POST MEASUREMENT ANALYSIS - LOOKING BEYOND THE SURFACE

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1. INTRODUCTION

Sound measurements are used for a wide range of applications to provide an objective basis for decision making purposes. The range of applications vary both in terms of the sensitivity of the assessment outcome to the precise measurement value, and importantly, in terms of the significance of any decisions that will be made on the basis of the measurement outcome (significance both in terms of the number of people affected, and the financial implications of the decision).

The inherent variability of sound fields creates the chance of sound measurements yielding a misrepresentative indication of the sound field in question. The quality of a sound measurement must ultimately be judged on the basis of the data's reliability for decision making purposes. The risk of an incorrect decision being made on the basis of misrepresentative data is therefore an important indication of a measurement's quality.

The required data quality will ideally be the key factor when designing the method by which measurement data will be acquired. Just as the measurement applications and their significance vary, so do the available measurement strategies, and thus, the types of measurement analysis that will be required. Accordingly the type of analysis techniques that will be needed vary on a case by case basis. However, irrespective of the type of measurement strategy employed, post measurement analysis represents a critical link between measurement outcomes and their use for the intended application. Fundamental to any robust form of analysis is an understanding of the characteristics of the sound field being studied combined with a clear understanding of the aspects of the sound field which are critical to the assessment outcome. In this context, post measurement analysis is the total process of:

- Scrutinising measurement data to determine its adequacy for the intended application.
- Processing measurement data into a form that enables informed decision making.

The initial aim of any measurement analysis is to determine if the available set of data is fit for purpose. The question of fit for purpose is judged by determining if the use of the measurement data is encumbered by an unacceptably high risk of an incorrect decision being reached. On this basis, measurement data may be encumbered by a relatively high level of uncertainty but still be deemed fit for purpose provided that the uncertainty, however small or large, can be shown to represent a negligible or acceptable risk of an incorrect outcome being reached.

This paper provides a discussion of post measurement analysis broken into three broad subject areas:

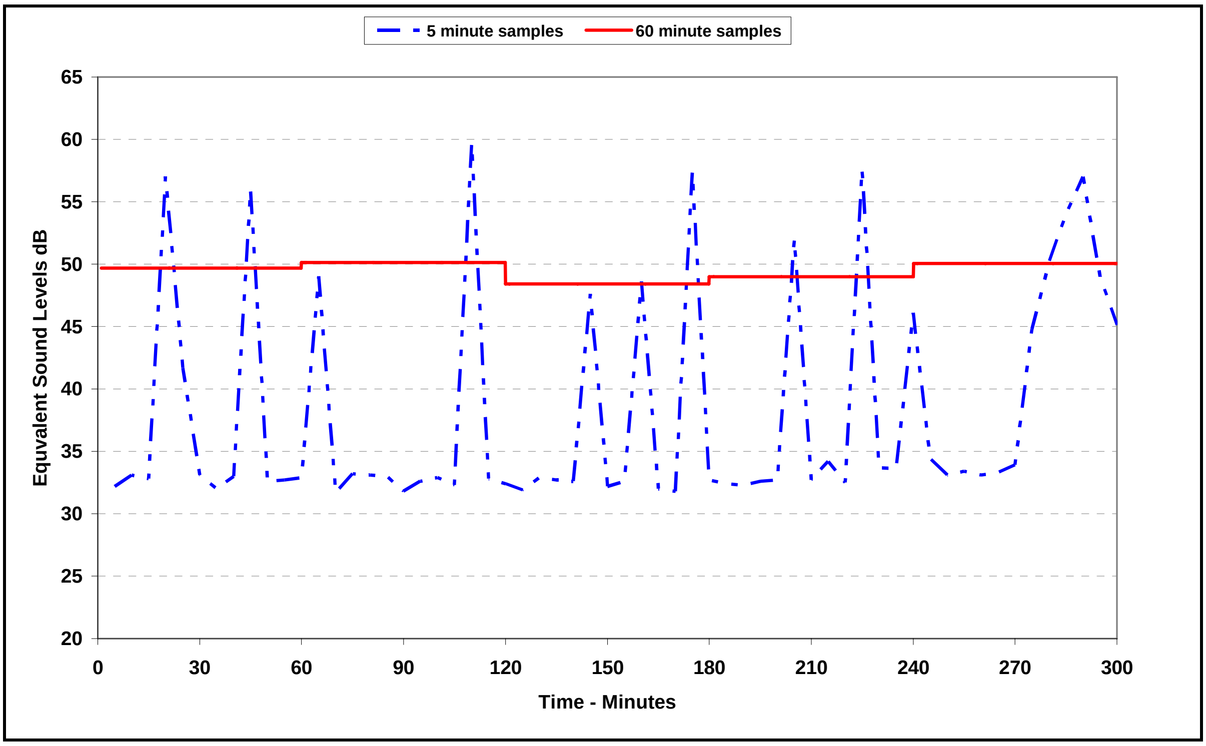
- The type of knowledge required for any measurement analysis
- Example measurement analysis techniques
- Information outputs of the measurement analysis

