Hessler Associates, Inc.
WORLDWIDE CONSULTING IN ENGINEERING ACOUSTICS

5096 N Silver Cloud Dr.
St. George, UT 84770 USA
703-303-0341
www.hesslernoise.com

TECHNICAL MEMORANDUM

Title: Crowned Ridge Wind Sound Testing Data Review and Assessment

Project: Crowned Ridge Wind
Location: Watertown, SD
Prepared For: South Dakota Public Utilities Commission
Prepared By: David M. Hessler, P.E., INCE
Revision: 0
Issue Date: May 22, 2020
Reference No: TM-2176-051820-0

Attachments: - -

1.0 Introduction

A temporary waiver was granted by the South Dakota Public Utilities Commission (SDPUC) on January 9, 2020 allowing the Crowned Ridge Wind Project (CRW) to operate before all of the turbine blades could be fitted with low noise trailing edge (LNTE) technology. One condition of this waiver was that certain units needed to be temporarily curtailed during the installation period to maintain compliance with the project's noise requirements in accordance with modeling projections and another condition was that a field sound test was required to verify that the predicted performance was, in fact, being realized during this specialized operating mode. This survey was carried out by Epsilon Associates, Inc. on behalf of the project owner over a two week period from March 3 to 18, 2020. Hessler Associates, Inc. has been engaged by the SDPUC to independently:

- Review and approve the protocol for the test (drafted by Epsilon)
- Witness and oversee the selection of specific measurement locations and instrument set up
- Analyze the raw data collected during the survey and assess the results
- Review Epsilon's survey report and assess the validity of its conclusions

All of these tasks have been completed. This report focuses on the latter two bullet points above.

In general, our independent analysis of the survey data carried out prior to receiving the Epsilon report indicates that the sound emissions from the project are, in fact, compliant with the noise limits contained in the permit conditions. This same conclusion was reached by Epsilon, who did an excellent job of both carrying out the survey and evaluating the results.

2.0 Independent Assessment

The sound emissions from wind turbines at typical setback distances to residences are quite difficult to measure and quantify. This is because the natural environmental sound level during the windy conditions necessary for the project to operate are similar to and often higher than the project-only sound level. Consequently, it can be generally stated as a fact that the total observed sound level at any given location under virtually all wind and weather conditions is not the project sound level, but rather is a combination of the project sound level and the natural sound level that would otherwise exist. During high wind conditions the project component of the total sound level essentially becomes negligible and is completely drowned out by wind-induced sounds, either actual, such as trees or crops rustling, or artificial, as in microphone distortion from wind.

In an effort to overcome this difficulty, the test procedure/permit language specifically includes the use of multiple, short-duration project shutdowns to enable the measurement of the total sound level (project + background) and the background level alone within a few minutes of each other so that the wind and atmospheric conditions are held reasonably constant. The project-only sound level, which is the quantity subject to the regulatory limits, can then be derived by logarithmically subtracting the background level from the total level with the project on. However, even this ostensibly simple approach doesn't always yield a valid, or any, answer because it only works when the differential between the on and off levels is significant, or at least about 3 to 4 dB. In practice, such a large signal (project sound) to noise (background noise) ratio is rarely seen because the project sound level is intentionally designed to be low at sensitive receptors while the natural sound level increases almost indefinitely with wind speed. When the signal to noise ratio is lower than about 4 dB a valid project-only sound level cannot be calculated. Even though the entire project was shutdown 30 times during this two week survey, there were only a handful on instances when the sound level actually decreased by a significant amount while the turbines were off. In most cases there was no measurable change, the sound level was higher during the shutdown than during the operational periods immediately before or after, or the winds were too light for the project operate anywhere near full output.

The graphics discussed below show, for each position, the measured sound levels, the electrical output of the two nearest units and the wind speed at the ground and at hub height. The first plot in each case shows the entire survey and the following three plots enlarge the periods when the project was consistently operating at or near full power.

2.1 Position 1 – Participating Residence, 50 dBA Permit Limit

The overall results for Position 1, at a participating residence near the center of the project, are shown below.

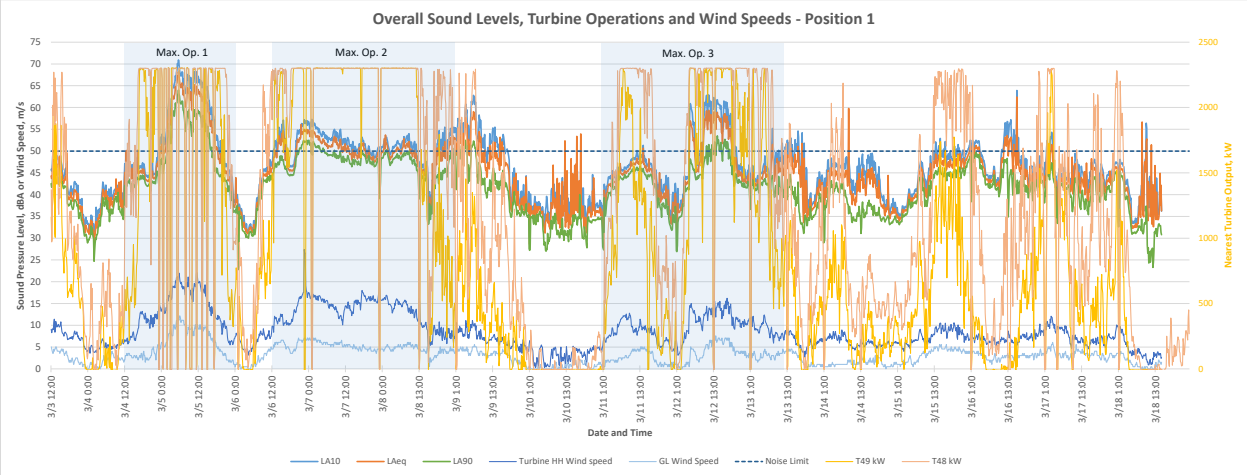

Figure 2.1.1

The yellow and tan lines are the electrical production of the two nearest turbines, T48 and T49. This overall plot shows that there were essentially three periods, shaded in blue, when the winds were sufficient for the turbines to consistently operate at or near their maximum rating of 2300 kW. These periods are enlarged and discussed below. Notes identifying the evaluation periods contained in the Epsilon report have been added to these figures for cross-referencing convenience.

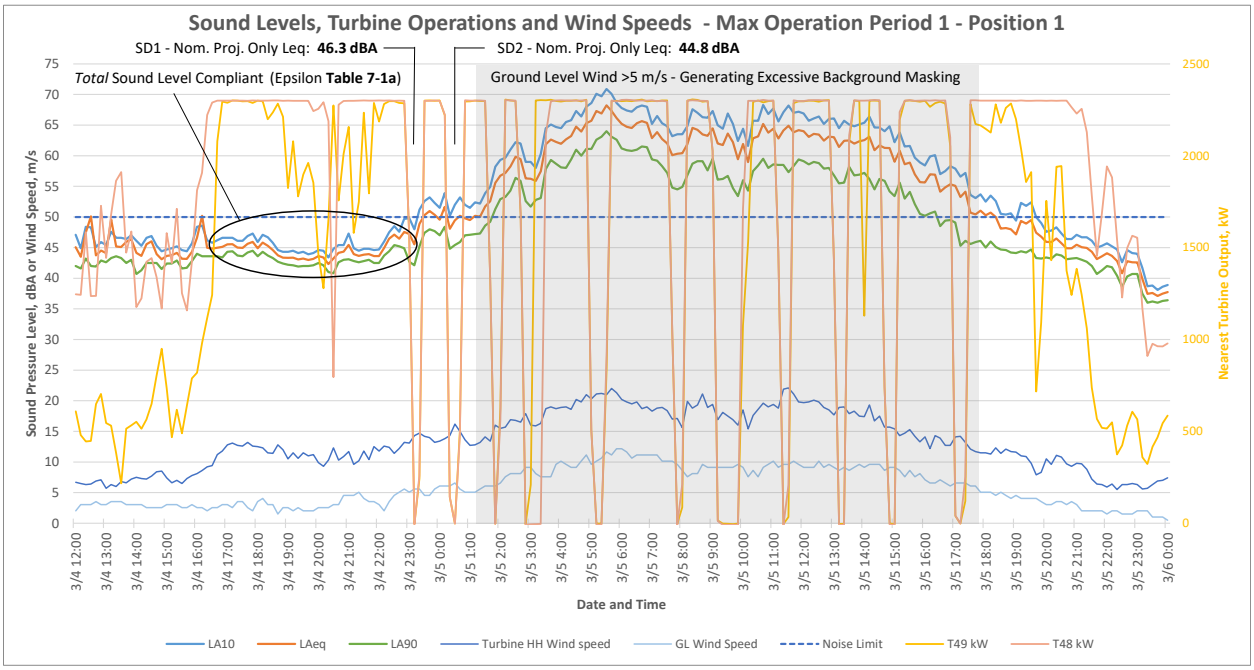

Figure 2.1.2

This graphic illustrates the first windy period to occur during the survey. Beginning about 5 p.m. on March 4 the hub height wind speed increased enough for the turbines to run at full power. From that point until about 11 p.m. later the same evening the total average, Leq(10 min), sound level (project + background) hovered around 45 dBA, unequivocally showing compliance with the 50 dBA permit limit. Just after 11 p.m., when the wind speed began picking up, a series of 10 shutdowns were made, since the project was consistently operating at full power. In the first two cases, a slight dip in the sound level is visible during the shutdowns. Apparent project-only sound levels of about 46 and 45 dBA can be calculated from the measurements before, during and after each shutdown, but the signal-to-noise ratio is fairly low and the ground level wind speed was just creeping above the allowable limit of 5 m/s. After these two shutdowns the ground level wind and local wind-induced noise increased significantly to the point where all the subsequent shutdowns had no effect whatsoever on the total sound level. Although the total Leq sound level goes as high as 67 dBA, all of the sound during this period can be ascribed to background noise, primarily from a dry field of cornstalks across the road from the house, probably exacerbated by wind-induced microphone distortion.

