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Calculating Cumulative Sound Levels from Large Industrial Wind Farms

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ABSTRACT

When determining noise limits for a new wind farm development, sound from other pre-existing wind farms must be considered for both the background sound levels and compliance levels. The new Turitea Wind Farm (**TWF**) being constructed in the Tararua Ranges, east of Palmerston North, will be less than 3km south from the existing Te Rere Hau Wind Farm (**TRH WF**) with some houses located between the two wind farms.

Mercury Energy engaged Marshall Day Acoustics (**MDA**) to assess sound from TWF and establish the wind farm noise limits. This involved a series of complex calculations to remove the influence of TRH WF from measured background sound levels, which are used to establish the TWF noise limits in accordance with the New Zealand wind farm noise standard, NZS 6808:2010 (**NZS 6808**). This noise limit is the 'overall noise limit' that the noise from both wind farms added together must comply with.

As TRH WF was pre-existing, TWF noise emissions had to be designed to achieve a lower 'noise budget' that would ensure, when added to the TRH noise, the combined noise did not exceed the TWF noise limit.

NZS 6808 recommends the ISO 9613-2 prediction method for calculating wind farm sound propagation. However, this method is conservative as it gives results for light downwind propagation in all directions simultaneously, which is not physically possible. To improve the accuracy of predictions, we calculated the directivity of sound propagation with wind direction using the Institute of Acoustics Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise (**IOA GPG**).

These complex calculations allowed Mercury and the turbine supplier to achieve a more accurate review of compliance and any consequential noise abatement techniques.

1 INTRODUCTION

Calculating windfarm noise limits can be a relatively straightforward process when there is only one wind farm to consider. It involves measuring the background sound levels at nearby receivers, while at the same time measuring wind speeds at the proposed wind farm site. The sound levels and wind speeds are plotted against each other. Depending on how well these two factors correlate, one can establish a regression line of best fit for the relationship. The wind farm noise limit for that measurement location then becomes the greater of 40 dB $L_{A90(10\ min)}$, or the background sound levels plus 5 decibels, according to NZS 6808.

If an existing wind farm is operating near the proposed wind farm site, the calculations become more complex. The existing wind farm will be potentially influencing the background sound levels at the nearest receivers. According to NZS 6808 wind farm sound from another wind farm shall not be considered as part of the background sound level in determining noise limits for a subsequent development.

When considering cumulative noise effects, sound levels from both wind farms should be accounted for as accurately as possible. Over-predicting sound levels from either the proposed wind farm or the existing one may result in unnecessary noise curtailment requirements. Noise curtailment requires certain turbines to be turned down at certain wind speeds and directions. This directly affects the proposed wind farms' energy output and financial feasibility.

MDA assessed wind farm sound levels from the proposed TWF, and nearby TRH WF. We calculated wind farm sound levels using the ISO 9613-2 prediction method (as provided in NZS 6808) and then adjusted the levels to account for wind directivity using the guidelines in the IOA GPG. We then adjusted the background sound levels using the predicted levels from TRH WF. From this, we established the overall noise limits and the allowable TWF 'noise budgets' so as not to exceed the noise limits while TRH WF is operating.

This paper outlines the three major calculation steps taken to predict the wind farm sound levels and establish the TWF noise budgets. These calculation steps are presented in the following three headings.

