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The Relevance of the Precautionary Principle to wind farm noise planning

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ABSTRACT

Wind farms consist of clusters of industrial wind turbines which, when placed in rural areas, are associated with intrusive and unwanted sound. Wind turbine noise has characteristics sufficiently different from other, more extensively studied, noise sources to suggest that standard industrial noise standards are not appropriate for measurement and assessment purposes. A seven year study is reported and, although limited in population size, it is clear that there are definite adverse health effects related to wind farm noise. Time-aggregated noise metrics have limited utility in assessing individual human health and well-being, and a cluster of metrics are needed to describe and estimate potential effects on individuals and communities. Sleep deprivation is a widely reported occurrence by people in the vicinity of a wind farm. At this time, however, the quantity and quality of research are insufficient to effectively describe the relationship between wind turbine noise and health, and until such time that a definitive relationship is obtained, legislation should apply the precautionary principle and conservative criteria when assessing proposed wind farm developments.

Keywords: Precautionary principle, intrusive noise, health
TransmissionI-INCE Classification of Subjects Number(s): 51.4

1. INTRODUCTION

1.1 Wind turbines and the precautionary principle

Wind farms consist of clusters of wind turbines which, when placed in rural areas, are associated with intrusive and unwanted sound. Wind turbine noise has characteristics sufficiently different from other, more extensively studied, noise sources to suggest that standard industrial noise standards are not appropriate for measurement and assessment purposes. Though research into the human impacts of wind turbine noise has appeared only in small quantity, the data suggest that, for equivalent exposures, wind turbine noise is more annoying than road or aviation noise, and at night the particular characteristics of wind turbine noise may be likely to cause sleep disruption. This research also clearly shows that time-aggregated noise metrics have limited utility in assessing individual human health and well-being, and widely used national standards for wind turbine noise do not take into account the potential effects on individuals and communities [1]. If public health is not to be compromised, the Precautionary Principle [2] could well be followed until more research findings are to hand.

The concept of the precautionary principle has its beginnings in Australia in 1992 with the application of the National Strategy for Ecologically Sustainable Development (ESD) and the intergovernmental Agreement on the Environment [3]. A core Objective of ESD is "To enhance individual and community well-being and welfare by following a path of economic development that safeguards the welfare of future generations."

Queensland, for example, adopted the principle [4] as “The precautionary principle is the principle that lack of full scientific certainty should not be used as a reason for postponing a measure to prevent degradation of the environment if there are threats of serious or irreversible environmental damage.”

Taking a precautionary approach can be achieved by identifying:

a) what is the risk of something occurring, and
b) what are the consequences of taking that risk.

The precautionary principle can therefore be applied through consideration of its component parts: degradation, environment, threats, serious, irreversible, environmental, damage. A review of standard dictionaries (Shorter Oxford, The Free Dictionary) gives the meanings:

- ‘degradation’ is a decline to a lower condition, quality or level;
- ‘environment’ is surroundings, especially as affecting people’s lives; conditions or circumstances of living;
- ‘threats’ are an indication of something undesirable coming;
- ‘serious’ is important, not slight or negligible;
- ‘irreversible’ is not reversible or alterable; and
- ‘damage’ is injury or harm impairing value or usefulness of something; loss of what is desirable.

The potential effects if any of a wind farm on its environment can therefore be considered with qualitative and quantitative measures for sound, noise and harm or damage. The precautionary principle may significantly alter the balance between the applicant for development approval of a wind farm and objectors in terms of who bears the onus of proof. For example, if case studies (or other evidence) support a submission that the threat is real, the decision maker is justified in refusing the application unless the applicant scientifically proves (the ‘onus of proof’) that the proposed development will not result in damage or that the “benefits” of the proposed development otherwise outweigh the “costs”. The decision maker must weigh the “costs” against the “benefits”. In so doing the decision maker must take into account how real the threat of the “costs” is and how serious the damage will be against how likely and great the “benefits” will be. Thus, the number of people in an affected locale and the percentage of people adversely affected are relevant considerations to be weighed against the “benefits” of a proposed development.