2. KNOWLEDGE REQUIREMENTS

Fundamental knowledge requirements for any measurement analysis is an understanding of the environment in which the measurements were obtained and a clear understanding of how the measurement data is to be used as a basis for assessment and decision making.

To illustrate the importance of knowledge of the sources that contribute to an environmental sound field, and how this will affect the measurement analysis, consider the following example noise data set. The two lines provide different time histories for the same single data set of noise, the only difference being that the solid red line represents contiguous samples of hourly average noise levels, whilst the dashed blue line relates to contiguous samples of 5 minute intervals.

It can be clearly seen from this simple example that, in the absence of any other knowledge concerning the measured sound levels or their causes, the hourly average noise levels mask a considerable degree of variability exhibited by the 5 minute sample data.



The one hour noise records may indeed be required by a given criteria to assess a particular noise source. However, in the absence any other information about the noise environment, the 5 minute records raise questions as to the type of source(s) affecting the measurement location, thus introducing doubts over the suitability of the analysis of 1 hour records as a representation for the intended assessment. For example, are the indicated peaks a feature of the assessment source in question, or has some extraneous noise source (such as a local vehicle pass-by) been responsible, thus rendering the 1 hour samples misrepresentative of the sound source being considered? If, on the other hand, the peaks are attributable to the assessment source itself, then is this measured variability a normal feature of its operation?

To demonstrate the importance of an understanding of how the measurement data is to be used, consider that for the above example there is some defined limit or trigger level against which the noise levels are to be compared. If the trigger level is above the highest measured peak level, then the limit is met irrespective of the portion of measured levels attributable to extraneous sources. The key question then becomes whether or not the contribution of the source being assessed is as high as could reasonably be expected during other valid sample periods or other valid assessment locations. The question becomes considerably more complex if the trigger noise level is set at some point between the highest and lowest measured levels. In such circumstances the contribution of extraneous sources to the overall measured sound level may be the significant factor causing the limit to be exceeded, in which case further investigation is required to quantify any such contributions.

The above simple example discusses only a portion of the possible complexities that the measurement analysis must address. In practice, assessment environments will commonly be more complex than this example, particularly where there are increasing numbers of noise sources, propagation effects are variable, and multiple receiver locations are to be assessed. Without knowledge of the sound field environment, its influences, and how the data will be used, the measurement analysis can only offer very limited conclusive outcomes.

3. ANALYSIS TECHNIQUES

3.1 Initial Plausibility Checks

The starting point of any measurement analysis is to review the plausibility of the available data. Any such review must have regard to the potential for errors or unexpected sources of variability to have affected the measurements.

