vibration mode Length	1	0	1	2	0	0	1	0	1	3	2	3	2
Vibration mode Width	0	1	1	0	0	2	0	1	1	0	2	1	1
Vibration mode Height	0	0	0	0	1	0	1	1	1	0	0	0	1
Resonant frequency Hz	31	38	49	63	72	76	78	81	87	94	99	101	103

All of these frequencies are present in wind turbine sound, so it would not be unreasonable to assume that a 5 to 10 dB amplification possible by this mechanism, and this, no doubt, is the reason for many people reporting severe sleep disturbance but then finding the noise apparently quieter outside. Thus the limit of low frequency sound, in the octave bands below 125 Hz, should be made not to exceed, say, 20 dB ($L_{Aeq, 10min}$) outside any residence. Energy companies' experts have categorically stated that windfarms emit no significant low frequency sound. Thus, if this is true, asking them to obey this rule would place no imposition on them.

Recommendation:
Insert a new requirement: 5.2.1 "To protect residents from sleep disturbance due to low frequency sound exciting resonances in a bedroom, the time average level ($L_{Aeq, 10mins}$) of windfarm sound immission in the octave bands from 31.5 Hz to 125 Hz, should in total not exceed 20 dB within the boundary or notional boundary of any noise sensitive area."

Concern 3
The sound from a windfarm is carried by the wind and as it has unique characteristics it penetrates the natural background sounds to make it clearly audible at fairly large distances. The natural background or the sound of wind in trees has a quite different timbre and does not mask wind turbine sound. The basis of the Standard should not be related to the background sound at all but be a fixed level not to be exceeded – 30 dB ($L_{Aeq,10min}$) as stated in Concern 1

From the public health point of view, there is also a problem in using the background sound plus 5 dB (or average maximum + 10 dB) as the design criteria. It is realised that for some years now planners have used this principle with some success as few if any people question it. It is based on the results of social surveys and the average maximum levels of noise at which people will take concerted action out of sheer desperation. It does not relate to annoyance and alleged ill health as a result. An average maximum level of 10 dB above the background sound level is just about the maximum one can get away with without incurring severe community action.

Figure 1 [6] shows a typical windfarm noise time history over a few seconds. The L90 is this case is about 3 dB below the average maximum level (L10) but in may cases it is about 5 dB below. So in many windfarm standards across the world (including this draft) the design criteria is set as an L90 of the background level + 5 dB or 40 dB whichever is greater – again theoretically the maximum one can get away with, without there being very severe repercussions from the community. At such levels there will be severe annoyance, but most people will knuckle down realising that there is almost nothing they can do about it without it costing them quite a lot of money. It does not limit annoyance and it does not protect public health.

Figure 1

Sound level 45 43 L_{Af} dB 41 39

Sound oscillates 4 to 5 dB per second

$L_{A90} = 40$ dB
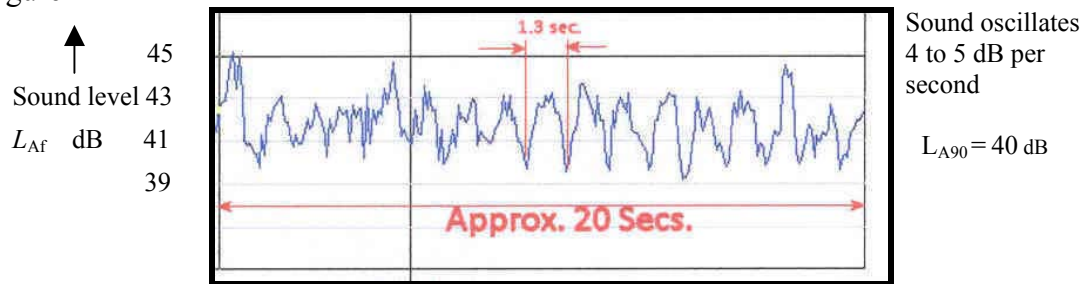
The draft assumes 10 to 15 dB attenuation through an open window and that the background masks the windfarm noise to such an extent, that it is not unreasonable to allow the wind farm to produce 40 dB (L_{A90}) at the property or an increase of 5 dB over the background sound level which ever is the greater. This is equivalent to saying that if the background sound is already over the WHO limits then an extra 5 dB over will not matter. This not sustainable management which under the Resource Management Act:1991 (Section 5) "enables people and communities to provide for ……. their health and safety …." Taking an analogy from an Environment Court judge, this is equivalent to hitting someone over the head with a hammer and saying it is all right to hit them 7 times as hard (5 dB) as they won't notice the difference.

