EXPLORING UNCERTAINTY IN LOW FREQUENCY NOISE (LFN) MEASUREMENT AND CONTROL: DOCUMENTING SPATIAL VARIABILITY

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Abstract

To understand whether the phenomenon of spatial variation is a significant source of uncertainty in measurements of Low Frequency Noise, operator attended monitoring was undertaken at several points along a transect in the far field of known sources of Low Frequency Noise. Results indicate that in some instances, small but statistically significant variations in both 1/3 octave and broadband SPLs may be returned when measurement locations are varied by distances of 5m to 15m. Results of the assessment are presented to help explore the potential impact that this phenomenon may have on uncertainties in impact assessment, or in defining baseline conditions for design of Low Frequency Noise controls.

1. Introduction

Mining and commodity handling operations in NSW are typically required to develop and implement programs to monitor potential noise impacts at sensitive receivers adjacent to their operations. These monitoring programs are designed to detect sustained exceedence of statutory noise goals, and signal the need to implement corrective action; this signalling may result in the implementation of noise controls or a Pollution Reduction Program (PRP).

Despite the sometimes quite complex interaction of competing objectives in a noise control project, the findings of a comparatively simple, routine environmental noise impact assessment are often established as a baseline against which the value of various control options may be evaluated. Understanding uncertainty in the baseline is critical to an effective cost-benefit analysis, but uncertainty and sensitivity analysis is not typically undertaken as part of the impact assessment works that ultimately define the baseline.

A common source of uncertainty in these baseline conditions relates to temporal variability; the primary control for this uncertainty is to ensure that the monitoring duration captures a representative range of events. Shorter monitoring periods may minimise the cost of the exercise, but may also fail to observe the full range of conditions that represent the typical noise environment at that location.

A less common (or less widely considered) source of uncertainty – particularly relevant to investigations of Low Frequency Noise (LFN) impact – relates to spatial uncertainty [1],[2]. As the wavelength of the noise under investigation increases with decreasing frequency, assumptions about spatial homogeneity of Sound Pressure Levels (SPL) should be tested to confirm that measurement methods are appropriately controlling for phenomena that don't generally present, or aren't targeted by typical environmental noise measurement.

To understand whether this phenomenon of spatial variation is significant, operator attended monitoring was undertaken at several points along a transect in the far field of a known LFN source. The results of this monitoring campaign are presented to help explore the potential impact that this phenomenon may have on the uncertainties in defining baseline conditions.

2. Methodology

In recognition that the definition of LFN varies with jurisdiction (and to permit some degree of flexibility in data analysis), the monitoring design targeted unweighted, 1/3 octave SPLs in the range 10Hz to 20kHz. Measurements were also configured to return total A-weighted and total C-weighted SPLs (and a range of their statistical distributions) as these descriptors are commonly applied to LFN assessment in NSW [3]. Configuring the instrumentation in this way also enabled the data to be returned in a format similar to that that might be obtained from routine environmental noise measurement.

Operator attended noise monitoring was undertaken at several locations to obtain measurements at 4 points along a 15m transect (sample interval spacing of 5metres (m)(+/-0.1m)). All measurements were obtained approximately 1.5m (+/-0.1m) above ground level. The standard transect interval of 5m (and 15m total transect length) was chosen in an effort to establish a simple experiment design with a relatively small footprint. Transects were established in the far field of a known LFN source, at locations that enabled the transect axis to be arranged approximately perpendicular to the source. A stylised monitoring arrangement is shown in Figure 1.