1.2 Noise pollution

The World Health Organization considers noise pollution to be of sufficient threat to public health to justify the publication of numerous treatises and guidelines on noise effects and mitigation. The impact of ‘community noise’ on health has largely been studied in the context of transportation and general neighbourhood noise, and extends beyond noise-induced hearing loss. Community exposure to wind turbine noise has been relatively understudied, for historical, methodological, and political reasons. Quite simply, however, Noise is unwanted sound.

Noise and sound are often used as being or meaning the same thing. Strictly speaking they are different. Sound can be measured objectively using sound level meters and acoustical standards. Noise is a perception and must be measured objectively and subjectively.

An environment consists of a place and an eco-system and for practical purposes a locale. A residence is a ‘place’ and the people living there are an ‘eco-system’. In simple planning terms a wind farm development is assessed against some form of guideline which rarely will make any recognition of the precautionary principle. Few studies assessing wind farm activity, consider the noise, human perception of that activity, and any threats of serious or irreversible environmental damage.

Noise is the human perception of a sound or sounds and is (normally) observed subjectively. Some measures of perception such as “the noise is loud and tonal” can be broadly assessed using objective measures of the physical character of the sound. Noise sensitivity is both a personal hearing concern treated by an audiologist and a stable personality trait covering attitudes to a wide range of environmental sounds. Both can be measured.

Individual annoyance reactions to noise depend on the physical character of the sound, the individual’s reaction to the source of sound (perception), the individual’s physical characteristics (e.g. noise sensitivity), and personal wellbeing.

Wellbeing can be related to degrees of quietness and the absence of intrusive noise, the character of sound within an environment (“soundscape”), as well as the overall level of sound. The quality of life experienced by individuals is related to that person’s physical and mental health, sense of amenity and wellbeing.

The expression ‘Peace and Quiet’ is often given as the benchmark for amenity in relation to sound in an environment, but what is meant by peace, quiet, amenity and noise can vary across contexts, and these expressions can mean different things to different people at different times.

Quiet is part of the "measure" between a tranquil environment and an intrusively noisy sound environment. As such, quiet possesses an intrinsic value in terms of the overall sound within the environment (soundscape) and how individuals and communities will react. People have expectations for their environment and tend to describe it in terms of 'quiet'; for example: "the environment is quiet"; "we like the sense of peace here"; "the locale is loud, vibrant, noisy"; and so on.

Rural environments such as those in the vicinity of a proposed wind farm tend to be thought of as being 'quiet'. These characteristics can be described in terms of subjective and objective measures, although this is not always easy and legislation tends to give guidance, either directly or indirectly, in objective terms of "maximum" sound levels to describe the acoustic environment.

Amenity values are based (in part) upon how people feel about an area, its pleasantness or some other value that makes it a desirable place in which to live. In particular, landscape and soundscape characteristics mark an environment as a desirable (high amenity) or undesirable (low amenity) place to occupy, as uniquely judged by the individual. Localities hosting stressors tend to provoke negative emotions, and motivate an avoidance response, while localities free from stressors may induce positive emotions and motivate an approach response.

Generally, people are motivated to seek places offering the greatest level of amenity, that is, that minimise stress, maximise restoration, and induce a positive sense of wellbeing. As a consequence, community groups, town planners and architects work to provide high amenity areas in terms of landscapes and soundscapes, typically parks or natural/wilderness areas that are often described by visitors as being "peaceful", "quiet" or "tranquil".

It has long been observed that the transformation of sound to noise, and thus the assessment of "intrusive" noise, or "nuisance" noise, depends upon individual sensitivity to the noise. Intrusive noise can be defined in terms of impact, referenced to before, during and after some identified noise event.

Factors that cause individuals to react positively or negatively to noise include: (a) attitude to noise source, (b) attitude to information content in the noise, (c) perceived control over the noise, (d) sensitivity to noise (in general and specific measures), and (e) sensitivity to specific character of the noise (e.g., changes in pitch or modulation). The factors can be brought together into definitions for intrusive sound, namely noise and intrusive noise, that can be applied to allow qualification (i.e., subjective) and quantification in physical units (i.e., objective):

Noise is a sound that is perceptible to an individual and has definable characteristics that modify the individual's emotional and informational responses to that sound from pleasurable or neutral to adverse.

Intrusive noise, to an individual, is a sound whose character (such as audibility, dissonance, duration, loudness, tonality, pitch or timbre) is perceived adversely compared to the character of the environment in the absence of that sound, i.e., it reduces amenity.

