Use of long term monitoring data for defining baseline sound levels

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ABSTRACT

With the trend towards semi-permanent sound monitoring, and collection of ambient sound levels over long periods of time, the method used for processing these data become increasingly important when identifying baseline sound levels. When calculating a single figure for "typical" baseline ambient sound levels from long term data, a number of different analysis options are available, which can result in differing results. This, in turn, can have an influence on noise limits which may be set, for example to control noise from construction works, or for noise from new operations. This paper considers different methods for the calculation of typical sound levels from long term monitoring data and demonstrates both the importance of this choice and the variability which can result. Consideration is given to the implications on large infrastructure projects where it is desirable to use a single methodology for setting baseline ambient sound levels and agreeing these with numerous local authorities and other stakeholders.

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(See . http://www.inceusa.org/links/Subj%20Class%20-%20Formatted.pdf .)

1. INTRODUCTION

1.1 Background to the Project

The Thames Tideway Tunnel is a nationally significant infrastructure project for the construction of a 25 km tunnel running mostly under the tidal section of the River Thames through central London. It will provide capture, storage and conveyance of almost all the combined raw sewage and rain water discharges that currently overflow into the river. The construction of the project requires 24 construction sites, with periods of 24 hour working required during the tunnelling phase at some of these. The central location of the project means that the construction sites are generally close to residential and other noise sensitive receptors.

Construction noise associated with the project has been predicted and assessed first as part of the Environmental Impact Assessment [1] (EIA) for the scheme, and subsequently for consents for the construction phase. Baseline monitoring has been a considerable element of this assessment process as described below

1.2 Assessment of Construction Noise in the UK

UK construction noise is assessed following guidance set out in British Standard 5228:2009+A2014 [2]. This document has been continually developed and improved since the Wilson report [3]. Action on noise pollution from construction sites is enforced through the Control of Pollution Act 1976 [4].

BS5228 assesses construction noise differently to noise of an industrial or commercial nature (which is addressed instead by British Standard BS4142:2014[5]).

As construction noise is required to be assessed in EIA, it is often necessary to consider the

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significance of construction noise effects on human receptors and the local environment. The 2009 edition (amended in 2014) of BS 5228 introduces three example methods for assessing the significance of construction noise in Annex E (Informative):

- Potential significance based on fixed noise limits:
  - This method suggests fixed noise limits for "rural, suburban and urban areas away from busy roads" (e.g. 70 dBA between 07:00 and 19:00) and a 5 dB higher limit for "urban areas near main roads in heavy industrial areas".
- Potential significance based on noise change:
  - The ABC method:
    - Places the receptor in a category (A, B or C) depending in the baseline[4] sound level, and from this derives the level at which a potentially significant effect could occur.
  - The 5 dB(A) change method:
    - Noise levels generated by site activities are deemed to be potentially significant if the total noise exceeds the baseline[4] level by 5 dB or more (subject to lower cut-off values)[5] and where the duration will be for a month or more.

In addition the standard also provides examples of thresholds ("trigger levels") that could be used to determine eligibility for sound insulation[6] or temporary rehousing. These are widely applied as shown in the standard, unless the baseline is already higher than the trigger level. On the project, the criteria for sound insulation and temporary rehousing for standard dwellings are as shown in Table 1.

Table 1 – PW17 trigger levels

Day	Time	Averaging period, T	Sound insulation trigger value dB $L_{Aeq,T}$	Temporary respite/rehousing trigger value dB $L_{Aeq,T}$
Mondays to Fridays	7am to 8am	1 hour	70	80
	8am to 6pm	10 hours	75	85
	6pm to 7pm	1 hour	70	80
	7pm to 10pm	1 hour	65	75
Saturdays	7am to 8am	1 hour	70	80
	8am to 1pm	5 hours	75	85
	1pm to 2pm	1 hour	70	80
	2pm to 10pm	1 hour	65	75
Sundays and public holidays	7am to 10pm	1 hour	65	75
Any day	10pm to 7am	1 hour	55	65
If the baseline level exceeds the trigger level(in the absence of construction noise) then the ambient noise level shall be used as the construction noise level required to trigger insulation and the ambient noise level +10dB shall be used as the temporary rehousing level.				

Source: Thames Tideway Tunnel DCO Schedule 3 Requirement PW17 [6]

It can be seen in both of the assessment methodologies that consider noise change, and in assessing eligibility for sound insulation, that it is essential that an accurate and robust sound baseline is established in order to correctly assess the potential impact and the significance of the effects. Under (or over) estimation of the baseline can result in over (or under) estimation of the effects and even result in an incorrect assessment of entitlement to sound insulation.