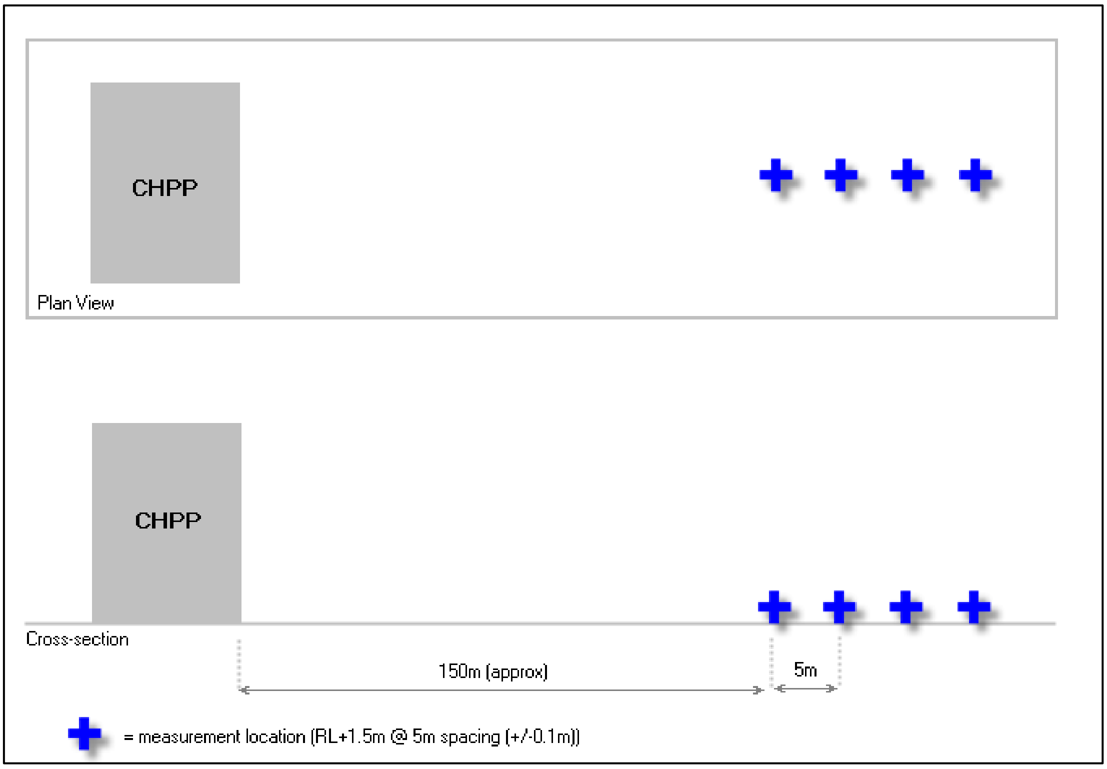

Figure 1. Stylised monitoring arrangement showing measurement transect

Measurements along each transect were synchronised, and monitoring was undertaken for a period of approximately 2 hours at each location. Measurements were obtained using a Sound Level Meter (SLM) with 1/3 Octave filter, and 15 minute L_{Aeq}, L_{Ceq} and L_{Zeq} (unweighted) results were returned. Time histories were also logged using a 1 second (s) averaging period to enable later analysis. The SLM instrumentation was calibrated prior to commencing measurements, and the response checked periodically throughout the monitoring to document any drift. Monitoring results were imported into Microsoft Excel for presentation and to undertake simple analysis to understand the statistical significance of any variation.

3. Results

Monitoring was undertaken at three locations as part of this experiment. Coal Handling and Preparation Plants (CHPP) with previously observed LFN emissions were selected for two of these assessment locations. The third set of measurement results were obtained at a control location with no observable LFN sources, in order to obtain comparison data.

Monitoring was undertaken using a 4-channel Svantek958 Sound Level Meter (SLM) (S/N:20777), enabling simultaneous measurements at 4 locations along the transect. Microphones were fitted with windshields, mounted on tripods, and attached to the SLM via extension cables. The calibration of all four channels was checked (94.0dB @ 1000Hz) using a Svantek SV30A field calibrator (S/N:7096). Results of periodic calibration checks indicate that drifts across all channels did not exceed 0.1dB during any of the measurement campaigns.

While not integral to the study, short term measurements were also (opportunistically) obtained using a Bruel and Kjaer 2270 SLM (S/N: 3000930) with BZ-7230 FFT analysis software. These data were used simply to identify any dominant LFN signals, and provide context to the broadband (1/3 octave) monitoring results. Detailed measurement results for each monitoring location are provided below.

3.1 Assessment results – CHPP Site 1

Measurements were undertaken adjacent to CHPP Site 1 between approximately midnight and 3:00am on 22 June, 2015. The monitoring location was approximately 150m from the nearest façade of the CHPP and the transect was established perpendicular to the façade.

Measurements were taken on a hard-packed gravel surface with a direct line of sight between the monitoring location and CHPP. There were no obvious barriers or obstacles to impact on the measurement, and the monitoring location was characterised as being in the free field.

A light and patchy fog was observed intermittently, but conditions were otherwise calm with a light cross-drifting wind observed. Ambient temperatures were on the order to +2 to +4degC.

Activities associated with the CHPP, including CHPP operation and intermittent stockpile dozers were the dominant source of noise during the measurement period. A sample of narrow band (FFT) results from this location is provided in Figure 2 and detailed transect measurement results are summarised in Figure 3 and Table 1.