Wellbeing is a defined determinant of population health under the WHO strategy "Health for all in the 21st century" [5]. Wellbeing and amenity can therefore be qualified and quantified in terms of "quiet" and "noise", for example on a scale of 1 to 5 as follows:

(1) No adverse effect, pleasurable sounds or peace and tranquility; quietness
(2) Minor adverse effect, minor irritation; minor intrusion of noise on occasion external to the home, no modulation or distinctive tonality
(3) Adverse effects more than minor; intrusive noise audible on occasion within the home, no modulation or distinctive tonality
(4) Nuisance adverse effect; intrusive noise heard within or exterior to the home on a regular or definable basis, modulation or distinctive tonality may be present; causing anger, annoyance, or adverse health reactions including sleep disturbance
(5) Significant adverse effect; irrespective of sound character causing annoyance or anger and or adverse health reactions including sleep disturbance.

Based on the foregoing: criterion (1) infers no noise whatsoever; criterion (2) is "reasonable noise"; criterion (3) is the transition stage between unreasonable and reasonable noise; and criteria (4) and (5) define "unreasonable noise". These are assessment tools used to evaluate the perception people hold of their environment and both objective and subjective measures are often required.

1.3 Noise and health

Both annoyance and sleep disruption mediate the relationship between noise sensitivity and health related quality of life. In relation to sleep it has long been accepted that disrupted sleep reduces psychological wellbeing, compromises biological processes such as the immune system, and degrades day-to-day functionality. However, even noise insufficient to cause awakening may cause brief arousals in state, with the sleeper moving from a deeper level of sleep to a lighter level and back to a deeper level. Because full waking is not reached, the sleeper has no memory of the event but the sleep has been disrupted just as effectively as if wakening had occurred.

The 2011 WHO Report 'Burden of disease from environmental noise – Quantification of healthy life years lost in Europe' [6], is a review of the scientific evidence supporting exposure-response relationships and case studies in calculating burden of disease. The report concludes that:

> *"There is sufficient evidence from large scale epidemiological studies linking the population's exposure to environmental noise with adverse health effects. Therefore, environmental noise should be considered not only as a cause for nuisance but also a concern for public health and environmental health."*

The Report considers sleep disturbance and its potential for adverse health effects. In 2009, WHO published the Night Noise Guidelines for Europe [7]. This publication presented new evidence of the health damage of night-time noise exposure and recommended threshold values that, if breached at night, would threaten health. The WHO recognises the existence of vulnerable groups (such as children, the elderly, people with ill health) and acknowledges the existence of individual differences in noise sensitivity. Health effects are identified:

- At an outside nighttime noise level (L_{Aeq}) of 30 – 40 dB: a number of sleep effects are observed; 40 dB is equivalent to the lowest observed adverse effect level (LOAEL).
- At an outside nighttime noise level (L_{Aeq}) of 40 – 55 dB: adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
- The outdoor levels are applied with an insulation value of 21 dB from outside to inside the home; a level of 40 dB outside is 19 dB inside
- Supplementary noise indicators (such as LA_{max} 35 dB) may be needed to describe and assess noise for night period protection.

In applying an insulation value of 21 dB the WHO took the A-weighted sound attenuation expected from road traffic noise and building standards applying in Europe. WHO did not (as far as can be ascertained from the text) take into account the lower frequencies produced by wind farms and the much lower attenuation – if any – of the sound from wind turbines in rural Australia [8]. Quality of life is defined by the WHO [9] as:

> *"An individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept affected in a complex way by the person's physical health, psychological state, personal beliefs, social relationships and their relationship to salient features of their environment"*

The above definition was tested in 2012 through a case-study [10] by the Author and colleagues. The study presented a range of objective instruments to assess individual quality of life, health effects and perception of the environment and wind farm noise. The following instruments are acknowledged:

- World Health Organization Quality of Life Assessment, WHO-BREF New Zealand Version 2010; applied and analysed by Dr Daniel Shepherd, Auckland University of Technology.
- SF-36v2 Health Survey, Quality Metric Inc, demo version and analysis from http://www.qualitymetric.com/demos/TP_Launch.aspx?SID=100#
- Noise Sensitivity Questionnaire (NoiSeQ); Schütte M et al. The development of the noise sensitivity questionnaire, Noise and Health, Jan-Mar 2007, Vol 9, pp.15-24; German sensitivity norm; as stated in Thorne(11].
- Epworth Sleepiness Scale, http://epworthsleepinessscale.com/
- Pittsburgh Sleep Quality Index, http://www.sleep.pitt.edu/content.asp?id=1484&subid=2316
- Environmental Noise Annoyance, Amended Questionnaire as stated in Thorne [ibid].
- Sound Character and Perception, Questionnaire and Sound files as stated in Thorne [ibid].
- Questionnaires relating to Sleep, Headaches, Before and After turbines were installed, Dr Michael M. Nissenbaum [12]

All questionnaires were administered personally after discussions with each respondent and collected by the Author. Respondents completed the surveys independently in their own time, and no incentives were offered. It was each person's choice whether or not a specific instrument would be completed. The responses were recorded into spreadsheets and analysed.

Taking just one of the above measures, the Pittsburgh Sleep Quality Index, the study suggested that the residents are affected by wind turbine noise. The PSQI is scored on the basis of component scores, each of which has a range of 0-3 points. In all cases, a score of '0' indicates no difficulty, while a score of '3' indicates severe difficulty. The seven component scores are added together to yield a single global score, with a range of 0-21 points. A score of '0' indicates no difficulty and a score of '21' indicates severe difficulties in all areas. In the responses to the component relating to Sleep Disturbances, 44% of the respondents recorded being disturbed 3 or more times a week; 28% recorded once or twice a week; 28% less than once a week; and 0% reported no disturbances at all. Of the people disturbed less than once per week, 8% have moved from the locale and 8% are in a greenfields locale that does not yet have turbines installed.

Of the 25 participants, 92% have noted a change in sleeping patterns since the turbines went online. The 8% who have not experienced sleep changes are living in a greenfields locale. The changed sleep patterns are described as being entirely new by 80% of the respondents, with 8% of the non-affected persons being in the greenfields locale. For 24 % of the participants the sleep problems described (with the exception of getting up to use the bathroom) existed before but are now worsened since the turbines went online. With the exception of the greenfields participants, 80% of the respondents agreed that sleep improves when away from home (that is, home near the turbines).

Overall, 80% of the participants had a global score greater than 5 points, the marker for good sleep. Above 6 points, sleep is gradually more difficult. Forty percent (40%) of the participants have a score of 15 or more, indicating severe difficulties in all areas of sleep quality. Only one participant (participant 7 from a green area) produced a zero response.

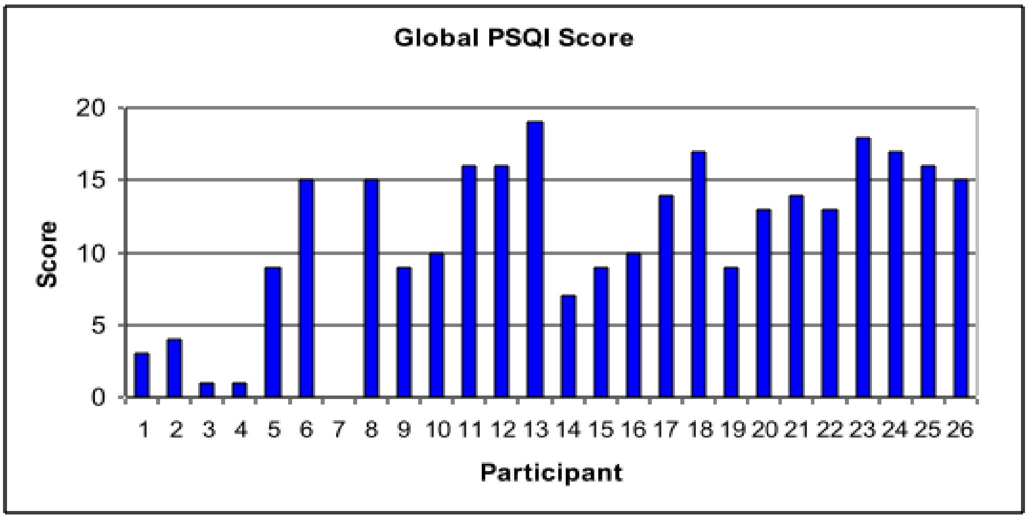

Figure 1 - Global PSQI Score

Based on the results of the case study it can be argued that, when exposed to wind farm noise and wind turbine generated air pressure variations, people will more likely than not be so affected that there is serious harm (also termed 'significant adverse effect') to health. By 'health' it is meant the definition given by the World Health Organization:

> *"A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"*

'Health' refers not only to physiological functioning, but also well-being, quality of life, and amenity. By 'serious harm' it is meant harm that is more than mere annoyance and that can be quantified in terms of reported illness, sleep disturbance or other physical effect. A measure of serious harm is if the exposed individual is adversely affected to such an extent that he or she is obliged to remove themselves from the exposure in order to mitigate the harm.

Wind turbine sound has a unique nature that is variable over time and is highly dependent on wind speed and directions, as well as at a locale. Objective measurement of such sound is not easy, yet can be achieved using suitable measurement methods. NZS6808 refers to "special audible characteristics" but in the Author's opinion the standard falls far short of providing a practical working methodology for measurement and analysis [13].

Observations at the different wind farms under different weather conditions and measurement distances indicate the sound of turbines are individually observable (swish, rumbles, clunks, whines) at distances of 200 – 500 metres. At around 900 metres only clearly distinctive turbines are identifiable (swish, rumbles) and by 2000-3000 metres the sound of turbines is cumulative and is heard as a general source of noise. At each location the wind farm could be clearly heard at dwellings approximately 2000 metres from the nearest turbines. The sound of turbines can be heard 2000 metres upwind and 2000 metres downwind, as well at an angle to the turbines. The sound, with turbines operating, can be described as a steady rumble with a mixture of rumble – thumps. Turbine sound character varies regularly both in "loudness" and "tonality". The general character of a long time period of an hour or so is of a steady rumble. This, however, depends considerably on wind speed and direction.

The sound of turbines is also evident and sometimes more pronounced inside a dwelling, windows open or closed. It is concluded that wind turbine sound at residences around 2000 metres or so is perceptible outside or inside a dwelling. The sound of turbines is often clearer inside a dwelling as higher frequencies from other sounds are reduced through the building fabric. Masking of turbine sound by tree rustle, wind noise or insects was not observed at the time of the study. The general wind speed at ground level was 2-3m/s with the breeze blowing from the turbines to the observer. Insect noise however affects the measurement at all the different broad band outside sound levels (LAeq, Ldn, Lden, LA95).

A working observation derived from the research in relation to noise measurement is:

> *Impact assessments applying only A-weighted sound pressure levels are unreliable. The application of C-weighted values may better identify the overall low-frequency character of wind turbine sound but narrow-band analysis with measures of sound quality, impulsiveness and tonality are required for properly assessing the noise.*

A working observation derived from the research in relation to health effects and wind farm noise is:

> *Adverse health effects are experienced by some individuals due to modulating (pulse coded) noise broadly measured as infrasound (also as modulating air pressures), low frequency and audible noise.*

1.4 Study limitations

First, the sample size was a major limiting factor in the analysis and interpretation of the data. However, while the findings reported here may be considered somewhat speculative and need to be confirmed with a larger sample, they are congruent with findings reported overseas on health-related quality of life and exposures to noises. Future studies capturing more participants would afford the use of structural equations modelling, a more powerful multivariate technique capable of elucidating and testing causal relationships.

Second, while objective measures of sound levels (A-weighted and Z-weighted values) have been recorded, such measurements have had very limited success in predicting health outcomes and they are severely lacking in predicting individual responses to noise. Additional objective measures of sound character are presented (loudness, sharpness, roughness, and fluctuation) but the study concludes they have limited application although more descriptive than measures of sound levels alone.

Third, it is essential to undertake outdoor and indoor noise measurements to further elucidate the relationship between noise and health. Additionally, estimating the time that residents are exposed to the measured noise would likely be an important covariate.

Finally, the use of subjective versus objective health measures to detect changes in health due to environmental factors may be viewed as "soft". Objective outcome metrics such as blood pressure or chronically elevated cortisol levels are arguably well defined and easily measured, while noise-induced sleep disruption, stress, and similar subjective symptoms are less easily measured and distinguished from the background levels present in the population. The rapid application of inexpensive health stress indicators into smartphones (e.g. iPhone apps for sleep disturbance, stress) will improve our ability to make simple measurements.