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4 Preconstruction ambient noise level dB $L_{Aeq,T}$

5 These are the same as the category A values in the ABC method

6 Sound insulation packages include secondary glazing, alternative ventilation and blinds to reduce solar gain

1.2.1 Establishing the baseline for the Environmental Statement

Prior to the submission of the application for development consent order[7] an EIA was prepared which included an assessment of noise, including construction noise [7]. Baseline monitoring was undertaken to represent the closest noise sensitive receptors to the scheme. Monitoring was generally undertaken as short sample attended measurements, during the interpeak periods, unless a secure location for continuous logging over several days could be arranged as shown in Tables 2 and 3.

Table 2 - Baseline noise survey methodology (Data requirements)

Source	Data	Notes
Measured data for daytime	$L_{Aeq,T}$, $L_{A90,T}$, L_{AFmax}. Data collected over minimum of 15 minutes, at least 2 sets of data in each 2 hour period	Time periods for noise surveys are shown in Table 3
Measured data for night-time (where 24 hour working proposed or operational ventilation noise if required)	$L_{Aeq,T}$, $L_{A90,T}$, L_{AFmax}. Data collected over minimum of 15 minutes, at least 2 sets of data in each 2 hour period	Time periods for noise surveys are shown in Table 3
Measured data for weekends (where 24 hour working proposed)	$L_{Aeq,T}$, $L_{A90,T}$, L_{AFmax}. Data collected over minimum of 15 minutes, at least 2 sets of data in each 2 hour period	Time periods for noise surveys are shown in Table 3
Measured continuous monitoring over a number of weekdays and one weekend	$L_{Aeq,T}$, $L_{A90,T}$, L_{AFmax}. Contiguous five minute samples	Unattended logged measurements taken at one receptor position as agreed with the relevant local authority

Source: Thames Tideway Tunnel ES Volume 2 Table 9.4.2[7]

[7] The legislation that authorizes the development

Table 3 - Baseline noise survey methodology (Time periods)

Data Collection		**24 hour sites**	**Standard hours sites**	**Operational ventilation (if required)**
Time period for measurements	Weekday	10am-12pm 2pm to 4pm 8pm to 10pm Midnight to 4am	10am to 12pm 2pm to 4pm	Midnight to 4am
	Weekend (Sunday)	2pm to 6pm Midnight to 4am	N/A	N/A
Duration of measurements		Minimum of two measurements each of 15 minutes duration logging the LAeq and LA90 for the whole period and at every 5 minutes so that shorter periods could be reported if required. Measurements for each site completed in circuits and not completed consecutively at any location		
Parameters		$L_{Aeq,T}$, $L_{A90,T}$, L_{AFmax}.		

Source: Thames Tideway Tunnel ES Volume 2 Table 9.4.3 [7]

1.2.2 Assessing significance in the ES

The ABC method was utilised for the assessment of significance in the Environmental Statement (ES).

1.2.3 Confirming the Baseline before construction

During the examination of the application for Development Consent a number of challenges were made that suggested that the baseline monitoring results did not always give a full representation of the baseline although further evidence submitted during the hearings confirmed that the baseline was suitable for the ES assessment. The Examining Authority included a project wide requirement (PW19) within the Development Consent Order (DCO) that all baseline data should be updated before construction commenced, primarily to ensure that entitlement to sound insulation was accurately determined.

To comply with PW19, the baseline monitoring was agreed with the relevant regulatory authorities in advance and in all cases consisted of continuous unattended sound monitoring for a period of a minimum of 7 days, although some local authorities requested 1 month or more. This has resulted in a large data set within a range of urban environments.

1.2.4 Monitoring during construction

A combination of attended and unattended monitoring will be conducted during the construction phase. The unattended monitoring has a system of real time alerts and so establishing a realistic baseline is important in avoiding false alerts caused by non-construction related activities that are typical of the baseline sound environment.

2. DATA COLLECTION

As part of the project, AECOM undertook long term baseline sound monitoring at a large number of project sites (as describer in 1.2.3 above). Sound level meters (SLMs) were used to log sound levels continuously over periods of several weeks, before the same instrumentation was used to monitor construction noise levels during early works.

These measurements have provided a rare opportunity to analyse long term monitoring data from many sites and investigate the implications of different data processing techniques on baseline sound levels which are used throughout the project.

3. DATA ANALYSIS

3.1 Sites

Sound monitoring data covering a period of one month for each of five baseline monitoring sites was selected to carry out an analysis of different data processing techniques. These sites are briefly described below.