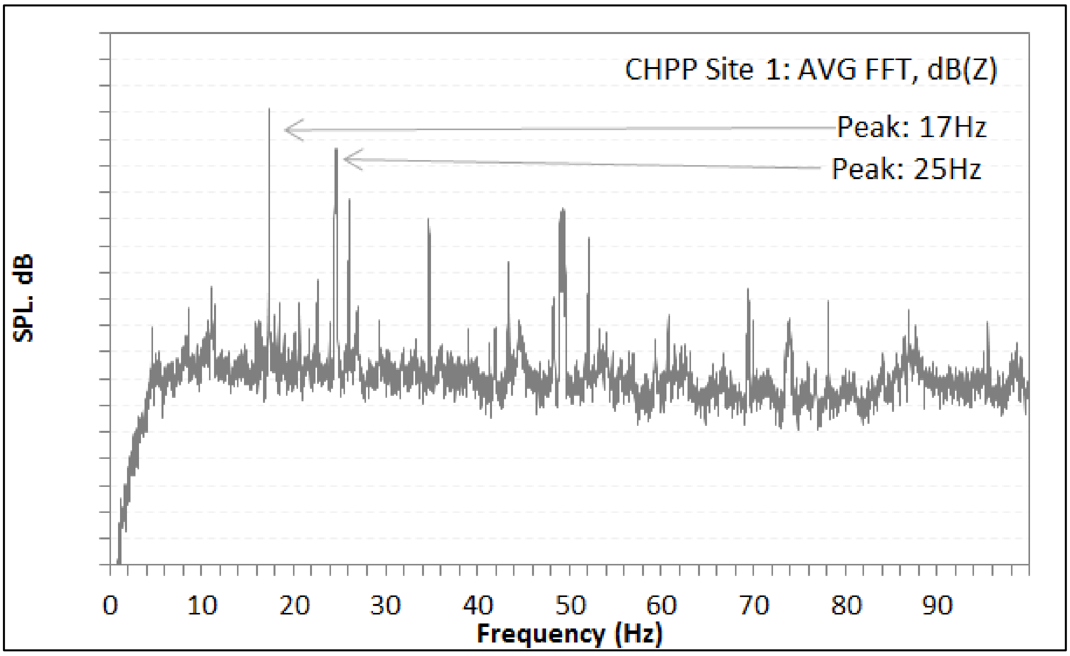

Figure 2. Sample FFT measurement data, CHPP Site 1. (Note: FFT measurement is provided only to assist in identification of narrow band peaks, not absolute levels. Increments of 5dB are presented on the Y-axis, but no absolute levels are provided)

Review of FFT sample data indicates that two narrow band tones at approximately 17Hz and 25Hz (and their higher order harmonics) were present at this monitoring location. On the basis of the relationship between frequency and wavelength provided in Equation (1), sounds at these frequencies would have a expected wavelength of approximately 20.1m and 13.7m respectively.

$$wavelength = \frac{speed\ of\ sound}{frequency} \tag{1}$$

Review of the monitoring arrangement indicates that a transect at 5m intervals would equate to a ¼ wavelength for the 17Hz tone, and may return measurements at positions approximating 0, ¼, ½ and ¾ wavelengths. Similarly, albeit with a less precise fit, this transect may observe SPLs at locations approximating 0, 1/3, 2/3 and 1 wavelengths of the 25Hz tone.