Objective manifestation of health effects associated with noise-related annoyance may emerge some years after the onset of exposure, whereas subjective appraisals of wellbeing and health suffer no such time lag. Thus for cross-sectional studies as reported here subjective measures are suitable and necessary, and can be supported by objective measures described previously.

1.5 Sound assessment of wind farms

Prediction of the potential sound levels at residences from turbines within a wind farm is a necessary first step in establishing potential effects. Table 1 presents predicted sound levels vs measured ambient levels and responses. The calculation methodology of ISO 9613-2 [14] is often employed as a simple approach to sound prediction and can be considered as the first 'rough-cut' or scoping risk assessment. Reasonably accurate noise predictions are complex. Meteorological conditions, topography, ground cover, wind turbine spacing and associated wake and turbulence effects, vortex effects, turbine synchronicity, tower height, blade length, and power settings all contribute to sound levels heard or perceived at residences. In addition to this the method of prediction has what is known as "uncertainty". ISO 9613-2 has an uncertainty of ±3dB(A) at 1000 metres. However, in an operational wind farm sound levels are not just from the turbines immediately upwind (that is, sending sound 'down' to residences) but also from turbines downwind. Observations indicate turbines at a distance of about 2000 metres upwind and downwind are audible and affect the received levels at a central residence. The scatter in Figure 2 and the '840 metre' data in Table 1 (for example) illustrates the effect of multiple turbines.

Figure 2 identifies the relationship between distance from a wind turbine (or group of turbines) and an affected residence. The distance is the shortest distance to a residence from the midpoint of the 3 nearest turbines. Spearman's Rho = -0.9, $p<.001$ indicate that there is a strong correlation that as distance increases, predicted sound level decreases.

3+ Turbines	Predicted Sound Levels		Outdoor measured sound levels (24 hr)					Turbine sound causes	
Distance (m)	LAeq	LA95	LAeq	Ldn	Lden	LA95	LA95 night	Distress	Annoyance
800	42	40						yes	yes
800	42	40						yes	yes
840*	44	42						yes	yes
840*	44	42	48	56	56	31	38-45	yes	yes
1000	41	39						yes	yes
1000	41	39						yes	yes
1100	40	38						yes	yes
1100	40	38	50	54	54	41	28-51	yes	yes
1190	40	38						yes	yes
1575	36	34	61	65	65	41	36-43	yes	yes
1575	36	34						yes	no
1435	38	36						yes	yes
1435	38	36						yes	yes
1525	37	35						yes	yes
1400	34	32						no	no
1740	38	36	43	46	47	33	25-35	no	yes
1915	38	36	49	54	54	38	39	yes	yes
1915	38	36						yes	yes
2245	30	28						yes	yes
2245	30	28						yes	yes
3400	<28	<26						yes	yes
3400	<28	<26						yes	yes
3500	<28	<26						yes	no
Note * this location is affected by more than 6 turbines within 1500-2000 metres in a 270 degree arc around the residence									

Table 1 - Measured and predicted sound levels at participant's homes from wind farms

It was concluded from the research program that the use of the A-weighted metric has little psychoacoustical merit when there is significant low-frequency rumble to be measured and assessed inside the home. The use of the C-weighting is recommended, in association with the A-weighting for broad-scale assessment. Narrow-band measurements (unweighted or Z-weighted with a defined lower frequency band) in 1/12 octave or FFT are necessary to help in determining sound character for noise mitigation.