3.1.1 Site A

This monitoring position is situated on the north bank of the River Thames, adjacent to Victoria Embankment to the west of Blackfriars Bridge.

This location has fairly high ambient sound levels throughout the day. Typical weekday daytime L_{Aeq} values range between 70 and 75 dB. Night time levels are slightly lower but remain around 70 dB L_{Aeq} in the evening and early morning dropping to 67 dB for the quietest periods of the night. Weekday sound levels typically peak at 06:00 before reducing and settling into daytime patterns.

3.1.2 Site B

This monitoring position is situated on the north bank of the River Thames, to the east of Blackfriars Bridge.

This location has also fairly high ambient sound levels throughout the day. Typical weekday daytime L_{Aeq} values range between 72 and 76 dB. Night time levels are slightly lower but remain around 71 dB L_{Aeq} in the evening and early morning, dropping to 67 dB for the quietest periods of the night. Weekday sound levels are typically highest at 06:00 to 08:00.

3.1.3 Site C

This monitoring position is situated at a school to the east of Blackfriars Bridge. This location has significantly lower ambient sound levels than Site A or Site B. Typical weekday daytime levels range between 53 and 64 dB L_{Aeq}. Night time levels are reduced to around 50 dB, dropping to 45-48 dB for the quietest periods of the night.

3.1.4 Site D

This monitoring position is situated near the south bank of the River Thames with a railway line nearby to the south.

This location has significantly lower ambient noise levels than Sites A and B. Typical weekday daytime L_{Aeq} values range between 60 and 65 dB. Night time levels are reduced but remain around 59 dB in the evening and early morning, dropping to as low as 51 dB for the quietest periods of the night.

For one Friday afternoon/evening during the selected monitoring period, levels were significantly lower than usual, recording at 47 to 56 dB between 14:00 and 23:00.

3.1.5 Site E

The monitoring location is located to the south of the River Thames in the Battersea area. Typical daytime L_{Aeq} sound levels are between 58 and 63 dB. Evening and early morning ambient sound levels are around 55 dB L_{Aeq}, dropping to below 50 dB L_{Aeq} during the quietest hours of the night.

3.2 Data Processing

The data from each site have been processed in an identical manner. An initial review of the measurement data was undertaken in conjunction with weather data from associated weather monitoring stations. To ensure consistency, data from any periods where wind speeds exceeded 5 m/s or any rainfall was recorded were excluded from the rest of the analysis.

Data were then separated into weekday and weekend data. The analysis presented in this paper has focussed on weekday data only, but conclusions for weekend data will be similar.

All data analysis was undertaken with the daytime (07:00 to 19:00), evening (19:00 to 23:00) and night time (23:00 to 07:00) periods, consistent with the “ABC” method from BS5228 described earlier in this paper. For each of these periods, the following descriptors of the data were then calculated:

- Arithmetic mean
- Mode

- Logarithmic energy average (i.e. energy $L_{Aeq,12hr}$, $L_{Aeq,4hr}$, and $L_{Aeq,8hr}$ values)

To calculate modal values for the sound level in each period, all measurements (after removal of weather affected data) were classified into "bins" of 0.5 dB width (e.g. 49.5-50.0dB, 50.0-50.5dB, etc.) The bin which contained the greatest number of measurements was then identified as the modal bin, and the centre value of the range represented by the bin as the modal value.

4. RESULTS

4.1 Weather Affected Data

The initial analysis of the effect of weather conditions on the measurement data was used to identify if it was necessary to exclude measured data from all periods of bad weather (i.e. any rainfall or wind speeds above 5 m/s).

Figures 1 and 2 below show two examples of 24-hour period when rainfall occurred, with the periods of rainfall highlighted.