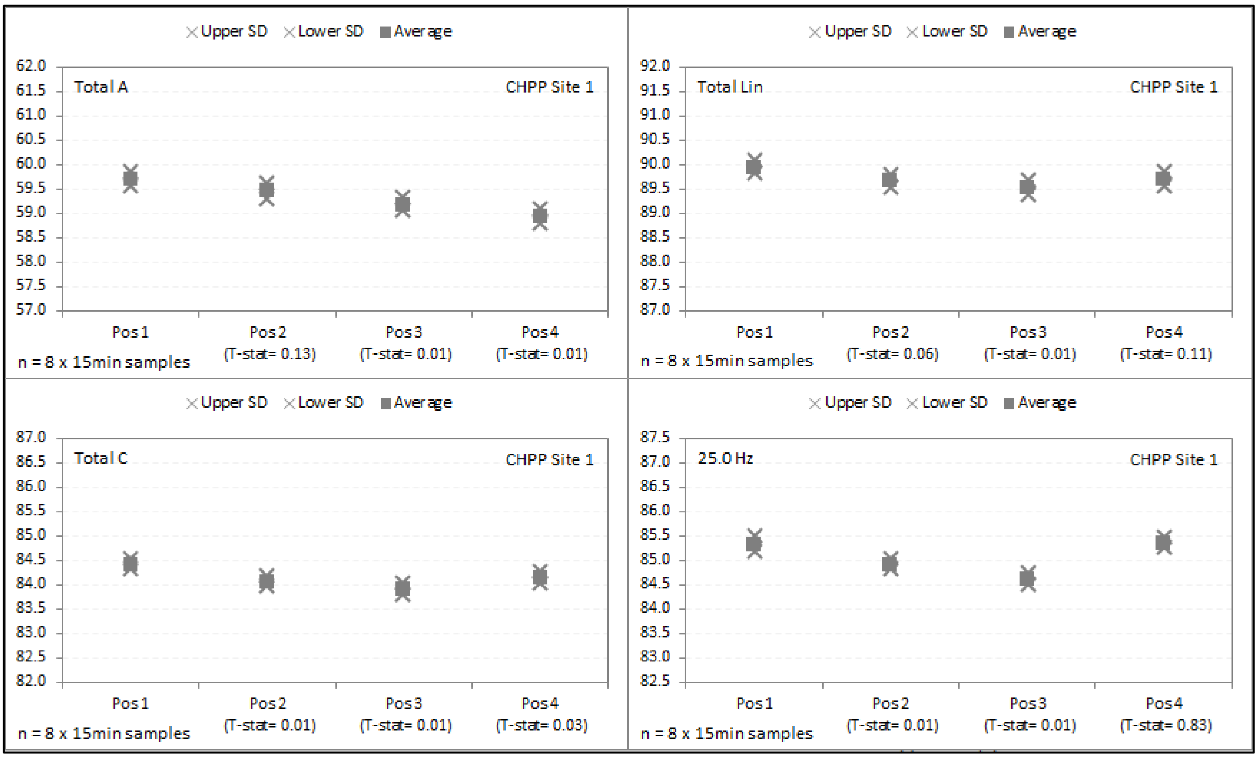

Figure 3. Analysis of transect monitoring results, CHPP Site 1

Table 1. Differentials between measured SPL and measured SPL at Transect Position 1, CHPP Site 1[1]

Metric	Transect Position 1	Transect Position 2	Transect Position 3	Transect Position 4	Max Transect Differential
Total C-wt	0.0	**-0.4**	**-0.5**	**-0.3**	-0.5
Total Z-wt	0.0	-0.3	**-0.4**	-0.2	-0.4
16Hz[2]	0.0	-0.1	-0.2	-0.3	-0.3
25Hz[2]	0.0	**-0.4**	**-0.7**	0.0	-0.7

Note 1: Bold results indicate differential is statistically significant ($p<0.05$)

Note 2: these are results of 1/3 octave bands, identified in terms of the central frequency of the band that most closely corresponds to tonal emissions identified via FFT analysis

Analysis presented in Figure 3 plots the average SPLs at each of the measurement positions along the transect in terms of descriptors commonly used in environmental and LFN measurement. The analysis also plots results from the 1/3 octave 25Hz band as sound in this frequency was observed to be a recurrent characteristic if LFN emissions from CHPP.

With reference to Equation (2) and the separation distance between observations points along this measurement transect, it is expected that SPLs would decrease at a rate of approximately 0.3dB per 5m due to simple geometric spreading. Monitoring results indicate that A-weighted noise levels do decrease with increasing distance from the noise source, at approximately the rate described by Equation (2). On this basis, it is considered that the variation and steady decrease in A-weighted noise levels is simply an expression of geometric spreading and increasing distance from the noise source.

$$\mathrm{SPL}_2 = \mathrm{SPL}_1 - 10\log\left(\frac{r_2^2}{r_1^2}\right) \tag{2}$$

Review of C-weighted and un-weighted SPLs indicate that these results follow a similar trend at measurement positions 2 and 3, but SPLs at the 4th measurement position appear to rebound and return to levels similar to position 1. This result is inconsistent with the expected result where the variation in SPLs is driven only by the relationship established in Equation (2).

Review of these results, and further analysis presented in Table 1, indicates that SPLs may vary by 0.5 to 0.8dB. Results of Students T-test (to evaluate whether SPLs at Positions 2, 3 and 4 are significantly different from SPLs at measurement Position 1 indicate that the statistically differentials were observed in all descriptors, except SPLs in the 16Hz 1/3 octave band.

3.2 Assessment Results – CHPP Site 2

Measurements were undertaken adjacent to CHPP Site 2 between approximately 20:30pm and 23:30pm on 22 June, 2015. The measurement instrumentation was set up at a roadside monitoring location, approximately 850m from the nearest façade of the CHPP. Owing to site specific constraints at the monitoring location, the transect could not be established perpendicular to the façade; subsequent review indicates that the transect was aligned approximately 30 degrees from perpendicular.

Measurements were taken adjacent to a sealed (bitumen) roadway surrounded by native pasture. With the exception of intervening and undulating terrain that partially obscured direct views of the CHPP, there were no obvious barriers or obstacles to impact on the measurement, and the monitoring location was characterised as being in the free field. Conditions were clear and calm, with ambient temperatures on the order to +6 to +8degC.

Activities associated with the CHPP, including CHPP operation and intermittent stockpile dozers were the dominant source of noise during the measurement period. A sample of narrow band (FFT) results from this location is provided in Figure 4 and detailed transect measurement results are summarised in Figure 5 and Table 2.

Analysis presented in Figure 5 plots the average SPLs at each of the measurement positions in terms of descriptors commonly used in environmental and LFN measurement. The analysis also plots results from the 1/3 octave 25Hz band as sound in this frequency was observed to be a recurrent characteristic of LFN emissions from CHPPs.

These analyses do not demonstrate any observable trend in SPL changes across the transect. However, review of results and further analysis presented in Table 2, indicates that a statistically significant differential of 0.5dB was observed when analysis of measured SPLs in the 12.5Hz 1/3 octave band was undertaken.