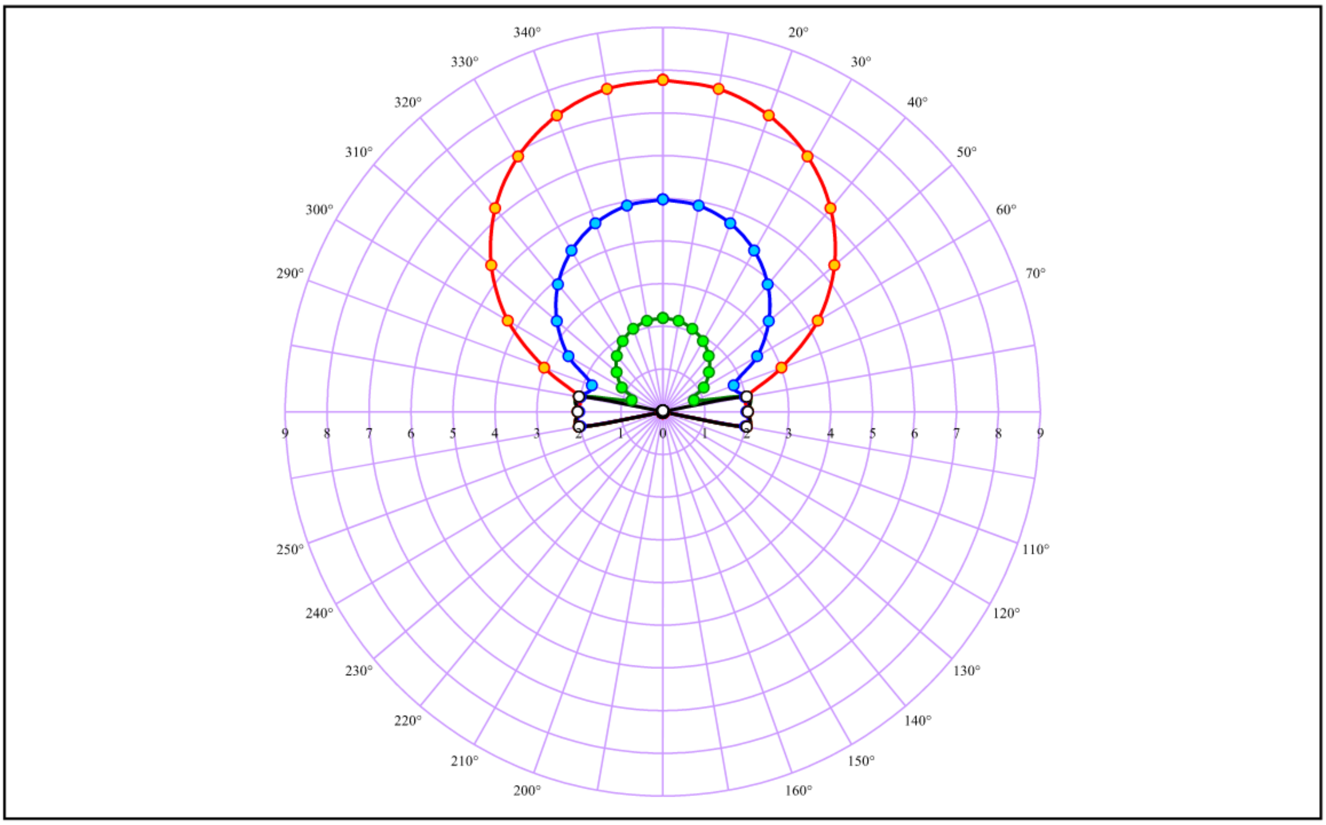
2 WIND DIRECTIVITY ATTENUATION

2.1 Derive directivity polynomials

The IOA GPG provides attenuation rates for predicted wind turbine sound levels for all wind directions (10-degree segments). Figure 1 below shows the attenuation rates for complex terrain (not flat terrain). It is interesting to note that the attenuation is zero for most of the 180-degree downwind segment. The attenuation also depends on the distance from the turbine to the receiver. This is represented by the four coloured lines and expressed in terms of the turbine tip height. I.e., black is a turbine-receiver distance equal to 5.25 tip heights; green is 7.5 tip heights; blue is 11 tip heights; and red is 18 tip heights. The tip height for TRH WF is 46.5m, and the tip height for TWF is 125m.

0° is a receiver location upwind of the turbine, where a maximum attenuation rate is possible, of just less than 8 decibels at large distances. Either side of 0°, the attenuation rate reduces to 2 decibels at crosswind (90° and 270°). 180° is fully downwind and no attenuation applies.

We modelled the four lines in the chart and derived polynomial functions to interpolate between the lines for other turbine-receiver distances.