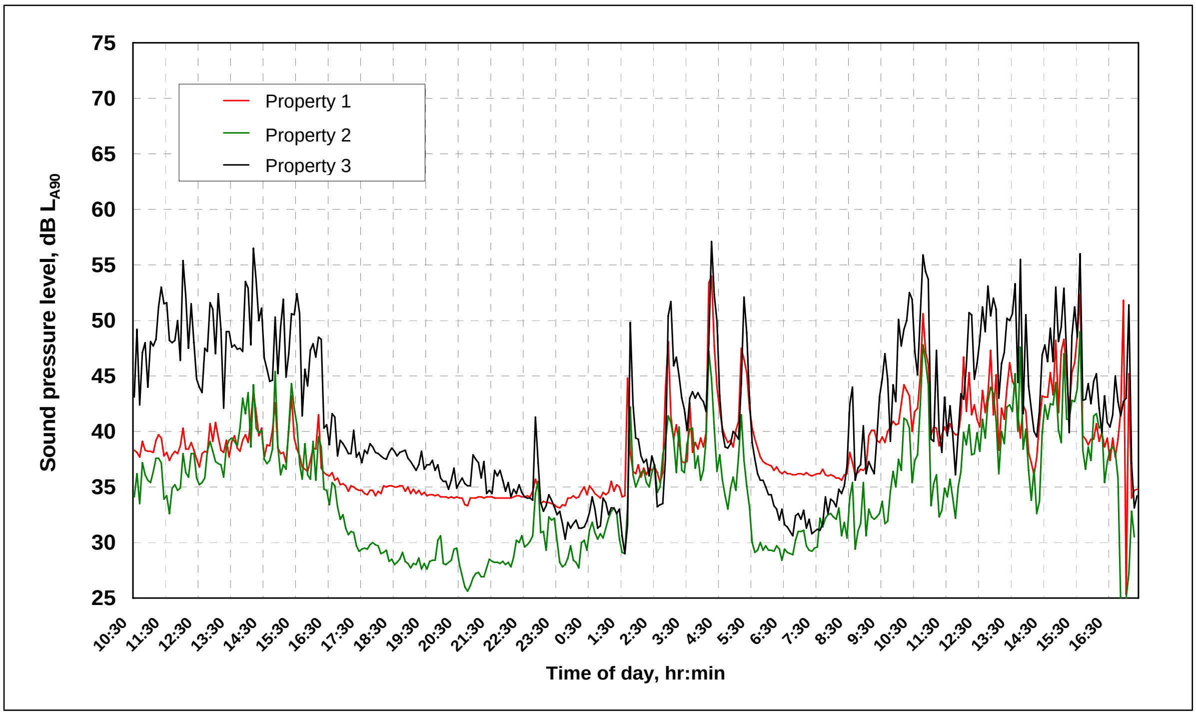
Common to all types of measurement strategy and application is to consider if the magnitude and range of noise levels returned by the measurement are consistent with expectations for the sound source being measured. For example, consistently high sound levels in a remote rural environment, or conversely, consistently low sound levels in a built up urban environment would need to be questioned and further investigated to gauge the validity of the measured data.

In many applications, logged data records over an extended period will be available and provide a useful means of further assessing the plausibility of a set of data. For example, most external environments exhibit a progressive increase and decline in noise level throughout the course of the day. Any sharp elevations/drops in sound level and/or periods of constant sound level in this type of environment may suggest either an equipment malfunction or the presence of an influencing source that may render the survey conditions invalid. The presence of such patterns would therefore warrant further investigation to review the validity of the measured data. To demonstrate this, consider the time history of sound levels shown in figure x. The data represents the background sound levels simultaneously measured at 3 separate and distant semi-rural locations over the duration of a day and night. At each of the properties a large, sudden and co-incident increase in noise levels was observed on 4 separate occasions during the night between 1:30 and 5:30 am. In the absence of any other information, it cannot be determined if the measurements were corrupted by an atypical event or if the spikes occur as a result of some regularly occurring industrial activity in the area. Only through subsequent inspection of rainfall records for the area was it possible to conclude that the data was valid, but had been influenced by drainage flow noise during brief intense periods of rain fall.

Inter-comparison of different measurement parameters provides a further valuable mechanism for understanding the types of sources that may have influenced a measurement and thus whether the result is consistent with expectations. Statistical noise levels, which indicate the percentage of measurement period that a given noise level is exceeded for (e.g. L_{90} denotes the level exceeded for 90% of the measurement period and thus the underlying level), are particularly useful for this purpose Examples of the utility of such comparisons are:

- In most types of environments, the average or equivalent noise level over a measurement period would be lower than the value which is exceeded for 10% of the measurement period (the L_{10} – a common measure of the upper noise levels occurring in a sound field). For example, the equivalent noise level would typically be around 3 to 5 dB below the L_{10} value in an area dominated by transportation noise. Thus, measurement data that indicated L10 noise levels less than the equivalent noise level would raise the question of whether or not the data is a true representation of an expected or unexpected feature of the sound field, such as impulsive sounds that are sufficiently high to raise the average level, but present for less than 10% of the measurement period and thus not affect the L_{10} value.
- Comparison of the lower statistical noise levels such as the L_{90} with the average or equivalent noise level provides an indication of the extent to which noise has varied over the measurement period. For example, a small margin between the L_{90} and the equivalent level would indicate the noise to have been relatively steady or constant over the measurement

period, as may be the case when the result has been dominated by the influence of constant machine noise.