The second period of maximum project operation is illustrated below.

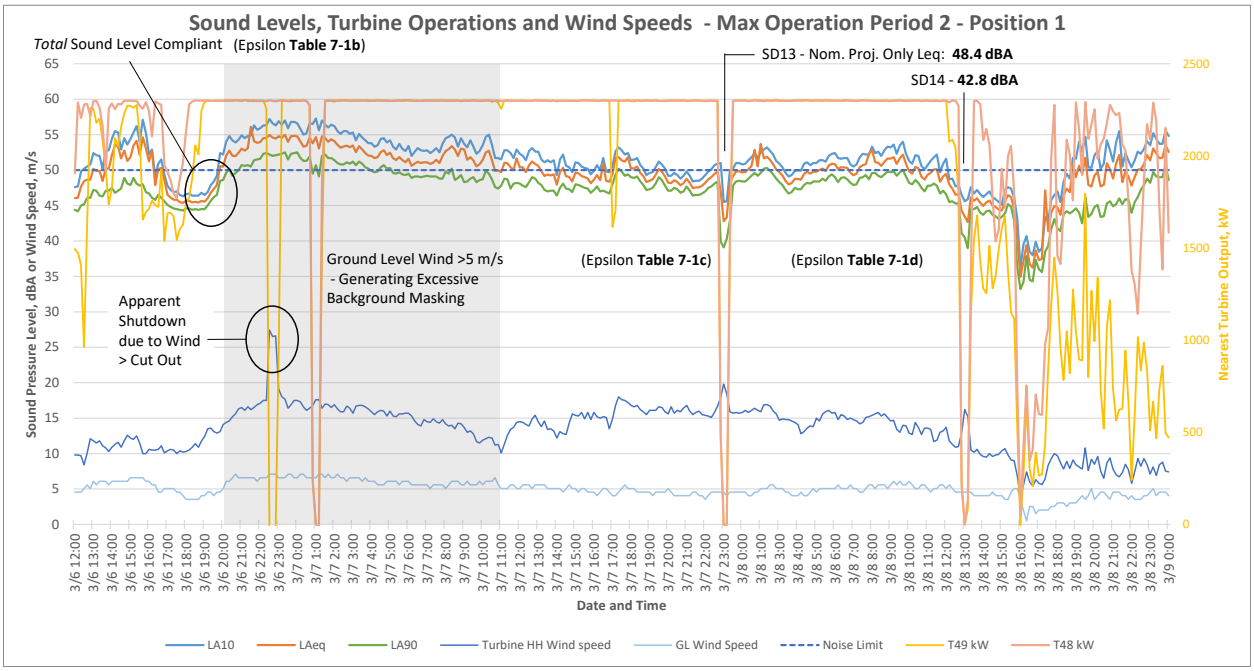

Figure 2.1.3

In this case, a total sound level of about 46 dBA occurred with both of the nearest turbines running at full power around 7 p.m. on March 6. After that point, the ground level wind speed went out of spec until about 11 a.m. the next day when an extended period of favorable conditions (i.e. acceptable ground level wind and full power operation) began and persisted for more than 24 hours. While the total level hovers around 50 dBA during this period, the project-only sound level can be calculated with some certainty at 48 dBA from the shutdown at 11 p.m. on March 7. This is one of the rare instances when a shutdown actually reduced the total sound level significantly, almost 7 dBA, from the levels immediately before and after. Consequently, it can be concluded that project sound level was just under 50 dBA during this period, although the total level generally fluctuated between about 48 and 52 dBA. The next shutdown at 1 p.m. on March 8 yields a project level of 43 dBA but T49 was not operating at full power at that particular moment.

The final period when the project was operating at full load is illustrated below.

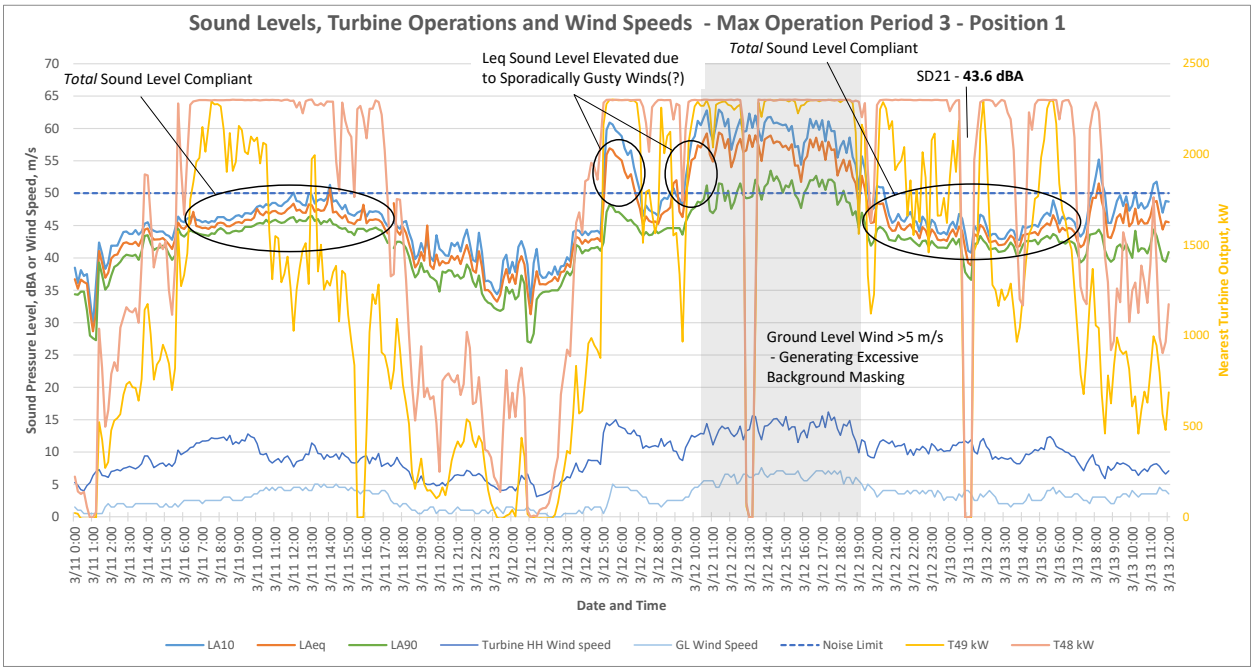

Figure 2.1.4

A total sound level between about 45 and 48 dBA occurred during the day on the 11th but T49 was only at full power for a short time during this period – when, in fact, the sound level was 45 dBA. The general rise and fall of the sound levels parallel the ground level wind speed indicating that much of the noise measured on that day was caused by the wind rather than the project. The shutdown at 1 a.m. on March 13 shows a clear dip in sound level and yields a project-only sound level of 44 dBA. Although T49 operation was choppy around this time, it was near full power, 2150 kW, just before and after this shutdown, so the result is considered valid.

In general, we would conclude that the project sound level ranges from about **43 to 48 dBA** at this location making it compliant with the 50 dBA limit for participating residences. Although total sound levels much higher than 50 dBA were recorded during some windy periods, the lack of any change in sound level during the numerous shutdowns on March 5, for example, demonstrates that all of this noise was generated by wind-induced background noise, most likely exacerbated in some cases by microphone distortion.

2.2 Position 2 – Non-Participating Residence, 45 dBA Permit Limit

The overall results for Position 2 are shown below.

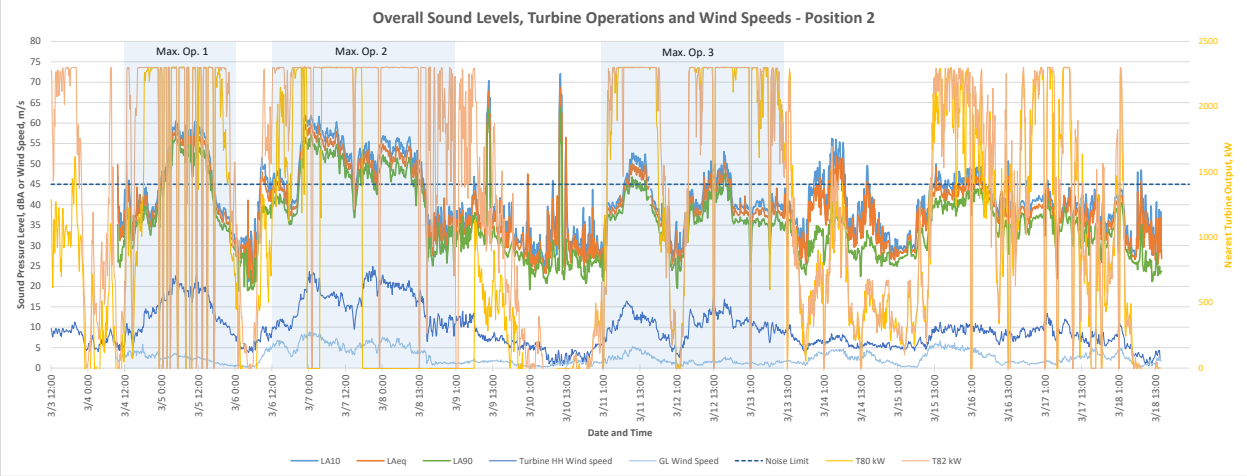

Figure 2.2.1

The first high wind period is enlarged below.

