Experimental Outdoor Sound Propagation

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ABSTRACT

Noise propagation is significantly affected by prevailing meteorological conditions, leading to variations in received noise levels. Several standard modelling methods rely on measured meteorological data and estimation techniques. Rather than accept the uncertainty of modelling methods, we decided to obtain realistic and actual noise level data including the effect of atmospheric conditions by conducting a year long experiment on sound propagation. Loud speakers were placed at a central location on a site, to be used as an artificial sound source. A constant sound signal of a set of pure tones with varying sound intensity levels between each frequency is triggered every hour, for one minute, twenty four hours per day and for a year. The primary frequencies in the source signal were chosen to adequately simulate the main frequency range of typical mechanical plant. The transmitter consists of a CD player with a CD containing the source noise, a timer to trigger playback, a power amplifier and loud speakers. The arrangement is powered by solar panels and housed in a wire mesh and roofed compound. The sound bursts were recorded by loggers at distant off-site locations, as well as at an intermediate position near the speakers. Each logger contains a calibrated measurement microphone and a Digital Audio Tape (DAT) recorder. The loggers are pre programmed to record the received noise levels. Meteorological data is continuously collected by a weather station. Each monitor's DAT was then analysed using narrow band spectral analysis to filter the discrete pure tones from the ambient noise recorded. In the first instance the fluctuation of sound at each monitoring site is quantified. The meteorological and noise data is correlated and analysed to quantify the effects of weather on noise propagation. The results are encouraging with significant differences in noise levels being recorded, attributed to weather influences.

INTRODUCTION

The influences on outdoor sound propagation include geometric spreading, atmospheric absorption, refraction and turbulence, ground effects, reflection and diffraction. Noise propagation is particularly affected by wind and temperature gradients. This leads to day-to-day and hour-to-hour variations in received sound levels from a source. If a temperature inversion is present, the region of the inversion can act as a boundary to noise. This atmospheric "boundary" can direct sound energy back toward the ground, resulting in an increase in the total noise level at the receiver. Source-to-receiver wind can also enhance noise significantly. The noise impact assessment of proposed industrial facilities in NSW, is required to consider adverse weather conditions. Hence, accurately quantifying sound propagation can be critical to the success of an industrial facility and can have significant economic consequences for that facility. Noise modelling methods rely on measured meteorological data and estimation techniques. This type of assessment has been conducted through noise modelling software incorporating prevailing wind conditions and atmospheric stability classes. The calculated stability classes are estimations based on historic wind data. Given the uncertainty of these modelling methods, it was decided to obtain realistic and site specific noise level data including the effect of atmospheric conditions by conducting a year long experiment on sound propagation in an area proposed for industrial development.

Methodology

The experiment involved installation of loud speakers at a central location on the proposed site, which is relatively remote from residential properties. The speakers were used as an artificial sound source. A constant sound signal made up of a set of pure tones with varying sound intensity levels between each frequency was triggered every hour on the hour, for a one-minute burst, twenty-four hours per day and for a full year. The primary frequencies in the source signal simulate the main frequency range of typical mechanical plant (100 – 1000Hz). The sound power levels for each frequency in the signal were chosen with regard to the performance specifications of the speakers and to ensure sound is not at an annoyingly loud level at residences. Some frequencies were added to the signal to mitigate the annoyance properties of singular tonal sounds.

The transmitter consists of a Compact Disc player with a CD containing the source noise and a timer to trigger playback every hour. The CD player output is routed through a power amplifier to the loud speakers. The entire arrangement is powered by solar panels and housed in a secure wire mesh and roofed compound. The sound bursts were recorded by permanently fixed sound level meters (accuracy of ±2dB) at three distant off-site locations, as well as at an intermediate position near the speakers. The separation distances between source and monitors are approximately 630m, 1400m and 1030m for Receivers 1, 2 and 3 respectively. The near-source monitor is 27m from and in front of the speakers. The distant loggers consist of a calibrated measurement microphone, a Digital Audio Tape (DAT) recorder and a power source. The loggers are pre-programmed to record the received noise levels during each of the 1-minute hourly bursts. During the noise monitoring period, which was from 4 May 2000 to 15 June 2001, meteorological data was continuously collected by a weather station located approximately 1.5 kilometres east of the sound source and measures wind direction, wind speed and sigma-theta (at 10m elevation), temperature, humidity and rainfall. Negligible climatic differences exist between the source and weather station sites. The tape analysis process was conducted by appropriately trained staff listening to all tape samples to ensure the appropriate tape section is input to the analyser. This ensures extraneous recordings are discarded from analysis. Each sample is then analysed using narrow band spectral analysis (1Hz step and 1600 lines) to identify the discrete pure tones from the ambient noise recorded. The noise level at all frequencies 1Hz to 1600Hz was quantified and outputted for further analysis. This included logarithmically subtracting the ambient noise contribution at the frequencies coinciding with the pure tones of interest. This was done by linear interpolation of noise levels either side of the tone of interest using the traditional linear equation form y = mx + b.