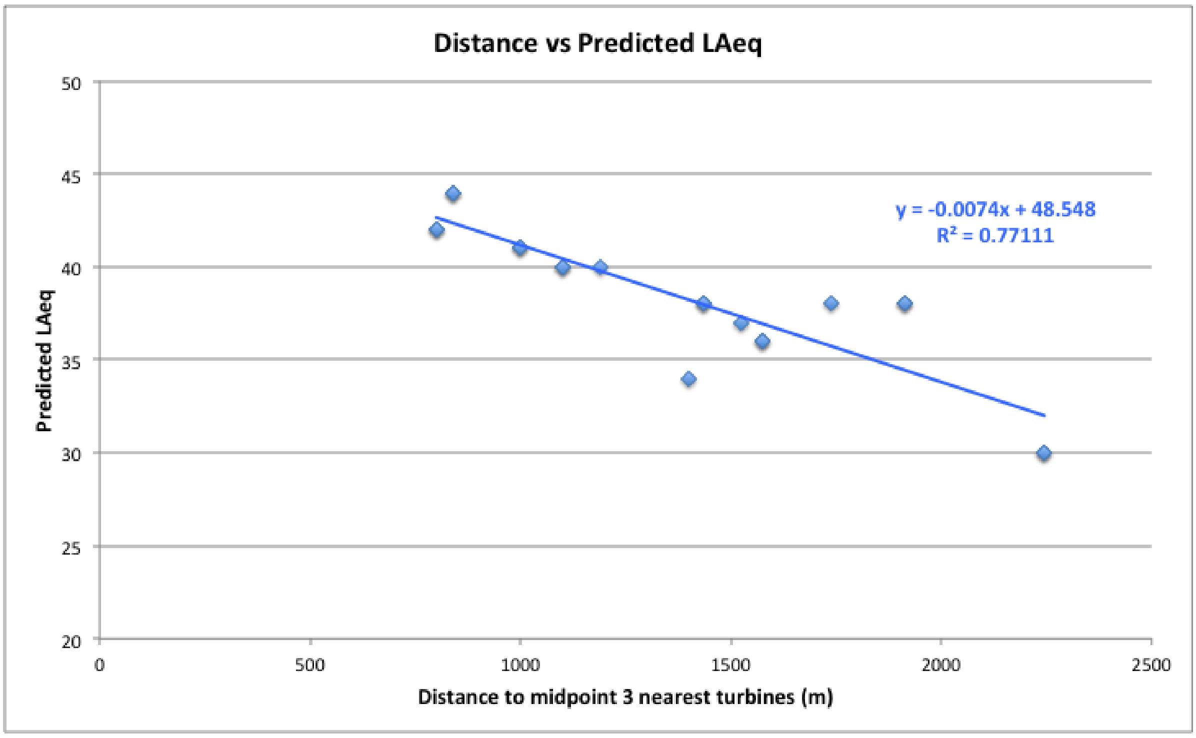

Figure 2 - Correlation of distance to predicted sound levels (LAeq)

As can be seen from Table 1 and Figure 2, there is significant variation between measured ambient sound levels, including wind farm sound, and predicted sound levels of turbines alone. There is no practical way to measure the influence of turbines in the environment unless the turbines are switched off and the ‘unaffected’ sound levels compared to an environment with ‘turbine affected sound levels’. Weather conditions (wind speed and direction, temperature, humidity) need to be similar for unaffected and affected observations made over at least 7 days to account for minor weather variations, atypical results, outliers and uncertainty. Predicted levels are determined under idealized conditions and measures of uncertainty must be applied to the model so it is very clear that the sound levels are calculated, and variations will occur in reality. Measurements and predictions utilising dB(A) sound levels do not confer any certainty as to individual or community responses to changes in sound character due to the presence of operational turbines in the environment. The methods described in the paragraph above are also required.

The Author had the opportunity to review survey data from the Waterloo wind farm study undertaken by the South Australian EPA [15] and independent acoustical professionals from the University of Adelaide and two consultancies. The Author also undertook independent measurement, observations, and discussions with participants. The study revealed significant noise issues at residences 1.2km, 3km, 3.5km, 4km, 7.5km and 9km distant from the wind farm. The survey data included participant observation diaries and audio data as well as undertaking own measurements, observations and discussions with participants. Reported health issues included sleep disturbance, stress and fatigue due to audible noise (“whump, whump”) and pulsing vibration (felt, not always heard as such). Vibration at 2.5km, for example, included audible noise and pressure sensations. The Waterloo study extends the Author’s research undertaken in New Zealand, Queensland and Victoria, Australia. The conclusion from the Waterloo study, as well as the main study research, is that wind farm assessment to current standards and guidelines will not provide a satisfactory guide to potential degradation of the environment with respect to audible noise, low frequency noise, or infrasound.