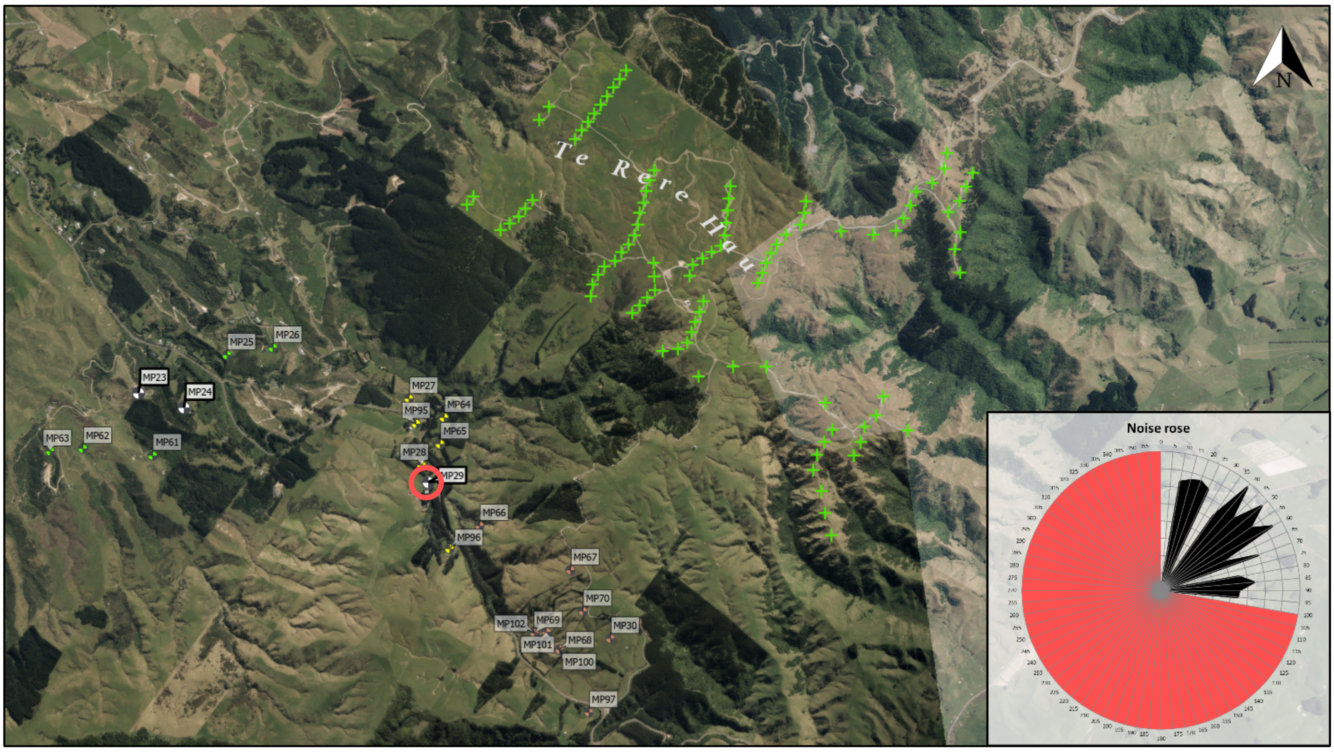


Source (IOA GPG, fig. 6b)
Figure 1: IOA directivity rates for complex terrain

2.2 Find the turbine contribution per wind angle

We modelled sound levels from TRH WF in SoundPlan v8.2 noise modelling software. The SoundPlan prediction method is based on ISO 9613-2, for all turbines operating in light downwind conditions simultaneously. Figure 2 overleaf shows an aerial view of TRH WF and neighbouring receivers.

We calculated the angle between each TRH WF wind turbine (green crosses) and each nearby receiver (labelled with 'MP'). This allowed us to sort and combine the predicted noise levels from each turbine into 'bins' for every turbine-receiver angle rounded to the nearest 5°. The chart at the bottom right of Figure 2 provides an example of a ‘noise rose’ for the receiver at MP29 (circled). The chart shows that the TRH WF wind turbines contribute downwind, or maximum, noise levels in a small north-east segment of the wind rose (black shading). At this stage, the attenuation rates have not yet been applied to the upwind directions (refer to the following section).



