



Acoustic Engineering Investigation into Airborne and Ground-Borne Pressure Pulses from Pacific Hydro's Wind Turbines at Cape Bridgewater

A Simplified Explanation of the Findings, Previous Research, and the Consequences

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1. Background

- Turbines create “waste energy” in the form of airborne pressure waves (**sound**) and ground-borne pressure waves (**vibration**).
- **Noise** is that part of the sound frequency spectrum which is audible, but “noise” is also defined by psychoacousticians as “unwanted sound”.
- The **strength** (sometimes expressed as a loudness in the case of noise) of the sound is measured in decibels (“dB”).
- The wavelength of individual sound waves is a measure of the distance between the peaks of the pressure waves. The speed of sound divided by the wavelength gives the frequency of the sound and is expressed in hertz (Hz).
- Where the frequency of the sound waves is below 20 Hz, the distance between the waves is relatively long, and the general term for this portion of the frequency spectrum is known as **infrasound**. Infrasound is only audible at very high levels (dB). However it can be damaging to the human body at levels well below audibility.
- Impulsive infrasound from a variety of industrial sources has long been known to have the potential to be harmful to humans, especially with chronic exposure. For example, human and animal studies have shown infrasound directly causes both physiological stress,¹ and collagen thickening in a variety of tissues including cardiac valves, arteries, and pericardium which themselves lead to a variety of cardiovascular diseases.²
- Infrasound persists for much greater distances than audible sound and, unlike audible sound, penetrates well insulated building structures (including double glazing) with ease; and often increases the impact by resonating within the house, like a drum.^{3 4} This occurs, regardless of the source of sound & vibration energy. Penetration of buildings and amplification via resonance can also occur from sound and vibration from natural sources such as earthquakes and thunder.
- Standards for wind turbine noise pollution in Australia are set in audible decibels (“dBA”) outside houses.⁵ Use of dBA excludes accurate measurement of frequencies below 200 Hz, including both **infrasound (0 – 20 Hz)** and **low frequency noise (20 – 200 Hz)**. These Standards do not require infrasound (either within or outside homes) to be predicted in planning submissions nor to be measured in the required compliance testing to the planning permit noise conditions. Most jurisdictions do not require wind turbine generated low frequency noise to be predicted or measured either (unlike other sources of industrial noise). In fact most noise measuring instruments and microphones are unable to measure accurately in the infrasound range, especially below 8 Hz.

and some Standards explicitly specify the use of equipment which cannot measure infrasound.

- Wind turbines produce infrasound along with audible noise. **The more powerful the wind turbine the greater the proportion of infrasound and low frequency noise emitted,**⁶ which then increases significantly if the turbines are sited too close together, now common practice in Australia.⁷ Most newer wind turbines are now 3 MW or 3.5 MW, compared to 2MW at Cape Bridgewater.
- **By the use of different sound meters and microphones, and in narrow (frequency) bands it is quite possible to identify and measure infrasound specifically from wind turbines, in the field.** This unique “*wind turbine signature*” has now been demonstrated by the acoustic consultants involved in the Health Canada Study,⁸ and by Professor Colin Hansen’s team at Waterloo,⁹ in addition to Mr Cooper’s measurements at a number of locations in Australia prior to and including the Cape Bridgewater Acoustic Investigation.
- Increasing numbers of residents living within 10km of wind turbines have suffered, and are still suffering, severe adverse health impacts since the wind turbines started operating.^{10 11} Many have left their homes repeatedly, and eventually permanently, to live in greatly diminished financial circumstances, as their homes are no longer habitable or saleable. Some residents become too unwell to work. Wind turbines are not the only source of impulsive infrasound and low frequency noise causing severe health damage. The same pattern of identical serious adverse health effects, sleep deprivation and home abandonments are being reported by neighbours to open cut coal mining, underground mines with large extractor fans, gas turbine power stations and numerous other sources.¹²
- Wind power projects and other energy generating noise polluting industrial developments involve very large sums of money in construction, in revenues and in the case of industrial wind turbines - public subsidies. It is not uncommon to find companies with large investments and large cash flows going to great and improper lengths to maintain their cash flows.
- The wind industry has never been asked to prove that their machines are safe, unlike other products on the market. When queries are raised about impacts on neighbours, the industry and its supporters trigger the “Four Ds” of **denial, dissemble, delay and destroy the messenger**, despite the wind industry being well aware of the seminal research by Dr Neil Kelley and NASA **which established direct causation of symptoms from impulsive infrasound and low frequency noise from wind turbines and other sources in the 1980s**, by both field and laboratory research.¹³