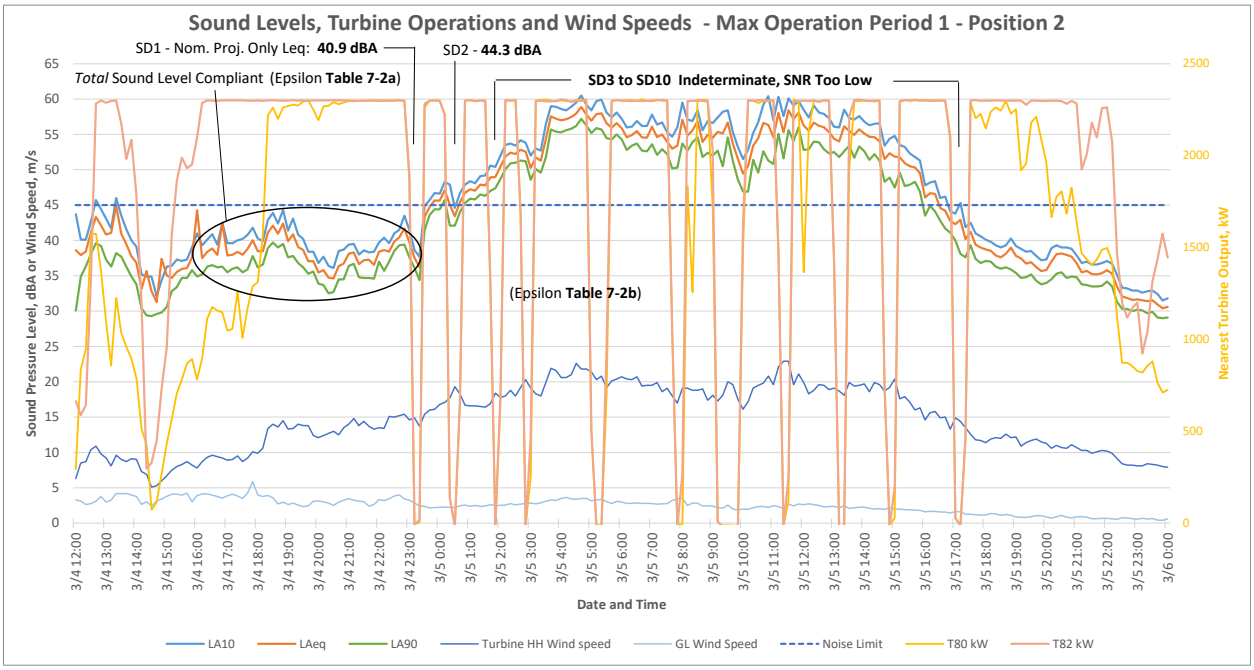

Figure 2.2.2

As at Position 1, the total sound level remained below the permissible limit on the evening of March 4 when the project was running at full capacity. The observed total sound level ranged

from about 35 to 43 dBA. A project-only sound level could be derived from first two shutdowns that evening at 41 and 44 dBA; although a low differential of only 3.5 dB between the on and off levels in the latter case makes that result somewhat dubious. The signal to noise ratio in the next eight shutdowns was insufficient to get a valid result, even though the ground level wind speed was well below the 5 m/s maximum.

High ground level winds prevented the collection of any definitive project sound levels during almost all of the second windy period (March 6 to 8), as illustrated in Figure 2.2.3. There was only one period on the evening of the 6th when the project was operating at maximum capacity while the ground level wind speed was sufficiently low for valid readings. A total level of about 39 dBA was observed at that time.

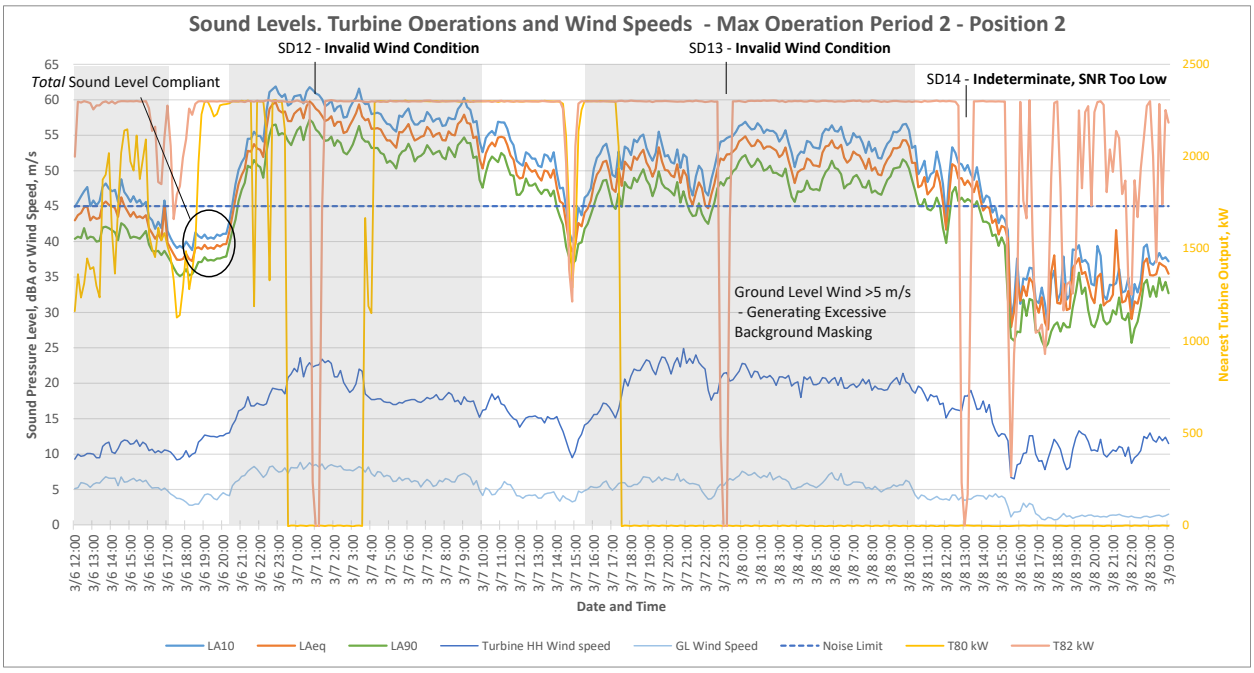

Figure 2.2.3

During the third windy period (Figure 2.2.4) there were two fairly extensive periods when the total level was in the mid- to high 30's dBA and therefore below the 45 dBA limit.

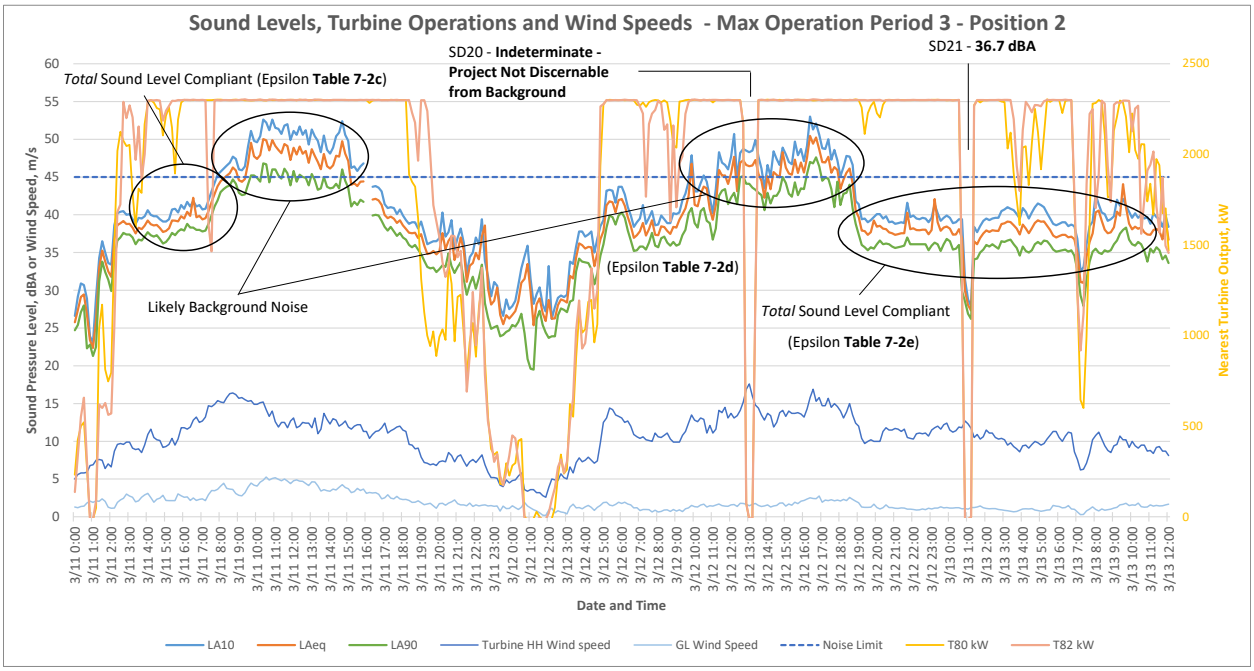

Figure 2.2.4

At the same time, there were also periods of ostensible satisfactory conditions when the total level was above 45 dBA, such as the afternoon of March 12. Fortunately, there was a random scheduled shutdown during this period at 1 p.m. that makes it clear that the project was not responsible for the elevated levels at that time, since there was literally no difference at all between the on and off sound levels.

In general, we would conclude that the project sound level at this position ranges from about **35 to 42 dBA**.

2.3 Position 3 – Non-Participating Residence, 45 dBA Permit Limit

The overall results for Position 3 are shown below.