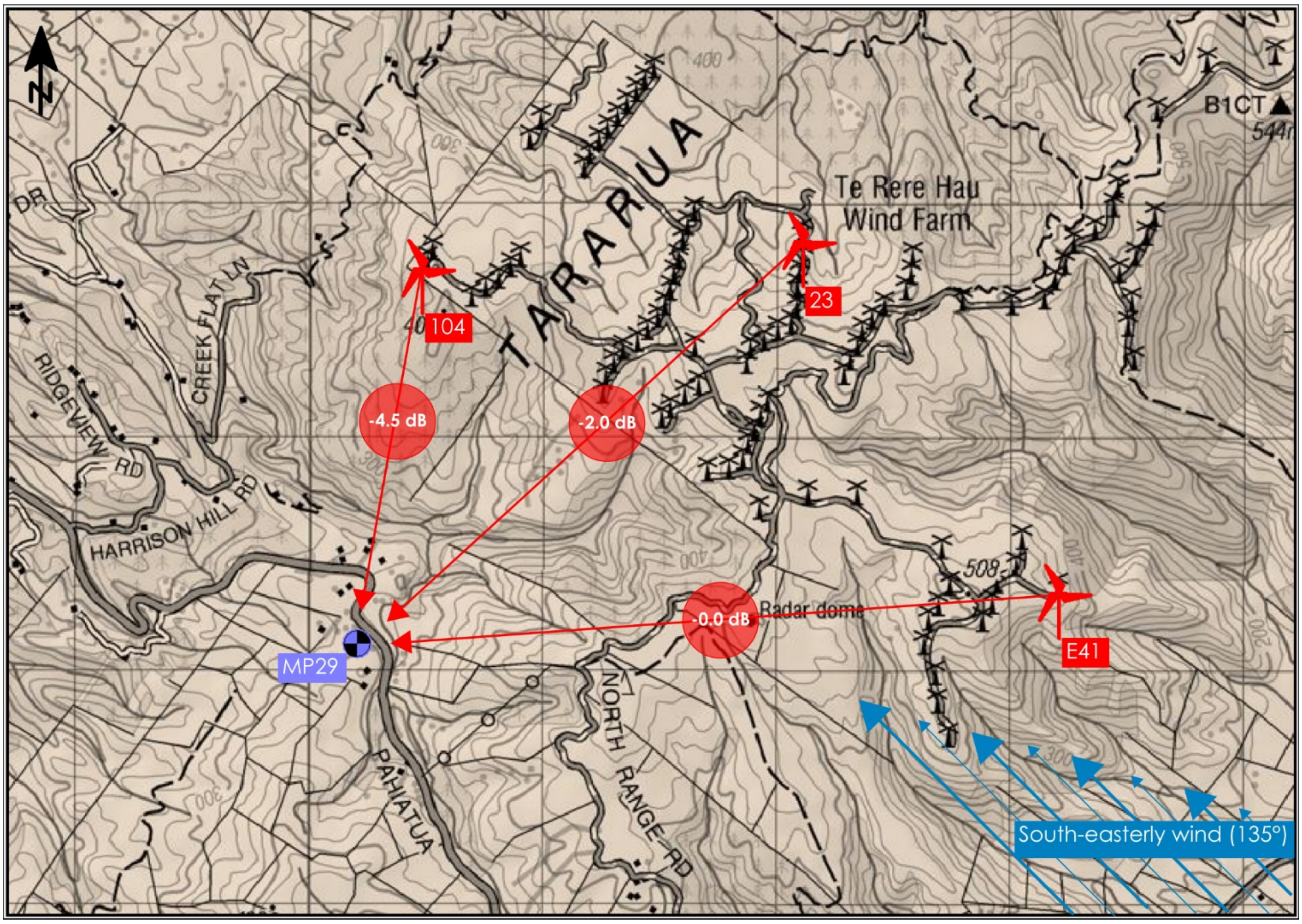
Source (Author, 2021)
Figure 2: Aerial map of TRH WF and neighbouring receivers

2.3 Adjust the sound levels using the IOA attenuation rates

We calculated the attenuation rates that apply to the predicted downwind noise levels for all wind directions (in 5° sectors). This involved determining the relative angle between each turbine-receiver pair and each wind direction. The relative angle and distance from each turbine were then used as inputs for the polynomial functions (see Section 2.1) that we used to model the IOA attenuation rates.

Figure 3 overleaf presents a diagrammatical representation of the adjustment. In the diagram, the wind is blowing at 135°. For turbine 104 and receiver MP29, the wind is blowing at an upwind angle from the receiver, but not directly upwind, so the attenuation rate is -4.5 dB (according to the IOA attenuation rate chart, Figure 1 above). For turbine 23, the wind is blowing crosswind to the receiver, so the attenuation factor is -2 dB. For turbine E41, the wind is blowing at a downwind angle to the receiver, so no attenuation applies.

We applied the attenuation rates for each turbine-receiver pair and each 5° wind angle to the predicted sound levels detailed in Section 2.2. The outcome was TRH sound levels at every 5° wind direction adjusted for directivity effects.



Source (Author, 2021)
Figure 3: IOA GPG (fig. 6b) attenuation rates relative to ISO9613 (downwind propagation) for south-easterly wind (135°) at MP29

3 BACKGROUND SOUND LEVEL CORRECTION

Background sound levels were measured over 2 -3 months at several properties within 1 – 2 kilometres of both TWF and TRH WF. We had to remove the influence of TRH WF on the background sound levels as the existing wind farm was operating during the measurements. Background sound levels were measured in 10-minute intervals in accordance with NZS 6808. We adjusted every 10-minute level by a corresponding predicted level from TRH WF. To do this, we needed to calculate sound levels for the range of wind speeds and directions experienced at TRH WF during the background sound measurements. This process is outlined in the following headings.