2. The Purpose of the Cape Bridgewater Acoustic Investigation

The purpose of the investigation was simply to find out what was causing the symptoms and sensations, resulting in sleep disturbance and health damage, reported to Pacific Hydro between 2009 and 2014 by the residents of three homes sited between 600 – 1600 metres from wind turbines sited at the Cape Bridgewater Wind Project in Victoria, Australia.¹⁴

3. What Are the Key Findings of the Cooper Acoustic Investigation?

The findings include:

- By using sound meters and microphones that can accurately measure infrasound and recording the infrasound levels in narrow frequency bands (rather than dBA or 1/3 octave bands) it was clear that ***infrasound generated specifically by the wind turbines was present in the three homes.***

- **Wind turbines emit a recognisable and repeatable sound “signature”** (or profile), being the relationship between the blade pass frequency and multiple harmonics of that frequency. At times the acoustic signature included audible characteristics and modulation across the full frequency spectrum. Further, this signature, whilst it contains significant energy in the infrasound range, is in no way comparable to other sources of infrasound such as waves on the beach, other fast rotating machinery, i.e. refrigerators, trains, road traffic, as claimed by wind industry “experts” and supporters.

This discovered profile “wind turbine signature” does not need further research, and has been independently documented by other acousticians and researchers around the world.

- Wind turbine infrasound is present inside each of the three homes investigated (when the turbines are operating), **at levels known thirty years ago to directly cause the same symptoms and sensations** including sleep disturbance and body vibrations. The intensity of the infrasound levels inside the houses varied between and within rooms (probably due to resonances and different outlooks to the wind farm).

A potentially causative energy problem was identified in each of the three houses.

- It was determined from early testing by Steven Cooper and the residents that recording of impacts solely by the previously used parameters of noise and vibration was not enough. A third impact being “sensation” was added to cover, as it transpired, the reaction of the body to infrasound.

Diaries used by the SA EPA at the Waterloo project were not designed to investigate the reported impacts from “sensations”. The SA EPA’s conclusions in that study were wrong, and are therefore now irrelevant.¹⁵

- The residents’ impact diaries (based on the South Australian EPA Waterloo Acoustic Survey diary format) were substantially modified to improve their ease of use, reliability and differentiation between perceptions of noise, vibration (external to the body), and “sensations” (determined in this study to be reactions to infrasound).¹⁶

The form of these diaries must be the minimum standard for future multidisciplinary investigations.

- Since measurements and predictive noise models for wind turbines being expressed in dBA exclude accurate measurement of infrasound and low frequency noise, it follows that dBA is useless as a proxy for predicting damage to neighbours, or for setting Standards to protect them from harm. Even before Steven Cooper’s investigation, the wind turbine noise Standards were known to be dangerously inadequate. Responsible authorities should have altered the Standards to include sound as a whole and infrasound in particular, especially after Dr Neil Kelley’s work establishing direct causation from infrasound and low frequency noise resurfaced in mid 2013. Steven Cooper’s work reinforces the need for urgent revision of existing Australian standards and regulations, and to develop a standard for sensation.

These current Standards are now known to be dangerous, clearly do not protect people, and must not ever be used again.

- Methods of measuring sound must: utilise instruments able to monitor the whole spectrum of sound; be conducted inside as well as outside homes; produce results in narrow bands not one third octaves or dBA as is currently standard, and must continue over sufficient periods of time, to cover most if not all environmental conditions (wind speed and direction etc.).