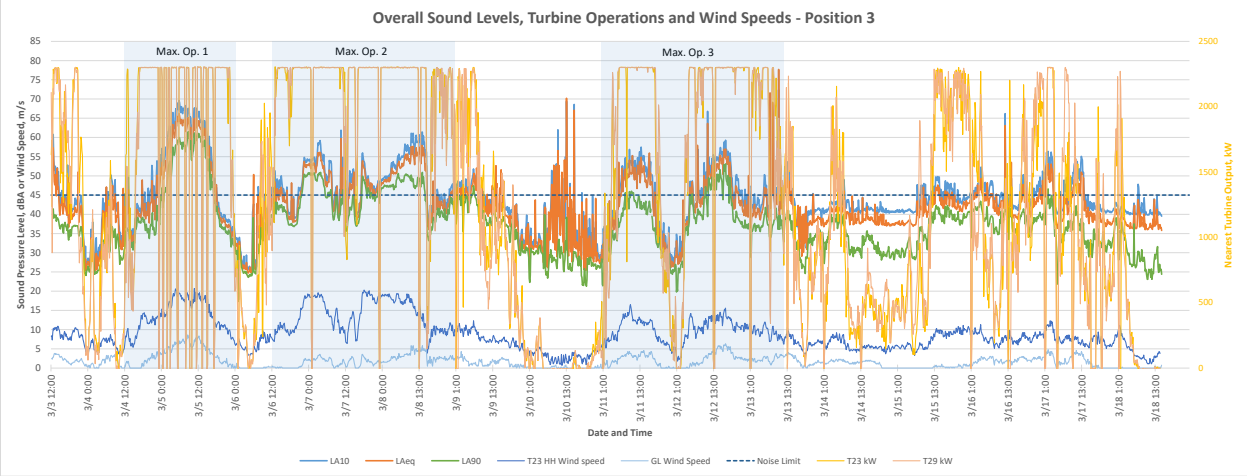

Figure 2.3.1

During the first windy period there were two periods when the total sound level was observed in the range from 37 to about 44 dBA, as illustrated in Figure 2.3.2.

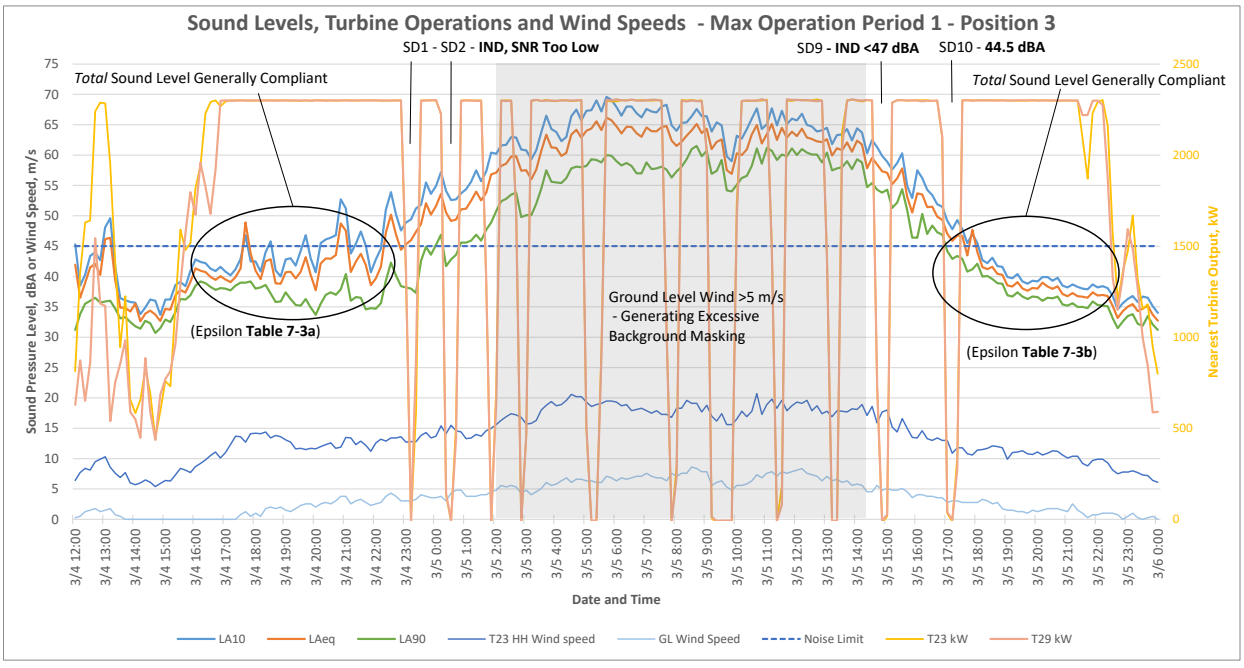

Figure 2.3.2

The first period on March 4 is characterized by choppy sound levels and shows a fairly large differential between the L10 and L90 statisticals, which means that the sound level was highly variable, most likely because of gusty winds. This was confirmed from a review of selected audio files during this period, such as the spike at 5:40 p.m. on March 4, which was clearly false signal noise from wind blowing over the microphone. High levels of background noise made it impossible to get a conclusive result from any of the 10 shutdowns that were carried out during this period. Although it is mathematically possible to calculate a level of 44.5 dBA during Shutdown 10, the audio files just before and during the shutdown sound exactly the same (tree and grass rustle), meaning that this apparent result almost certainly over-estimates the project-only sound level.

During the second windy period the total level was observed at about 38 dBA on the evening of March 6 when the project was operating at full power (Figure 2.3.3). For the remainder of this period the total sound level was generally higher than 45 dBA but intermittent shutdowns show that the sound level either remains the same or, in the case Shutdown 13, only goes down slightly when the project is temporarily idled. The on-off differential of only 2.5 dB during Shutdown 13 makes it technically impossible to quantify the project, but its level must be below 44 dBA.

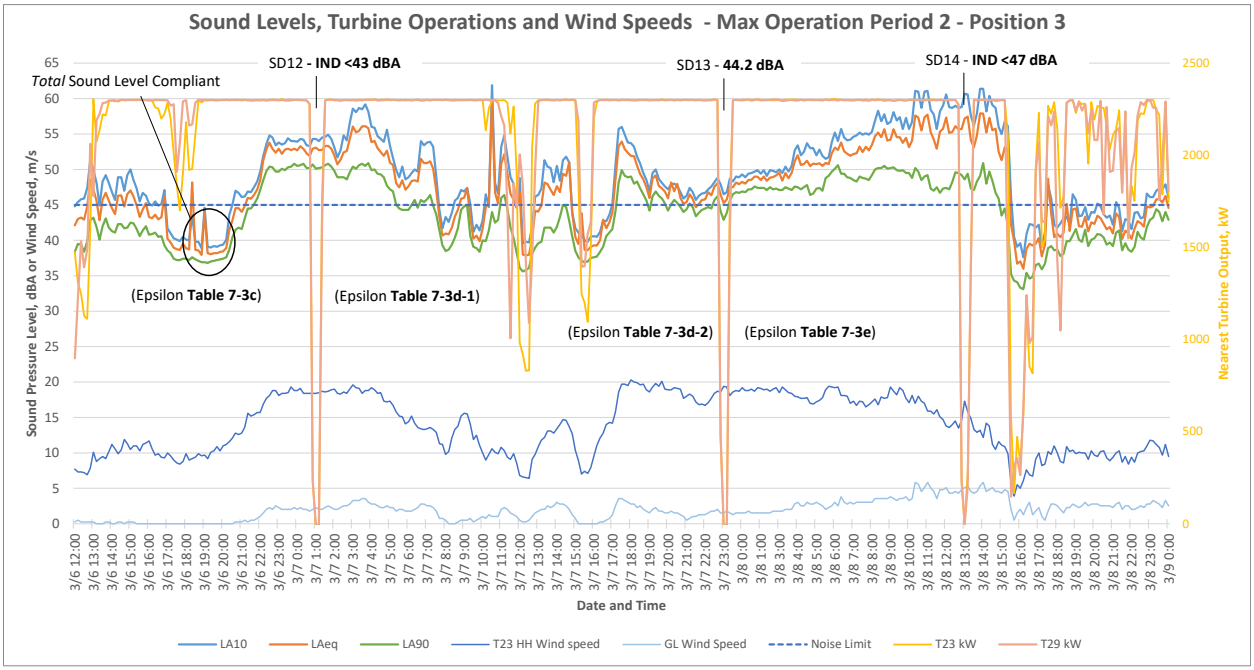

Figure 2.3.3

Figure 2.3.4 shows that in the third windy period there is a shutdown (SD 21 at 1 a.m. on March 13) where the total sound drops significantly when the turbines are turned off and then goes back up when they start. This results in a solid reading of 38 dBA for the project-only sound level.

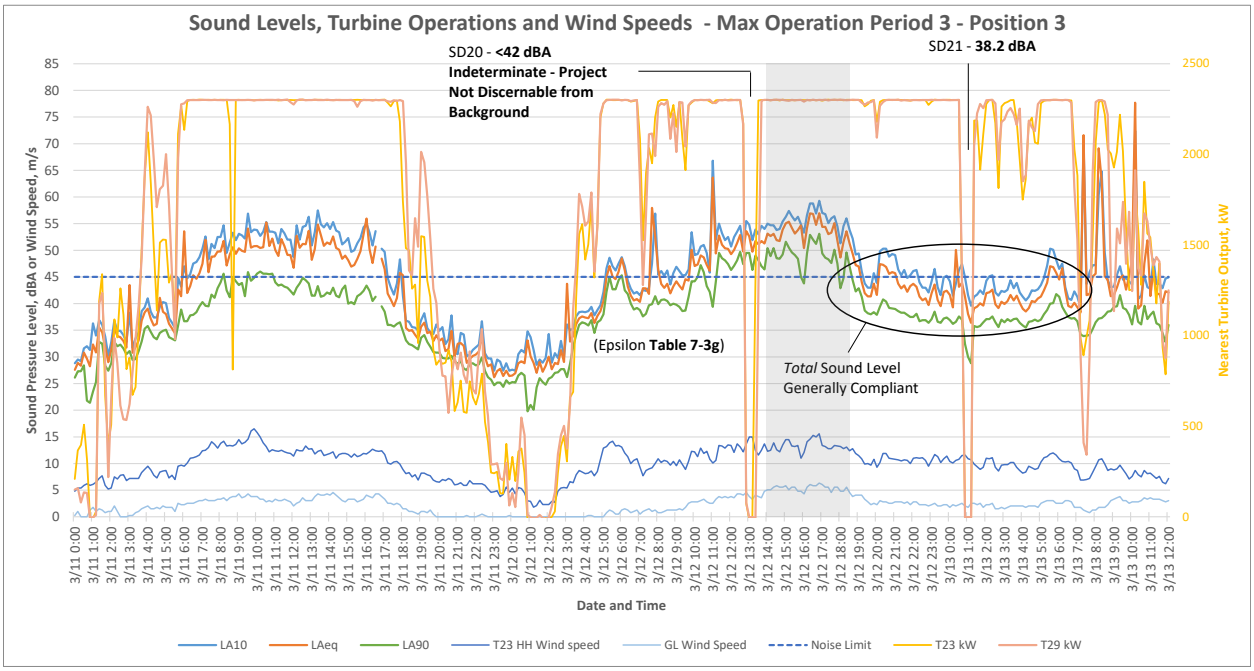

Figure 2.3.4

In general, it is difficult to put a definitive number on the project performance at this location but the available evidence suggests that the project is most likely in the low end of the **37 to 44 dBA** range.