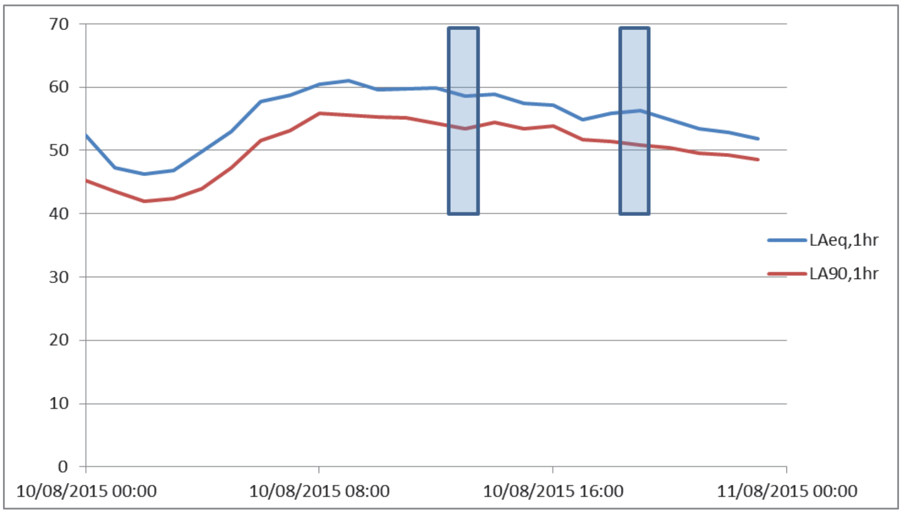

Figure 1 – Example of rain affected measurement data (periods of rainfall highlighted in blue box)

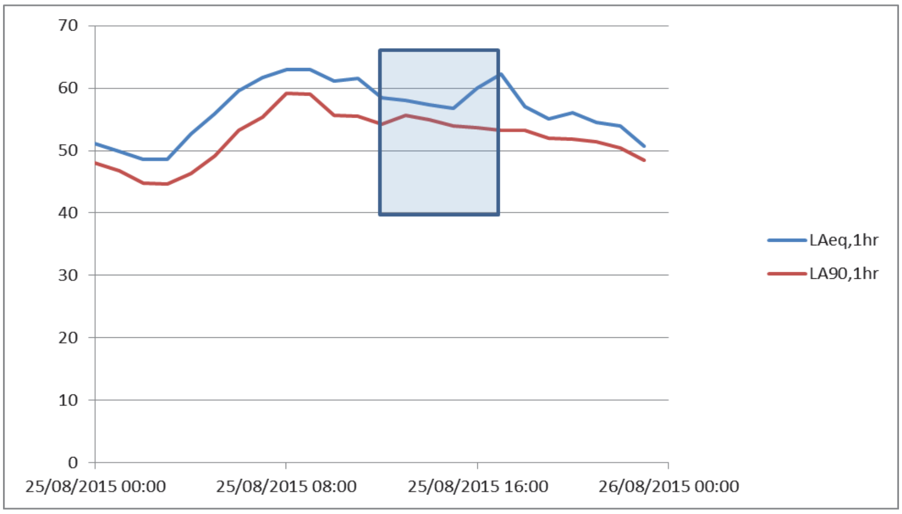

Figure 2 – Example of rain affected measurement data (periods of rainfall highlighted in blue box)

It can be seen that measured $L_{A90,1hr}$ sound levels were not affected by the rainfall in any case, but for some periods the $L_{Aeq,1hr}$ values are increased during the rainfall.

A more detailed analysis of the data found a typical reduction in longer duration L_{Aeq} sound levels of 0.1 to 0.2 dB by removing data affected by rain.

It was considered that two options could be appropriate to minimise the effect of rainfall on the measured baseline levels:

1) Automated removal of all data with rain or high wind speeds. This is a simple approach to implement, and ensures that no contaminated data is used.
2) Manual review of data from all periods of adverse weather to ascertain whether the weather conditions have influenced the measured sound levels. This approach is significantly more time consuming and labour intensive, but minimises the amount of data which is removed due to bad weather conditions.

For the purposes of the project, it was recommended that option (1) was used, and all data affected by rainfall or high wind speeds should be removed. The advantages of this approach are both in terms of labour savings and in that it removes any potential for challenge to the data used due to weather effects. Given the large amount of baseline data collected at each site, it was not considered that the slightly increased quantity of data excluded would have a significant effect on the reliability of the baseline sound levels.

4.2 Averaging Techniques

Sound levels for each of the five example sites considered are presented in subsections below. For each site, a graph displays the spread of $L_{Aeq,1hr}$ sound levels alongside lines representing the daytime, evening and night time L_{Aeq} values which are calculated as the mean, logarithmic average and modal values.