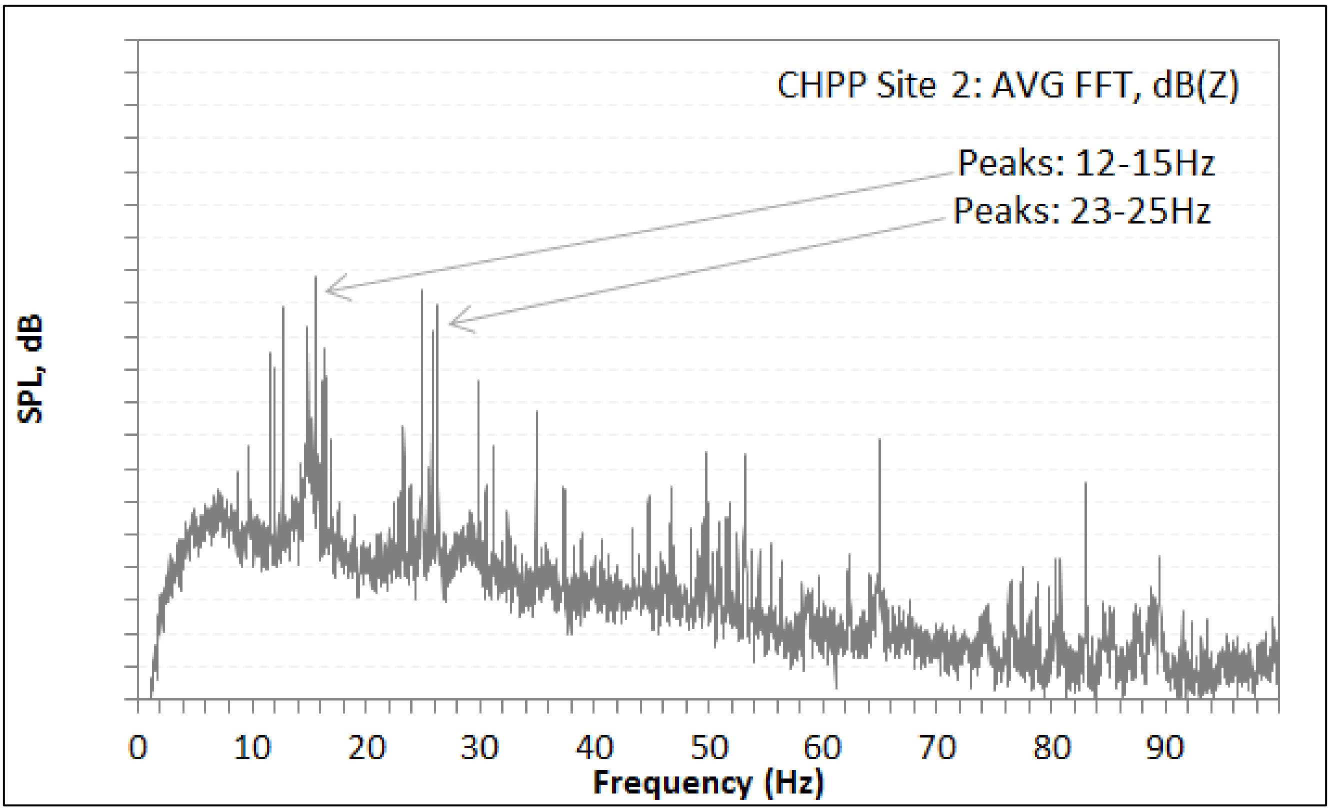

Figure 4. Sample FFT measurement data, CHPP Site 2. (Note: FFT measurement is provided only to assist in identification of narrow band peaks, not absolute levels. Increments of 5dB are presented on the Y-axis, but no absolute levels are provided)