The ambient noise level at the tone of interest was interpolated based on the gradient and y-intercept values. This is then subtracted from the total measured noise level at the tone of interest, resulting in the noise level contribution of the artificial source at that tone. This was done for each of the six tones of interest at the three distant monitoring locations with varying success depending on the frequency and ambient conditions at the time. During this process, samples having too much background 'noise' relative to the signal of interest (the six pure frequency tones) were discarded. This provides a secondary data quality check, the first being that of the operator listening to the original signal. The output file consists of the measured level at each location and frequency of interest, the background level at that frequency and the subtraction of the two, which results in the final actual source level. Other considerations include directivity characteristics of the source, quantified by attended measurements on four occasions during the year. The energy of the source was also checked over the year using data collected at close range during both attended spectral (20m) and unattended overall (27m) measurements.

EXPERIMENTAL DESCRIPTION

The pure tones used as the artificial source is described in *Figure 1*. Location C is directly in front of the speakers and hence generally giving highest sound pressure level. Locations A and E are to the side and perpendicular to the speakers, and hence showing least sound energy. Locations B and D are intermediate positions between Location C and A or E respectively. The two speakers used were placed side by side but skewed from one another and facing north west. This meant that some directivity characteristics of the source would be observed and this is also summarised in *Figure 1*. It was evident from the outset that the lower frequencies (tones 100Hz, 200Hz and 400Hz) would yield better results due to the higher sound energy produced by the speakers and by the expected propagation characteristics at these frequencies.

The site, surrounds, artificial source and monitoring locations are shown in *Figure 2*. The terrain between the source and monitors can be described as typical rural agricultural grasslands and treed in various areas as depicted in the aerial photograph of *Figure 2*. The source was positioned in a power transmission line easement clearing, which can be seen in the centre of the photo. A major freeway exists to the east of the source as labelled. The topographic sections between the source and each distant monitor are shown in *Figure 3*, with two of the three distant monitors having some topographic shielding due to an isolated hill.