4.2.1 Site A

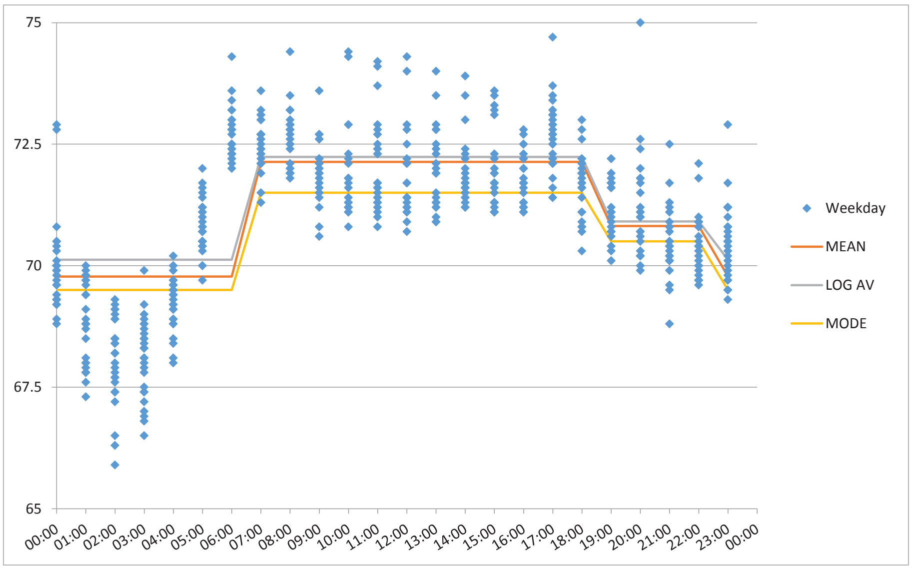

Figure 3 – 23 hour noise level variations, Site A

Table 4 – Noise level descriptors – Site A

Weekday	Sound Level ($L_{Aeq,1hr}$ (dB))		
	0700-1900	1900-2300	2300-0700
Minimum	70.3	68.8	65.9
Maximum	76.1	75.0	75.3
Range	5.8	6.2	9.4
Log Average	72.2	70.9	70.1
Mean	72.1	70.8	69.8
Mode	71.5	70.5	69.5

4.2.2 Site B

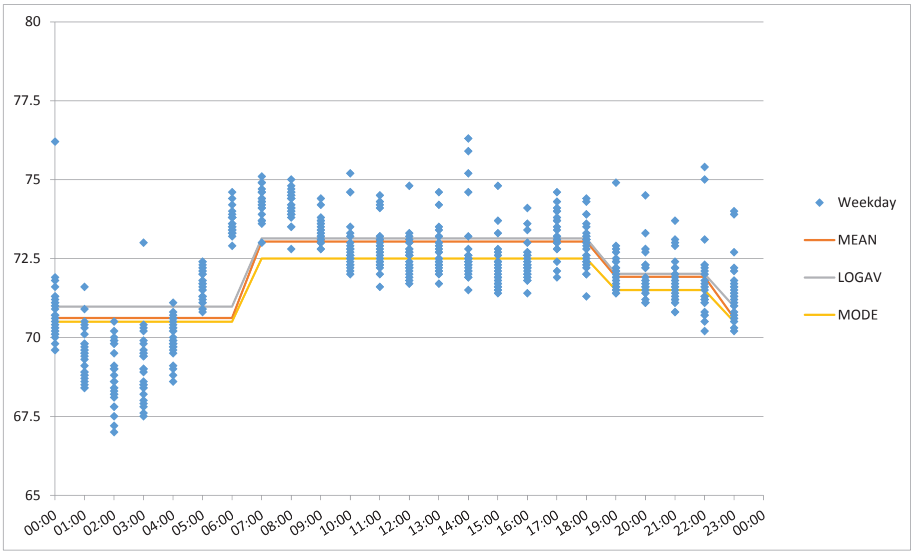

Figure 4 – 24 hour sound level variations, Site B

Table 5 – Noise level descriptors – Site B

Weekday	0700-1900	1900-2300	2300-0700
Minimum	71.3	70.2	67.0
Maximum	76.3	75.4	76.2
Range	5.0	5.2	9.2
Log Average	73.1	72.0	71.0
Mean	73.0	71.9	70.6
Mode	72.5	71.5	70.5