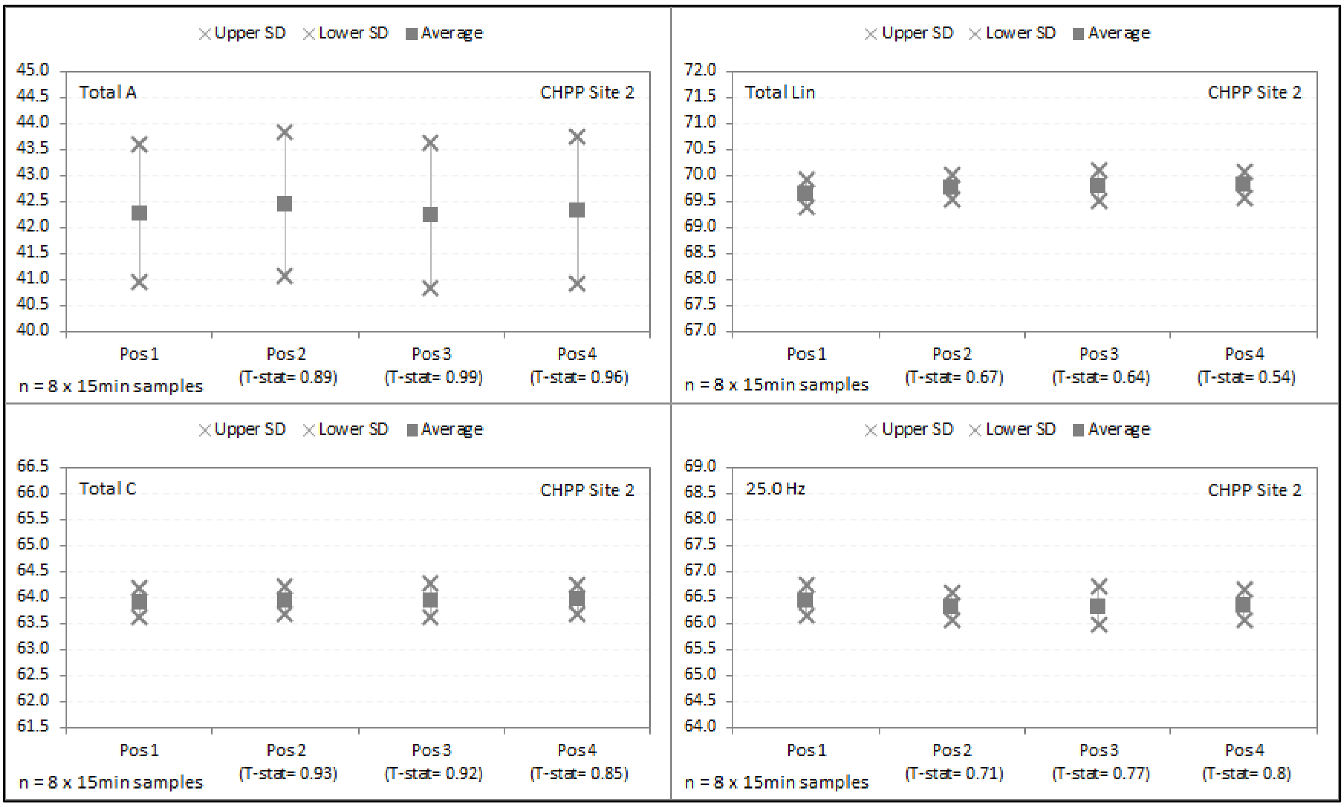

Figure 5. Analysis of transect monitoring results, CHPP Site 2

Table 2. Differentials between measured SPL and measured SPL at Transect Position 1, CHPP Site 2[1]

Metric	Transect Position 1	Transect Position 2	Transect Position 3	Transect Position 4	Max Transect Differential
Total C-wt	0.0	0.0	0.0	0.1	-0.1
Total Z-wt	0.0	0.1	0.1	0.2	-0.2
12.5Hz[2]	0.0	0.3	0.3	**0.5**	-0.5
16Hz[2]	0.0	0.3	0.4	0.4	-0.4
25Hz[2]	0.0	-0.1	-0.1	-0.1	-0.1

Note 1: Bold results indicate differential is statistically significant ($p<0.05$)

Note 2: these are results of 1/3 octave bands, identified in terms of the central frequency of the band that most closely corresponds to tonal emissions identified via FFT analysis

3.3 Assessment results – Control Site 3

Measurements were undertaken at a control site between approximately midday and 14:00hrs on 22 June, 2015. The measurement instrumentation was set up in a rural receiving environment, approximately 3km from the nearest major roadway, and more than 20km from the nearest CHPP. Measurements were taken adjacent to a sealed (bitumen) roadway surrounded by broad acre pasture on flat terrain. Conditions were clear and calm, with ambient temperatures on the order to +15 to +20degC.

While ambient noise levels were generally low, contributions from both environmental and transportation noise sources were observed. Distant road and rail noise contributed to background noise levels, while variation in ambient noise levels in both space (across the transect) and time (over duration of measurement) was driven by a small number of vehicle passbys and localised bird noise

A sample of narrow band (FFT) results from this location is provided in Figure 6 and detailed transect measurement results are summarised in Figure 7 and Table 3.