3.1 Predict sound levels using TRH hub height wind speeds

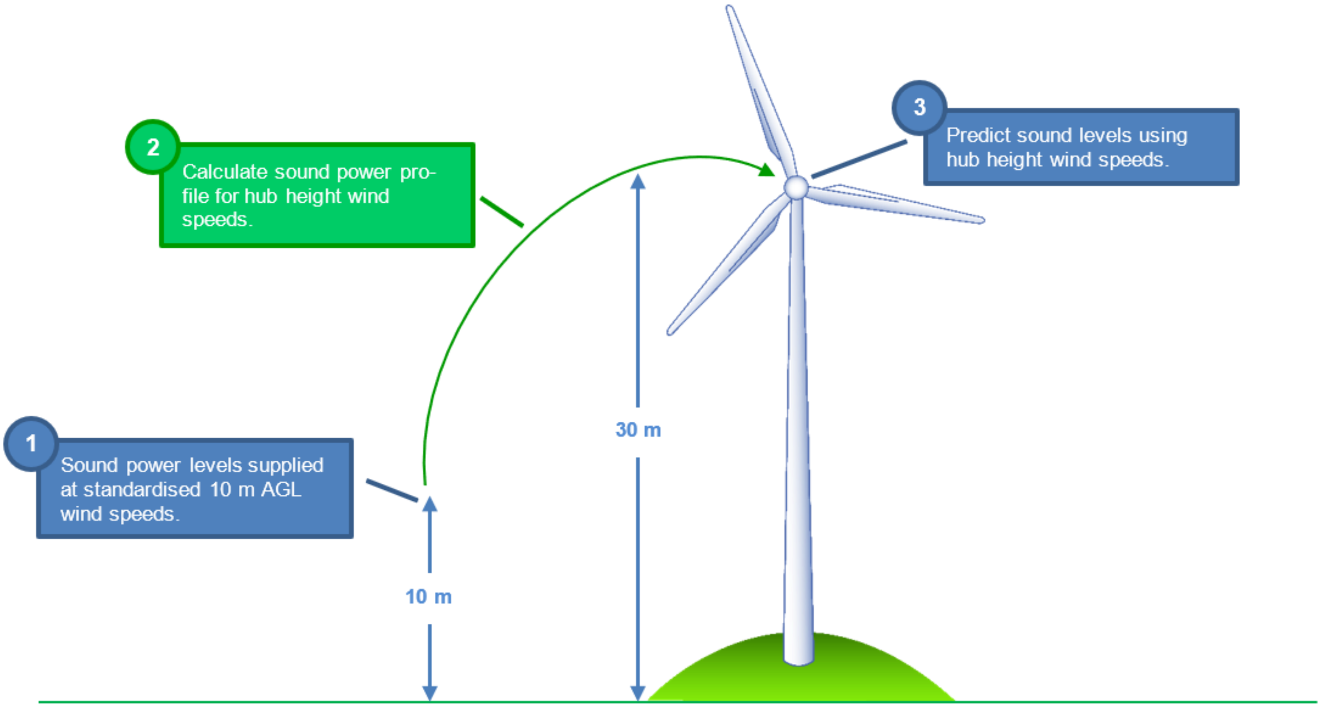
The sound power of a wind turbine varies with wind speed, and wind speeds change depending on the height above ground level (AGL). We were provided with sound power data for the TRH WF wind turbines at hub height wind speeds standardised to 10 m AGL (as in accordance with the IEC 61400-11 standard). This data was used to determine the predicted sound levels detailed in Section 2.2. The sound levels were calculated using a maximum sound power level reached at 9 m/s (standardised 10 m AGL wind speed).

However, NZS 6808 assesses background sound levels using hub height wind speeds. The standard provides an equation to convert standardised 10 m AGL wind speeds to the hub height equivalents. The equation is reproduced below, where H is the hub-height, Vs is the 10 m AGL wind speeds, and Vz is the hub-height equivalents.

$$V_z = V_s \times \ln\left(\frac{H}{0.05}\right) \times 0.1887$$

(1) (NZS6808 equation 6)

We used the hub height wind speeds to calculate a sound power level profile for the TRH WF turbines across their range of operating hub height wind speeds, from 5 m/s to 20 m/s. The sound power level profile was based on a polynomial relationship between the supplied sound power levels and standardised 10 m AGL wind speeds. We then used the sound power level profile to calculate TRH WF sound levels at the receivers for all operating hub height wind speeds and for a range of wind directions. The process is shown schematically in Figure 4.



Source (Author, 2021)
Figure 4: Schematic representation of calculating sound levels using TRH hub height wind speeds

3.2 Match the predicted levels to time-stamped TRH wind speeds

We were supplied with TRH WF met data for the period of background sound monitoring. The met data included the wind farm wind speeds and directions in 10-minute intervals. Using the calculated receiver sound levels (as detailed in Section 3.1), we could match a predicted level to the met data for every 10-minute interval at the specific wind speed and direction recorded.

3.3 Adjust the background sound measurements

We subtracted the calculated TRH sound levels from the corresponding measured background sound levels. The approach we took for this subtraction is based on the method outlined in Section 8.2 of IEC 61400-11: 2002 - *Wind turbine generator systems - Part 11: Acoustic noise measurement techniques* (**IEC 61400-11**). However, we amended the approach to reduce the amount of measured data that would have otherwise been discarded. This is explained further in Table 1 overleaf.