4.2.3 Site C

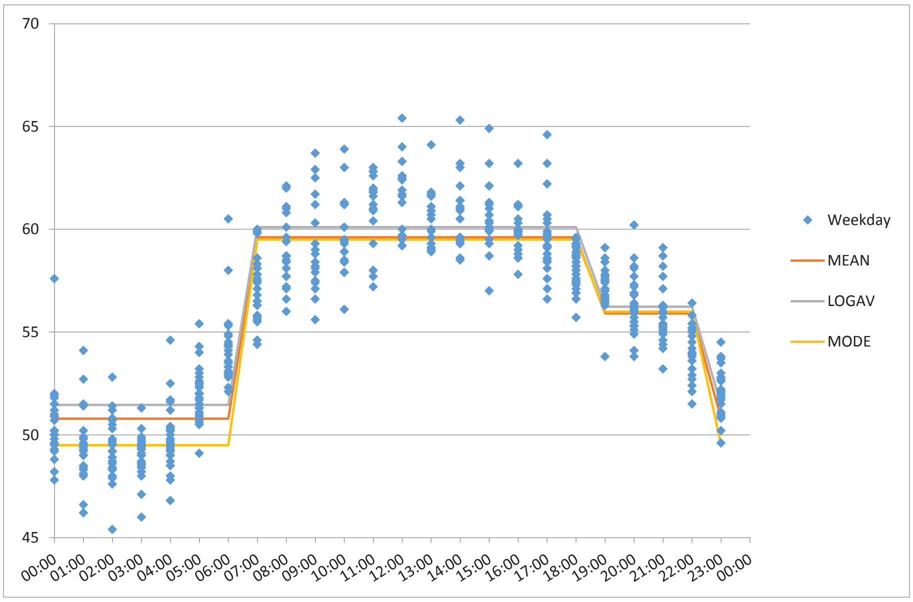

Figure 5 – 24 hour sound level variations, Site C

Table 6 – Noise level descriptors – Site C

Weekday	0700-1900	1900-2300	2300-0700
Minimum	54.4	51.5	45.4
Maximum	65.4	60.2	60.5
Range	11.0	8.7	15.1
Log Average	60.1	56.2	51.5
Mean	59.6	55.9	50.8
Mode	59.5	56.0	49.5

4.2.4 Site D

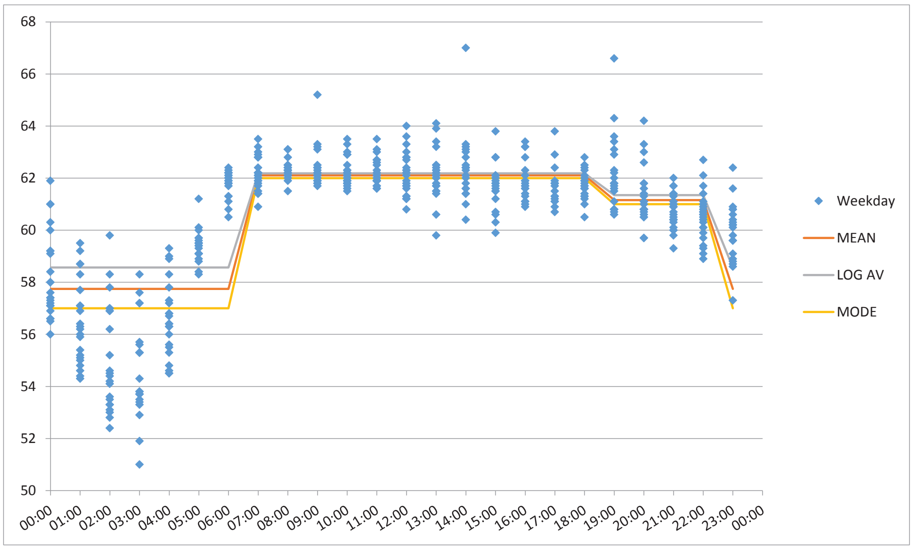

Figure 6 – 24 hour sound level variations, Site D

Table 7 – Noise level descriptors – Site D

Weekday	0700-1900	1900-2300	2300-0700
Minimum	59.8	58.9	51.0
Maximum	67.0	66.6	62.4
Range	7.2	7.7	11.4
Log Average	62.2	61.3	58.6
Mean	62.1	61.2	57.7
Mode	62.0	61.0	57.0