To my knowledge, the only scientific study of environmental noise at a national level in New Zealand, was undertaken by the Board of Health in 1973. In its report [7] one can find the following table:

Table I—Background Noise Levels Generally Considered Acceptable in New Zealand		
Zone	7 a.m.-10 p.m. dBA	10 p.m.-7 a.m. dBA
Z1—Rural and outer suburban areas with negligible transportation	35	25
Z2—Generally suburban areas with infrequent transportation	40	30
Z3—Generally suburban areas with medium density transport	45	35
Z4—Suburban areas with mixed commerce and in-dustry or close to dense transportation	50	40
Z5—City or commercial areas or residential areas close to industry	55	45
Z6—Predominantly industrial areas	60	50

The report may well be 35 years old, but people's needs are the same now as they were then. One wonders why territorial authorities have let these levels increase over

the last few decades. The New Zealand Standards, published during that time, must bear some of the blame, and in that I have been guilty also in not noticing what was happening, but much of the blame must lie with those that have advised the territorial authorities, and have possibly more interest in industry than in public health.

The rural areas in New Zealand are generally extremely quiet most nights. In my own area of Camborne, on numerous occasions at night I have measured the ambient sound at 20 dB - the noise floor of the sound level meter I had to hand. At such background sound levels, a sound even at only 35 dB outside a residence can be very noticeable, and if continuous and rhythmically modulating up and down one or two decibels for hours on end, as it does for a wind farm (Figure 1), it can be extremely irritating and stressful – similar to the old Chinese water torture. Each impact in itself may be quite insignificant but repeated hours on end for weeks at a time can drive people to desperation. In these areas in particular, any such sound from industry should at the boundary, not exceed 30 dB at the very most, and preferably not exceed 25 dB as the Board of Health recommended all those years ago.

- • Once again we come back to the philosophy that the design limit should be no more than the World Health recommendation of 30 dB (L_{Aeq}) and this should be the level outside any residence.

Concern 4
The proposed methodology of obtaining matched data pairs, relating wind speed at the hub to local background sound level, is not mathematically or scientifically valid when the variation between the data pairs from the norm is so great.

Figure 8 shows a plot of such data pairs as would be produced for a windfarm resource consent [8]

The graph compares a 10 percentile level (L_{A90}) with a linear parameter and then takes a 50 percentile regression line on which to base the alleged relationship between the background sound level at the recipient property with the wind speed at the hub of the turbine which may be on an elevated position some distance away. Not only is there such a wide scatter of data pairs – more than 15 dB on several occasions – but using a 50 percentile regression line for a 10 percentile function rather than a 10 percentile regression line, artificially raises the value of the background sound level and is mathematically incorrect. If such a regression line is to be taken, and the computer program used to analyse the data does not contain the means to use such a regression line, then one standard deviation below the 50 percentile regression line would be nearer the truth.

Then there are errors produced by the way the sounds are measured.