No other acoustic investigations have been so inclusive of a range of environmental conditions, apart from Dr Neil Kelley and NASA's work, funded by the US Department of Energy in the 1980's which originally identified the direct causal relationship between symptoms and sensations and impulsive ILFN from the various sound sources which included wind turbines, gas turbines and military aircraft.¹⁷

- Changes in wind speed, wind direction, turbine start up, and operating at near shutdown speed coincided with sensations being at the highest level (characterised as equivalent to a compulsive need to flee the house).

Causality of intolerable symptoms and sensations from infrasound has been established, repeatedly and predictably. This means it is now indefensible for any public authority or official to rely on the nocebo nonsense to explain residents' symptoms and sensations.

- Without any argument the investigation showed that the six residents in the three houses were regularly subject to wind turbine derived infrasound, inside their homes particularly in the 4 to 5 hertz range of infrasound frequencies, at levels known thirty years ago to be dangerous to health. The residents' own diaries and personal health histories demonstrate that all of the residents have been severely impacted.

4. Commentary

With better instruments, more reliable and useful diaries, plus eight weeks of data and the opportunity to measure sound and vibration when the turbines were shut down, this thorough acoustic investigation by a highly regarded, ethical acoustic engineer was established to find the truth *whatever it may be*.

A number of lesser studies previously conducted by other acousticians, show signs of intellectual corruption and/or ineptitude, and of being designed to find no problems; thereby shielding the flow of cash to wind project owners; whilst holding off the liability for supposedly expert but incorrect opinions delivered by a group of acousticians on behalf of project operators and of companies seeking planning permits.

Predictably, the wind turbine product defence team are still trying to fault the Cooper investigation.

A guide to understanding the key claims follows.

- a) **Misrepresenting an Engineering Investigation** as an all embracing academic research project, and then criticizing it because it was not.

The brief was very specific - to determine whether certain wind speeds and certain sound levels related to disturbances related to specific local residents. This was a thorough, independent, acoustic investigation into why these three houses were virtually uninhabitable. The answer was found and the cause established. Evidence of court quality has been established. It was not a generously funded academic research project.

- b) **No Peer Review**

It is correct that this report was not peer reviewed prior to public release.

Pacific Hydro did not allow peer review to occur, prior to its publication. However, peer reviews by acoustic consultants are occurring now, and preliminary peer reviews from acousticians with first

hand knowledge of the reported health problems and the challenges of conducting research inside the homes of impacted residents have acknowledged the quality and usefulness of this acoustic investigation.

Engineers seek a repeatable result. The way a repeatable result is sought includes checking the suitability and location of the instruments, then painstakingly calibrating them before measurements start. The calibration and measurement processes are repeated ad nauseum **until it is clear, without out any doubt, that the results are repeatable**. This is precisely what Steven Cooper has done. It is also of great value that the methodology of the study, and the problems he encountered, have been so clearly described in detail in the report, for the benefit of future researchers.

c) No Control Group

Some non epidemiologists who have commented on this research have said it is meaningless because there is no “control” group for comparison. The brief from Pacific Hydro prohibited a separate control group of separate non exposed “controls”. In fact, ***the residents were their own controls in this acoustic investigation, which in epidemiological terms is a “prospective case (series) crossover” design***, also used in pharmacological research to assess the individual responses to differing doses of drugs over time.¹⁸

In other words this particular study design gives detailed information about a number of individuals’ responses to specific doses (in this instance “exposure doses at specific sound frequencies”) over time, and also the human responses when no drug (wind turbine infrasound) is present. Prospective case (series) crossover studies are well known to epidemiologists as a powerful epidemiological study design, and help to establish causation, as well as therapeutic and safety thresholds, depending on those varied individual responses.

d) Small Sample Size

This was a detailed investigation into three houses, over eight weeks, with six residents who had reported serious adverse health impacts for many years. The sample size limits were established by Pacific Hydro, who commissioned the study, and are to be commended for doing so. This level of detailed direct investigation of acoustic exposures and human impacts has not been seen for thirty years, since the US Department of Energy funded acoustic field research conducted by Dr Neil Kelley and NASA in 1985.¹⁹

The results are consistent with Kelley’s research, which established direct causation between infrasound and low frequency noise emissions and reported sensations. Predictably the wind industry and its supporters have denied the current relevance of the Kelley research, ***despite it being instrumental in forcing a significant design change of wind turbines to reduce the generation of impulsive infrasound and low frequency noise, in order to prevent health damage***.

e) Can the Results be Extrapolated to Other Locations?