4.2.5 Site E

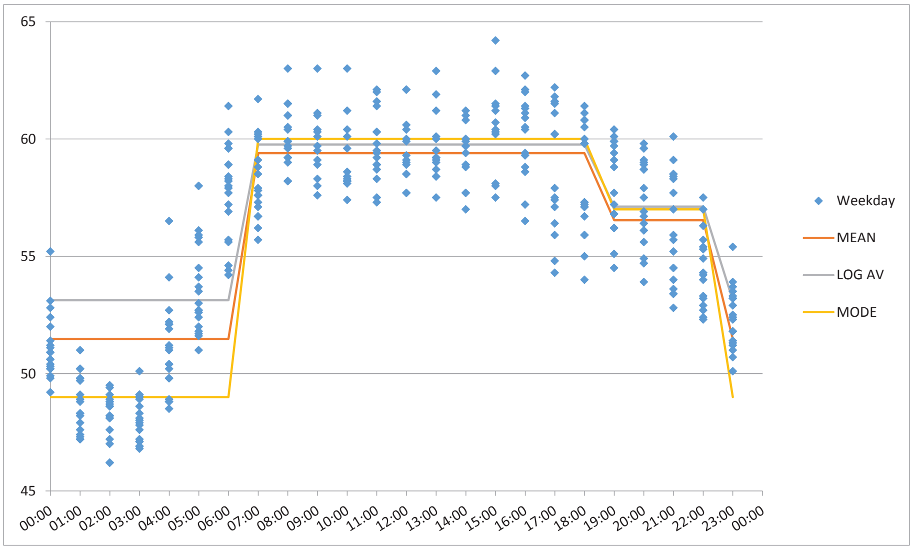

Figure 7 – 24 hour sound level variations, Site E

Table 8 – Noise level descriptors – Site E

Weekday	0700-1900	1900-2300	2300-0700
Minimum	54.0	52.3	46.2
Maximum	64.2	60.4	61.4
Range	10.2	8.1	15.2
Log Average	59.8	57.1	53.1
Mean	59.4	56.5	51.5
Mode	60.0	57.0	49.0

5. DISCUSSION

5.1 Averaging for Baseline Sound Levels

The following patterns can be noted from a review of the data presented above:

- Logarithmic (L_{Aeq}) average sound levels are always greater than arithmetic mean values
- Mode values can be either greater or less than other forms of average, dependent on the degree of variation on sound levels over the day and between different days of data.
- The variation on calculated levels for different forms of average can be very high, particularly at night, when the range of measured sound level is generally higher.

5.1.1 Variations in mode levels

The wide variation on modal sound levels has been considered further. In particular, consideration has been given to night time levels where the greatest variation is seen. Figures 8 and 9 below present two theoretical variations in sound level at night, for which the levels at the beginning and end of the night time period (23:00 and 07:00 are identical), as they are during the quietest period of the night. The difference between these two scenarios is simply the amount of the night time period for which sound levels are lower, but this results in a difference of some 4 dB in the mode value over the night time period. Average values (arithmetic and logarithmic) will also be affected, but to a much lesser degree.

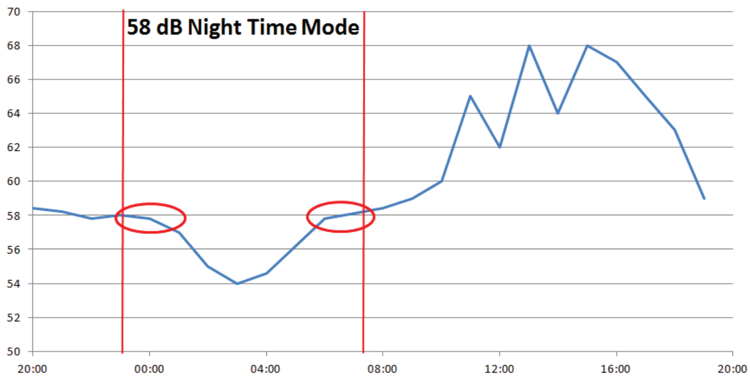

Figure 8 – Example night time sound levels resulting in high mode value

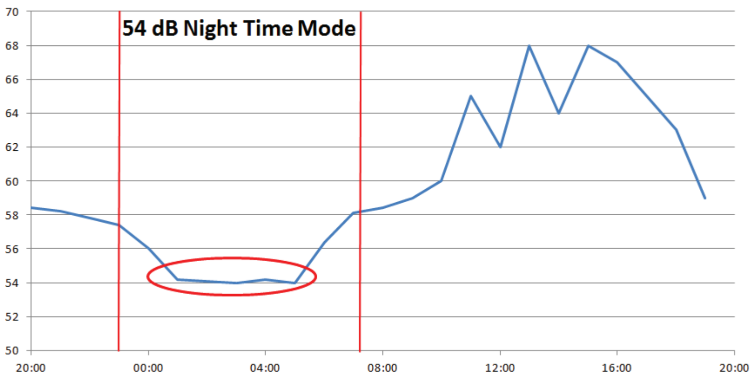

Figure 9 – Example night time sound levels resulting in low mode value

This example above shows how a wide range of results can be obtained for similar sound situations through use of the mode to provide a typical level. This may in turn result in a different categorisation of baseline sound level (in accordance with the ABC method), and hence trigger values for identifying significant effects in the EIA process, or trigger values for action during construction works.