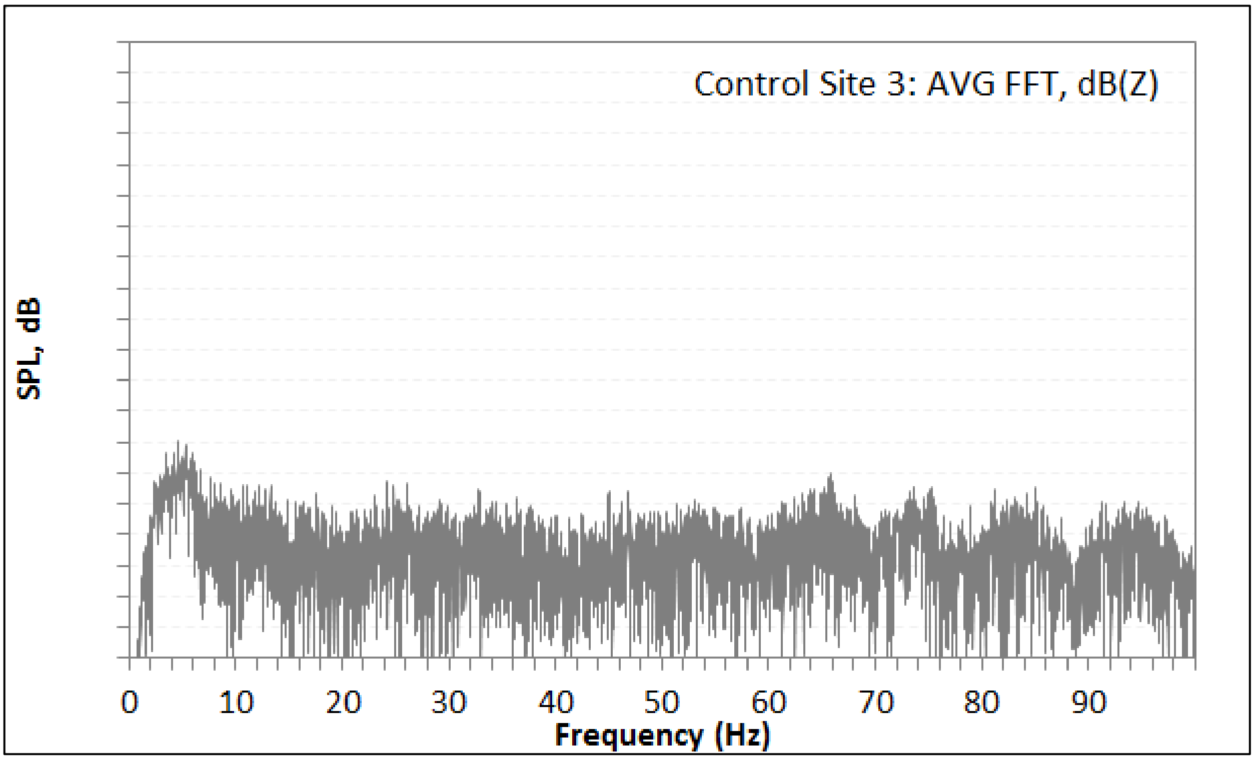

Figure 6. Sample FFT measurement data, Control Site 3. (Note: FFT measurement is provided only to assist in identification of narrow band peaks, not absolute levels. Increments of 5dB are presented on the Y-axis, but no absolute levels are provided)

Table 3. Differentials between measured SPL and SPL at Transect Position 1, Control Site 3[1]

Metric	Transect Position 1	Transect Position 2	Transect Position 3	Transect Position 4	Max Transect Differential
Total C-wt	0.0	-2.3	-1.9	-2.1	-2.3
Total Z-wt	0.0	-2.5	1.2	1.0	-3.6
$L_{A90,15minute}$	0.0	0.6	**1.6**	0.5	-1.6
25Hz[2]	0.0	-1.0	3.8	4.1	-5.2

Note 1: Bold results indicate differential is statistically significant ($p<0.05$)

Review of FFT sample data indicates that this monitoring location is free of any dominant tones or peaks in the LFN contribution, and hence may be considered a viable control location. Analysis presented in Figure 7 plots the average SPL at each of the measurement positions along the transect; in reporting these results it is important to note that the y-axis scale has been modified (to a range of 20dB) to accommodate the larger range of SPLs observed at this location.

It is also noted that the analysis of unweighted SPLs has been replaced (graphically) with an assessment measured background ($L_{A90,15minute}$) noise levels. This is done to show that, despite significant spatial variation in the energy average metrics, background noise levels were consistent; this serves to demonstrate the impact that a larger dynamic range of SPLs exerts over the results at this monitoring location. Notwithstanding these considerations, the tabular analysis presents summary of unweighted SPLs, and 1/3 octave measurements in the 25Hz band are also presented to maintain consistency with presentation of results from other sites.

These analyses demonstrate that there is significant variation in SPLs in both space and time compared to measurement results from CHPP monitoring locations. This may be attributed to the lower background noise levels, and more dynamic characteristics of the noise environment at this location. The monitoring results are also considered to reflect the impacts of localised bird noise at Positions 3 and 4 of the transect. While the graphical analyses indicate large variation in SPLs across all metrics, analysis presented in Table 3 indicates that these differences are largely not statistically significant.