3.2 Isolating Sound Sources of Interest

One of the most frequent challenges to measurement analysis is isolating the noise level contribution of a specific source, or group of sources, from the influence of other ambient or contaminating sound sources. Ideally this analysis is based on subtraction of the ambient noise from the total measured level, however practical constraints may preclude this. For example, it may be the case that the source of interest cannot be suppressed to enable an ambient reading to be obtained, or the ambient may be so variable as to introduce considerable uncertainty over the ambient noise level actually occurring during the measurement of the specific source of interest. It is also not uncommon for the source of interest to be below the ambient and lower background level, as is frequently the case when compliance measurements are required for comparison with planning condition limits which set target values 10 dB below background sound levels.

Frequency and statistical analysis of measurement data can provide a means of estimating the contribution of a specific noise in question. The principle of each of these techniques is to identify an aspect of the source in question, such as its temporal or frequency characteristics, which distinguish it from the ambient sound environment and which can be in some way related to the total level of the source of interest. Examples for frequency and statistical analysis include:

- Industrial sources of noise often possess distinct frequency characteristics that are dissimilar to that of the general ambient environment. At distant measurement locations, the total level of an industrial source may be below the total ambient noise level thus precluding direct measurement. However, individual frequencies of the industrial noise may still be well above the ambient noise level and thus directly measurable. The frequency level can then either be referenced as a minimum value for the source in question, or where more information is required, correlated with measurements taken nearer to the source to understand the relationship between the frequency level and the total noise level. Caution must be exercised for the latter type of analysis though, as the frequency characteristics of the source may vary significantly with distance, thus changing the relationship between the total noise level and any given frequency.
- The nature of the statistical parameter is such that a portion of the incident sound levels are discarded from the measurement value. This feature can be used for distinguishing the steady contribution of a source of interest from a varying ambient noise environment which is

fluctuating at higher and lower noise levels. For sources of a steady or quasi steady nature, the lower steady noise level, such as the level exceeded for 90% of the measurement period, can be used as an estimate for the total equivalent or average level of the source in question. Caution is required to ensure that the chosen statistical parameter and the level of variation exhibited by the sound source are not mismatched, otherwise significant features of the specific source will not be included in the measurement. This limitation can sometimes be addressed by comparisons with specific source measurements at a position where a direct measure of the equivalent sound level can be obtained without the contamination of the extraneous sources. The relationship between any proposed statistical measure and the equivalent sound level at the near field position can thus be quantified. It may then be possible to apply this relationship (between statistical and equivalent sound levels) to the same statistical parameter measured at the actual assessment location. Note however that this relationship will only be applicable in instances where all element emissions of a total specific source exhibit the same relative contributions at the near and far positions. An example of a situation where this would not be the case, is when the close measurement is screened from a time varying source (e.g. a roof mounted item of plant) that significantly contributes to sound levels at more distant locations when the screening effect is lost.

Another mechanism for distinguishing the contribution of a specific source, or group of sources, is the inter-comparison of measurement records at various locations within the sound field of interest. These comparisons may reveal trends in the distribution of sound levels within the area of interest. More complex comparisons may also provide further information relating to the relative significance and position of sound sources within an area of interest. From this, it may be possible to justify extrapolation of the data for the purpose of estimating sound levels occurring at other locations. To demonstrate, consider a set of measurement records obtained from simultaneous monitoring positions located at varying distances from a specific source in question:

1. If sound levels progressively decreased with increasing distance from a source in question, this would provide a positive indication that the source in question is a significant contributor to sound levels across the survey area. This trend, subject to further comparison of theoretical expectations, may then provide an acceptable method of estimating sound levels at increased distances where measurements may not have been possible (for example, at positions progressively nearing a dominant background sound source).
2. If sound levels remained relatively constant, or progressively increased with increasing distance from the source, this would be a positive indication that the source in question may not be a significant contributor to the total sound field.
3. If sound levels indicate a progressive decrease with increasing distance, but show a step increase in sound levels in the mid-region, and then continue to progressively decrease, this may suggest the presence of a residual sound source in the region of interest.