To answer this question it is necessary to consider probabilities. The relevant inputs are:

- modern wind turbines produce impulsive infrasound, in increasing proportions as the turbine power increases;
- impulsive infrasound can and does cause serious impacts on humans, known for thirty years;

- Impulsive infrasound from wind turbines penetrates homes, and the characteristic symptoms are being reported by residents at distances of at least 8km -10km from wind turbines, and correlate directly with exposure to operating wind turbines.
- multiple home abandonments at multiple wind projects have taken place because the owners are suffering symptoms associated with turbine proximity, and their medical practitioners are increasingly advising them to move, in order to prevent further serious health damage;
- in Australia nearly every wind project with turbines of 1.5MW or more has generated public complaints from residents who live nearby, unless those residents have been silenced with non disclosure clauses in various agreements – the use of which have been denied by the industry despite documented evidence to the contrary.²⁰

The answer to the question posed is:

“where there are or have been multiple complaints of the characteristic symptoms and “sensations” by residents, there is a very high probability of infrasound at health damaging levels being present inside those homes, and that being the cause of the complaints and serious adverse health effects reported by residents.”

The research protocol and tools developed by Steven Cooper and the residents are easily reproducible at other locations where similar adverse health impacts are being reported, regardless of the source of the sound and vibration.

This study can be easily extended to include concurrent physiological data collection with the full spectrum acoustic measurements inside and outside homes. There is no reason why information about specific indicators of health status cannot also be collected from study participants, such as those used by Dr Bob Thorne²¹, Dr Daniel Shepherd²² and Dr Michael Nissenbaum²³ in their respective studies, which have established adverse health effects in different wind turbine noise affected study populations previously.

The realization that this acoustic investigation study design is also a prospective case (series) cross over design increases the power of this specific study design to provide important answers as to causation and safety thresholds, when replicated at any site where these characteristic symptom and sensation complaints have been reported by residents living within ten km. As one of the acoustic peer reviewers said, “may the medical testing begin”.^{24 25}

5. Finally – the Consequences

The operator at Cape Bridgewater and the responsible authorities now have to deal fairly and equitably with these three families.

More broadly, the various public authorities involved in regulating the wind industry (and indeed noise pollution regulation in Australia from any source) need to take notice.

Steven Cooper’s study design can now be used to investigate the acoustic impacts at any wind power or other noise emitting development where the characteristic health problems have been reported by nearby residents. When combined with the concurrent physiological data collection (e.g. heart rate, sleep EEG, non invasive blood pressure, and stress hormones) the results will demonstrate both direct causation of the physiological impacts the residents are clearly describing, and also reliable and consistent thresholds of perception for those chronically exposed, from which new and much safer “noise” pollution guidelines can be implemented and properly enforced, to prevent further serious harm to physical and mental health.²⁶

The relevant politicians, public authorities and officials need to ensure that the requisite research is adequately funded, and properly conducted, as a matter of urgency. Research directly investigating the sound frequencies inside people’s homes was recommended “**as a priority**” in June 2011, by the Senate Committee Report into the Social and Economic Impacts of Rural Wind Farms, chaired by Greens Senator Rachel Siewert²⁷ and has since been endorsed by both houses of Australian Federal Parliament. This multidisciplinary research was also a pre election promise of the current Federal Government.

The conduct of such research must be undertaken in a transparent manner adhering to the highest ethical standards and must involve the community in such investigations and vetting the investigation team. It cannot be conducted in laboratories but must use operational wind farms and existing residents (for both affected and control groups). The wind development operators and owners must be required to provide all necessary operational data, and to cooperate without restriction with “on off testing”.