The ‘amended approach’ typically results in comparatively lower measured levels. This in turn results in lower sound levels being included in the regression analysis used for determining noise limits (refer to Section 1) and would, generally result in determining more conservative (lower) overall noise limits.

Table 1: Comparison of TRH WF background correction method with IEC 61400-11:2002

Difference in level: Measured level minus TRH predicted level (dB)	Correction method		Comments
	IEC 61400-11	Amended Method	
x ≥ 6	Logarithmic subtraction	Logarithmic subtraction	-
6 > x > 3	Reduce measured level by 1.3 dB	Logarithmic subtraction	The reduction in measured level is equal or larger with the amended method.
3 ≥ x ≥ 0	Do not use	Logarithmic subtraction	Data in this range is retained by the amended method, often with a significant reduction in measured level.
0 ≥ x	Do not use	Reduce measured level by 3 dB	The logarithmic subtraction equation is not valid for negative differences. In this range, the amended method adopts a somewhat qualitative approach, recognising that where a negative difference occurs is likely due to either the predicted TRH level being too conservative (high) or that TRH was perhaps not operating in a state that is well represented by the noise model. We consider that, even if TRH sound dominated the background environment, actual ambient sound at the receiver location (excluding wind farm noise) would still contribute some amount, notionally chosen at a 50% contribution or, in other words, 3dB down on the measured level.