2.4 Position 4 – Non-Participating Residence, 45 dBA Permit Limit

The overall results for Position 4 are shown below.

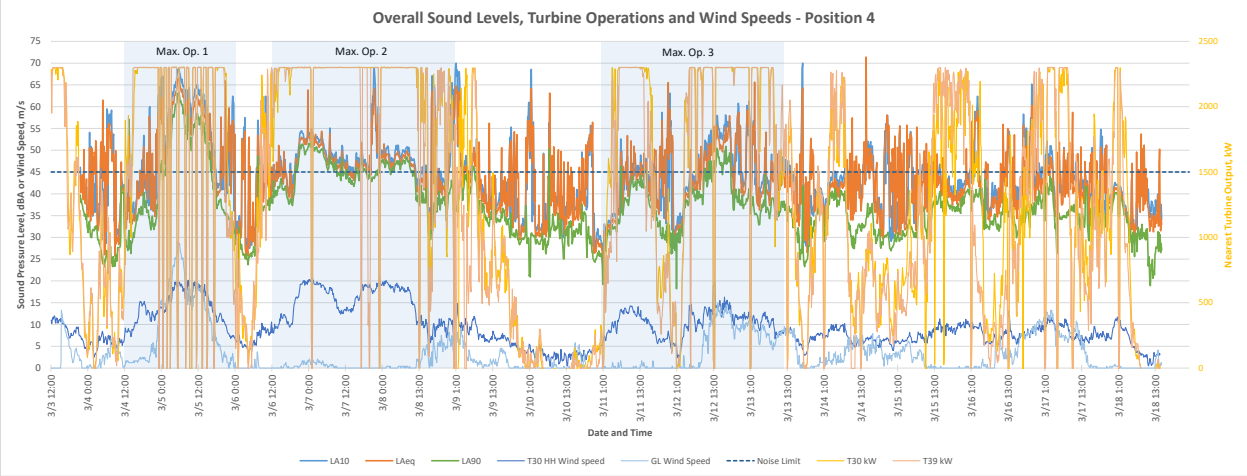

Figure 2.4.1

During the first windy period (Figure 2.4.2) a total sound level generally in the 35 to 43 dBA range was recorded with the project at full power on the afternoon and evening of the 4th. The noise spikes during this period, one going as high as 57 dBA, are almost certainly wind gusts and microphone distortion, based on a review of the audio files for essentially identical spikes occurring during at this same time at Position 3. After about 10 p.m. the same day the ground level wind speed increased dramatically at this location and background noise completely obscured the project through all 10 of the shutdowns that occurred during this windy period; i.e. no dip in sound level occurred during any of the idle periods.

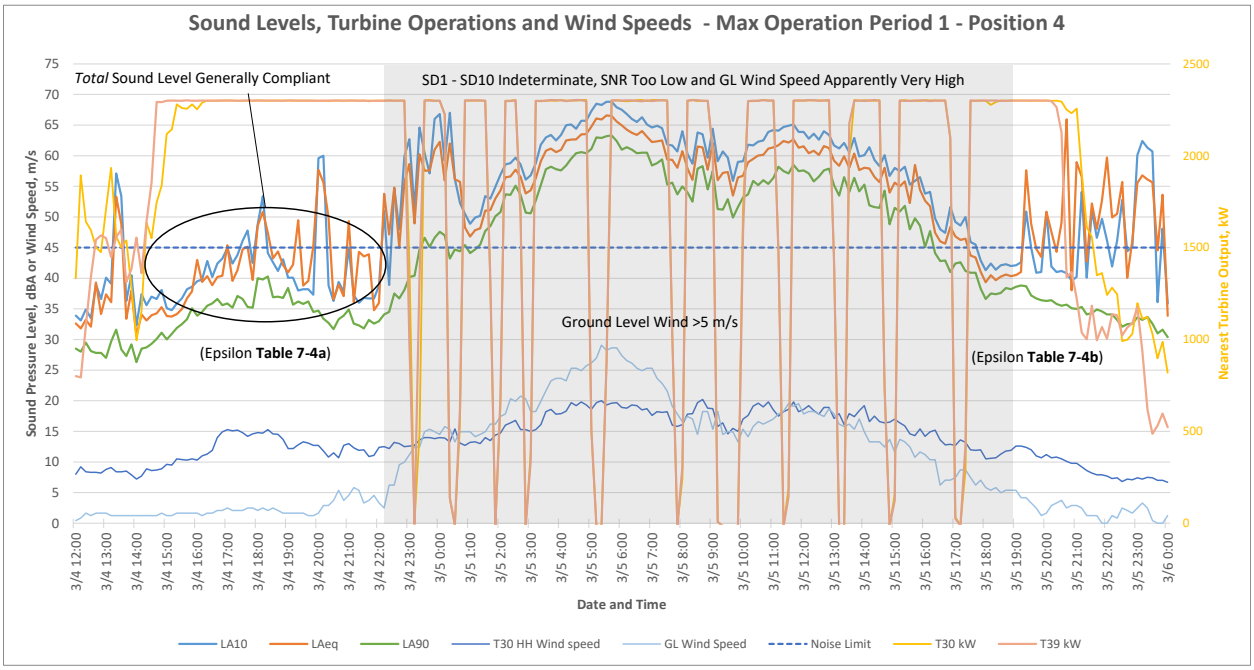

Figure 2.4.2

As shown in Figure 2.4.3, a total level of about 39 to 42 dBA occurred during the initial part of the second maximum output period but sound levels at or above the 45 dBA limit occurred for the next 40 hours under ostensibly ideal conditions with essentially calm surface winds. If the project were dominant and causing these sound levels, one would expect to see a significant drop during the three full-project shutdowns that occurred during this period. However, there was no change at all, indicating that the project component of the total measured level was inconsequential and had to be significantly lower than the total measured level. In fact, the total sound level increased when T39 (only) temporarily shut down at 5 p.m. on March 7.

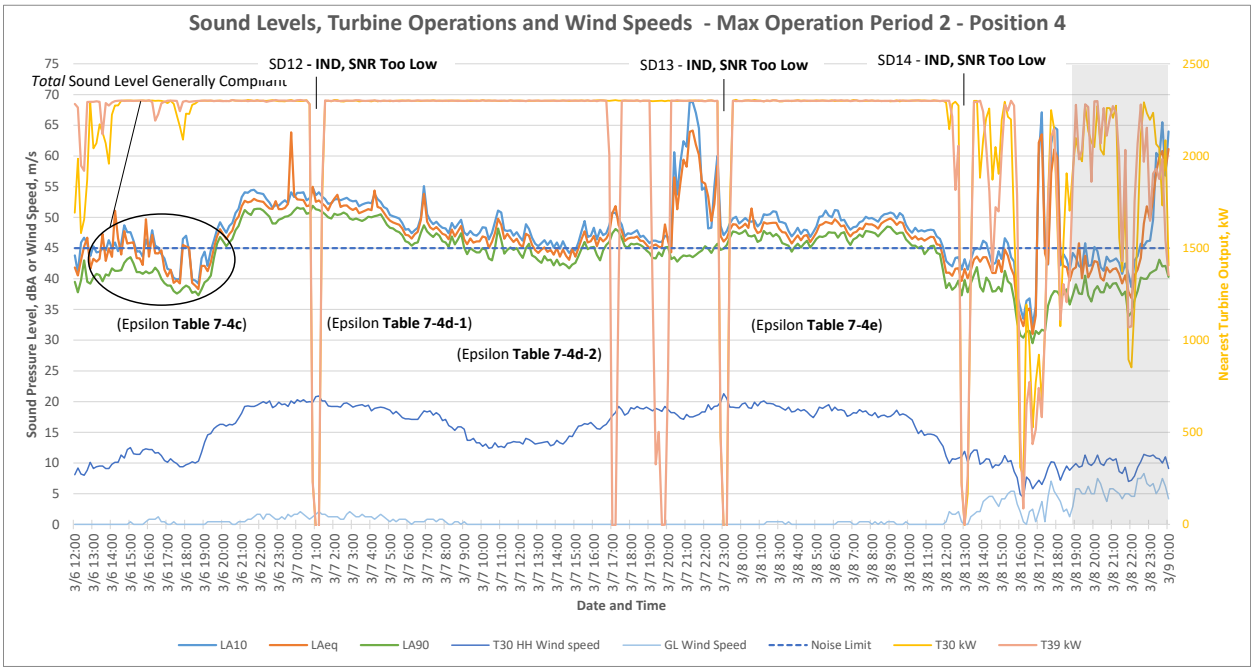

Figure 2.4.3

During the final windy period generally compliant levels were recorded on the mornings of the 9th and 12th; i.e. neglecting noise spikes, the total sound level was below the 45 dBA limit in roughly the 40 to 44 dBA range.