If this Cape Bridgewater research, commissioned by a wind developer, conducted by an ethical independent acoustician with the cooperation of both the wind developer and the affected residents, is not acted upon immediately to prevent further harm, *the public authorities and politicians who choose not to act are then in a position of knowingly allowing the serious damage to physical and mental health from impulsive infrasound and low frequency noise from wind turbines to continue.*

The most serious and common complaint around the world from neighbours to industrial wind turbines and other sources of impulsive infrasound and low frequency noise is repeatedly disturbed and interrupted sleep, (resulting in prolonged and chronic sleep deprivation, which itself is acknowledged as a method of torture by the UN Committee against Torture). The serious adverse health consequences of chronic sleep deprivation alone are well known to clinical medicine, and to noise pollution, planning and health authorities.

Immediate action by all those public officials responsible for the current situation is therefore required, to prevent further harm.

¹ For example the 1985 study from the University of Toronto by Nussbaum and Reinis <https://www.wind-watch.org/documents/some-individual-differences-in-human-response-to-infrasound/>, the Chinese study from 2004 <http://waubrafoundation.org.au/resources/an-investigation-physiological-and-psychological-effects-infrasound-persons/>, the work cited in the National Institute of Environmental Health Sciences Literature Review in 2001 <http://waubrafoundation.org.au/resources/infrasound-brief-review-toxicological-literature/>

² the extensive body of work by the Portuguese research team into Vibroacoustic disease and collagen thickening is summarised in this review article: <http://waubrafoundation.org.au/resources/vibroacoustic-disease-biological-effects-infrasound-alves-periera-castelo-branco/>

³ see for example the Falmouth acoustic survey by Rand and Ambrose, December 2012 <http://waubrafoundation.org.au/resources/bruce-mcpherson-infrasound-low-frequency-noise-study/>

⁴ Also Mr William Palmer’s research measuring infrasound from wind turbines inside rural farmhouses in Ontario <https://www.wind-watch.org/documents/wind-turbine-annoyance-a-clue-from-acoustic-room-modes/>

⁵ for a discussion about the origins of the various Australian Standards by two acousticians who helped write the South Australian Wind Turbine Noise guidelines see Chris Turnbull and Jason Turner’s paper delivered in Denver, Colorado in 2013 <http://waubrafoundation.org.au/resources/turnbull-c-turner-j-recent-developments-wind-farm-noise-australia/>

⁶ The Danish research which established this was by Professors Moller and Pedersen in 2011

<http://waubrafoundation.org.au/resources/moller-pedersen-low-frequency-noise-from-large-wind-turbines/>

⁷ see the exchanges between Dr Malcolm Swinbanks and Mr Les Huson about the distances between wind turbines at AGL's Macarthur Wind Development in Western Victoria at the end of the Waubra Foundation submission to the RET review

<http://waubrafoundation.org.au/resources/renewable-energy-target-review-waubra-foundation-submission-2014/>

⁸ MG Acoustics, Ottawa and Ontario, Canada, "Wind Turbine Noise Propagation" report for Health Canada Study, 2014, Figure 3

⁹ <https://www.wind-watch.org/documents/comparison-of-the-noise-levels-measured-in-the-vicinity-of-a-wind-farm-for-shutdown-and-operational-conditions/>

¹⁰ Please see the noise impact surveys on the Waubra Foundation website for further details of the systematically gathered data which concur with what the Waubra Foundation has been told by individuals living near wind developments in Australia:

<http://waubrafoundation.org.au/library/community-noise-impact-surveys/>

¹¹ For adverse health effects confirmed in residents at Waubra and Cape Bridgewater wind developments, see Dr Bob Thorne's study from 2012, reissued in 2014 <http://waubrafoundation.org.au/resources/thorne-r-victorian-wind-farm-review-updated-june-2014/>

¹² For other details see the references at the bottom of the document "Environmental Noise, Sleep Deprivation, and Torture"

<http://waubrafoundation.org.au/resources/environmental-noise-sleep-deprivation-torture-september-2014/>

¹³ Dr Neil Kelley's research is summarised in the Waubra Foundation's Explicit Warning Notice, November 2013.