In all cases, there will be a number of possible explanations for an observed trend. For example, in the second and third scenarios described above, the observed patterns could potentially be explained as follows:

- The sound source in question comprises multiple emitting elements, some of which are screened at short distances (for example, roof mounted equipment), however at increased distance, the screening is lost and the sound level increases.
- The sound levels may not be related in any way to the assessment source, but instead relate to extraneous sources local to each survey position, and the observed trends are merely coincidental.

It is therefore essential to exercise a high level caution when proposing the use of this technique. In particular, this further highlights the need for knowledge of the characteristics of the contributing sources when employing certain types of measurement analysis techniques.

3.5 Accounting for Variability

Most measurement applications will involve developing a rating value for a sound field that exhibits significant variability both in time and space. The challenge this presents to measurement analysis is to address the following key questions:

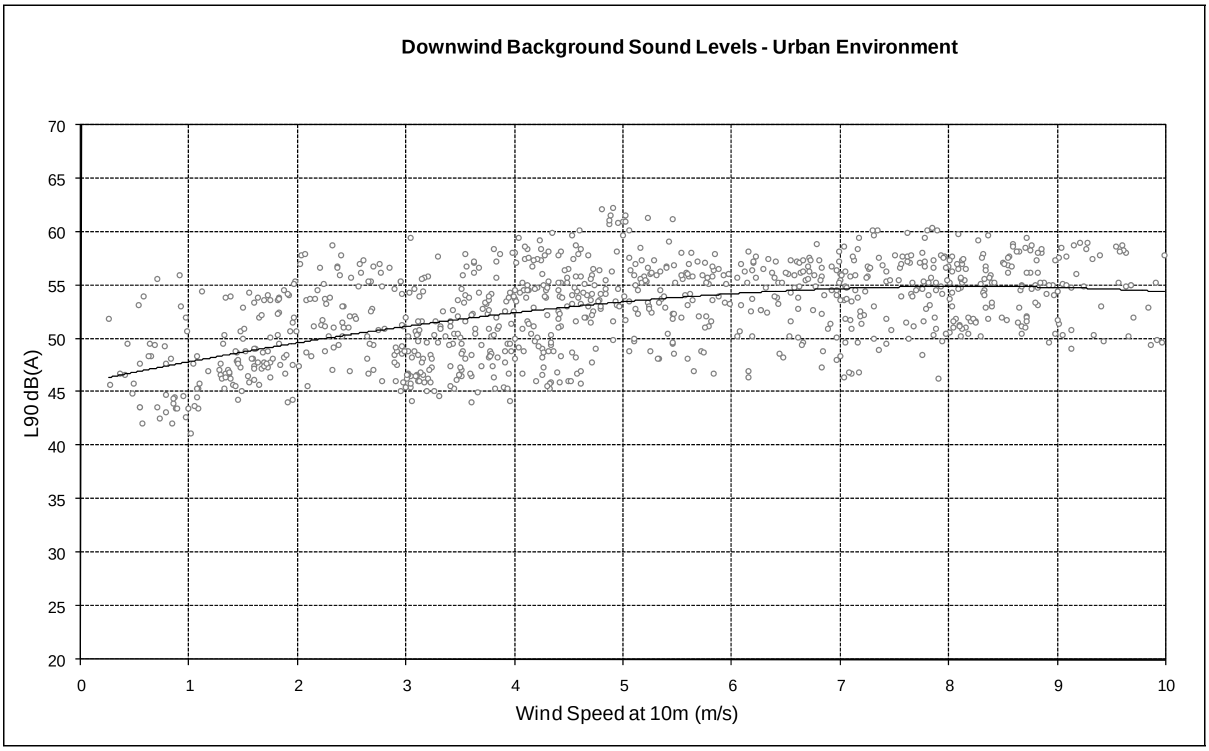
- Does the measurement data set include for the full range of variability that occurs in the sound field of interest? If not, how could the data differ in any other time period or location in which the measurements could have reasonably been made?
- How does the range of measurement values affect the rating value that will be used for assessment purposes? Does the range of variability in measurement values translate into similar variability in the range of rating values that could be selected?