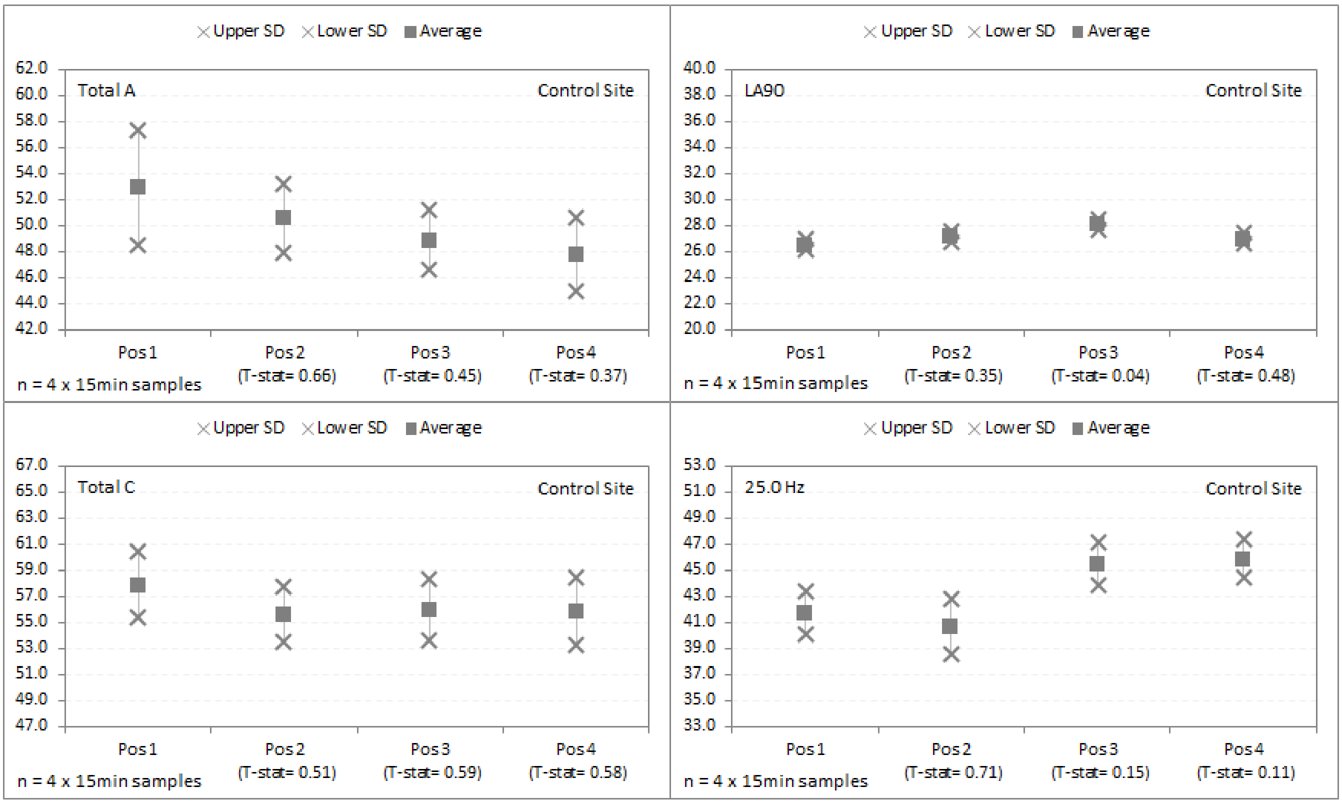

Figure 7. Analysis of transect monitoring results, Control Site 3

4. Discussion

Review of monitoring results from Control Site 3 indicates that there is potential for significant variability in SPLs (in terms of many common measurement metrics) across a 15m measurement transect. While analysis indicates this variation may be significant in terms of the range of values that were returned, the spatial variation (that is differences between measurement locations on the transect) was not statistically significant.

Analysis of measurement data from CHPP Site 2 indicates that while the noise environment was dominated by LFN contributions, and variations of up to 0.5dB were observed across the measurement transect, the variation in these SPLs was not statistically significant. The results of monitoring at both the Control Site 3 and CHPP Site 2 lend support to the hypothesis that the results obtained from LFN monitoring are not sensitive to changes in monitoring location.

Notwithstanding this, review of measurement data from CHPP Site 1 indicates that statistically significant variation in unweighted and C-weighted broadband SPLs were observed. Analysis of monitoring results indicate that variation may be associated with small changes (on the order of 5m) in measurement location, and that these changes may occur independently to changes attributable to the inverse square law. While these variations are minor (on the order of 0.4 to 0.7dB), statistically significant differences were also observed in the 25Hz 1/3 octave band indicating that assumptions about the homogenous distribution of LFN may not be supported.

While the test group is small and no data is available to validate the potential reasons that significant spatial variation might be observed at one CHPP but not at another, it is speculated that the poor repeatability across sites may be attributed to methodological variations and slight differences in test conditions. This includes different source receiver separation distances (which may change signal to noise characteristics), potentially different ground effects, or differences driven by the non-perpendicular alignment of the monitoring transect at CHPP Site 2.

While it is acknowledged that variation of methodological assumptions does not necessarily represent good experimental practice, these types of challenges represent a recurring constraint in field based environmental noise assessment, and this research is specifically prepared with regards to documenting and reducing the challenges of obtaining high quality data on the basis of field methods.

Despite opportunities for future refinement of the research, the assessment suggests that while statistically significant spatial variation may be observed, the differences in SPLs that are returned may not be sufficiently large to warrant changes to measurement and assessment practices to evaluate this source uncertainty.

As a precautionary measure, LFN monitoring results may reasonably be interpreted in the context of a potential uncertainty envelope of +/-1dB. Further monitoring at additional sites will provide insight into the effects of separation distance and directionality and may contribute to improved understanding and future guidance.

References

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