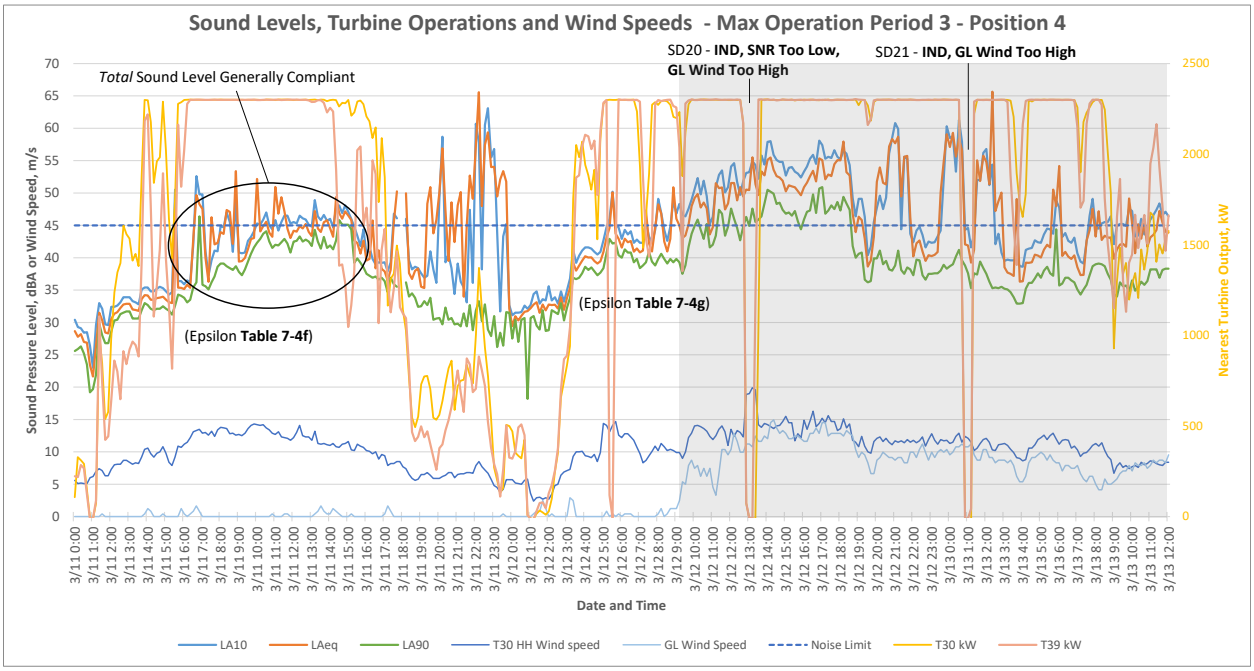

Figure 2.4.4

The survey results at this position show that the sound emissions from the project were essentially indistinguishable for the natural background level. Either the wind conditions were not right or there was no observable difference between the on and off sound levels during any of the 30 shutdowns. It can only be surmised that the project-only sound level is equal to or, more likely, lower than the total levels in the **35 to 44 dBA** range measured during full power operation.

2.5 Position 5 – Non-Participating Residence, 45 dBA Permit Limit

The overall results for Position 5 are plotted below. Instrumentation problems limited the data collection so that only portions of the three maximum operation periods were recorded.

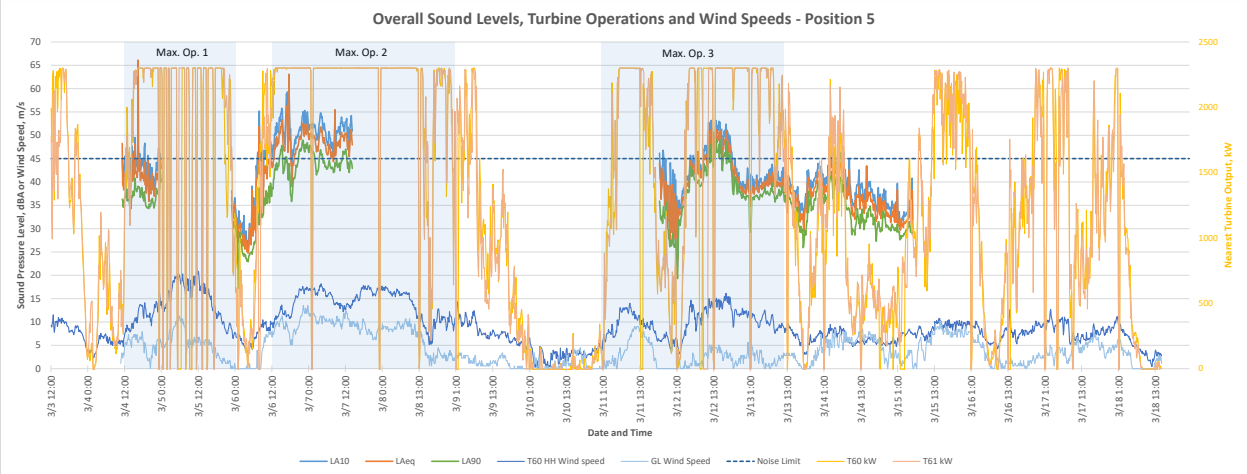

Figure 2.5.1

During the first part of first high wind period (Figure 2.5.2) enough measurements were made to show that the total sound level was in the 37 to 43 dBA range and below the 45 dBA limit. The data collection just managed to cover the first shutdown where it can be seen that the sound level does not change in any meaningful way with the project off. All that can concluded is that the project level must be lower than total measured level of 43 dBA that occurred just before and after the shutdown.

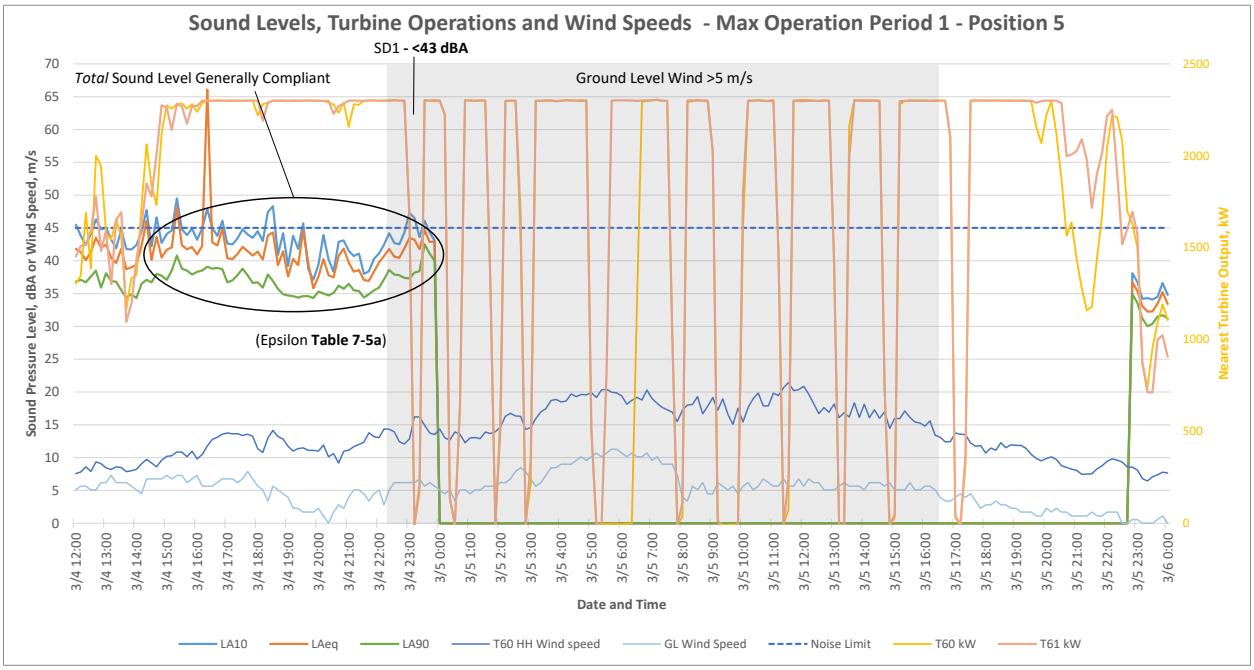

Figure 2.5.2

During the second windy period high ground level winds made it impossible to discern the project during Shutdown 12; i.e. the signal to noise ratio was not only low but non-existent.