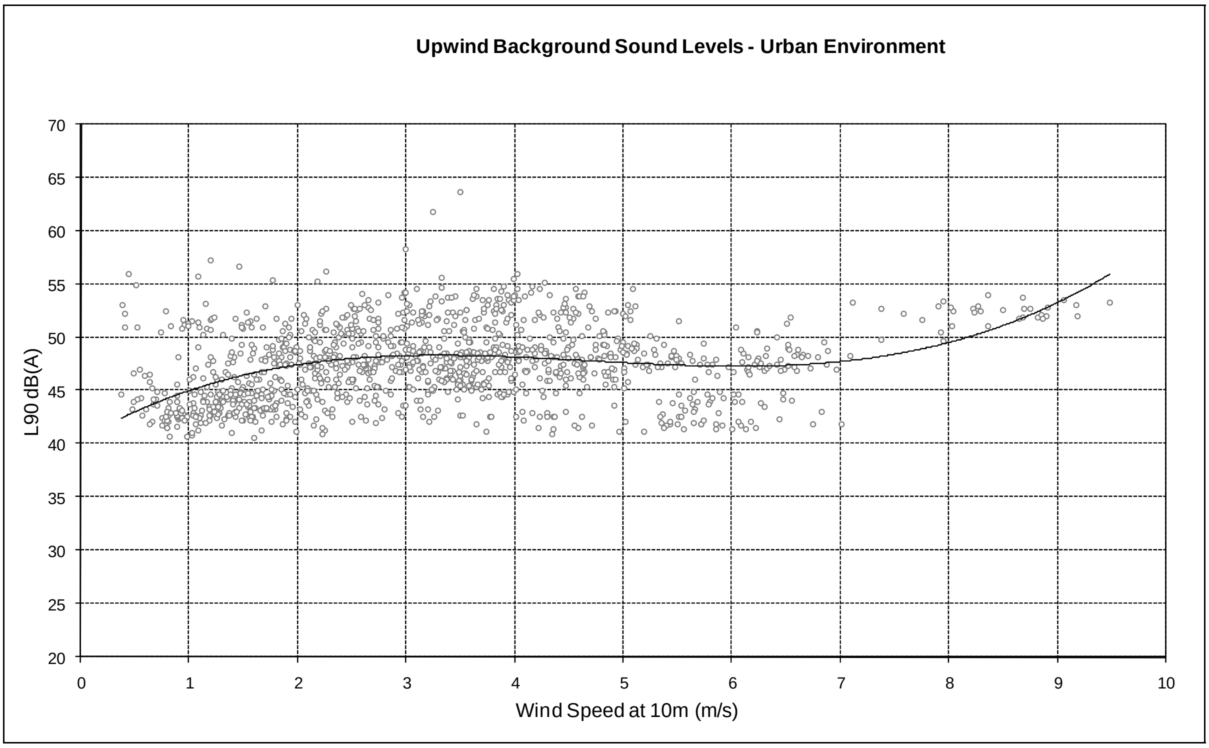
The types of questions noted above are critical to understanding the level of risk that may be involved in relying on the measurements as an assessment basis. In almost all cases, addressing these questions will involve correlating the acoustic information with general knowledge of the site or non-acoustic measurement data. For example, the question of whether the full or relevant range of variability has been measured can only be addressed with an understanding of how and why the noise levels vary and how the measurement conditions relate to other possible conditions.

The extent to which variability must be addressed in the measurement analysis will ultimately be governed by the propensity for assessment outcome to change according to different measurement values. For example, if a measurement is known to have represented the maximum sound level that could reasonably be expected to occur, and the associated rating value is only required for comparison with a benchmark that is considerably higher, then the possible range of variability is inconsequential to the assessment, and no further analysis would be required. In contrast, rating values that are of a similar magnitude to such a benchmark and are known to potentially be higher in other conditions would require considerable analysis to gauge the risk of an exceedance occurring.