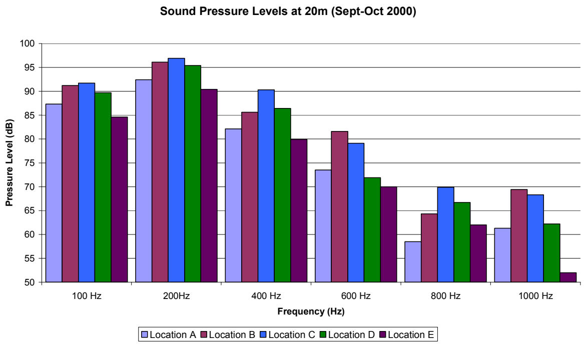

Figure 1 20m Sound Pressure Level of Pure Tones

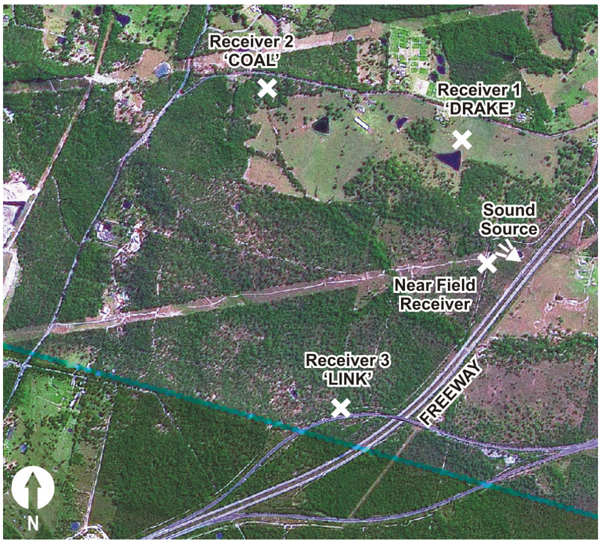

Figure 2 Site, Surrounds, Artificial Source And Monitoring Locations

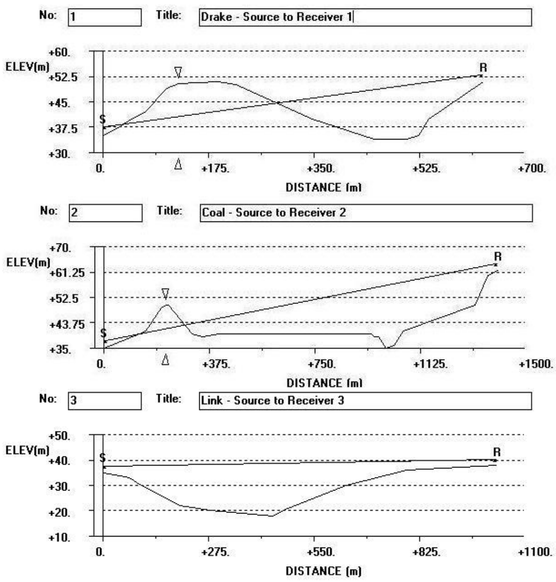

Figure 3 Topographical Cross Section Between Source (S) And Receivers (R)

RESULTS

At Source or Near-field Data

The near field sound energy of the speakers was quantified by attended measurements on several occasions for each tone using a narrow band analyser. This was also done by unattended overall noise levels measured at close range (27m from the speakers) over the duration of the monitoring period and at 15 minute sample intervals. The monitor at 27m from the source indicates an overall dB(A) sound pressure level that is relatively constant, as summarised in *Table 1*. The sound power drift during the course of the monitoring was observed to be as summarised in *Figure 4*. This indicates relatively marginal reduction in sound output over the duration of the experiment for the lower frequencies with higher fluctuations at higher frequencies.

Table 1 27m Overall Noise Level, Lmax – 18 May 2000 to 2 May 2001

Lmax Noise Level, dB(A)			**Standard Deviation**	**Number of Samples**
Minimum	**Maximum**	**Mean**		
82.0	88.5	85.3	1.4	1601

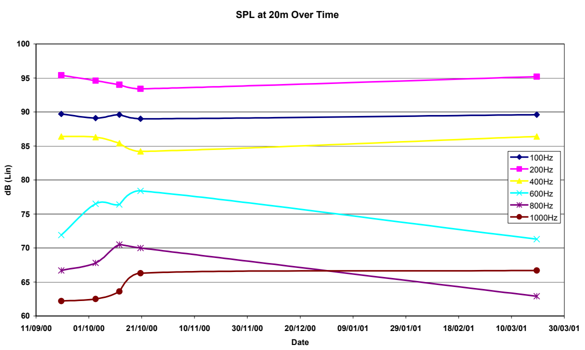

Figure 4 Sound Energy Drift

At Receiver Data

The monitoring extended over 408 contiguous days, for over 9792 hours of possible data for each of the six tones of interest. *Table 2* summarises the statistical information of the data collected and analysed. A further relatively minor number of samples were discarded due to the final noise level of interest being erroneous (eg too small <5dB). This generally applied to the frequency tones above 600Hz.

Table 2 Data Statistical Information

Location	**Number of Samples Collected and Analysed**				
	Summer	**Autumn**	**Winter**	**Spring**	**Total**
Receiver 1 (Drake)	299	2401	1975	1837	6512 (67%)
Receiver 2 (Coal)	777	1609	1459	1477	5322 (54%)
Receiver 3 (Link)	1378	2166	1558	1190	6292 (64%)

The tone noise levels over the course of the experiment and for each of the three lower tones (100Hz, 200Hz and 400Hz) are shown in Figures 5 to 7. These tones demonstrated good source signal correlation as compared to the remaining three higher frequency tones. A running average curve fit is shown and demonstrates the lower frequency having the higher energy as expected. The data demonstrates a marked fluctuation over the monitoring period. This is considered mostly due to variations in weather conditions, given the relatively constant energy of the source. There exists a profound increase in sound for the two monitors that were shielded from the source by topography in March and April 2001 as shown in the charts below. These two monitors are at similar bearings from the source and it is often shown that topographic shielding can result in significant differences in received sound between calm and adverse weather conditions. Initial analysis of wind data did not yield strong correlation at these times, however further analysis is continuing. A preliminary review of temperature inversion data did however indicate some correlation with enhanced received sound. The wind speed and directional data for vector source-to-receiver was analysed for Receiver 2 (which is in a similar direction to Receiver 1) as shown in *Figure 8*. This demonstrates the significant fluctuation in wind speed and direction, being positive value when towards the receiver and negative when away from the receiver.