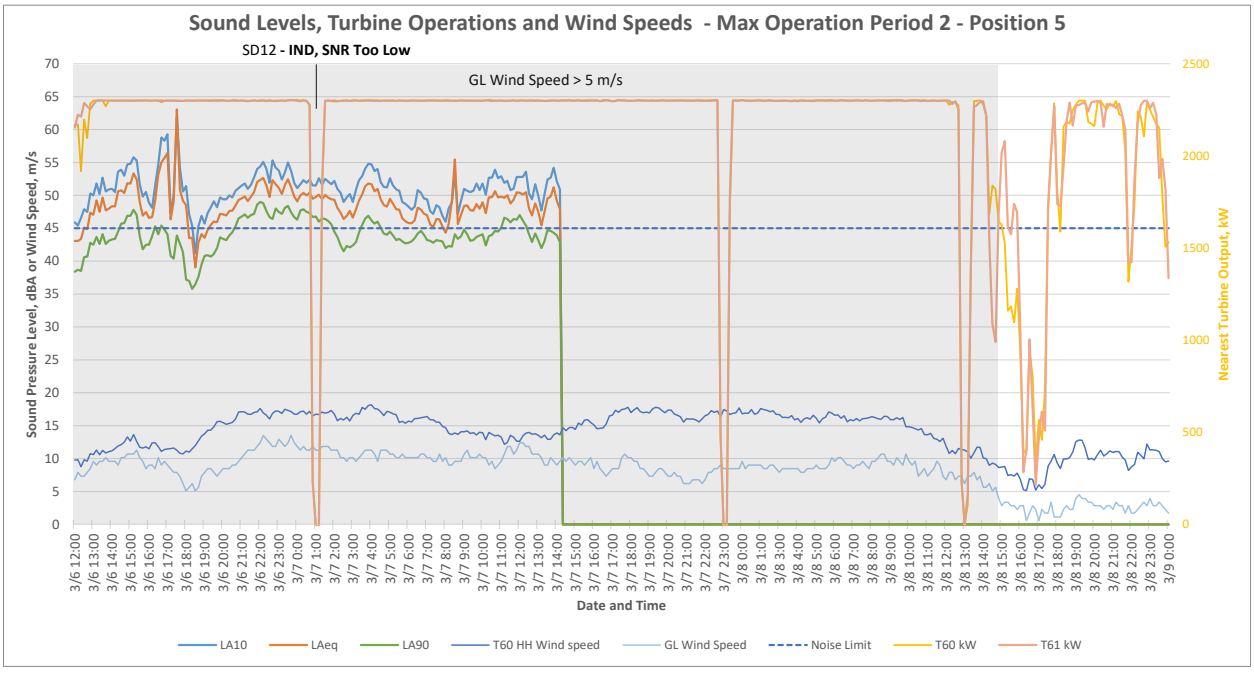

Figure 2.5.3

During the third evaluation period a drop in sound level was observed during Shutdown 21. While the shutdown is clearly evident in the L90 statistical, the Leq level only went down by a negligible 0.2 dB making it impossible to actually calculate a result; however, it can be definitively concluded that the project level must be lower than 38 dBA, the Leq sound level with the project on at the time. A subtraction can be made in L90 measurements, which capture the underlying minimum sound level between sporadic wind gusts or other contaminating noises, indicating a project-only sound level of 34 dBA.

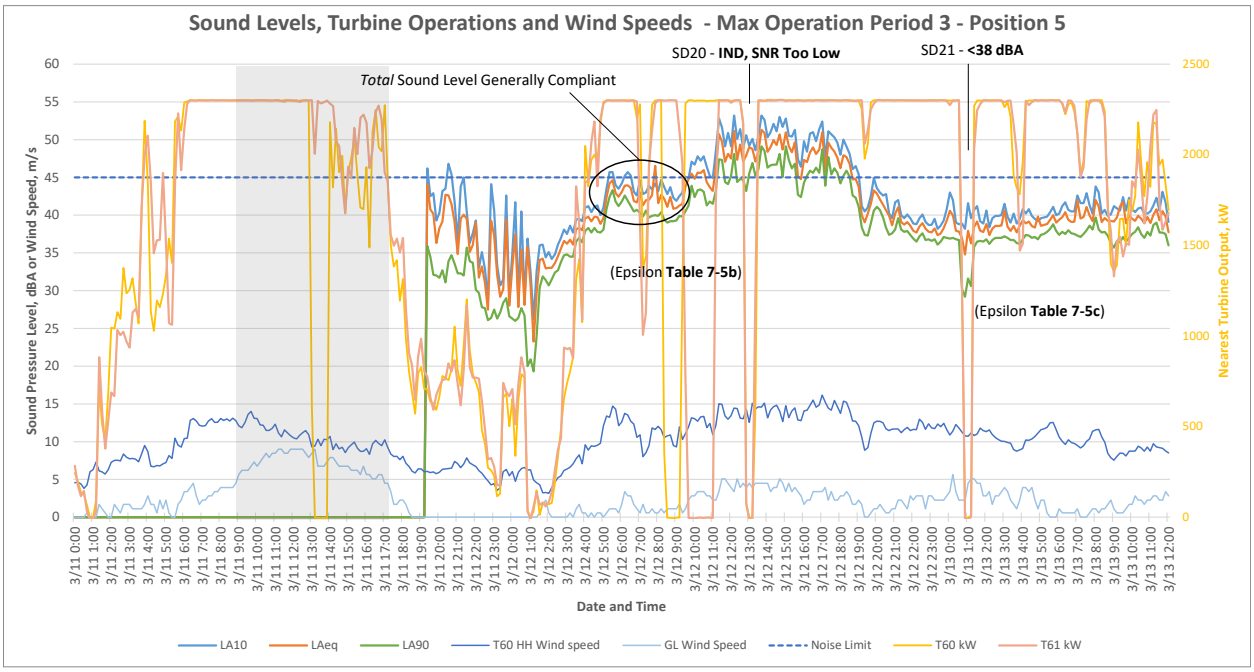

Figure 2.5.4

In general, we would conclude that the project sound level at this location is in the **34 to 43 dBA** range.

2.6 Position 6 – Non-Participating Residence, 50 dBA Property Line Limit

The overall results for Position 6 are plotted below.

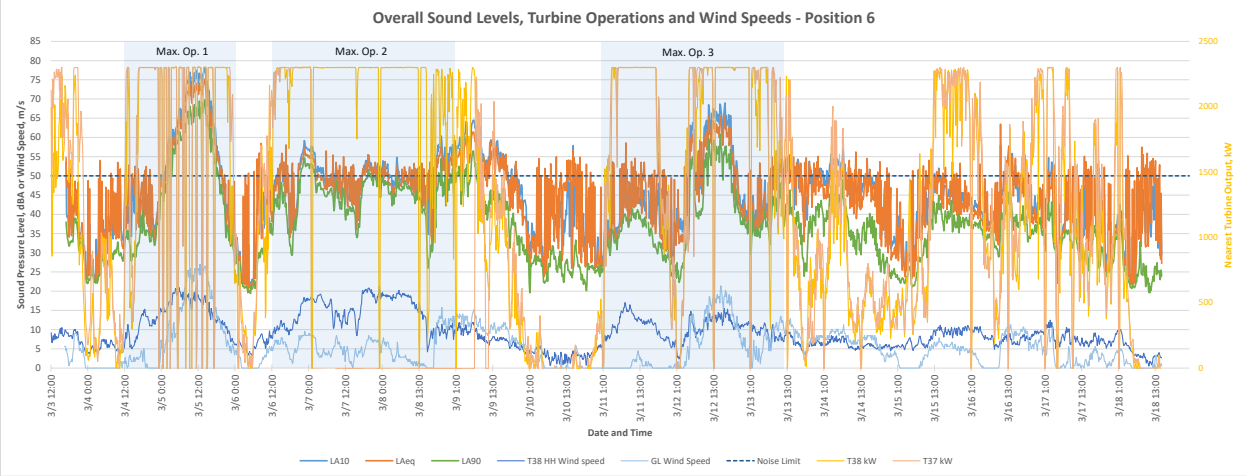

Figure 2.6.1

During the first windy period the total sound level remained below the applicable 50 dBA county property line limit on the evening of March 4 while the project was running at full power. The total Leq sound level, while variable, was generally in 34 to 45 dBA range. The sound spikes during this period are most likely to due wind gusts, cars or some other sporadic sounds.

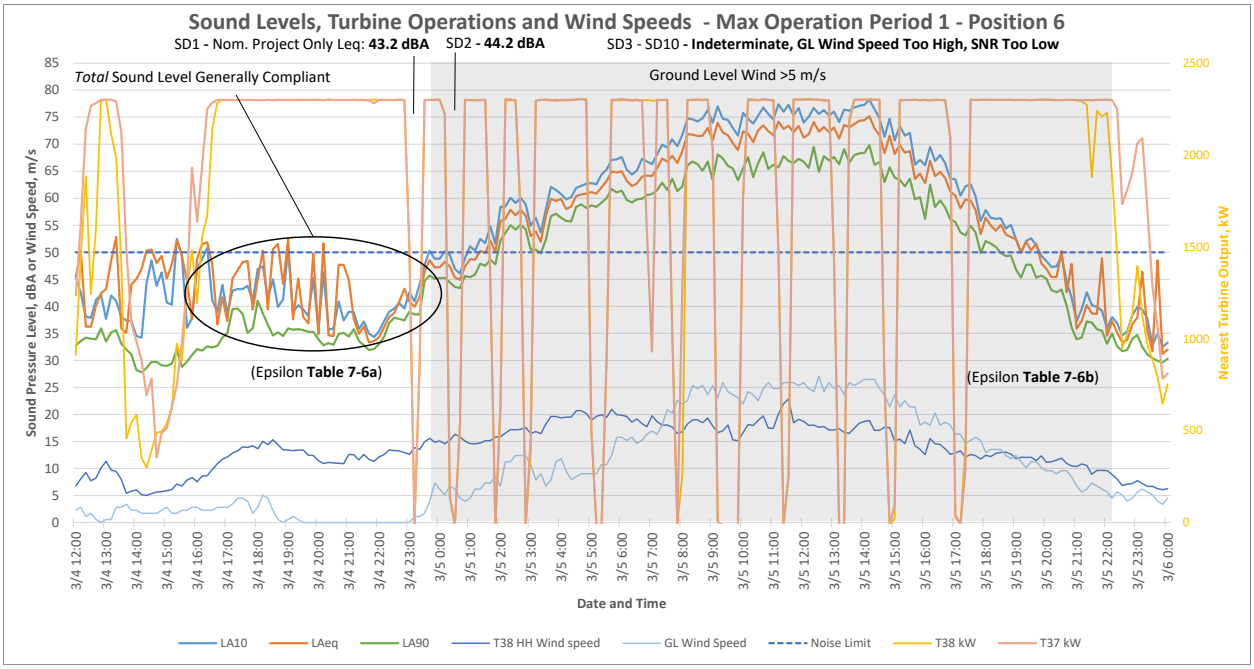

Figure 2.6.2

During the first shutdown the differential between the on and off levels was sufficient to calculate a project sound level of 43 dBA. During the second shutdown, only a short time later, the ground level wind speed had picked up and the on/off differential was too low for a definitive result but the ostensible project sound level was 44 dBA. From that point on the ground level winds became very strong, up to 25 m/s, and the sound from wind in the trees at this position rose to a remarkably high level of 75 dBA. There is a wooded buffer along this property line approximately 100 feet thick. None of the project shutdowns during this extremely windy period had any influence on the total sound level indicating that all project sound was obscured by local background noise.