To demonstrate the importance and value of non-acoustic data to the analysis of measurement variability, consider the following set of figures which demonstrate day time background sound levels measured in a rural and urban environment which have been correlated with measured wind speed data. The background sound levels were measured in 10 minute samples and only relate to dry conditions (rainfall and subsequent periods removed). The first figure below depicts the rural environment and indicates background noise levels ranging from approximately 21 dB to 55 dB – a range of variation of more than 30 dB. Analysis of the acoustic measurement data in isolation would represent a significant challenge to deducing a meaningful rating value, depending on the type of application that the rating value is required for. However, the correlation of acoustic data with wind speed provides an account of the variability by depicting a strong relation between the two, consistent with an environment dominated by natural background sources such as wind disturbance of vegetation.

The following two figures depict background noise levels measured in an urban environment where road traffic noise is the dominant source (approximately 1km from a motorway). The difference in the two charts is that the first has been filtered to only include data that has been recorded in downwind conditions from the dominant road traffic route, whilst the second depicts upwind data points. Variability of 15 to 20 dB is observed in the range data points for both, however the correlation of noise levels with wind speed shows a very weak relation in this instance. The slight trend increase with wind speed is likely to be more a function of availability of data points, and an increase of the minimum background sound level rather than a broader influence on sound levels. Comparison of the upwind and downwind charts shows the downwind values to be regularly 3 to 5 dB higher than the upwind case; the increase being consistent with expectations, but the value of the increase being less than the effect that could be associated with a change in wind direction (changes of 15 dB or more are possible due to wind direction changes) suggesting that noise levels at the location are dominated by different sources depending on wind direction. Thus, whilst the data for any given wind speed or direction depicts significant variability, the correlation focuses the analysis of variability on to understanding the changes of a particular dominant source rather than the much wider range of possible factors affecting background sound levels.





4. ANALYSIS OUTPUTS

The output of a measurement analysis will ultimately be the processed sound field rating in a form that can be used as the basis of assessment and communicated to interested parties either responsible for the decision or affected by the assessment outcome. In presenting the analysis outputs, account must be made for any residual uncertainty in the derived rating. The presented uncertainty may be a calculated value where known elements of uncertainty can be numerically quantified. In many cases though, numerical quantification of all uncertainties may be not be practically achievable and/or may offer little assistance, and may be presented as a simpler discussion of any sources of change that would be expected to increase or decrease the measured values. For example, where targeted/limited sound measurement data has been gathered under known conditions of interest, the discussion of uncertainty may be focused on the non-acoustic data that supports the relevance of the measurement conditions (such as weather records or the operational status of a sound source) which can then be used to demonstrate the sound data is representative for assessment purposes.

In presenting measurement results and associated uncertainty estimates, consideration must be given to their combined influence on the assessment outcome. In instances where the influence of the estimated uncertainty surrounding the measurement value does not alter the assessment outcome, it will be reasonable to expect that no further measurements or analysis are required. However, where the deduced uncertainty is of consequence to the assessment outcome, the risk that the measurements could incorrectly inform the assessment must be reviewed. Depending on the type and scale of assessment being informed, possible courses of action that emerge from this review may include:

- Further intensive analysis of the data where the possibility exists to reduce the level of uncertainty surrounding the data.
- Evaluation of the potential for additional measurements, possibly by way of a modified measurement strategy, to reduce the uncertainty.
- Following communication of the uncertainties surrounding the measurement data, the end users of the measurement data may opt to accept a higher than preferred level of risk.
- The existing measurement data, and any measurement data that could be obtained from a modified measurement program, may ultimately be deemed to be encumbered by an unacceptably high degree of uncertainty, potentially leading to measurements being abandoned as a basis for informing the assessment in question.

Irrespective of the implications of the estimated uncertainty or the final action taken in relation to such uncertainty, the measurement analysis must demonstrate to the party commissioning the measurement whether or not the intent of the measurement has been adequately addressed, as judged by the quality of the measurement for the intended application. Importantly, irrespective of the scale and sophistication of a measurement strategy, the quality of a measurement outcome cannot be assumed until it has been demonstrated by thorough post measurement analysis.