Figure 9 below shows another data pair graph as would be used for a resource consent hearing. [ibid]
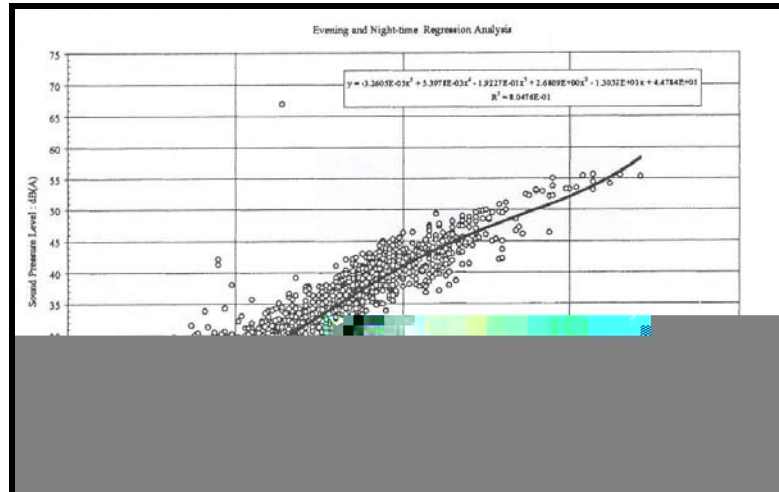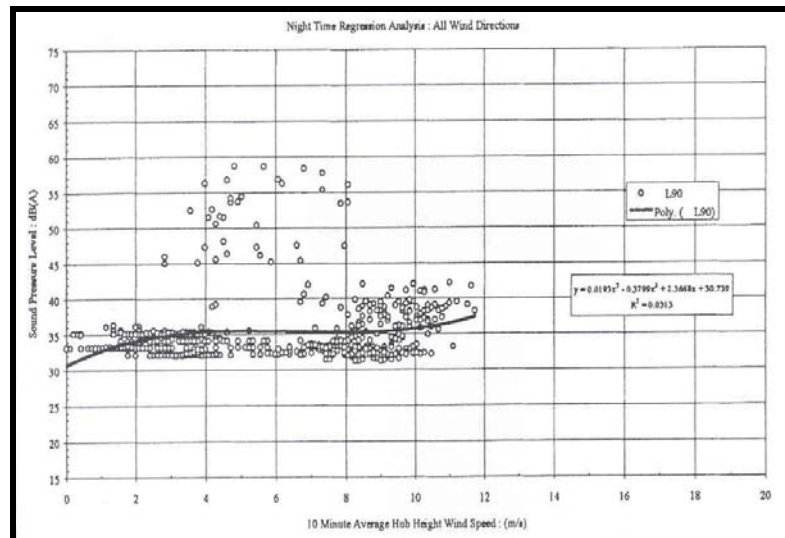
Figure 8

Figure 9

On this graph there is an even greater scatter – more than 20 dB on several occasions – but more worrying is the possibility that the instrumentation used in the unaccompanied monitoring has not truly measured the background sound level at all.

First of all it would appear that the instrumentation did not have a sufficiently low noise floor to record all the sounds at their true level. It will be noticed there is no scatter of results below 32 dB, but tremendous scatter above 40 dB. This suggests the noise floor of the instrumentation used was as high as 32 dB, so anything below 28 dB was recorded as 32 dB or anything between 28 and 32 dB recorded as 33 dB or over. The background sound level may well have been well below 25 dB, even below 20 dB, but the instrumentation has recorded it as being 32 dB. This has artificially raised the value of the background sound level possibly by several dB. It may be noted that some of the equipment seen to be used by noise consultants in New Zealand for such purposes, has this limitation.

Secondly, those using sound level meters have to be very careful that the wind at the microphone does not exceed 5 metres/second (18 km/hr) when measuring sounds between 40 dB and 50 dB, and not exceed 3 metres/second (11 km/hr) when

measuring sounds between 30 dB and 40 dB, even with a good windshield in place. Figure 10 below shows the effect of a wind shield on a sound level meter [9]. If the wind at the microphone is 20 km/hr, the sound level meter will register 40 dB without any other sound present even with a windshield in place.

Figure 10
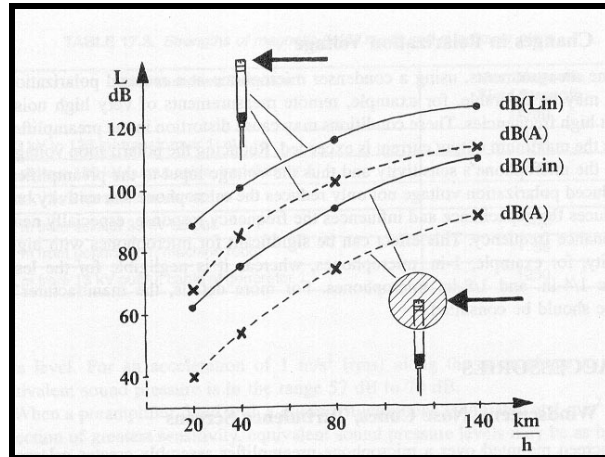
The draft Standard places no limits to the wind speeds in which the measurements are to be taken. If the wind is over 5 metres per second, much of the measurement will be noise from the wind on the microphone and not the background level at all – even with a very good windshield in place. The background sound level is being artificially raised even more – again to the benefit of the noise maker. Such rank manipulations would not be acceptable from any other industry so why is it allowed in the current standard for windfarms and carried over into the new draft? It is mathematically, scientifically and ethically wrong