5.2 Noise Management, Alert Levels and Trigger Levels

In the example above, the receptor's entitlement to sound insulation could be affected depending on the methodology used. For example, a value of the 54 dB (night time mode in the second example) would indicate that sound insulation should be offered if the construction noise exceeded 55dB $L_{Aeq,1h}$. However, the hourly level is up to 4 dB higher than this for a substantial period of the night. In the first example, a mode value of 58 dB baseline would result in sound insulation only being offered only if the construction noise was 58 dB $L_{Aeq,\,1h}$ or higher even though levels during the quietest part of the night are up to 4 dB lower than this.

When trigger levels are set to inform the contractors to inform when noise levels are approaching the noise limits, the baseline needs to be added to the construction noise level. Adding too low a baseline will result in "false" alerts being generated simply due to ambient levels (excluding construction works). This then may result in a genuine alert being ignored. However, use of a baseline sound level which is too high might not provide an alert when construction noise limits have been exceeded.

Based on the full range of measurement data within a site, it can be seen that setting the limits based on the quietest measured night time sound levels could apply as much as a 15dB penalty on construction noise (12 dB on average), whereas setting it based on the highest night time level would similarly disadvantage the residents by exposing them to a change in noise level of a similar magnitude.

Even the variances between different averaging techniques used to produce a "typical" average sound pressure level can be significant, and it is important that an appropriate method is selected. Once a baseline value has been defined for setting construction noise limit values, it may then be necessary to use a time-varying baseline level in order to set trigger levels for construction noise monitors. For example, if a construction noise limit of 60 dB $L_{Aeq,1hr}$ is defined for the night time period, but baseline levels vary between 52 dB $L_{Aeq,1hr}$ and 62 dB $L_{Aeq,1hr}$ over the night time, then trigger levels ranging from 61 dB to 64 dB $L_{Aeq,1hr}$ would be necessary. Failure to correctly account for the variation of baseline levels when setting these trigger values could result in exceedances of construction noise limits being undetected, or alerts being issued simply due to higher baseline levels at some times of the night.

5.3 Implications for Interpretation of Baseline Data

The results indicate that baseline reports should include all parameters to enable further discussion with the regulators. This is considered to be good practice as it is transparent and allows the regulator to understand the range of data and the extent to which this might affect the use of the data.

It is best practice to exclude all data affected by rainfall or high wind speeds from the baseline reports and from calculations of baseline ambient levels. However, with large data sets these adverse weather conditions appear to have very little influence on the ambient noise level. Exclusion of the measurements during adverse weather conditions prevents potential challenges to the veracity of the data.

Tideway considers it a priority to work with the contractors to take extra care to set alert levels and noise limits that do not subject residents to unnecessary noise at night but that allow reasonable activities to take place. With large data sets, additional uncertainty is introduced due to the range of hourly noise levels, particularly at night. The implications of this are that the baseline for the "night" period (e.g. 11pm – 7am) may need to be considered as three sub-periods; e.g. early night, middle of night and early morning. This approach introduces additional complications for the contractors as levels will change several times during the night.

CONCLUSIONS

While large data sets are useful in understanding the range of sound levels in an area, the disadvantage of these is that they introduce additional uncertainty by extending the range of measured values. Analysis of the data should be completed with an awareness of the differences and uncertainty introduced by the averaging methods, as well as the range of the data set.

The analysis has not indicated that use of any one of the mean, mode or arithmetic average is more representative, however, the following key conclusions can be drawn:

- Logarithmic average values (i.e. longer duration L_{Aeq} levels, and using logarithmic averaging across days) tends to result in levels biased towards the higher measurements, and hence may result in unduly high trigger levels or thresholds for identifying significant effects.
- Use of mode values can give a good indication of the "typical" baseline levels, but are open to significant variation, particularly when there is a wide range of measured baseline levels, or significant variation in level with time over the calculation period.

ACKNOWLEDGEMENTS

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REFERENCES

1. The Town and Country Planning (Environmental Impact Assessment) Regulations 2011
2. BSI, 2014. BS 5228 Code of Practice for noise and vibration control on construction and open sites - Part 1: Noise, London: British Standards Limited.
3. Committee on the problem of noise, 1963. Final Report Command Paper 2056, London: HMSO.
4. Control of Pollution Act 1974
5. BSI, 2014. BS 4142 Methods for rating and assessing industrial and commercial sound, London: British Standards Limited
6. The Thames Water Utilities Limited (Thames Tideway Tunnel) Order 2014 (as amended by SI 2015/723 and notice of variation No.1 issued on 17 March 2015 in respect of the deemed Marine Licence)
7. Thames Tideway Tunnel, 2013. Application for Development Consent Order Environmental Statement, London: Thames Water Utilities Ltd.