<http://waubrafoundation.org.au/2013/explicit-warning-notice/>

¹⁴ the Cape Bridgewater Acoustic Survey can be accessed on the Pacific Hydro website:

<http://www.pacifichydro.com.au/english/our-communities/communities/cape-bridgewater-acoustic-study-report/?language=en> and the resident's statement can be found here: <http://waubrafoundation.org.au/2015/steven-coopers-cape-bridgewater-acoustic-research-commissioned-by-pacific-hydro-released/>

¹⁵ Further information about the SA EPA Acoustic survey is here: <http://waubrafoundation.org.au/resources/open-letter-premier-south-australia-clean-energy-regulator-concerning-sa-epa-acoustic-survey-2/> and Professor Colin Hansen's team's report of their acoustic survey (concurrent with the SA EPA is here: <http://waubrafoundation.org.au/resources/hansen-zajamsek-hansen-noise-monitoring-waterloo-wind-farm/>

¹⁶ The pro forma of the diaries used by the residents can be downloaded here (scroll down to the bottom of the webpage):

<http://waubrafoundation.org.au/information/residents/journals/>

¹⁷ The research in the USA into military aircraft noise perception by Harvey Hubbard in 1982 is here:

<http://waubrafoundation.org.au/resources/hubbard-h-1982-noise-induced-house-vibrations-human-perception/>, and the early research into gas and wind turbines from 1982 is here: <http://waubrafoundation.org.au/resources/kelley-et-al-methodology-for-assessment-wind-turbine-noise-generation-1982/>

¹⁸ For a simple explanation of a case cross over designed study, see this description:

<https://onlinecourses.science.psu.edu/stat507/node/51> and for an example of how it can be used in pharmaceutical and clinical epidemiological research please see <http://smm.sagepub.com/content/18/1/53.abstract>

¹⁹ The 1985 Kelley / NASA acoustic field research report: <http://waubrafoundation.org.au/resources/kelley-et-al-1985-acoustic-noise-associated-with-mod-1-wind-turbine/>

²⁰ Senator Chris Back's speech to Federal Parliament in October 2012 contains extracts from a number of contracts which contain non disclosure clauses (also known as "gag" clauses) <http://waubrafoundation.org.au/resources/senator-back-reveals-gag-clauses-wind-developer-contracts/>

²¹ Thorne's research at Cape Bridgewater and Waubra in Victoria, Australia, first submitted to the Senate Inquiry in 2012, and reissued in 2014 : <http://waubrafoundation.org.au/resources/thorne-r-victorian-wind-farm-review-updated-june-2014/>

²² Shepherd et al's research at Makara in New Zealand, published in Noise and Health in 2011 <http://waubrafoundation.org.au/resources/evaluating-impact-wind-turbine-noise-health-related-quality-life/>

²³ Nissenbaum et al's research at Maine and Vinalhaven, USA, published in Noise and Health in October 2012 <http://waubrafoundation.org.au/resources/effects-industrial-wind-turbine-noise-sleep-and-health/>

²⁴ Mr Rob Rand, acoustician from the USA <http://waubrafoundation.org.au/resources/rand-r-congratulations-cape-bridgewater-acoustic-study-report/>

²⁵ other acoustic peer reviewers include Mr Steven Ambrose <http://waubrafoundation.org.au/resources/ambrose-se-congratulations-steven-cooper-cape-bridgewater-report/> and Dr Bob Thorne <http://waubrafoundation.org.au/resources/thorne-r-congratulation-cape-bridgewater-investigation/>

²⁶ Justice Muse, in Falmouth USA issued an injunction in December 2013 to prevent wind turbines operating at night time in order to "prevent irreparable harm to physical and psychological health" <http://waubrafoundation.org.au/resources/falmouth-mass-judge-muse-decision-shut-down-wind-turbines-causing-irreparable-harm/>

²⁷ The Australian Senate inquiry recommendations from 2011 are here: <http://waubrafoundation.org.au/resources/australian-federal-senate-inquiry-into-wind-farms-health-report/>