Again we come back to the main premise:

- Wind farms should be given a fixed level to meet at any residence in all conditions at all times - not one based on a supposed relationship between the wind speed at the hub of the turbine and the background sound level at the recipient - and this level should be no more than 30 dB ($L_{Aeq,10min}$).

A total rewording of section 3 is needed, removing all references to L90. An entirely new measurement and prediction methodology is also required.

Concern 5
The draft standard gives no simple measurement method to show compliance (or non-compliance) once the windfarm is fully operational. A windfarm is an industry and should be no different from any other industry in having to meet noise rules, and be monitored from time to time. There is no scientific reason why an enforcement officer could not take a series of simple short term measurements say twenty or so two minute time average level measurements ($L_{Aeq,2mins}$), to prove compliance or not with any rules set for the windfarm. As the draft stands, once operational the windfarm can make almost any noise it likes without redress. This is totally unacceptable. Section 7.6 should be totally rewritten to bring the assessment within the resources of local territorial authorities.

The use of the L95 metric in the current NZS 6808, which is translated to the L90 metric in this draft, may have seemed a good idea to almost everyone at the time. The sound from a windfarm becomes the major component of the background sound, and the thinking no doubt was that if it were considered as background sound, one could use the L95 to eliminate transient sounds from general daily activities, and then simply compare the measurement with one in similar wind conditions when the windfarm was not operational – and a noise monitoring system could do this without anyone being present i.e., unaccompanied monitoring. Unfortunately it very cleverly introduces a confounding factor into the equation whereby, once the windfarm is in operation, it becomes almost impossible to prove any non-compliance with any rules set under the consent conditions in the present draft.

Windfarm sound is clearly heard downwind, certainly from experience at distances of some kilometres, and could easily be monitored as a time average level over a few minutes as long as an observer is present.

Recommendation:
Remove Section 7 in its entirety and replace it with a simple protocol such as that used in NZS 6801:2008 and NZS 6802:2008.
And add a new subsection including the words:
"At any time, if there is concern that the windfarm is not complying with the rules set for it, a series of not less than 20 measurements of the five minute time average level ($L_{Aeq,5min}$) may be taken when the wind farm sound is clearly heard above everything else, and if 90% of the set of measurements is in excess of the rule set, then the windfarm shall be deemed in non-compliance with the rules set for it".

Concern 6
The World Health Organization recommendation is for steady continuous noise, and thus it is not a long term average but a level not to be exceeded – similar to the speed limit set on our roads to protect health and safety. The methodology in the present, and in the draft wind farm standard, is based on a long term average. The Standard should use a short term measure such as a 10 minute time average level, and include a measurement protocol that those with the responsibility for maintaining public health within the territorial authority concerned, i.e., the environmental health officers, can handle with the instrumentation to hand, the time feasible and the resources available.

Recommendation:
3.1.1 The metric shall be the 10 minute time average level ($L_{Aeq,10min}$)
Delete existing 3.1.1, C3.1.1, 3.1.2, 3.1.3 and C3.1.3

Concern 7
The draft as it stands does not protect the sound environment from a build up of noise by a multitude of wind farms each producing the legal limit of sound at a particular noise sensitive position. For example: Two farms each producing 35 dB would give a total of 38 dB, and four farms each producing 35 dB would give 41 dB. There would be nothing to stop a company registering each wind turbine generator as a wind farm in its own right. So theoretically one could have 50 or more windfarms each giving a legal 35 dB at one position, but the total amount of noise would then be over 50 dB and still legal. To protect public health, all windfarms in existence must be included in

the determination of noise levels - not solely the windfarm under consideration - and the total noise then should not exceed the WHO recommendations.