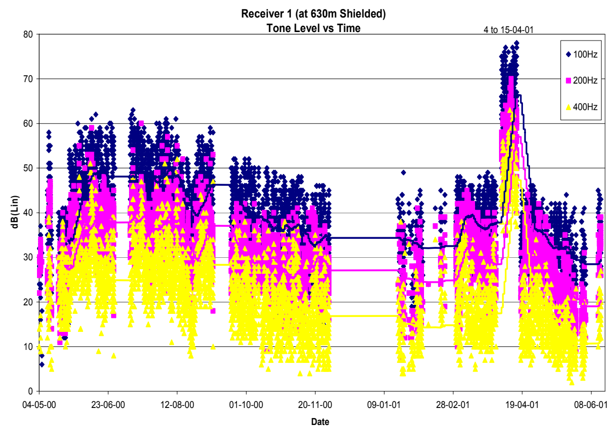

Figure 5 Receiver 1 – Measured Tone Sound Level For The Duration Of Monitoring

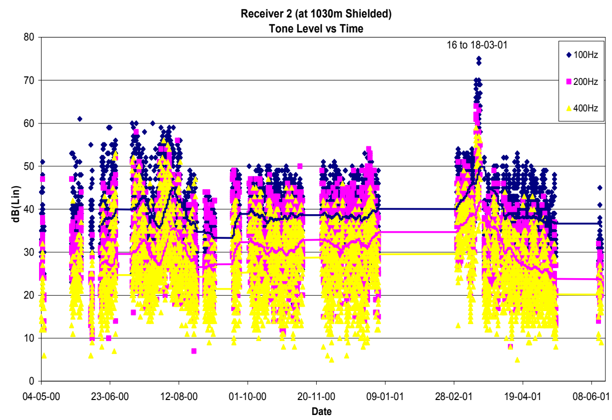

Figure 6 Receiver2 – Measured Tone Sound Level For The Duration Of Monitoring

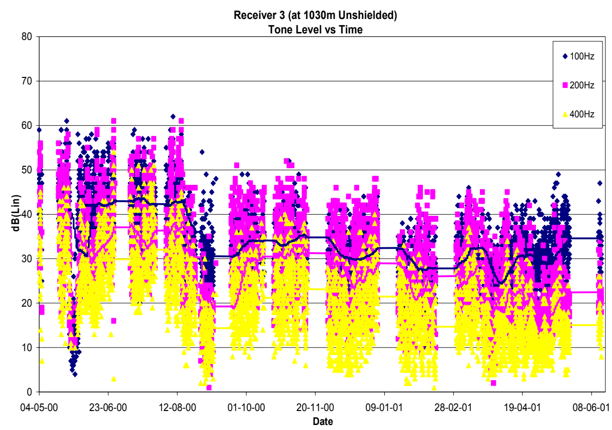

Figure 7 Receiver 3 – Measured Tone Sound Level For The Duration Of Monitoring

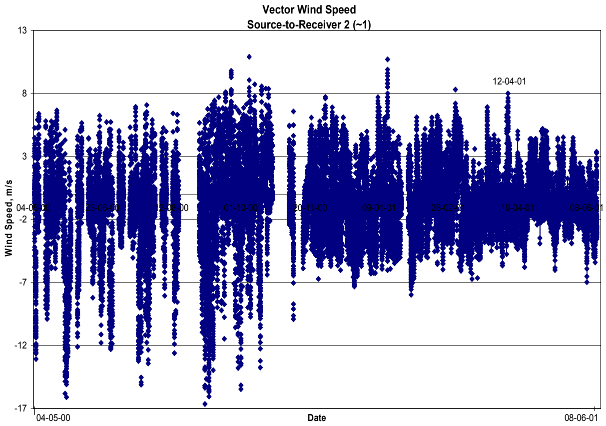

Figure 8 Vector Wind Speed (Source-To-Receiver 2 (& ~1))

SUMMARY

The experimental outdoor sound propagation monitoring was conducted over a period of approximately 13 months with over half to two-thirds of the possible data collected and analysed. Statistically the data gathered at the three receivers is substantial and valid. The sound levels demonstrated strong correlation at the three lower frequency tones (100Hz, 200Hz and 400Hz). The results indicate significant fluctuation of received sound level for a demonstrated relatively consistent source energy. These fluctuations were pronounced on occasion for the two receivers that had topographic shielding. This phenomenon is often simulated by weather conditions in modelling software. Whilst preliminary analysis of wind data did not yield strong correlation with received sound, further analysis is continuing. A preliminary review of temperature inversion data did however indicate some correlation with enhanced received sound. Further analysis of weather conditions is expected to provide the cause of the fluctuation in sound as weather remains the only significant variable that influences sound propagation. In the most, the results show that predicting received noise becomes complex and difficult over extended periods and when so obviously influenced by weather.

References

NSW EPA Australia, *Industrial Noise Policy* (2000).

David A Bies and Colin H Hansen, Engineering Noise Control Theory and Practice, Second Edition. (1996).