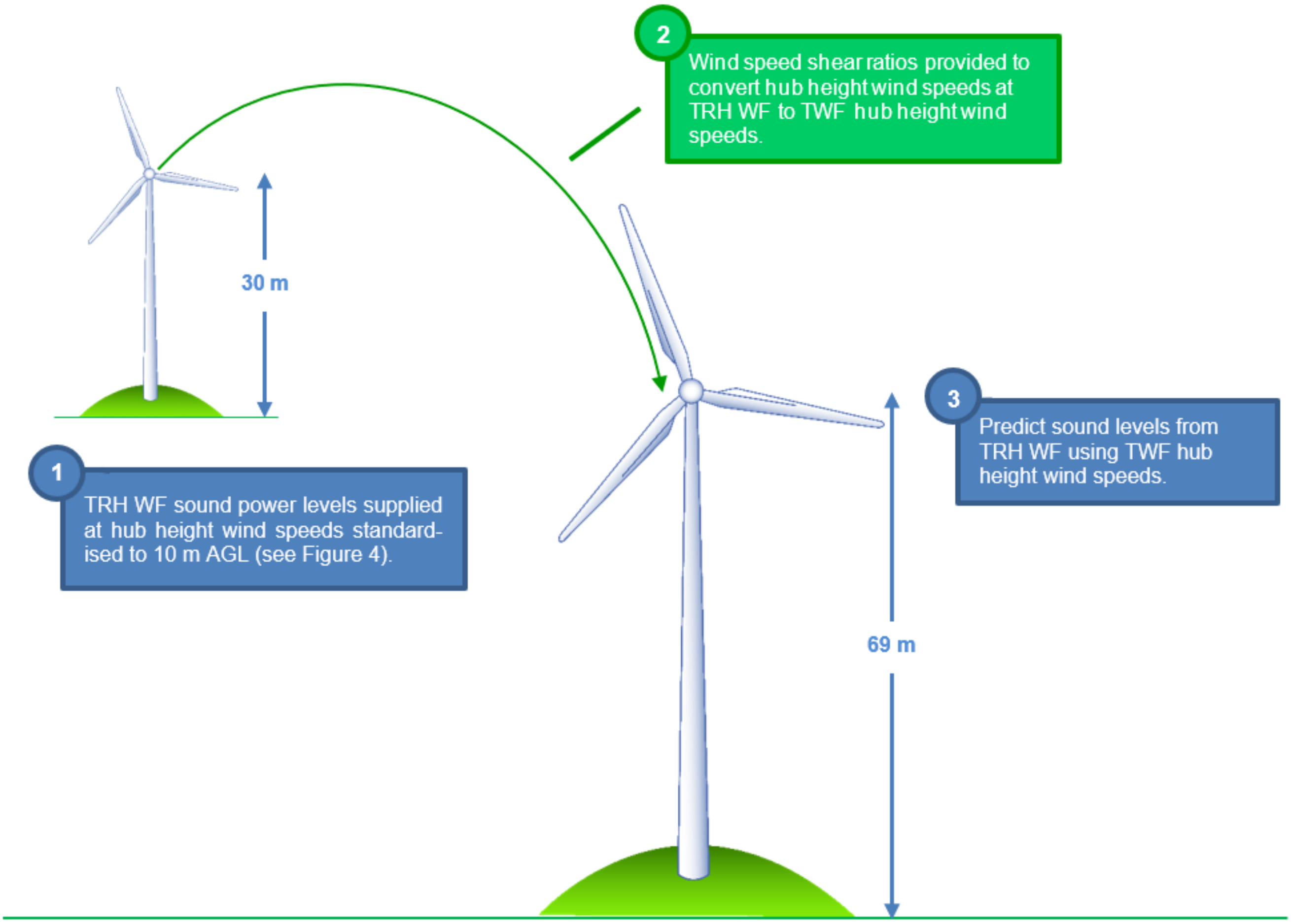
4 CALCULATING NOISE BUDGETS

At this point, it is important to make clear that there are two uses for the TRH WF predicted sound levels. The first is described above, in that the predicted levels are used to adjust the background sound level measurements and remove the influence of TRH WF. The adjusted background sound levels are then used to establish the overall noise limits. The second use of TRH WF predicted sound levels is to inform noise budgets for TWF. The noise budgets are the allowable sound levels from TWF, so as not to exceed the overall noise limits while TRH WF is operating.

4.1 Calculate TRH sound levels using TWF hub height wind speeds

As the overall noise limits for TWF are based on wind measurements at TWF hub height, sound level predictions for TRH WF are needed using TWF hub height wind speeds. The simple equation for converting wind speeds to different heights (equation 1, Section 3.1) is not sufficient for this calculation. This is because we are not only converting wind speeds from 30 m AGL (TRH WF hub height) to 69 m AGL (TWF hub height), but we are also converting to wind speeds at a completely different location. The process is shown schematically in Figure 5 overleaf.

We were provided with wind speed shear ratios to convert TRH WF hub height wind speeds to TWF hub height wind speeds by wind flow experts. The wind speed shear ratios depended on the wind direction at TWF. To calculate the TRH WF sound levels at the receivers we followed the same process outlined in Section 3.1, but calculated a sound power level profile for each supplied wind direction. We could then predict the sound levels from TRH WF using TWF hub height wind speeds for all wind directions in 5° segments.



Source (Author, 2021)

Figure 5: Schematic representation of calculating sound levels using TWF hub height wind speeds

4.2 Establish the TWF noise budgets

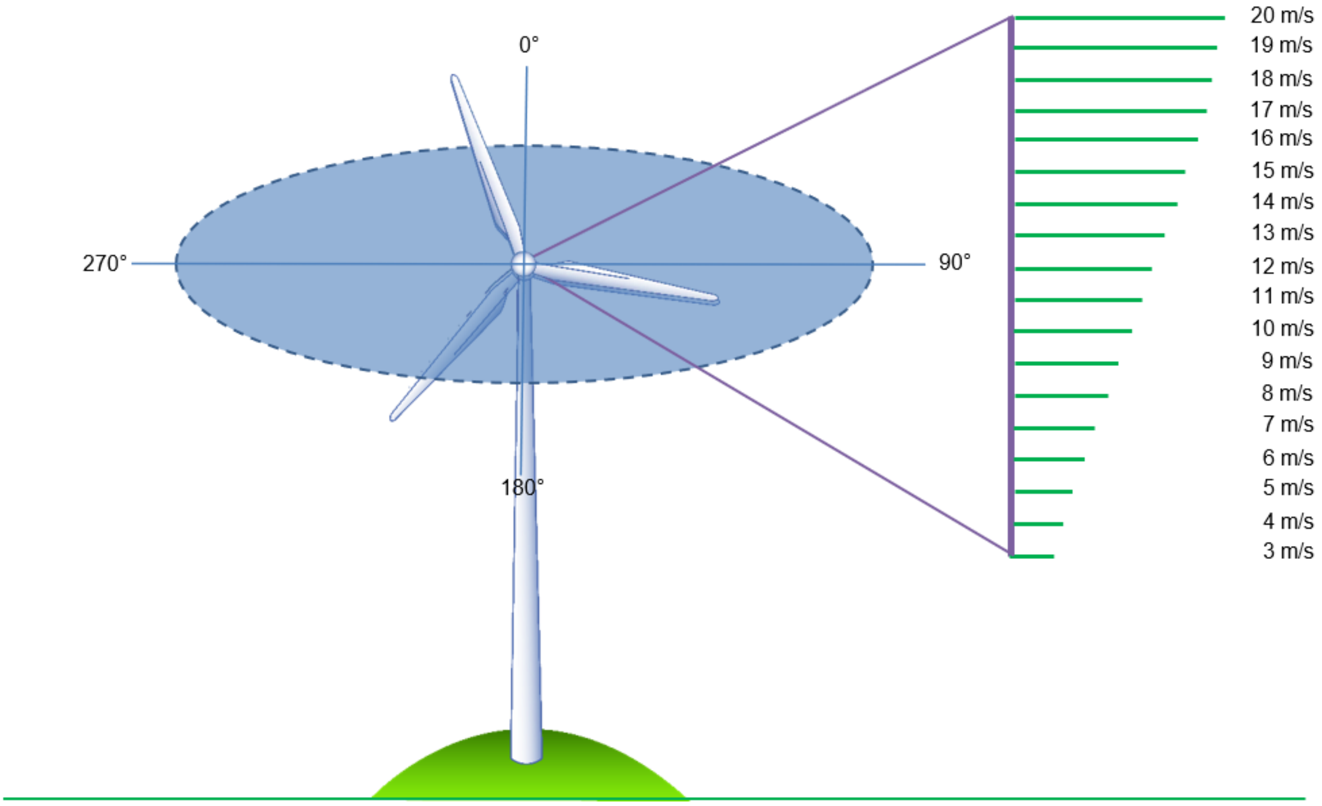
We determined the noise budgets using logarithmic subtraction of the TRH WF predicted sound levels from the overall noise limits. In cases where TRH WF predicted levels exceeded the overall noise limits, we considered two options for deriving the budget values:

- Option A: TRH WF predicted level minus 10 dB
- Option B: Noise limit minus 10 dB

The budgets were determined using Option B, which resulted in more conservative noise budget values.

4.3 Predict compliance with the noise budgets

We could predict compliance with the noise budgets by comparing them with predicted TWF sound levels. The process of predicting TWF sound levels followed a similar, but simplified version of the above process used for determining the TRH WF predicted sound levels. We were supplied with TWF turbine sound power data at hub height wind speeds, so no wind speed conversions were required. We predicted TWF sound levels in SoundPlan v8.2 and adjusted the levels to account for wind directivity in accordance with the process outlined in Section 2. Using the predicted TWF levels and the provided sound power data at hub height wind speeds we could predict a noise level for every 5° wind segment at all hub height wind speeds, from 3 m/s to 20 m/s. Figure 6 overleaf shows this schematically. The data output was a matrix of predicted sound levels, 35 rows high and 72 columns wide, for each of the 76 receiver locations.



Source (Author, 2021)
Figure 6: TWF predicted receiver levels for every 5° wind segment and each operating hub height wind speed

5 CONCLUSIONS

The above calculation process outlines a method for calculating cumulative noise effects from multiple wind farms and accounting for sound attenuation due to wind directivity. This is particularly important for projects where there are dwellings close to the wind farms, and where the cost of noise curtailment will inform the financial feasibility of the new wind farm project. In this case, the existing wind farm TRH WF, is approximately 3km north of the proposed TWF.

To determine whether TWF would comply with noise limits at the nearby dwellings while TRH WF is operating, we utilised various standards and guidelines, which required interpreting and implementing in practice. These standards and guidelines include ISO 9613-2, NZS 6808, the IOA GPG and IEC 61400-11.

We predicted wind farm sound levels using the ISO 9613-2 prediction method, which is recommended in NZS 6808. The method calculates for light downwind conditions in all directions simultaneously. We then developed a calculation method to apply the IOA GPG wind directivity attenuation rates to the ISO 9613-2 predicted wind farm sound levels. The rates are presented diagrammatically in the guide and only offer values for receivers at certain distances away from the wind turbines. Our calculations involved using the attenuation rates provided in the guide and interpolating between them to apply values at receivers at any distance away from the wind farm. This allowed us to adjust the predicted levels from the wind farms at all receivers to account for wind directivity.

Measuring background sound levels at dwellings is required to establish noise limits in accordance with NZS 6808. However, background sound levels cannot include noise from other windfarms as this may unfairly elevate the noise limit for the new wind farm development. So, we developed a procedure to correct the measured background levels by predicting levels from TRH WF. We used the recommendations in IEC 61400-11 for correcting the background sound levels. However, we amended the method as the standard suggests discarding data where the difference in the measured and predicted level is less than 3 dB. We found this to be impractical and limiting on our data set. The method we adopted resulted in generally more conservative noise limits, but reduced the amount of measured data that would have otherwise been discarded.

Finally, using wind speed shear ratios, we predicted sound levels from TRH WF using TWF hub height wind speeds for every 5° wind segment. This involved establishing a sound power level profile for the TRH WF wind turbines for each TWF hub height wind speed and 5° wind segment. The predicted TRH WF sound levels could then be subtracted from the overall noise limits to establish ‘noise budgets’ for TWF. The noise budgets are the allowable sound levels from TWF, so as not to exceed the overall noise limit while TRH WF is operating.

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