Recommendation:
Renumber section 5.1.5 as 5.1.6 and insert a section:
5.1.5   The noise limit to be met to provide protection against sleep disturbance and to maintain reasonable residential amenity shall apply to the sum total of noise from the windfarm in question and that from all existing windfarms.

Concern 8
Computer prediction is obscure and notoriously inaccurate. Indeed it may be said that one can design the computer output to be whatever one wishes [10]. There is no guarantee that any computer prediction of windfarm sound emission will be close to the value of that received. It is for this reason that the airport noise standard and similar New Zealand Standards use an airnoise boundary, set by the territorial authorities, a boundary based on physical features in the area, within which all noise emission over a certain level must be contained. The control is by the measured noise levels and computer prediction is not involved.

Regrettably one cannot rely on any computer predictions of noise even if definitive methodology is given. The only transparent way is to show (print out) all calculations and all assumptions, and with modern techniques a spreadsheet is the most practical way of doing this.

The predictions also should not be based on a long-term average. The WHO Recommendations are levels not to be exceeded – they are not design levels to try to achieve on average.

Recommendation: As for Concern 9 below

Concern 9
Section 6.1.3 of the draft standard recommends the use of ISO 9613-2 to predict windfarm sound and states "..which has been shown to correlate well with measured data for wind farms …" This is a very sweeping statement with no scientific evidence to back it up. Indeed, rarely, if ever, do windfarm noise predictions match measured noise levels – except at about 100 metres downwind where the sound power measurements are gleaned. This statement should be removed.

NASA studies [11] show that at distances greater than about 750 m the sound propagation more closely follows that of cylindrical spreading i.e., a line source. In the Manawatu, an average of more than a dozen measurements at 2.5 km from the nearest turbine, gave a time average level of 50 dB at a time when the turbines were clearly predominant over all other sounds, and no other intrusive sounds were noticed. If we use the prediction method used in the current Standard the predicted sound level is 29 dB (Table 4 below) – an under-prediction of 21 dB. If we use the prediction methodology in the draft Standard (Table 5 below) we get 32 dB – an under-prediction of 18 dB. Using a line source as suggested in the NASA studies [11] we get 49 dB Table 6 – which is not far from being within the tolerances of the Class 1 instrumentation used.

Table 4

Using method in NZS 6808:1998 and 24 wind turbines - the number visible in daylight								
Octave band frequency	31.5	63	125	250	500	1000	2000	4000
Sound Power Level dB	119.8	116	109.2	105.5	102	100.7	95.4	90.8
At 2500 m distance, 15 degree C, 50% relative humidity, ground cover short grass								
Hemispherical spread	-76	-76	-76	-76	-76	-76	-76	-76
Air absorption	-12.5	-12.5	-12.5	-12.5	-12.5	-12.5	-12.5	-12.5
Resulting band level	31.3	27.5	20.7	17	13.5	12.2	6.9	2.3
A-frequency weighting	-39.4	-26.2	-16.1	-8.6	-3.2	0	1.2	1
A-frequency weighted Level	-8.1	1.3	4.6	8.4	10.3	12.2	8.1	3.3
Level from 24 turbines	3.9	13.3	16.6	20.4	22.3	24.2	20.1	15.3
L_{Aeq} in dB	29 dB	i.e., prediction by NZS 6808:1998 is 21 dB below measured level						

Table 5

Using method in draft DZ 6808:2009 and 24 turbines								
Octave band frequency	31.5	63	125	250	500	1000	2000	4000
Sound Power Level dB	119.8	116	109.2	105.5	102	100.7	95.4	90.8
At 2500 m distance, 15 degree C, 50% relative humidity, ground cover short grass								
Spherical spread + Dcr (= 3)	-76	-76	-76	-76	-76	-76	-76	-76
Air absorption viscous effects	0	0	0	0	0	-0.3	-1.3	-4.8
Oxygen and nitrogen relaxation	-0.3	-0.3	-1.3	-3	-5.5	-10.3	-25.8	-86
Ground absorption	-0.2	-0.7	-1.3	-3.7	-3.8	-4.3	-4.5	-7
Resulting band level	43.3	39	30.6	22.8	16.7	9.8	-12.2	-83
A-frequency weighting	-39.4	-26.2	-16.1	-8.6	-3.2	0	1.2	1
A-frequency weighted Level	3.9	12.8	14.5	14.2	13.5	9.8	-11	-82
Level from 24 turbines	15.9	24.8	26.5	26.2	25.5	21.8	1	-70
L_{Aeq} in dB	32 dB	i.e., prediction by draft standard is 18 dB below measured level						