2. DISCUSSION

The study referenced in this paper is the final in a 7-year research program into low amplitude intrusive noise. The persons who took part in the study (apart from the greenfields’ respondents) are all adversely affected by wind farm activity and, as recorded in individuals’ case study, there is evidence of serious harm to health. The subjective experience of annoyance is a common reaction to noise. The harm is constant while the affected individuals remain in the locale with the wind farm and are abated once they leave the locale, either temporarily over a period of days, or permanently. The personal harm or damage can therefore be said to be reversible but potential economic harm or damage is irreversible. Different individuals can exhibit different annoyance reactions to the same noise, and these individual differences can be ascribed partly to differences in noise sensitivity. The findings suggest that the individuals living near the wind farms of this study have a degraded Health-Related Quality of Life through annoyance and sleep disruption and that their health is significantly and seriously adversely affected (harmed) by noise.

The World Health Organization considers noise pollution to be of sufficient threat to public health to justify the publication of numerous treatises and guidelines on noise effects and mitigation. The impact of ‘community noise’ on health has largely been studied in the context of transportation and general neighbourhood noise, and extends beyond noise-induced hearing loss. Community exposure to wind turbine noise has been relatively understudied, for historical, methodological, and political reasons. This Report presents the findings from a small study undertaken in Victoria, Australia. A sample of individuals (n=25) exposed to wind farm noise completed a survey probing health-related quality of life (WHOQOL), health status (SF-36), sleep (Epworth Sleepiness Scale, Pittsburgh Sleep Quality Index), noise sensitivity (NoiSeQ), and noise annoyance (generic items). Compared to normative data, the sample had lower health-related quality of life, and health status average or below average. Self-report changes to sleep patterns (re: pre-wind farm operation) were common amongst the sample, as were re-evaluations of the local soundscape. The use of a case study approach limits the generalisation of the results, but as an inductive exercise the study successfully identifies a number of avenues for future research.

The precautionary principle is a risk management tool [16] that has importance in public health as well as the environment. Kriebel [17] argues that a precautionary approach is not purely scientific and poses the question “when do we know enough to act as if something is causal?” This may in part be from anecdotal information; for example, “Anecdotes are very valuable ways of honing the questions to be asked” as stated by Anderson [18] before the Senate Committee hearing submissions concerning the social and economic impact of rural wind farms.

Based on the results of the study it is argued that, when exposed to wind farm noise and wind turbine generated air pressure variations, some individuals will more likely than not be so affected that there is a known risk of serious harm (also termed ‘significant adverse effect’) to health. By ‘serious harm’ it is meant harm that is more than mere annoyance and that can be quantified in terms of reported illness, sleep disturbance or other physical effect such as “landsickness” nausea created by pulsing (modulating) infrasonic pressure waves. A definition of ‘serious harm’ proposed is: nausea created by pulsing (modulating) infrasonic pressure waves. A measure of ‘serious harm’ proposed is:

1) If the exposed individual is adversely affected to the extent that he or she is obliged to remove himself or herself from the exposure in order to mitigate the harm; and / or
2) If three or more serious adverse health effects are recorded for an individual. Three serious adverse health effects are established from this study as being:
    a) sleep disturbance with a global PSQI greater than 5,
    b) a state of constant anxiety, anger and helplessness,
    c) an SF36v2 mental health value of less than 40.

The outcomes of the study are concerned with the potential for adverse health effects due to wind farm modified audible and low frequency sound and infrasound. Sound recordings and spectral analysis are needed to confirm the character of the sound being recorded. The study confirms that the collection of sound levels without a detailed knowledge of what the sound levels relate to renders the data uncertain in nature and content. Observation is needed to confirm the character of the sound being recorded.

3. CONCLUSIONS

The precautionary principle seeks to “prevent degradation of the environment if there are threats of serious or irreversible environmental damage”. This study and published anecdotal and observational information indicates that serious damage or harm does exist and is measurable in economic and health related terms. Even though this study is limited in population size, there is ample evidence that, until such time as a definitive noise/health relationship has been obtained for wind turbine noise, the precautionary principle should be used in wind farm noise planning.

Consequently, this means that the potential adverse effects from the threat/risk of the development to the environment must be taken into account in weighing up the balance between the benefits and costs of the development. In the absence of the precautionary principle this process may not occur. The difficult question then becomes: is there a balance and if so, where does the balance lie?

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