The total Leq sound level at the beginning of the second period when the project was running at full power (Figure 2.6.3) dropped back down into the 34 to 45 dBA range for a few hours and then generally fluctuated in the high 40's dBA for the next 40 hours, at least when the ground level wind speed was below the 5 m/s threshold. It is important to reiterate in this context that the measurements reflect the total sound level and not the project alone. The lack of any differential between the on/off sound levels during Shutdowns 12, 13 and 14 demonstrate that the project component of the total level was small and that background noise was dominant during this period.

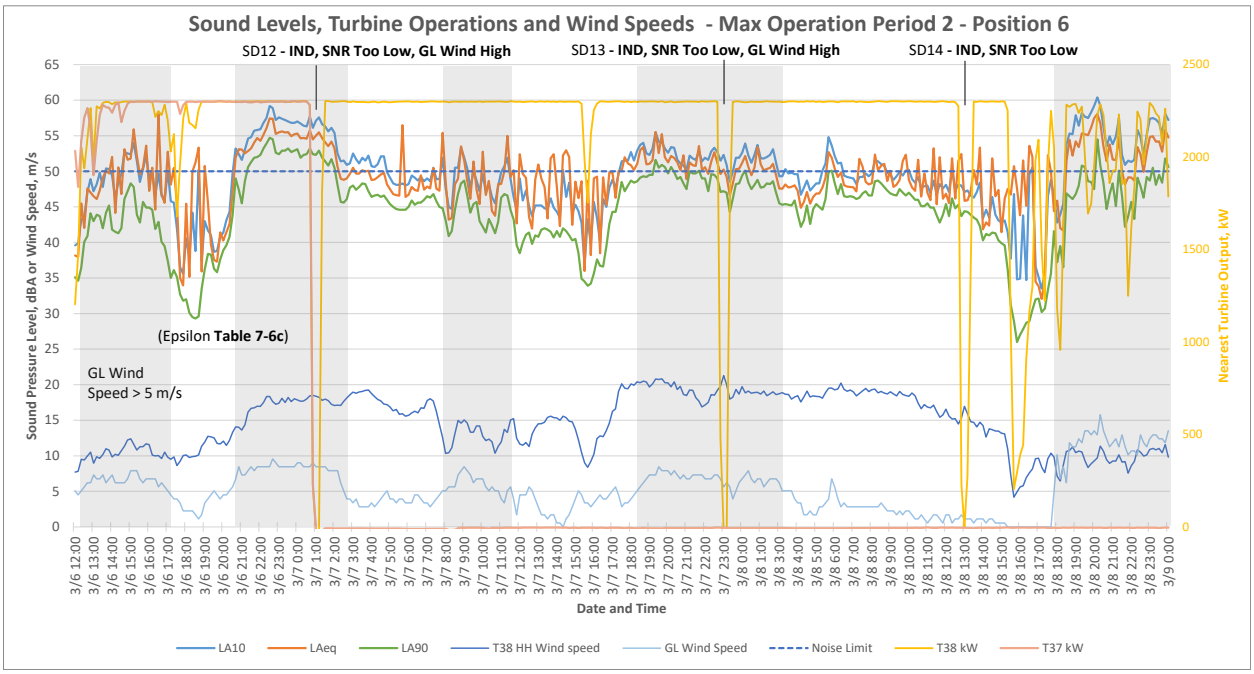

Figure 2.6.3

During the third windy period (Figure 2.6.4) another extended period of sound levels below the limit was recorded during the day on the 11th with the project at maximum production. Total sound levels as low at 34 dBA were again observed as had been seen during the two previous windy periods.

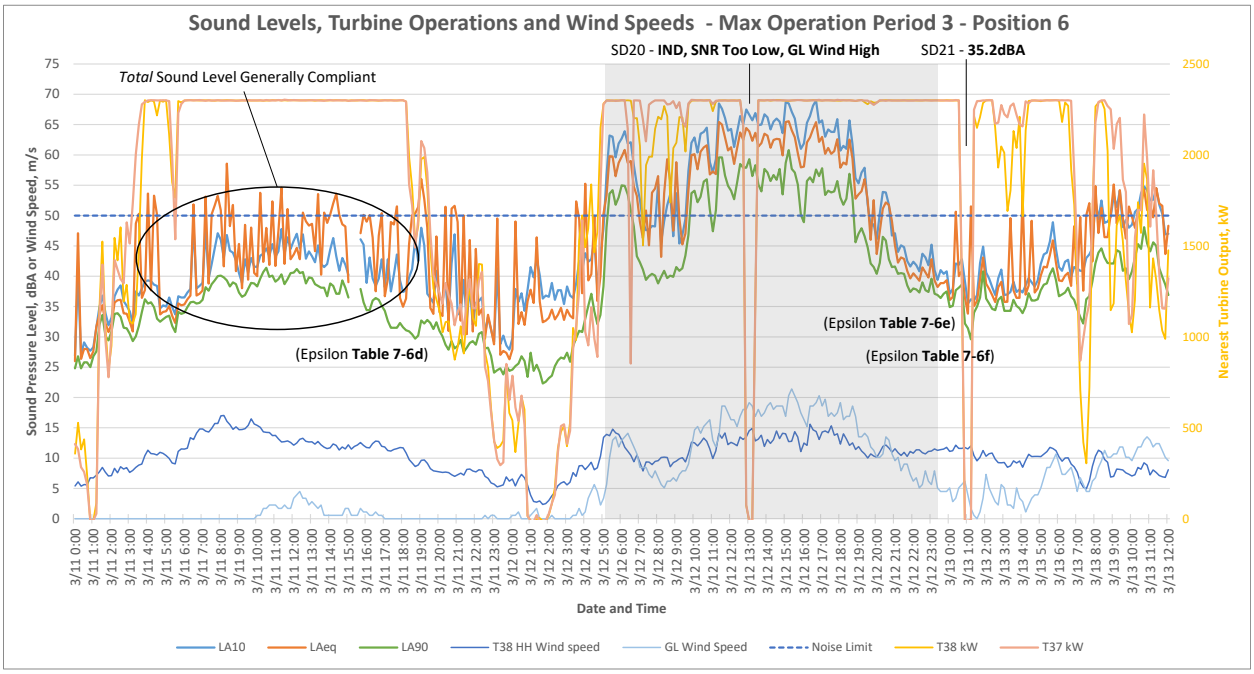

Figure 2.6.4

Shutdown 20 at 1 p.m. on March 12 occurred during another period of high winds and the temporary idling of the project had no effect whatsoever on the total Leq sound level, which was about 64 dBA at the time. This indicates that the project was not a significant contributor to the total sound level at that time and that its sound level was *much* less than 64 dBA.

When the surface winds calmed down again during the overnight/early morning hours of 13th the total sound level returned to the high 30's dBA while the project was still operating at or near full power. From the measurements before, during and after the scheduled shutdown at 1 a.m. a project-only sound level of 35 dBA can be calculated.

At this position the preponderance of the evidence points to a project-only sound level of about **34 or 35 dBA**, which is well below the county's 50 dBA property line noise limit. While the total sound level at this location occasionally reached much higher levels (up to 75 dBA), the study results show that those high levels are unrelated to the project and may be attributed to wind in the wooded property line buffer where the instruments were set up.

3.0 Epsilon Report and Comparison of Results

We have reviewed the "Sound Level Compliance Evaluation Report", dated May 13, 2020 prepared by Epsilon Associates, Inc. for Crowned Ridge Wind. In general, we believe that Epsilon did an excellent job with both the conduct of the survey itself and with the subsequent very meticulous analysis of the voluminous data. We agree with the report's methodology and conclusions.

Interestingly, two entirely different approaches were taken by Epsilon and us with regard to evaluating the field data and both essentially came to the same conclusions. Whereas we looked at the results from a graphical, level vs. time perspective focusing on the shutdowns to discern the project-only sound levels, Epsilon used a purely numerical, tabular sorting process to look at only those measurements satisfying a number of pre-set conditions, such as the variability of the sound levels during each sample, the outputs of all the nearest non-curtailed units, the average and gust wind speeds and wind direction. The following table summarizes and compares the results from both studies.

Table 3.0.1
Comparison of Independent Analysis Results

Location	Project-only Leq Sound Level Range, dBA		Applicable Regulatory Limit, dBA
	Epsilon	Hessler	
1	43 to 50	43 to 48	50
2	37 to 45	35 to 42	45
3	37 to 43	37 to 44	45
4	35 to 43	35 to 44	45
5	36 to 43	34 to 43	45
6	33 to 38	34 to 35	50

That the results differ slightly speaks to the fact that it is not practical to easily and precisely quantify the sound from any wind turbine project at distant receptor locations because the project sound is normally similar to, or more often, lower than the natural background level. That the two completely different approaches independently arrive at similar answers speaks to the validity of the study in general.

4.0 Conclusions

The sound level survey of the Crowned Ridge Wind Project required as a condition of the temporary waiver granted by the SDPUC to operate in a specially curtailed mode before all the turbines were fitted with low noise trailing edge noise mitigation has demonstrated that the project is meeting the noise limits mandated for the project. We have independently evaluated the survey data and have concluded that the project sound levels are compliant. We have also reviewed and approve of the final sound level compliance report submitted by Epsilon Associates, Inc. on behalf of the project that also indicates that the project sound levels are below the permissible limits.