It should be understood: The wind speed at the hub was not available and had to be estimated at 10 m/s.
so the base sound power levels may have been slightly lower, making the prediction even lower

Table 6

As I believe it should be predicted: Using a line source with no directivity correction, corrected for spacing (400m), 24 turbines								
Octave band frequency	31.5	63	125	250	500	1000	2000	4000
Sound Power Level dB	119.8	116	109.2	105.5	102	100.7	95.4	90.8
At 2500 m distance, 15 degree C, 50% relative humidity, ground cover short grass								
90m blade 310m space between	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4
Line source	-42	-42	-42	-42	-42	-42	-42	-42
Air absorption viscous effects	0	0	0	0	0	-0.3	-1.3	-4.8
Oxygen and nitrogen relaxation	-0.3	-0.3	-1.3	-3	-5.5	-10.3	-25.8	-86
Ground absorption	-0.2	-0.7	-1.3	-3.7	-3.8	-4.3	-4.5	-7
Resulting band level	71.9	67.6	59.2	51.4	45.3	38.4	16.4	-54.4
A-frequency weighting	-39.4	-26.2	-16.1	-8.6	-3.2	0	1.2	1
A-frequency weighted Level	32.5	41.4	43.1	42.8	42.1	38.4	17.6	-53.4
L_{Aeq} in dB	49	i.e., prediction using line source is within measurement tolerance.						

I believe this clearly shows that, from experience, prediction of sound from a windfarm by the existing Standard NZS 6808 methodology, and by the methodology promoted in the draft Standard, is wrong and should not have been used. A little thought and research will show that it should not have been contemplated in the first case:

The new draft wind farm standard promotes the use of ISO 9613 [12] even though the ISO standard clearly states it is not to be used for aircraft sound propagation, and is limited to distances under 1000m distance by the uncertainties. As the sound from aircraft is also produced by blades and turbines, why should the standard be applicable to wind farms if it is not to aircraft?

The noise generation from a windfarm is like no other noise source or set of noise sources. A major source is by air thrown outwards from the blade tips interacting with the surrounding air, which is itself moving with the wind flow. This forms vortices, which travel downwind in the form of a helix, rotating about its axis with each vortex replacing the previous one in space at approximately 1 second intervals – sometimes more, sometimes less depending on the speed of rotation and number of blades. Figure 11 shows a simulation of this form of propagation in a cavitation tank, albeit without the lateral centrifugal flow as with a high aspect ratio blade rotating in air which will throw vortices out from the blade tip until the outward momentum is balanced by that of the airflow in the wind and viscous forces.

Figure 11 Cavitation behind a propeller in a cavitation tank [13]
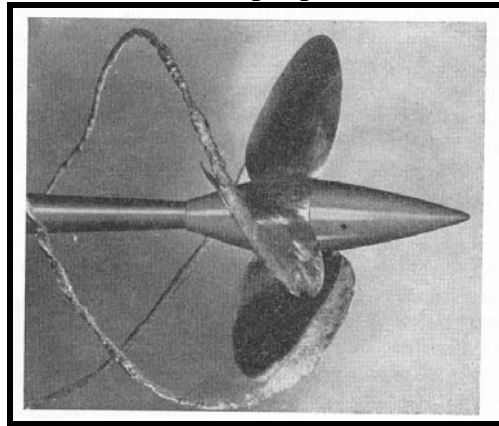
For a 45 m radius blade rotating at 20 rpm in an airflow of 10 m/s, the balance of momentum would give the vortex stream stabilising somewhere between 15 and 20 metres outside the tip – the swish one can hear when standing near a turbine.

Another major source is boundary layer air breaking away from the trailing edge of the blade, as shown in Figure 12.

Figure 12 Airflow around a rotor blade [14]
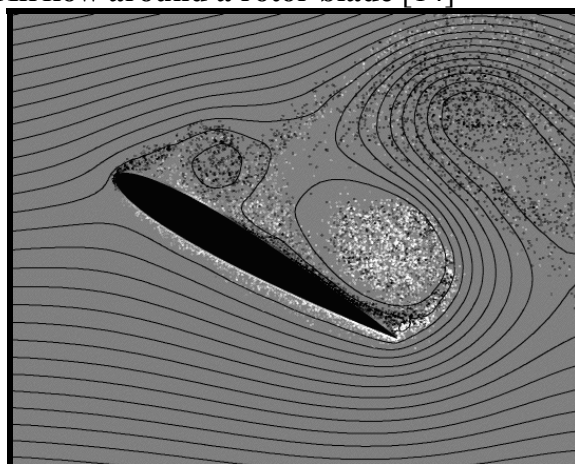
In the far field, this is the rumbling and modulation up and down 3 or 4 dB each second as the helical pressure waves reach the recipient, that is characteristic of the

noise from a wind turbine making it stand out from all natural sounds – except that of running water or surf.

Then there is a slicing of the airflow as the blades pass the pylon on which the wind turbine is supported; there may be a thumping sound as the blades stall and then pick up again in certain airflows; and there is the noise of the turbine itself and associated equipment. The sound sources are thus asymmetrical and may cover an area bigger than 3 football fields. (And a windfarm may have many wind turbine generators situated, often in line, only 400 metres apart.)

Perhaps most important: ISO 9613 suggests in section 4a) the sources have approximately the same strength and height above the local ground plane and b) the same propagation conditions exist from the source to the point of reception. From the above description, one should be able to see that for a windfarm, the sound sources are well outside any of these conditions. Clearly ISO 9613 is not suitable for the prediction of sound from a windfarm.

All windfarm standards assume the sounds from a wind turbine can be represented by a point source at the location of the turbine hub, and rarely if ever is directionality taken into account. Nor is any account taken of the carrying of sound by the wind itself. If these factors are not taken into account, large under-prediction results – which seems to be the norm in hearings across the world.

The effect of sound convection by the wind itself Figure 13 has been studied in the past [15] but it is believed has not been included in any prediction methodology, no doubt because the vagaries of the wind flow introduce large uncertainties. Such allowances have to be made if we are to approach reality, but even so as the distances increase so do the uncertainties. Nevertheless, some acknowledgement of sound convection should be made when determining the uncertainties, and allowance made when designing windfarms to conform to public health requirements as recommended by WHO.

Figure 13 Sound convection on the wind [16]
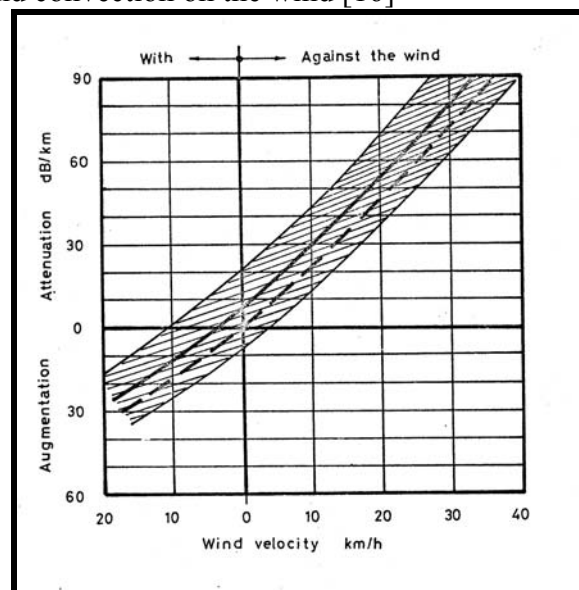
Recommendation

The standard should recommend that cylindrical spreading be used for all predictions of sound from a windfarm, but that as the uncertainties are still large, prediction should not come into any part of the conditions that the windfarm has to meet. The conditions should be a fixed level by measurement at any residence (30 dB L_{Aeq}) and how the developers decide this can be achieved, is up to them.

- **The entire standard needs completely rewriting.**

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